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FLIGHT TEST DEMONSTRATION FOR TCAS-II LOGIC VERSION 6.04

TEST PLAN

FEDERAL AVIATION ADMINISTRATION

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July 1992



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EXECUTIVE SUMMARY

This document describes the flight test demonstration plan to gather pilot acceptance information of the Traffic Alert and Collision Avoidance System (TCAS)-II version 6.04 logic.

The version 6.04 logic was designed to reduce the number of resolution advisories (RAs) generated by TCAS while maintaining adequate separation. Specifically, it was designed to reduce RA levels in standard Air Traffic Control (ATC) environment situations. Numerous logic corrections were also included.

Four encounters have been designed to demonstrate typical geometries which cause RAs with the version 6.0 logic. These include the airport corner post geometry and minimally spaced head-ons. A fifth encounter demonstrates the effect of the delayed RA on a near-miss geometry. The encounters are to be flown with a selection of airline industry pilots.

Prior to each flight, the pilots will be presented with a description of the logic changes and the expected results of each encounter using the version 6.0 logic. Pilots comments on the actual flight results using version 6.04 will be noted and discussed at post-flight briefings.

INTRODUCTION

PURPOSE AND SCOPE OF THIS DOCUMENT.

This document is intended to provide a description of the flight test demonstration for the TCAS-II change 6.04 logic.

DESCRIPTION OF THE LOGIC CHANGES.

Several requests for changes to the TCAS-II version 6.0 logic have been made since its acceptance by RTCA in September 1989. Many of these requests have been generated through analysis of TCAS performance using simulated and recorded data, and by the FAA, its contractors, TCAS manufacturers, and airframe manufacturers. Many other requests have come through pilot and air traffic controller questionnaires. Overall, the changes can be classified into two categories; corrections and enhancements.

CORRECTIONS. The bulk of the changes in the version 6.04 logic are corrections to the logic. Most of these problems were discovered only through the continuing analysis of TCAS performance through simulation. Generally, these corrections involve extremely specific circumstances which are unlikely to be encountered in flight. Since they generally have little or no observable impact on TCAS performance, they are not included in the flight test demonstration.

ENHANCEMENTS. The most obvious changes to the logic are the enhancements, which are included to address several frequently recurring complaints about TCAS performance. These complaints can generally be summed up by saying that TCAS issues corrective RAs on legally separated air traffic, and even more generally by saying that TCAS issues too many unnecessary RAs.

The enhancements contained in version 6.04 are an attempt to make the TCAS logic more compatible with the air traffic control (ATC) system, and less distracting to the flight crew through fewer RAs. However, the TCAS must still perform for its intended function, which is to prevent near-miss and mid-air collisions. The enhancements were accomplished by using reduced warning times, closer aircraft spacing, and more system performance levels. The versions 6.0 and 6.04 logic threshold summaries are included on pages A-1 and A-2 of appendix A. The encounters in the test flight demonstration include tests of the reduced thresholds, closer spacing, and cover four performance levels.

The benefits of the enhancements have been shown by The MITRE Corporation through a comparison of simulated advisory levels at numerous airports in the United States. Pages A-3 through A-10 in appendix A show the results of The MITRE Corporation's study of the expected RA rates simulated at various airports

using either version of the logic. The simulations were conducted using ATC radar data as a source for the encounter geometries, and simulating TCAS performance in these geometries. Vast reductions in RA levels were found in these areas when using version 6.04 instead of version 6.0. Overall effects of these changes on system safety are being analyzed at the FAA Technical Center and the MITRE Corporation.

TEST OBJECTIVES

Simulation tests at the FAA Technical Center and The MITRE Corporation have shown the benefits of the version 6.04 logic to both ATC and pilots. They have not, however, investigated pilot perceptions of the changes. The objective of the flight test demonstration is to expose a selection of pilots to various aspects of the logic to determine their acceptance of the changes.

EQUIPMENT DESCRIPTION

The test flights will be conducted using a production Bendix TCAS-II unit equipped with version 6.04 of the TCAS-II logic.

TEST DESIGN

Version 6.04 benefits were achieved mainly by delaying TAs and RAs and lowering TCAS desired separations. While a delayed RA and reduced separation is obvious during a single encounter, the benefits derived from the delay and reduced separation are not immediately obvious. As such, the flight test is designed to stress the benefits to be expected of the version 6.04 logic in the pre-flight briefing. These benefits will be demonstrated by providing the pilots with each encounter description using the version 6.0 logic. The pilots will actually fly with the version 6.04 logic, however, and will see the difference in performance immediately as they fly the encounters.

Five encounters were selected for the tests. These encounter cover four sensitivity levels of the system, and provide examples of some of the non-compatibility between TCAS and ATC when using logic version 6.0. The encounters are defined in both appendix B and appendix C. Appendix B shows expected TCAS response using version 6.0. Appendix C shows expected TCAS response using version 6.04 for comparison. Note that four of the encounters would be "legally separated" by ATC due to altitude rounding as implemented in their display equipment. The other encounter would result in a "near-miss" without TCAS, and is provided as a case where an RA is actually needed to generate separation, but the RA is delayed due to the logic enhancements.

The test encounters were designed through computer simulation using the FAA Technical Center's Fast Time Encounter Generator (FTEG) program. They were chosen because they demonstrate a variety of features of the new logic, and the way these features align TCAS performance more closely with ATC guidance. Encounters 1 and 5 represent typical VFR-IFR spaced head-on encounters. Encounter 2 represents a typical corner post geometry. Encounters 3 and 4 were included to further demonstrate the effect of the reduced altitude separations and delayed RAs. These two encounters are not necessarily representative of the type of encounters experienced in normal flight operations. The planned encounters do not represent the distribution of actual encounters in the airspace. This is especially true of encounter 3, which would be a collision if simulated without the TCAS and the horizontal safety offset. The performance of version 6.0 and version 6.04 varies significantly in these five encounters, but is very similar in most encounters geometries.

TEST CONDUCT

SUBJECT PILOTS.

Subject pilots will be an important part of the test demonstration, as the objective is to get pilot reactions to the revised logic. The FAA Technical Center requested that approximately twelve subject pilots be supplied through the ALPA and APA. These pilots are to represent both commuter and jet passenger airline service. Other pilots and industry people were invited to participate in the flights as observers.

PRE-FLIGHT BRIEFINGS.

Prior to each flight, the pilots and observers will be briefed on the changes involved in the new logic. This will include an overview of the reasons for the changes, and the expected reductions in the RA rates. The reduced alarm times and separations will also be discussed.

The five encounters will be presented with the expected results using the version 6.0 logic. The changes to the logic, and reasons for those changes, will be related to each encounter. However, the actual expected results using the version 6.04 logic will not be discussed at this time. This briefing should provide an adequate preparation for the pilots without predisposing them to the actual outcome.

TEST FLIGHTS.

FLIGHT TEST PERFORMANCE. The five encounters will be conducted in sequence with each of the subject pilots. Pilot comments will be collected after each encounter for later discussion.

ENCOUNTER DESCRIPTIONS. The full encounter descriptions, including drawings and the associated logic tests, are contained in appendices A and B. These descriptions provide all information needed by the pilots to perform the desired encounters. Information not provided may be chosen by the pilots for their convenience. Although not specified on the encounter descriptions, each run is designed with a 1/4 nmi horizontal safety offset.

Each encounter description states:

The equipage of the two aircraft.

A brief description of the encounter type and expected results using the specified TCAS logic version.

The slant ranges of any significant events during the encounters.

The closing speed of the encounter (true airspeed).

The starting separation for the encounter.

The acceptable base altitude range of the encounter. The base altitude is the starting altitude of the TCAS airplane (PLANE 1).

The intruder altitude offset relative to the base altitude.

The intruder altitude vertical rate, if not level.

The expected advisories from the Traffic Alert and Collision Avoidance System (TCAS) unit (version 6.0 logic in appendix A, version 6.04 logic in appendix B).

Additionally, each encounter includes a side view drawing of the run to scale. The altitude scale appears on the left side of the drawing and indicates relative altitudes. The base altitude is indicated as the zero point.

The other scale on all runs is a time scale. These are all based on the time from PLANE 1 traffic alert (TA). They are actually two scales which meet in the center (at closest point of approach (CPA)).

PILOT DELAYS AND ACCELERATIONS. There are two types of maneuvers included in the encounter drawings: Response to TCAS maneuvers, and encounter geometry maneuvers. The expected results and drawings for each encounter include delays for pilot response to the TCAS advisories, and the aircraft acceleration times.

The expected pilot delay times and aircraft accelerations for responding to TCAS advisories are as follows:

	Initial RA	Subsequent RAs
Pilot Delay	5 seconds	2.5 seconds

Acceleration .25 g
Vertical Rate 1500 fpm

Level-offs by the target airplane should be conducted at .25 g to the specified altitude.

FLIGHT DATA COLLECTION. The TCAS flight data recorder will be used to record encounter data. This data may be used to examine any particular pilot questions of system performance, or any system peculiarities noted in flight.

POST-FLIGHT BRIEFINGS.

After each flight, another briefing will be held. These briefings will allow discussion of pilot concerns and comments generated in the flights. The expected results of each encounter using the 6.04 logic will be compared to the results using the 6.0 logic. Discussions on the benefits and trade-offs of the new logic will be held.

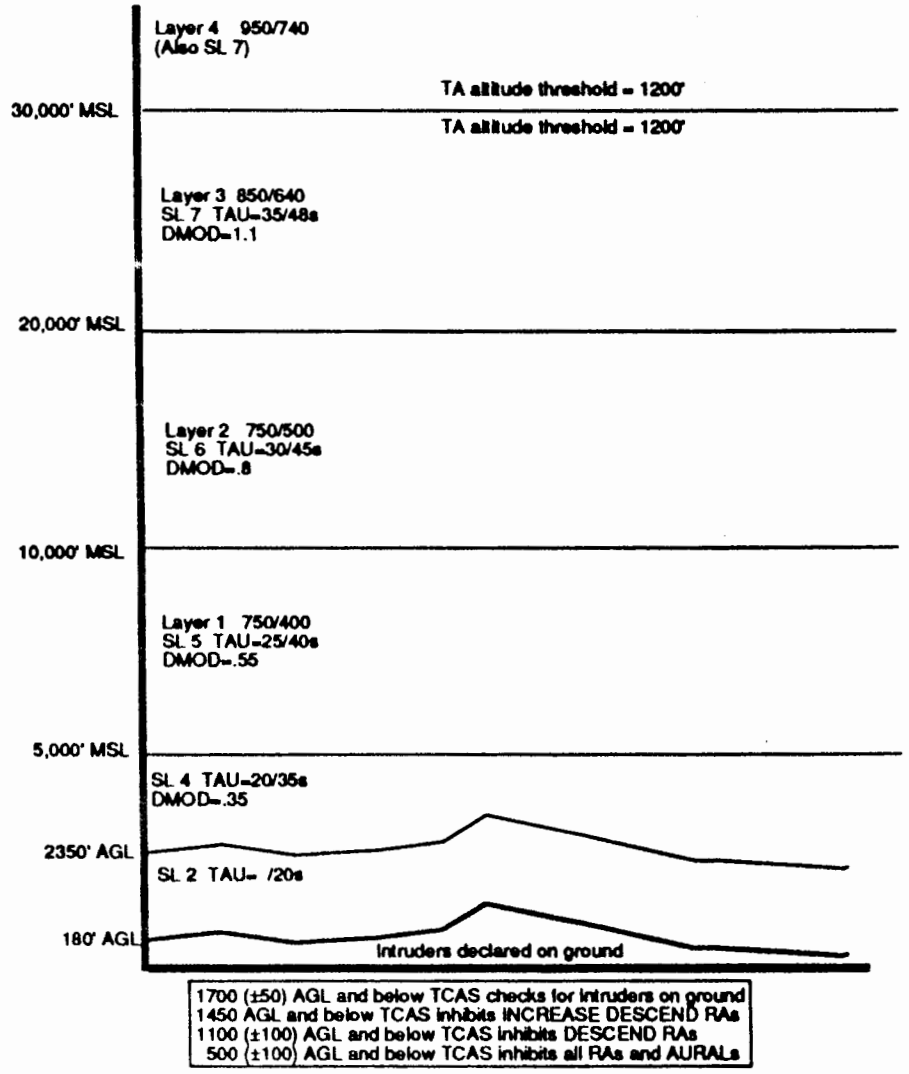
TEST RESULTS

The only results required of these tests are to provide information and experience with the TCAS-II version 6.04 logic to the subject pilots, and to gather pilot comments on their acceptance of the new logic. Flight data will be recorded to analyze system performnace should any questions arise during the flights.

APPENDIX A

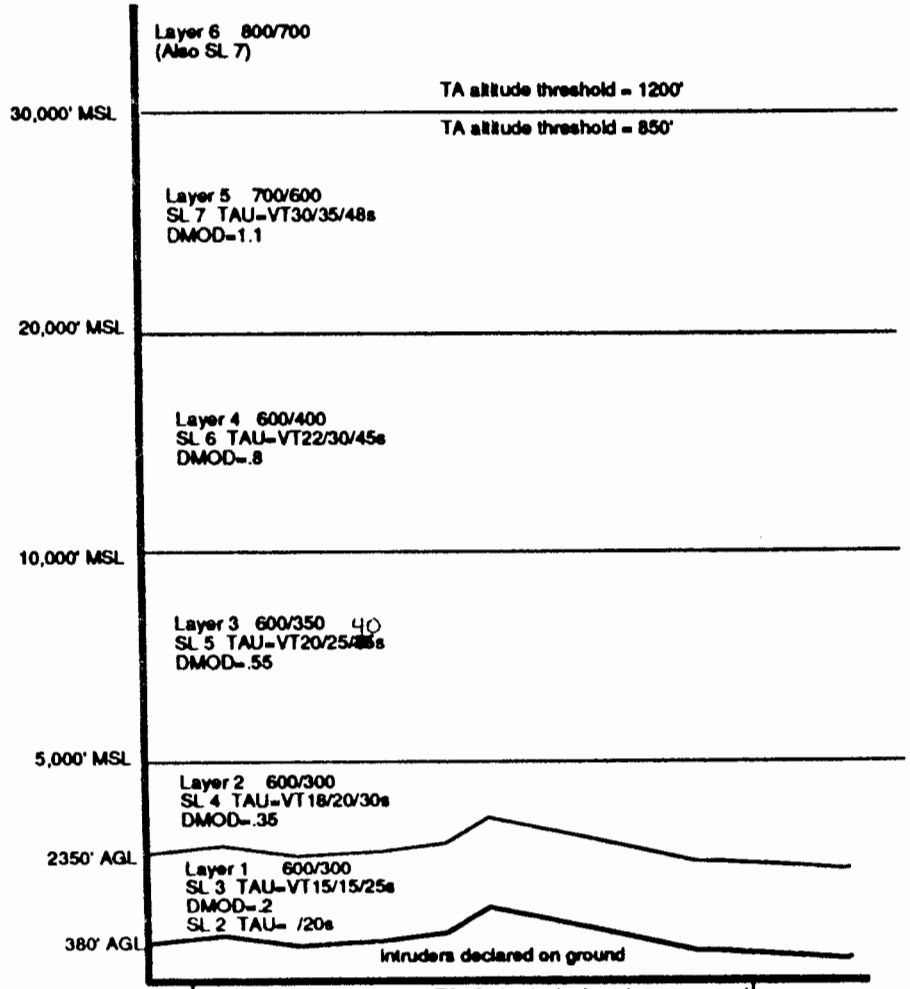
BENEFITS OF THE VERSION 6.04 LOGIC

Version 6.0 (v6.0) Logic Thresholds



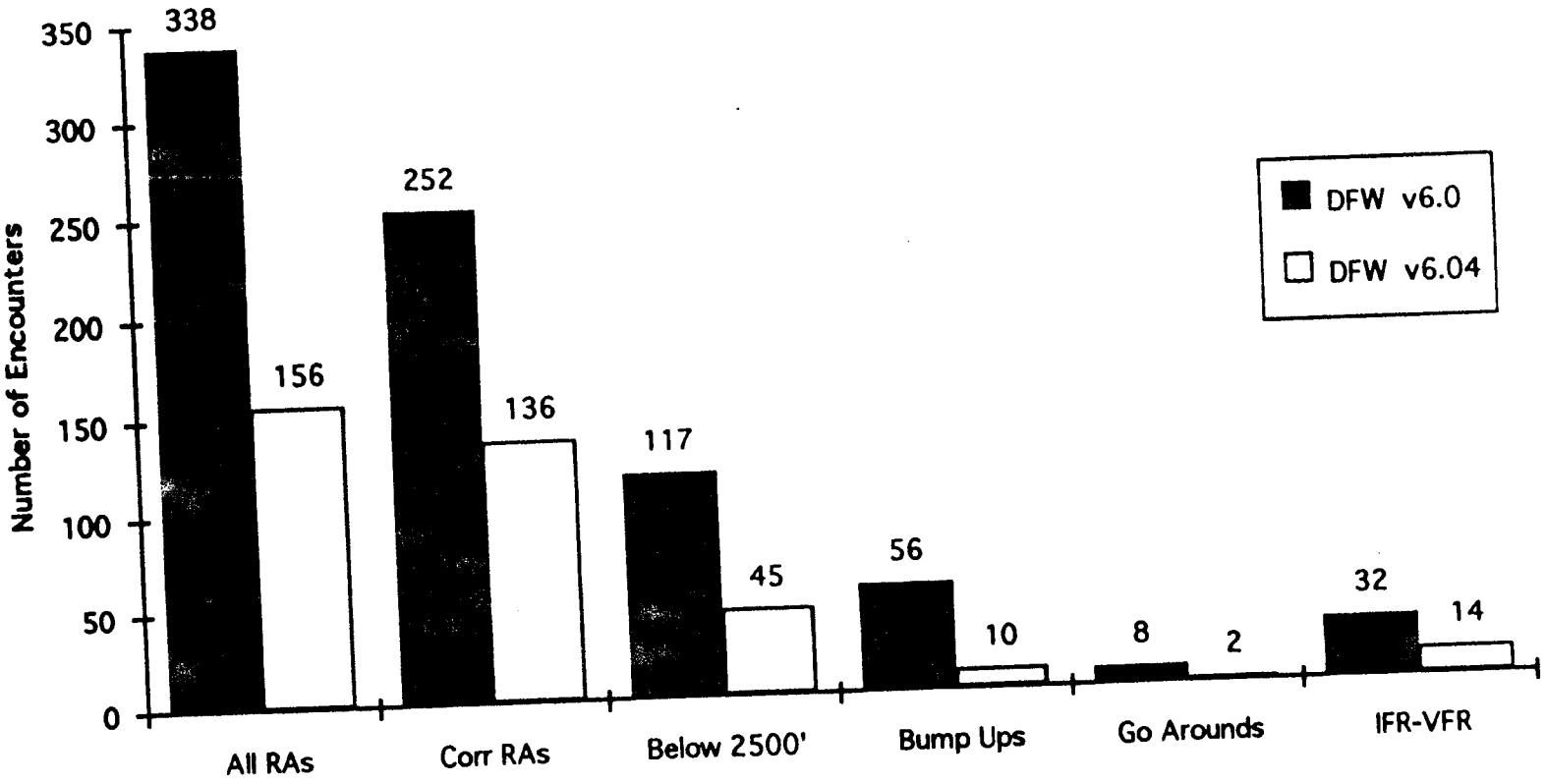
MITRE

Version 6.04 (v6.04) Logic Thresholds



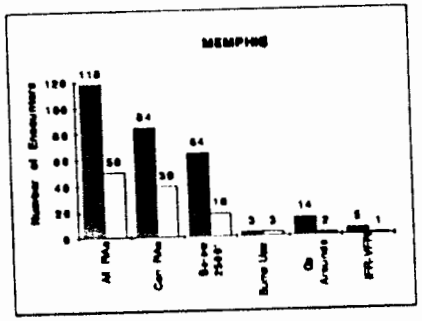
MITRE

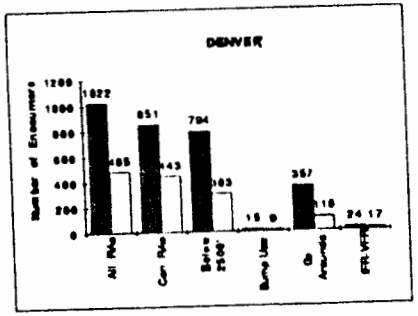
Overall Effectiveness of v6.04 at Dallas-Ft. Worth

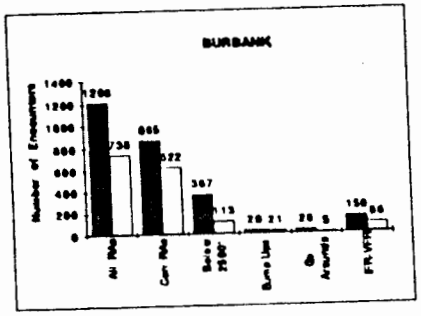


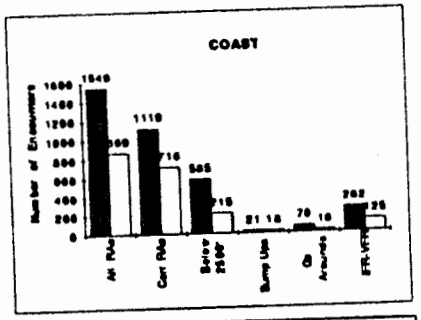
MITRE

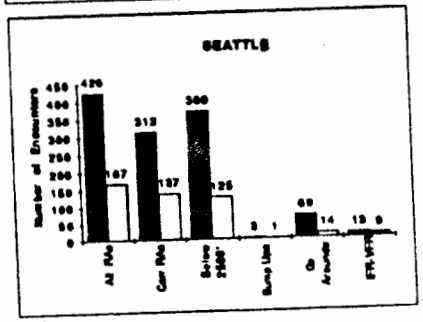
Overall Effectiveness of v6.04 (continued)





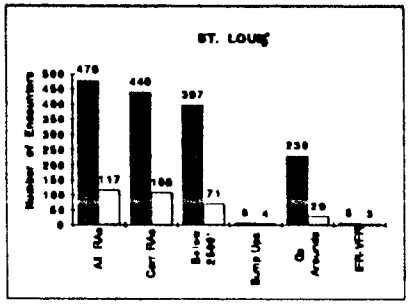


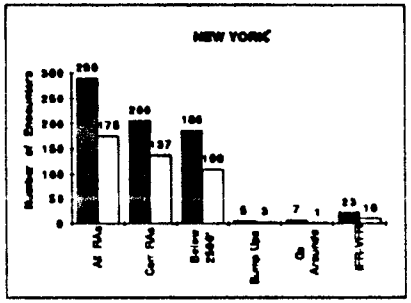


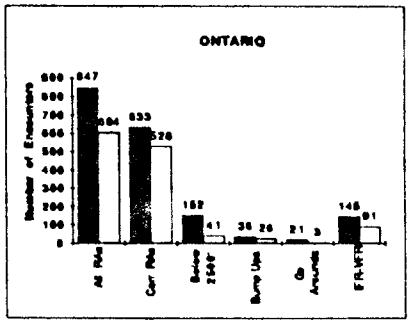


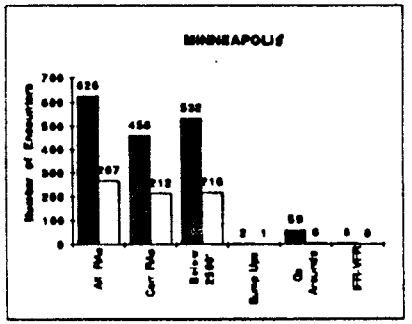
MITRE

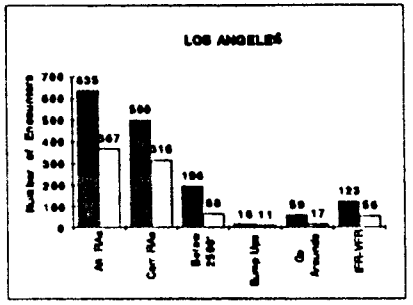
Overall Effectiveness of v6.04 (concluded)





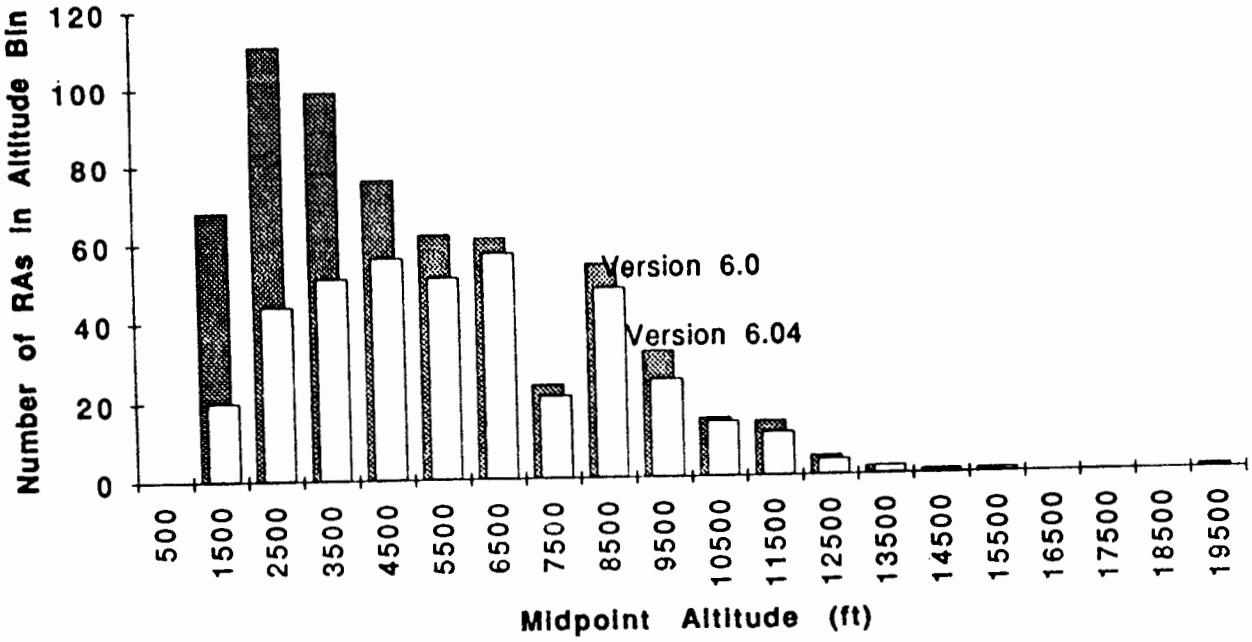






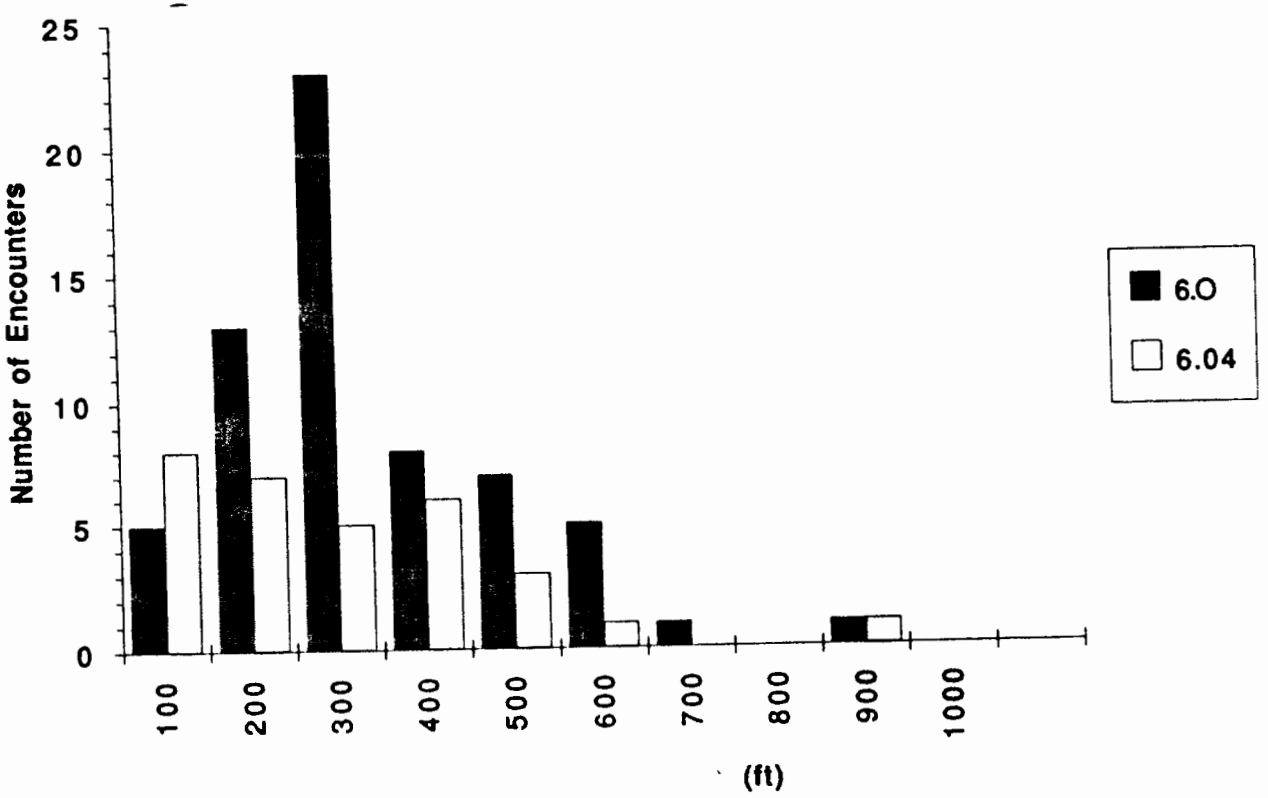
MITRE

Distribution by Altitude for RAs at Burbank



MITRE

Vertical Displacement at Denver



MITRE

Conclusions

- With the new logic there are fewer RAs (preventive and corrective). The overall reduction in the number of RAs issued varies from 30% in Ontario to about 75% in St. Louis.
- At all locations, the percentage of preventive RAs went down for v6.04, showing that the RAs retained were predominantly corrective and necessary.
- RAs issued below 2500 feet AGL at most sites constituted a substantial portion of the total. Reductions were seen at most of the sites; however, at New York the improvement was less noticeable.
- The reduction in the number of "bump-ups" at Dallas-Ft. Worth is striking, and at most other locations there was some improvement as well.

Conclusions (continued)

- Go arounds on approach due to v6.0 RAs were identified at nearly half of the locations, and improvements were substantial at these locations for v6.04.
- The new logic reduced the occurrence of displacements against legally separated VFR traffic by 50%.
- For all locations, separation at CPA for encounters no longer resulting in an RA with v6.04 appears to be adequate. → some were met
- Vertical displacement experienced due to RA responses will be substantially less for v6.04 than for v6.0. Average displacement from level flight for v6.04 was approximately 300 feet, compared to 320 feet for v6.0.

Conclusions (concluded)

- Most v6.04 RAs are issued when the two aircraft are within nominal IFR ATC separation standards (i.e., less than 1000 feet away vertically and less than 3 miles horizontally, or 5 miles at higher altitudes).

AND THE BOTTOM LINE IS:



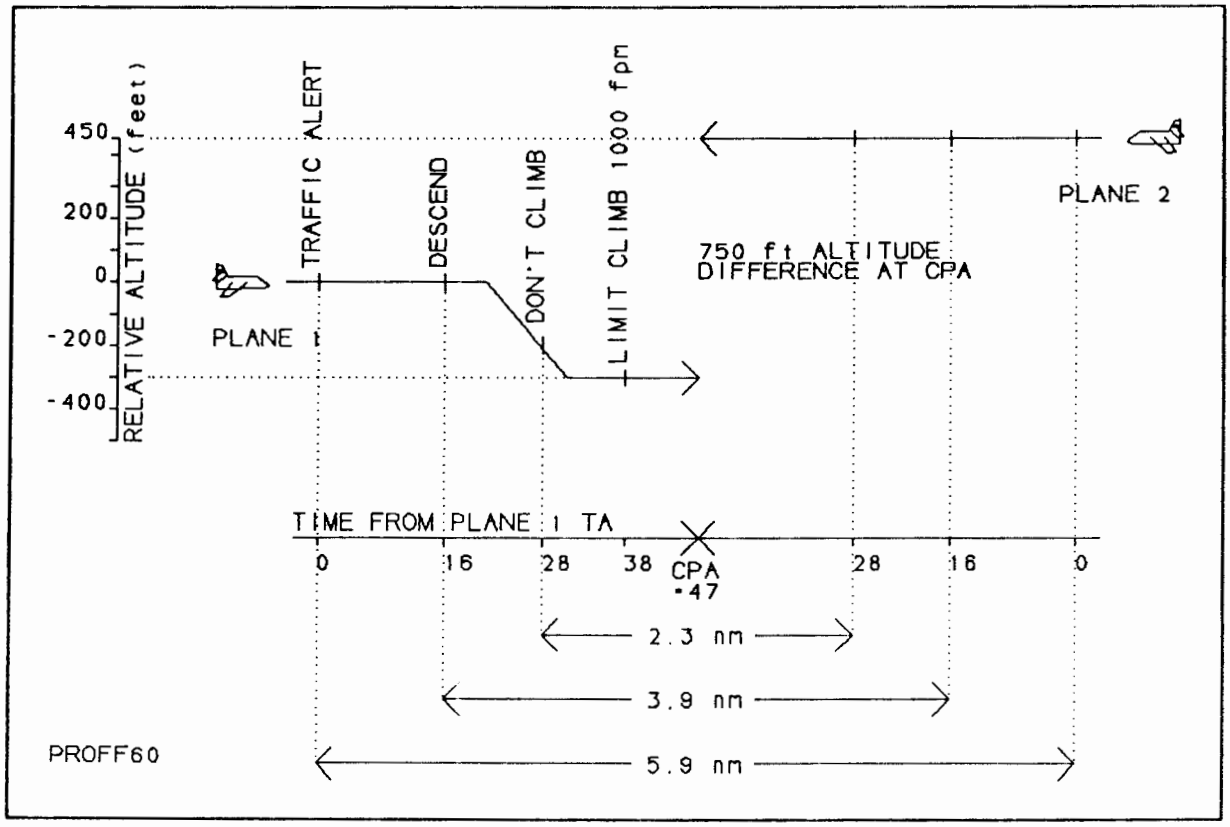
Based on these observations, it can be concluded that the v6.04 logic will be about half as intrusive as the v6.0 logic.

APPENDIX B

DETAILED DESCRIPTIONS OF THE ENCOUNTERS USING LOGIC VERSION 6.0

Encounter 1
with version 6.0 logic

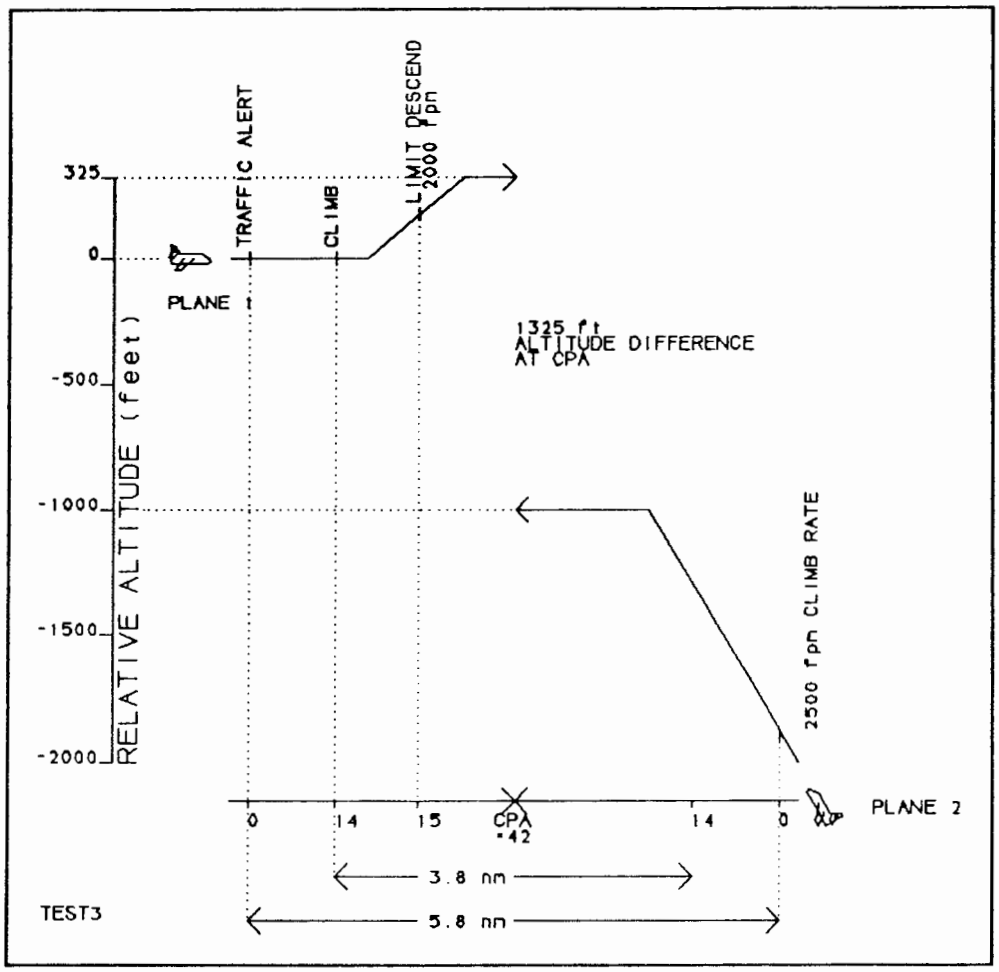
The planes are flying at legal separation, as far as ATC is concerned. TCAS will issue an RA which results in altitude deviation.



ADDITIONAL FLIGHT INFORMATION:
- Encounter starting separation is 12 nmi.
- Encounter closing speed is 460 kts.
- Base altitude is above 10,000 ft.

Encounter 2
with version 6.0 logic

This encounter simulates a "bump-up" situation, as commonly occurs at corner posts at airports. Legal separation is maintained. TCAS issues an RA which results in altitude deviation.

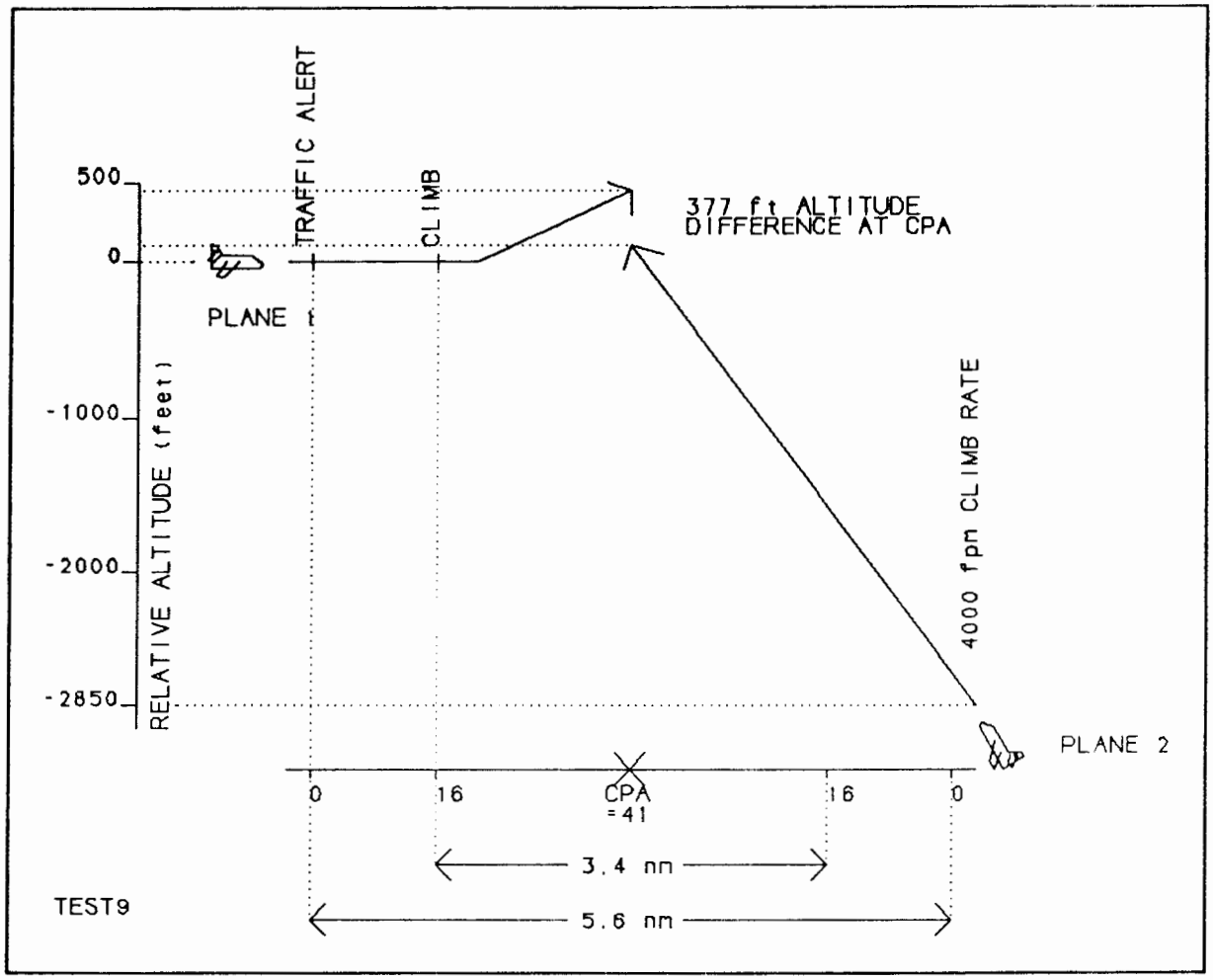


ADDITIONAL FLIGHT INFORMATION:

- Encounter starting separation is 12 nmi.
- Encounter closing speed is 500 kts.
- Base altitude is above 10,000 ft.
- Intruder base is -3725 ft. and levels at -1000 ft.

Encounter 3
with version 6.0 logic

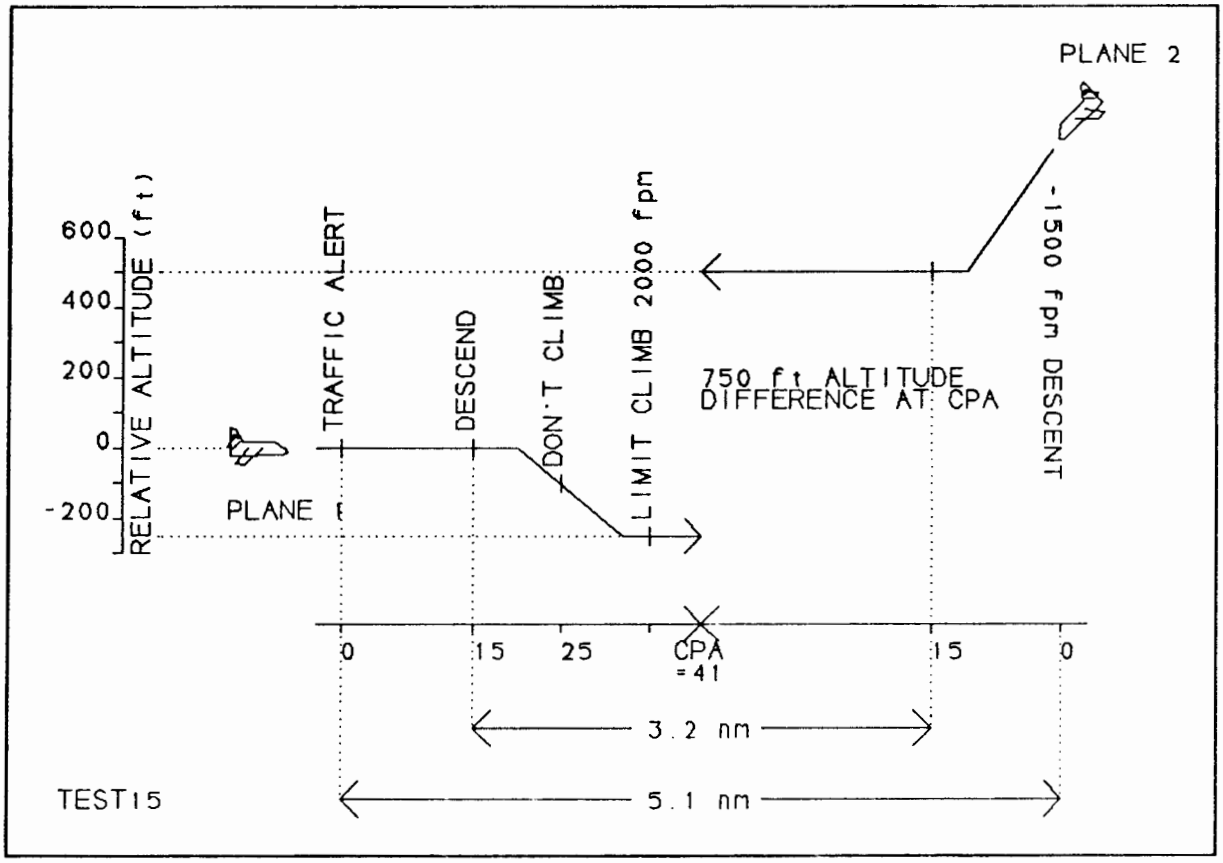
This encounter demonstrates TCAS response to a "bump-up" encounter in which the intruder doesn't level-off.



ADDITIONAL FLIGHT INFORMATION:
- Encounter starting separation is 12 nmi.
- Encounter closing speed is 500 kts.
- Base altitude is between 5,000 and 10,000 ft.
- Intruder base is -5743 ft.

Encounter 4
with version 6.0 logic

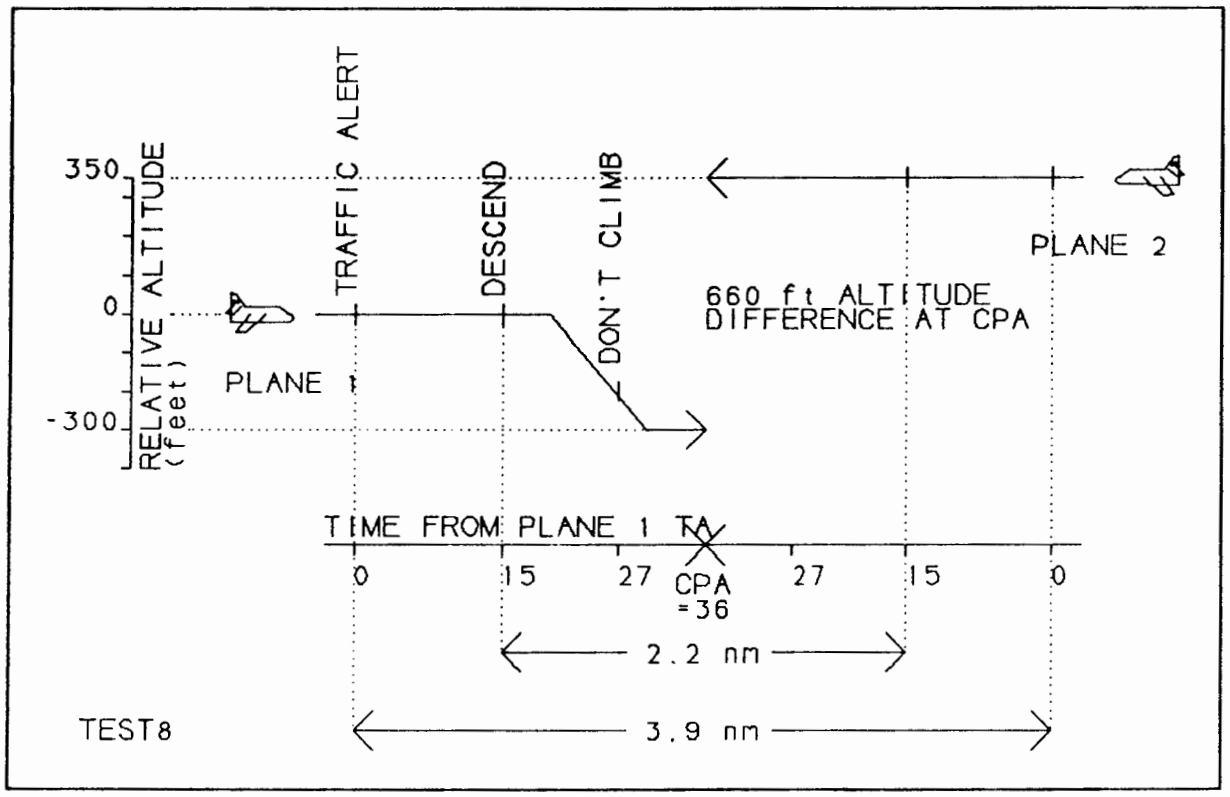
The target aircraft in this encounter levels-off and maintains legal separation with TCAS. TCAS will issue an RA, resulting in altitude deviation.



ADDITIONAL FLIGHT INFORMATION:
- Encounter starting separation is 12 nmi.
- Encounter closing speed is 460 kts.
- Base altitude is between 2350 ft AGL and 5,000 ft MSL.
- Intruder base is +2100 ft.

Encounter 5
with version 6.0 logic

The target aircraft is legally separated, as far as ATC is concerned. Both aircraft are close to the ground. The TCAS RA requires an altitude deviation.



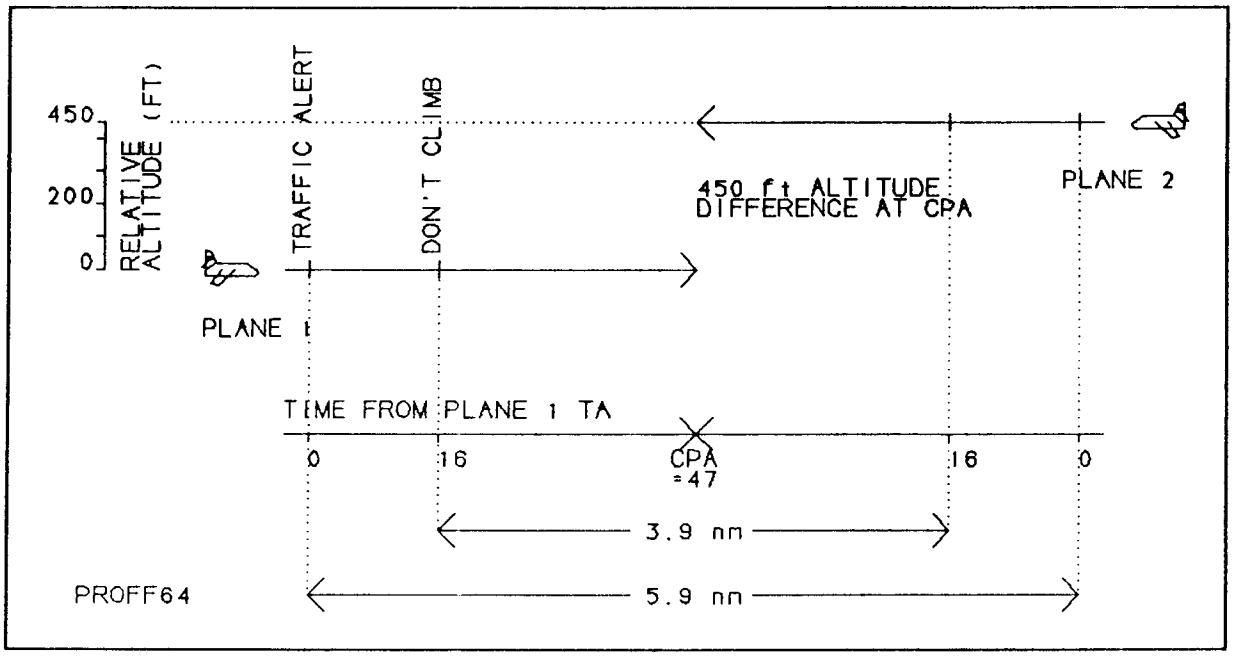
ADDITIONAL FLIGHT INFORMATION:
- Encounter starting separation is 12 nmi.
- Encounter closing speed is 400 kts.
- Base altitude is between 1100 ft and 2350 ft AGL.

APPENDIX C

DETAILED DESCRIPTIONS OF THE ENCOUNTERS USING LOGIC VERSION 6.04

Encounter 1
with version 6.04 logic

The planes are flying at legal separation, as far as ATC is concerned. TCAS issues only a preventive advisory due to the reduction of ALIM by 100 ft to 400 ft. (Note that a slightly smaller altitude difference would cause a corrective RA.)

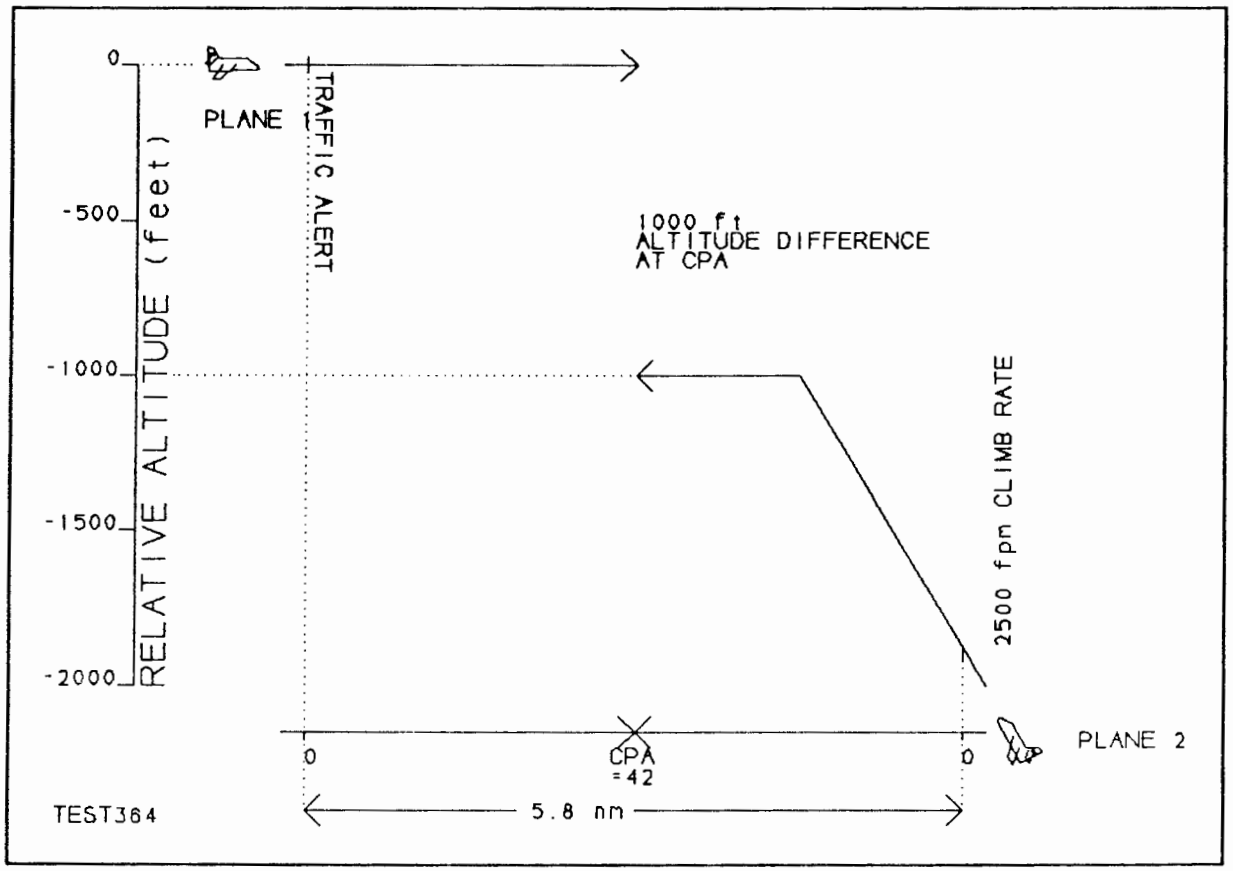


ADDITIONAL FLIGHT INFORMATION:

- Encounter starting separation is 12 nmi.
- Encounter closing speed is 460 kts.
- Base altitude is between 10,000 and 20,000 ft.

Encounter 2
with version 6.04 logic

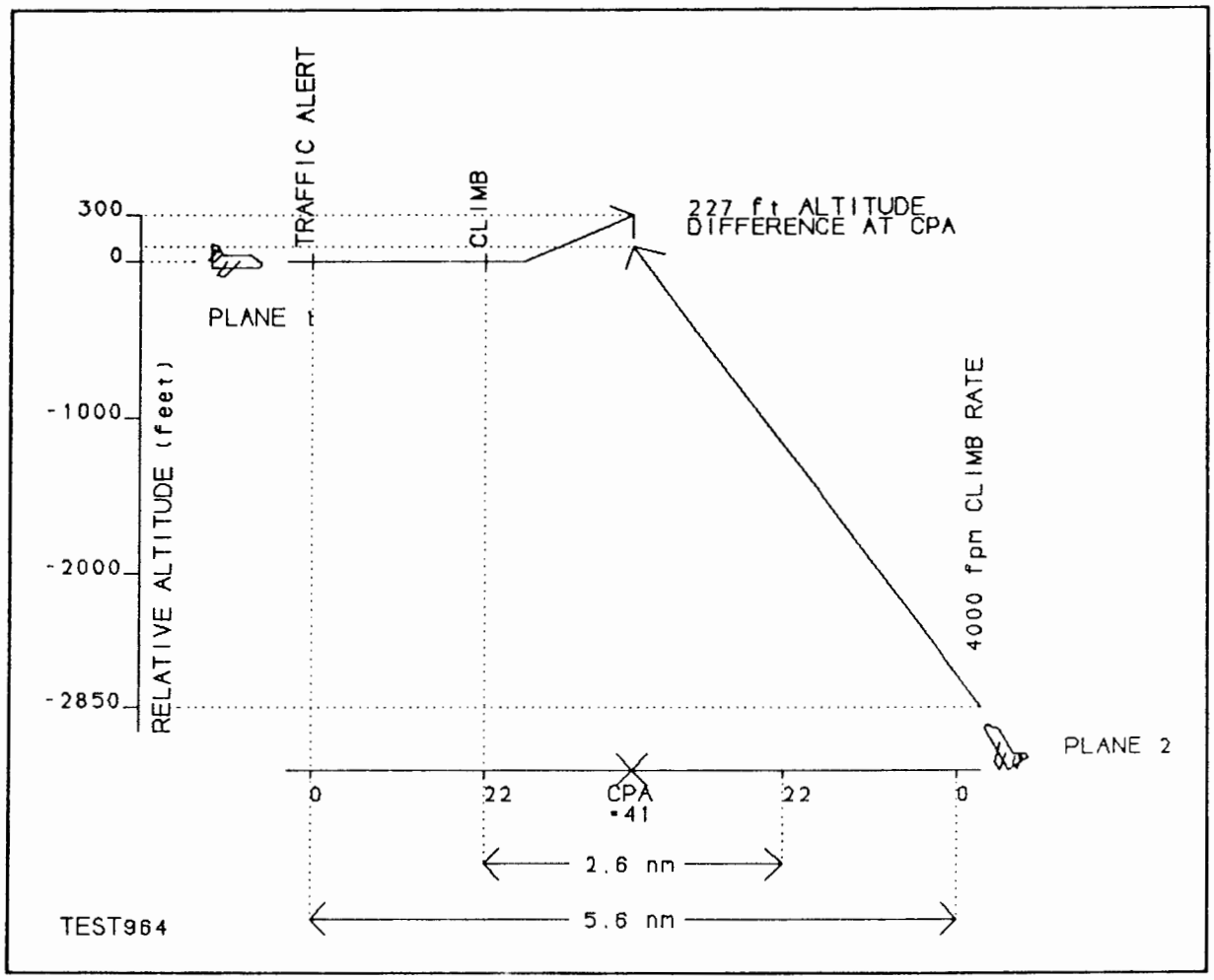
This encounter simulates the corner post situation at many airports. TCAS delays issuing an advisory due to the vertical threshold test (VTT) logic. The delay allows time for the TCAS tracker to detect the level-off, and eliminates the need for any RA.



ADDITIONAL FLIGHT INFORMATION:
- Encounter starting separation is 12 nmi.
- Encounter closing speed is 500 kts.
- Base altitude is above 10,000 ft.
- Intruder base is -3725 ft. and levels at -1000 ft.

Encounter 3
with version 6.04 logic

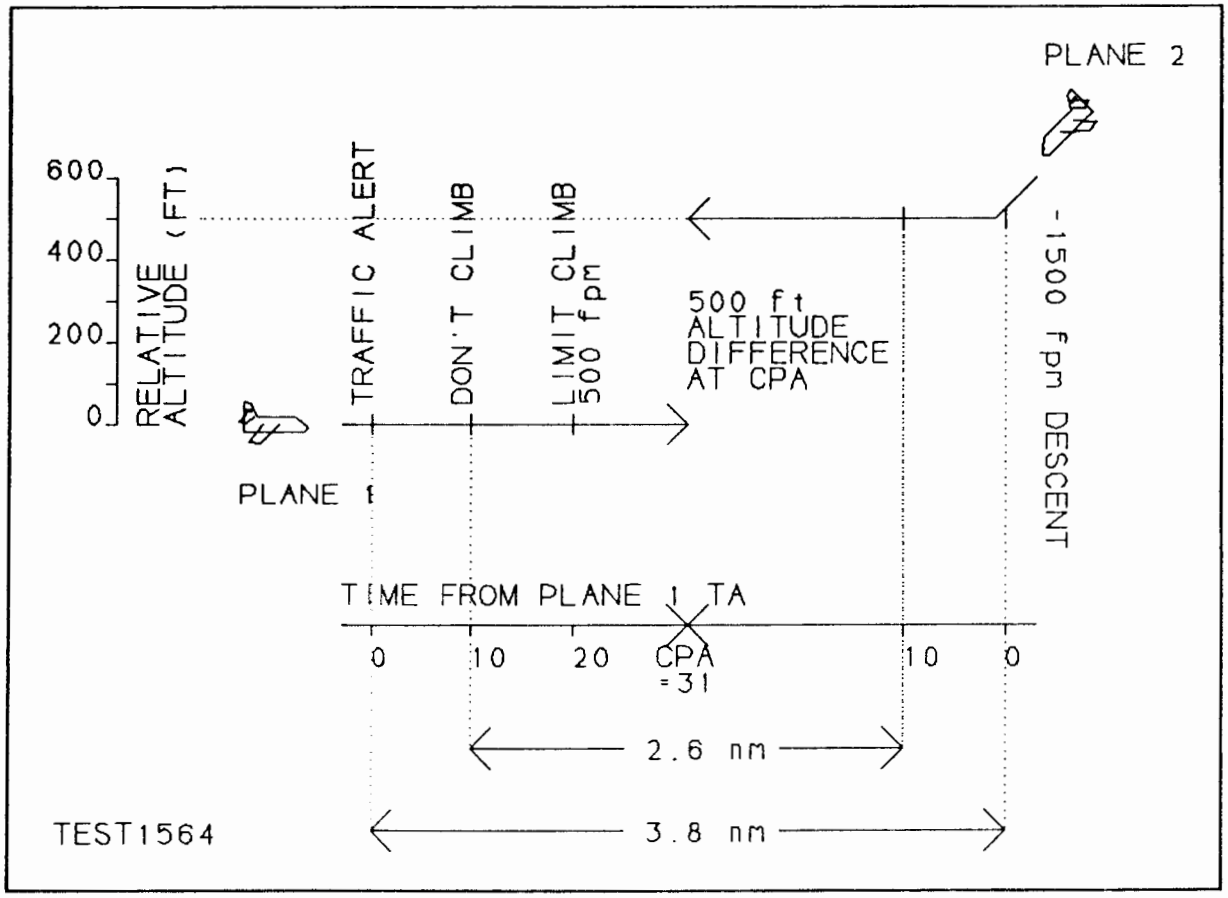
This encounter simulates a corner post situation gone wrong. The TCAS logic uses the VVT logic to delay the advisory in case of level-off. However, there is no level-off, and the delayed advisory provides less separation at CPA. (Note: This encounter would be a collision without TCAS and the horizontal safety offset.)



ADDITIONAL FLIGHT INFORMATION:
- Encounter starting separation is 12 nmi.
- Encounter closing speed is 500 kts.
- Base altitude is between 5,000 and 10,000 ft.
- Intruder base is -5743 ft.

Encounter 4
with version 6.04 logic

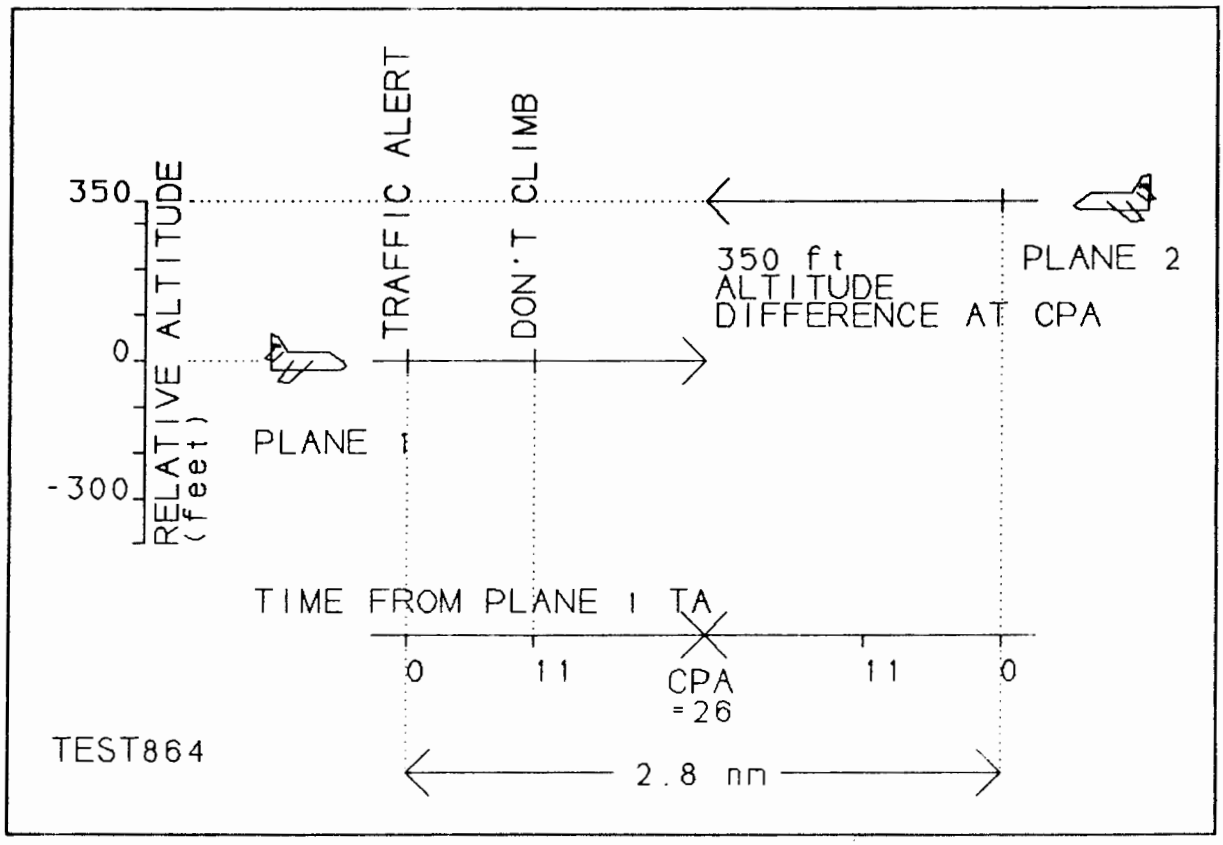
This encounter simulates a target levelling off to a legal separation at low altitude. The TA and RA are delayed by the new lower TAU values, allowing the tracker to detect the level-off. TCAS issues only a preventive advisory.



ADDITIONAL FLIGHT INFORMATION:
- Encounter starting separation is 12 nmi.
- Encounter closing speed is 460 kts.
- Base altitude is between 2350 ft AGL and 5,000 ft MSL.
- Intruder base is +2100 ft.

Encounter 5
with version 6.04 logic

The planes are flying at legal separations as far as ATC is concerned. The reduced TAU and ALIM values delay the TA and prevent a positive RA from being issued. (Note: The descend inhibit altitude is 1100 ft. A slight decrease in the relative altitudes would result in a positive RA.)



ADDITIONAL FLIGHT INFORMATION:
- Encounter starting separation is 12 nmi.
- Encounter closing speed is 400 kts.
- Base altitude is between 1100 ft and 2350 ft AGL.