technical note

Evaluation of En Route Host Computer System's Tactical Alert Processing

Simulation Results

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16. Abstract

The technical note is the fourth in a series of metric reports related to the En Route Automation Modernization Program's Surveillance Data Processing Function. This study's focus is on the performance of the tactical conflict alert function. This study applied metrics described in the third report to quantify the missed and nuisance detections of this tactical conflict probe. Two simulated scenarios of en route air traffic were developed in the Integration and Interoperability Facility. They were then applied to the legacy Host Computer System and tactical conflict alerts recorded. The results of the simulations using the legacy Host Computer System are presented in this report. Example aircraft conflicts are included.

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Executive Summary

The FAA's ERAM Test Group formed the Automation Metrics Test Working Group (AMTWG) in 2004. The team's charter is to support the developmental and operational testing of ERAM by developing a set of metrics that quantify the effectiveness of key system functions in ERAM. The targeted system functions are Surveillance Data Processing (SDP), Flight Data Processing (FDP), Conflict Probe Tool (CPT), and the Display System (DS) modules. The metrics are designed to measure the performance of ERAM. They also are designed to measure the performance of the legacy En Route automation systems in operation today. When appropriate, they will allow comparison of similar functionality in ERAM to legacy systems.

The project is divided into key phases: first a metrics identification process was performed. A list of approximately one hundred metrics was generated by the AMTWG and mapped to the Air Traffic services and capabilities found in the Blueprint for the National Airspace System Modernization 2002 Update. This took place mostly in fiscal year 2004 and initial metrics results were published in June 2004 in the document titled, "ERAM Automation Metrics Progress Report of the Automation Metrics Test Working Group" (WJHTC, 2003). Next, an implementation-planning phase was performed. In this step, the identified metrics were prioritized for more detailed refinement during 2005. The plan "ERAM Automation Metrics and Preliminary Test Implementation Plan," (WJHTC, 2005) documents the implementation-planning phase. It lists these metrics, gives the rational for selecting them, and provides a high level description on how the highest priority metrics will be measured.

The final project phase is the data collection and analysis phase. In this step, AMTWG will document the further refinement and application of these metrics on the current legacy systems in a series of Metric Reports. AMTWG is planning the delivery of four Metric Reports for fiscal years 2005 through 2007 covering several of the ERAM subsystems.

The current technical note is the fourth in a series of metric reports related to the ERAM's SDP function. The focus here is on the performance of the tactical conflict alert function. Detailed metrics to quantify the missed and nuisance detections of this tactical conflict probe were developed and reported in the third report (Paglione et al, 2006). Two simulations were developed and implemented in the Integration and Interoperability Facility using the Host Computer System (HCS). The methodology applied is described in the third report, but the numerical results are presented in this report. The legacy HCS's missed alerts rate, for timely alerts, was approximately 0.35 for both scenarios but reduced to 0.05 to 0.01 if the timeliness requirement was not considered. The false alert rate was the highest, as expected, for encounters which were close to being conflicts and dropped as the minimum separation distances became larger. The overall false alert rates were 0.60 and 0.56 for the two scenarios. A number of detailed examples illustrate the simulated flights and the processing applied to the data.

The objective is to develop statistics that provide a baseline of performance for the legacy Host tactical conflict probe that can later be referred to in the ERAM Testing Program for similar SDP functionality. This study like its predecessors provides a strong foundation to address the critical operational issue (COI 1.0), as documented in the FAA's *Test and Evaluation Master Plan* for ERAM. COI 1.0 requires the ERAM Test Program to verify that ERAM supports air traffic control operations with at least the same effectiveness as the current system. Furthermore, the tools and metrics developed can be used to verify the accuracy of the tools being used by the development contractor for the formal testing of SDP.

Table of Contents

1 INTRODUCTION 1

1.1 PURPOSE 1
1.2 BACKGROUND 1
1.3 SCOPE 2
1.4 DOCUMENT ORGANIZATION 3

2 SIMULATION VALIDATION 4

2.1 EVALUATION OF SIMULATION ERRORS 4
2.1.1 GSGT HCS Simulation Errors 5
2.1.2 GSGT/ERIT Simulation Errors 7
2.2 CONFLICT AND ENCOUNTER PROPERTIES 9

3 ANALYSIS RESULTS 12

3.1 ILLUSTRATION OF THE ANALYSIS PROCESSING 12
3.2 RESULTS FOR GSGT HCS SIMULATION 14
3.2.1 Scenario Counts 14
3.2.2 Performance Metric Values 15
3.2.2.1 Error Event Rates 15
3.2.2.2 Timeliness Metrics 18
3.2.3 Analysis of the Missed Alerts 19
3.2.3.1 Missed Alerts – No Notification Sets 19
3.2.3.2 Missed Alerts – With Notification Sets 20
3.2.3.3 Missed Alerts – Late 20
3.2.3.4 Missed Alerts - Discard 21
3.2.4 Analysis of False Alerts 21
3.2.5 Analysis of Valid Alerts 21
3.2.6 Analysis of Discards 22
3.2.6.1 False Alert No Track Discards 22
3.2.6.2 False Alert After Conflict Start Time Discard 22
3.2.6.3 False Alert Event Discard A 23
3.2.6.4 False Alert Event Discard B 23
3.3 RESULTS FOR GSGT/ERIT SIMULATION 24
3.3.1 Scenario Counts 24
3.3.2 Performance Metric Values 25
3.3.2.1 Error Event Rates 25
3.3.2.2 Timeliness Metrics 27
3.3.3 Analysis of the Missed Alerts 28
3.3.3.1 Missed Alerts – No Notification Sets 28
3.3.3.2 Missed Alerts – With Notification Sets 28
3.3.3.3 Missed Alerts - Late 30
3.3.3.4 Missed Alerts - Discard 30
3.3.4 Analysis of False Alerts 31
3.3.5 Analysis of Valid Alerts 31
3.3.6 Analysis of Discards 31
3.3.6.1 False Alerts No Track Discards 31
3.3.6.2 False Alert After Conflict Start Time Discard 32

3.3.6.3 False Alert Event Discard A 32
3.3.6.4 False Alert Event Discard B 32

4 SAMPLE EVENTS FROM SCENARIOS 33

4.1 VALID ALERT EXAMPLES 33
4.1.1 Valid Standard Example 33
4.1.1.1 Flight Description 33
4.1.1.2 Conflict Geometry 34
4.1.1.3 Analysis 36
4.1.2 Valid Late Example 36
4.1.2.1 Flight Description 36
4.1.2.2 Conflict Geometry 37
4.1.2.3 Analysis 38
4.2 MISSED ALERT EXAMPLES 39
4.2.1 Missed Standard Type A Example 39
4.2.1.1 Flight Description 39
4.2.1.2 Conflict Geometry 39
4.2.1.3 Analysis 42
4.2.2 Missed Late Example 42
4.2.2.1 Flight Description 42
4.2.2.2 Conflict Geometry 43
4.2.2.3 Analysis 44
4.3 FALSE ALERT EXAMPLES 45
4.3.1 False Alert Standard 1 Example 45
4.3.1.1 Flight Description 45
4.3.1.2 Encounter Geometry 45
4.3.1.3 Analysis 47
4.3.2 False Alert Event Discard B Example 48
4.3.2.1 Flight Description 48
4.3.2.2 Encounter Geometry 49
4.3.2.3 Analysis 50

5 CONCLUSION 51

6 LIST OF ACRONYMS/ABBREVIATIONS 53

7 LIST OF SELECTED AIRPORT IDENTIFIERS 55

8 REFERENCES 56

List of Figures

Figure 1: Illustration of Application of Trajectory Prediction Metrics to 4
Figure 2: Horizontal Errors 6
Figure 3: Vertical Error 6
Figure 4: Worse Case – Flight's Maximum Cross Track Error..... 6
Figure 5: Best Case – Flight's Median Cross Track Error 6
Figure 6: Worse Case – Flight's Maximum Vertical Error 7
Figure 7: Best Case – Flight's Median Vertical Error..... 7
Figure 8: Worse Case –Flight's Maximum Cross Track Error..... 8
Figure 9: Best Case – Flight's Median Cross Track Error 8
Figure 10: Worse Case – Flights Maximum Vertical Error 8
Figure 11: Best Case - Flight's Median Vertical Error 8
Figure 12: Illustration of Tactical Alert Processing 13
Figure 13: False Alert Rates for the GSGT Scenario 17
Figure 14: Warning Time Histogram of Valid Alerts for GSGT Scenario 18
Figure 15: False Alert Rates for the GSGT/ERIT Scenario 26
Figure 16: Warning Time Histogram for Valid Alerts of the GSGT/ERIT Scenario..... 27
Figure 17: Time Sequence of Track Data, Conflicts, and Notification Sets 29
Figure 18: Flight Paths of Flights CPAT01 and CPAT02..... 33
Figure 19: CPAT01 and CPAT02 at Start of Conflict..... 35
Figure 20: CPAT01 and CPAT02 at End of Conflict..... 35
Figure 21: Flight Paths of Flights CPAT21 and CPAT22..... 36
Figure 22: CPAT21 and CPAT22 at Start of Conflict..... 37
Figure 23: CPAT21 and CPAT22 at End of Conflict..... 38
Figure 24: Flight Paths of Flights CPAT11 and CPAT12..... 40
Figure 25: CPAT11 and CPAT12 at Start of Conflict..... 41
Figure 26: CPAT11 and CPAT12 at End of Conflict..... 41
Figure 27: Flight Paths of Flights CPAT31 and CPAT32..... 42
Figure 28: CPAT31 and CPAT32 at Start of Conflict..... 43
Figure 29: CPAT31 and CPAT32 at End of Conflict..... 44
Figure 30: Flight Paths of Flights CPAT41 and CPAT42..... 46
Figure 31: Encounter of Flights CPAT41 and CPAT42..... 47
Figure 32: Flight Paths of Flights CPAT51 and CPAT52..... 48
Figure 33: Encounter of Flights CPAT51 and CPAT52..... 49

List of Tables

Table 1: Conflict & Encounter Distributions for the GSGT HCS Scenario 10
Table 2: Conflict & Encounter Distributions for the GSGT/ERIT Scenario..... 11
Table 3: Time Sequence of Events for AIR1000_261 and AIR2000_944 14
Table 4: Event Count Summary for GSGT Scenario 15
Table 5: Detailed Event Count for GSGT Scenario 15
Table 6: False Alert Probabilities for GSGT Scenario 16
Table 7: Warning Time Counts of Valid Alerts for GSGT Scenario 19
Table 8: Missed Alert Conflicts 20
Table 9: Event Count Summary for GSGT/ERIT Scenario 24
Table 10: Detailed Event Count for GSGT/ERIT Scenario 25
Table 11: False Alert Rates for GSGT/ERIT Scenario 26
Table 12: Warning Time Counts for Valid Alerts of the GSGT/ERIT Scenario 27
Table 13: Missed Alert Conflict - No Notification Sets – GSGT/ERIT Scenario..... 28
Table 14: Time Sequence of Events for AIR1100_221 and AIR2100_116 30
Table 15: Conflict Prediction Results for Flights CPAT21 & CPAT22 39
Table 16: Conflict Prediction Results for Flights CPAT31 &CPAT32 45
Table 17: Encounter of Flights CPAT41 and CPAT42 46
Table 18: FA Extrapolations for CPAT41 and CPAT42 Encounter 48
Table 19: Encounter of Flights CPAT51 and CPAT52 50
Table 20: FA Extrapolations for CPAT51 and CPAT52 Encounter 50

1 Introduction

1.1 Purpose

The Federal Aviation Administration (FAA) is developing a new Air Traffic Control (ATC) system to replace the existing Host Computer System (HCS) in the en route domain. The Host system is used by all twenty en route ATC Centers in the continental United States. The new system, called ERAM (for En Route Automation Modernization), is being developed by the Lockheed Martin Corporation. As documented in the FAA's *Test and Evaluation Master Plan*, the ERAM Test Program is required to ensure key operational issues are verified (WJHTC/ACB-550, 2003). These issues are organized as "Critical Operational Issues" (COI's). The first critical operational issue (COI 1.0) requires that ERAM supports ATC operations with at least the same effectiveness as the current system. Therefore, the performance of the radar track subsystem in ERAM must be as good as the performance of the existing Host radar tracking. To determine this, a baseline performance of the Host is required to provide performance standards to later compare to ERAM.

This technical note documents the processing involved in measuring the performance of the Host Computer System (HCS) prediction of tactical aircraft-to-aircraft conflicts. A conflict is the loss of the minimum required aircraft separation which in en route airspace is five nautical miles and 1000 feet vertically.

This study is one of several being conducted by the Automation Metrics Test Working Group (AMTWG). The studies are described in the "ERAM Automation Metrics and Preliminary Test Implementation Plan," published in June 2005 (WJHTC/ACB-330, 2005).

The task has been documented in two reports. The first report (Paglione et al, 2006), defines the performance metrics and describes the methodology, this second report gives the results of the simulation study.

1.2 Background

The FAA's ERAM Test Group formed the Automation Metrics Test Working Group (AMTWG) in August 2003. The team's charter is to support the developmental and operational testing of ERAM by developing a set of metrics that quantify the effectiveness of key system functions in ERAM. The targeted system functions are Surveillance Data Processing (SDP), Flight Data Processing (FDP), Conflict Probe Tool (CPT), and the Display System (DS) modules. The metrics are designed to measure the performance of ERAM. They also are designed to measure the performance of the legacy En Route automation systems in operation today. Many of the metrics will allow comparison of the functionality in ERAM to similar functionality in the HCS and URET (User Request Evaluation Tool) legacy systems.

The project was divided into key phases: first a metrics identification process was performed. A list of approximately one hundred metrics was generated by the AMTWG and mapped to the Air Traffic services and capabilities found in the Blueprint for the National Airspace System Modernization 2002 Update (FAA, 2002). This took place most of Fiscal Year 2004 and initial metrics results were published in June 2004 in the document, "ERAM Automation Metrics Progress Report of the Automation Metrics Test Working Group" (WJHTC/ACB-550, 2004).

Next, an implementation-planning phase was performed. In this step, the identified metrics were prioritized for more detailed refinement during 2005 and 2006.

The report "ERAM Automation Metrics and Preliminary Test Implementation Plan," (WJHTC, 2005) documents the implementation-planning phase. It lists these metrics, gives the rational for selecting them, and provides a high level description on how the highest priority metrics will be measured. The Implementation Plan provides the metric's traceability to the basic controller decisions, ERAM Critical Operational Issues (COIs), and the development contractor's Technical Performance Measurements (TPMs). The categories of high priority metrics are: (1) SDP radar tracking, (2) SDP tactical alert processing, (3) FDP flight plan route expansion, (4) FDP aircraft trajectory generation, (5) CPT strategic aircraft-to-aircraft conflict prediction, (6) CPT aircraft-to-airspace conflict prediction, (7) additional system level metrics, and (8) DS human factor and performance metrics.

Currently the AMTWG is analyzing the performance of different aspects of the FAA's en route air traffic control system. The AMTWG is refining and then applying the previously defined metrics to the legacy systems. This work is being documented in a series of metric reports. Four metric reports are planned; one covering each of the ERAM modules discussed above, SDP, FDP, CPT, and DS. These reports are being published in multiple drops to provide the ERAM Test Team on-time information. The drops coincide with the approaches used to implement the metrics.

This technical note is the fourth in a series which document metrics for the SDP functions. It documents the processing accuracy of the HCS in predicting aircraft to aircraft conflicts. This study is similar to one performed previously on the accuracy of the User Request Evaluation Tool (URET) to predict strategic aircraft-to-aircraft conflicts (Cale et al, 1998).

1.3 Scope

A representative sample of en route air traffic was processed by the Host and the Host's tactical conflict alert performance measured. The sample or scenario of en route air traffic was recorded in March 2005 at the Washington ARTCC (ZDC). It contains approximately four hours of flight data and 1500 flights. The flight times were adjusted to create conflicts to be processed. This adjustment procedure is described in detail in (Paglione et al, 2003b). For the simulation approximately 160 conflicts were induced in the scenario above Flight Level 180. The performance of the Host is based on its ability to accurately predict these conflicts.

The simulation used the recorded and time shifted data to create simulated aircraft flights and simulated radar target reports for these flights. A second simulation used the recorded and time shifted data to create simulated aircraft flights but utilized recorded data directly for the radar target reports.

The ERAM A-Level requirements specify that all tactical conflict alerts be presented with a minimum warning time of 75 seconds and a maximum warning time of 135 seconds. This translates to a zero missed alert rate. The companion requirement specifies that the nuisance or false alarm rate remain at or below six percent. The details of how these requirements are measured are still being finalized between the FAA and the development contractor. This study may provide additional insights into how this can be accomplished.

The two evaluation scenarios were processed by the HCS at the Integration and Interoperability Facility (IIF) at the Wm. J. Hughes Technical Center (WJHTC). The data was collected and

analyzed by computer software tools developed by the Simulation and Analysis Group at the WJHTC. A first report (Paglione, 2006) describes the methodology employed in the study and a second report (this report) documents the results.

1.4 Document organization

This technical note is organized into the following primary sections. Section 2 describes the validation of the simulation, Section 3 gives the analysis results of the simulation, Section 4 presents a set of detailed flight examples, and Section 5 gives the summary and conclusions. These sections are followed by an acronym list, airport identifier list, and a list of references.

2 Simulation Validation

The two simulation runs (the GSGT and the GSGT/ERIT scenarios) were validated by evaluating the simulated radar tracks against the actual track reports recorded from the field. The simulations are driven by the Graphical Simulation Generation Tool (GSGT) which due to the nature of the sampling process and complexity of the modeling involved could create, on occasion, unrealistic flight paths. In general, the data was checked for outliers such as 1500 knot airspeeds, zero foot altitudes, and misbehavior such as uncharacteristically steep climbs and descents. The flaws in the simulations were corrected by tweaking some of the run time parameters, changing some aspect of the GSGT design, by fixing computer software bugs in the GSGT, or as a last resort, by deleting the erroneous flight from the scenario. Various software tools of the Simulation and Analysis Group were used to look for and find problems with the simulation data. Borrowing from a body of work studying the accuracy of aircraft trajectory predictions, the following Section 2.1 presents the methods used to examine the anomalies in the simulated positions. Section 2.1 provides statistics on both the GSGT HCS and GSGT/ERIT Simulation runs. These are reported in the sub-sections 2.1.1 and 2.1.2, respectively.

2.1 Evaluation of Simulation Errors

A common thread in most Decision Support Tools (DSTs) is the accurate and timely modeling of the aircraft's current state and anticipated future path. This function is referred to as the trajectory predictor (TP) process. The trajectory is the 4-dimensional path of the aircraft. It can either be the actual path that was flown or a prediction of the path to be flown. TP accuracy can be measured by post flight comparisons of predicted and observed aircraft trajectories. Since the predicted trajectory is the fundamental input that sustains the DST's capabilities and functions, the accuracy of the trajectory prediction has a direct impact on the DST's overall performance and usability.

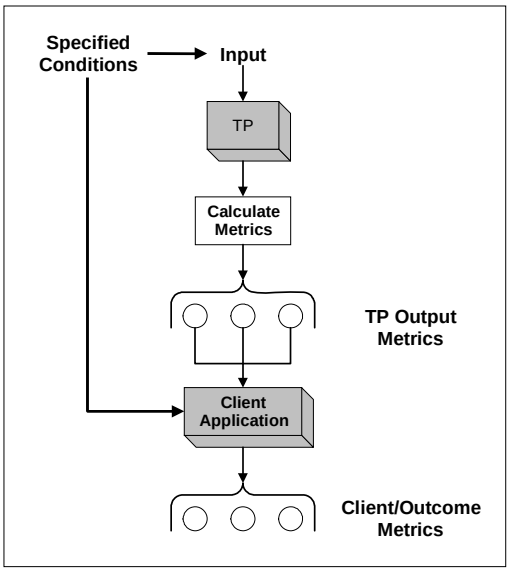

Figure 1: Illustration of Application of Trajectory Prediction Metrics to Higher Level Applications[1]

[1] Adapted from Figure 8 in (Mondoloni et al, 2005).

In order to attain the specified accuracy requirements of a DST, it is necessary to validate the DST's TP. (Paglione et al, 2005b) presents a TP validation methodology that can drive the performance of a TP toward a targeted level. (Mondoloni et al, 2005) defines the metrics used within this methodology and shows how these metrics can assess a TP's impact on a DST. Figure 1 summarizes this process graphically. The TP's performance is evaluated with metrics and driven by specified input conditions. The TP generates predictions that allow measurement of higher level DST functionality. The objective of trajectory accuracy measurement is the validation of the accuracy of the DST's TP. This process of validating a DST's TP is analogous to validating an aircraft simulator's TP.

Like a DST, the aircraft simulator is a TP as well. The overall objective of this study is to evaluate not the simulator but the HCS that the simulator is driving. If the aircraft paths generated by the aircraft simulator are inaccurate or deviate sufficiently from how an aircraft really flies, then the result could confound the study of the HCS. Therefore, to ensure the trajectories generated by the simulator are valid, the simulator aircraft positions were compared to the actual recorded surveillance data. The process utilized a set of software tools used for validating a DST's TP, called TrajTools, described in (Paglione, 1999a) and (Cale et al, 2001). These post analysis tools are input with the aircraft ground truth positions (e.g. radar track data) and the 4-dimensional aircraft trajectory positions. The tool then compares them using a sampling method, resulting in a table of metrics per flight per sample point.

For analysis of the simulations, first a special software program was developed that modified the format of the original actual flight path positions to look like aircraft trajectory predictions and simulator positions as ground truth track positions[2]. Next, the TrajTools were run to calculate the various trajectory errors. These errors, as defined in detail in (Cale et al, 2001) and (Ryan, 2004), are focused mainly on two key metrics: cross track error, which defines the spatially coincident side-to-side prediction error illustrated in Figure 2, and the vertical error, which defines the time coincident difference in predicted versus actual altitude illustrated in Figure 3. Finally, the metrics are applied using the Interval Based Sampling Technique (IBST) defined in (Cale et al, 2001) and the maximum error per flight per metric is calculated. Flights that have any one of these metrics exhibiting a maximum error above a defined threshold are removed from the study. This method ensures a level of confidence in that the remaining flights are at most a specified distance from the original flight's path.

For both sets of simulations, the threshold used for the cross track errors was 2.5 nautical miles and altitude error was a maximum of 1000 feet. The following sub-sections will highlight the resulting distributions of these errors per simulation run.

2.1.1 GSGT HCS Simulation Errors

As discussed previously for the GSGT HCS Simulation, several error metrics were calculated, but the focus of this study is the cross track and vertical errors. The true original position of the aircraft, as indicated in footnote 2, is formatted to represent the trajectory prediction and the simulated tracks as the surveillance position. For each flight, its original ground track trajectory is sampled against the simulated positions of the aircraft. This produces over 86,000 measurements for 1,186 flights. The results are stored in a relational database and queried via Structured Query Language (SQL), utilizing an off-the-shelf statistical package called JMP[3]. For each flight both the maximum and median unsigned error was calculated from all the

[2] The analysis could have easily considered the simulator output as trajectory predictions and the original track positions as track positions. Either approach is reasonable.
[3] JMP is a commercial product developed by SAS Institute, see http://www.jmp.com/ for details.

measurements taken for each metric, cross track and vertical error. The worst possible performance is captured in the maximum statistic due to its sensitivity to outliers. The best is represented by the median due its lack of sensitivity to outliers.

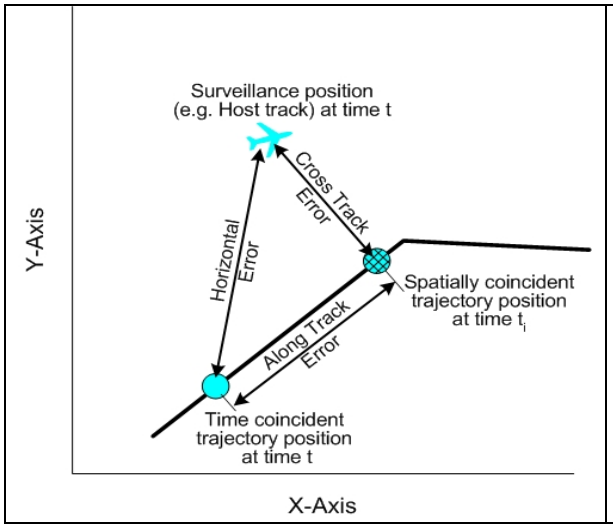

Figure 2: Horizontal Errors

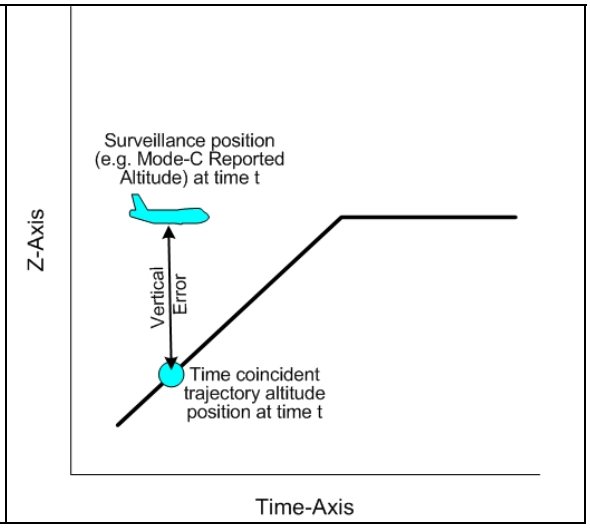

Figure 3: Vertical Error

For this study of the GSGT simulated position, after eliminating several hundred flights that had maximum cross track errors above the upper threshold (2.5 nm), the following Figure 4 illustrates the distribution of these errors. Unfortunately a faulty processing step caused exactly four flights to remain that had maximum errors above the 2.5 nautical miles (still generally below 3.5 nm), explaining the tail of the distribution in Figure 4[4]. The maximum cross track error per flight peaks around 0.75 to 1 nautical mile.

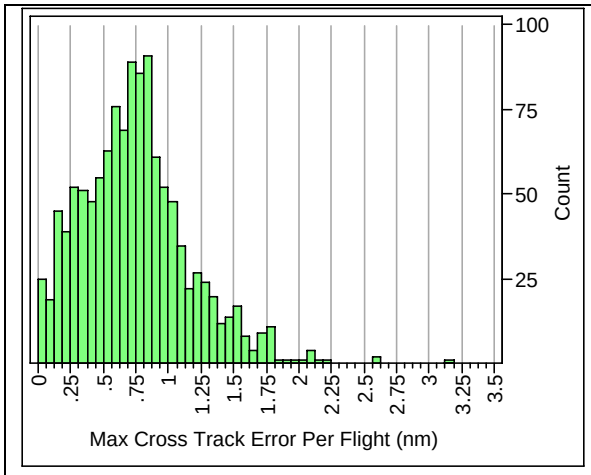

Figure 4: Worse Case – Flight's Maximum Cross Track Error

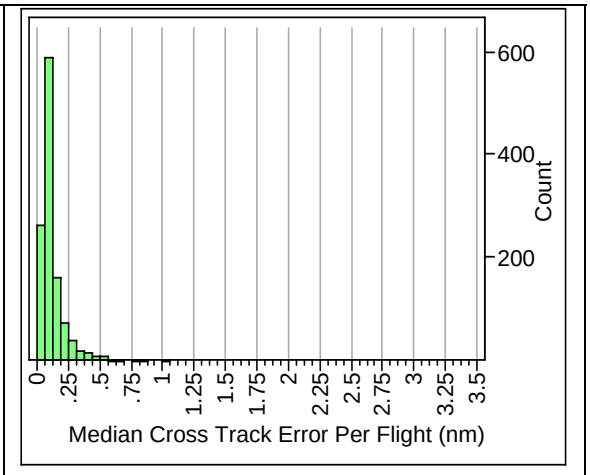

Figure 5: Best Case – Flight's Median Cross Track Error

[4] It was concluded that inclusion of these four flights would not significantly effect the overall results.

The performance is significantly better when looking at the median statistic for each flight. In Figure 5, the median distribution is highly skewed to the left and peaks between 0 to 0.1 nautical miles. Thus, the central tendency of the cross track error for the remaining 1186 flights is relatively low.

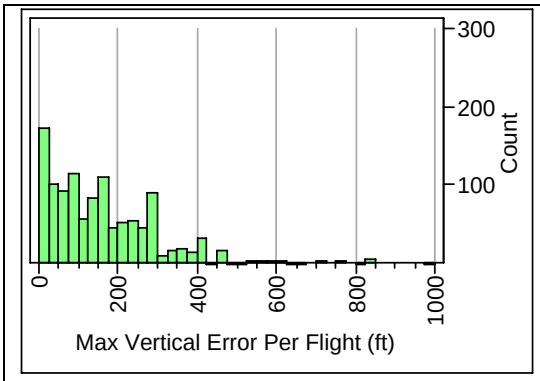

Figure 6: Worse Case – Flight's Maximum Vertical Error

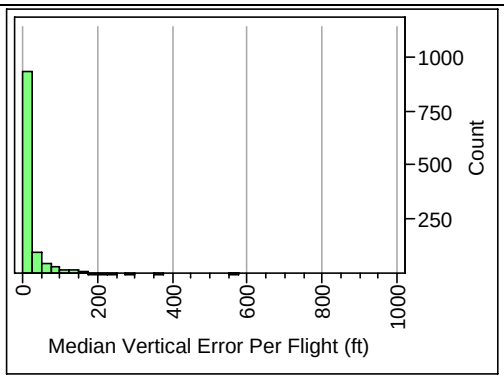

Figure 7: Best Case – Flight's Median Vertical Error

In Figure 6, the maximum unsigned vertical error was calculated for each flight. As in the horizontal dimension, flights that were above a maximum vertical threshold (1000 feet) were dropped. Unfortunately the same processing error as in the horizontal dimension discussed previously, caused eight flights to remain above the threshold. In Figure 7, the median for unsigned vertical error, like the cross track error, is highly skewed to the left and peaked significantly at zero.

Overall, after reviewing these statistics and eliminating flights above the upper threshold, the authors of this study are confident that the flights simulated by GSGT followed the original trajectory paths fairly well.

2.1.2 GSGT/ERIT Simulation Errors

Analogous to the GSGT HCS Simulation, the cross track and vertical errors were calculated for the GSGT/ERIT Simulation. The true original position of the aircraft, as indicated in footnote 2, is formatted to represent the trajectory prediction and the simulated tracks sampled from recorded radar from the ERIT system as the surveillance position. For each flight, its original ground track trajectory is sampled against the simulated positions of the aircraft. This produces over 66,000 measurements for 928 flights. Once again, the results are stored in a relational database and queried via SQL, utilizing the JMP statistical package. For each flight both the maximum and median unsigned error was calculated from all the measurements taken for each metric, cross track and vertical error. The worst possible performance is captured in the maximum statistic due to its sensitivity to outliers. The best is represented by the median due its lack of sensitivity to outliers.

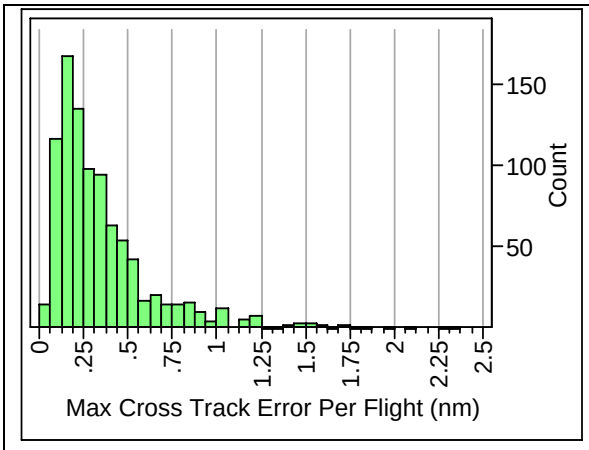

Figure 8: Worse Case –Flight's Maximum Cross Track Error

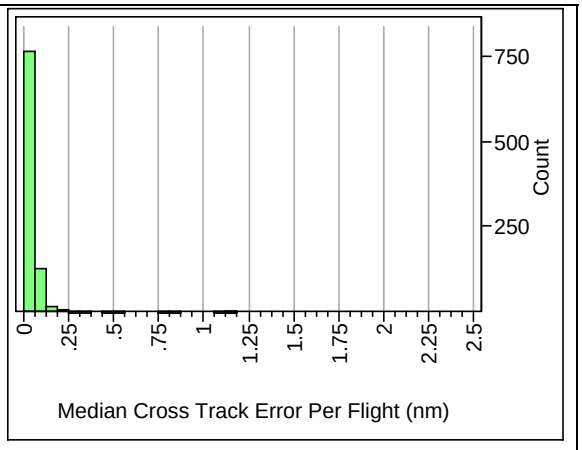

Figure 9: Best Case – Flight's Median Cross Track Error

For this study of the GSGT/ERIT simulated position, after eliminating several hundred flights that had maximum cross track errors above the upper threshold (2.5 nm), the Figure 8 above illustrates the distribution of the remaining flight's errors. The maximum cross track error peaks around 0.20 to 0.25 nautical miles. Figure 9 above illustrates the best case results per flight as well. The peak of the meadian cross track error per flight is much smaller with a peak from 0.0 to 0.05 nautical miles.

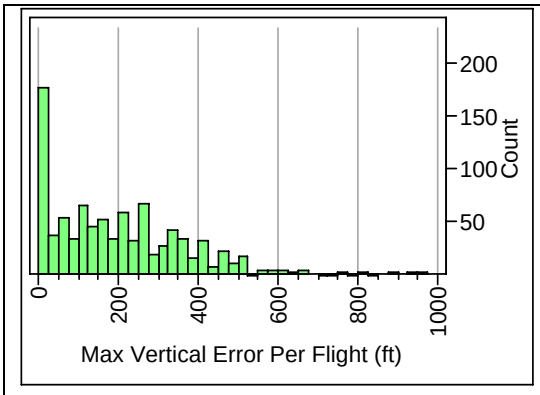

Figure 10: Worse Case – Flights Maximum Vertical Error

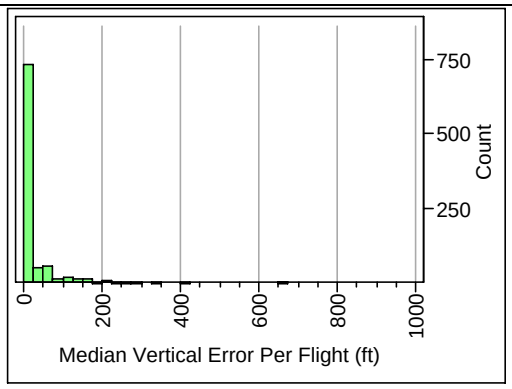

Figure 11: Best Case - Flight's Median Vertical Error

In Figure 10, the maximum unsigned vertical error was calculated for each flight. As in the horizontal dimension, flights that were above a maximum vertical threshold (1000 feet) were dropped. Unfortunately the same processing error that occurred in the GSGT HCS simulation discussed previously, caused two flights to remain above the vertical threshold. In Figure 11, the median for unsigned vertical error, like the cross track error, is highly skewed to the left and peaked significantly at zero.

Overall, after reviewing these statistics and eliminating flights above the upper threshold, the authors of this study are confident that the flights simulated by GSGT from ERIT radar followed the original trajectory paths fairly well.

2.2 Conflict and Encounter Properties

A sample of real air traffic recorded after intervention by Controllers has very few if any conflicts to be used as test data. The flight times in the data recorded at ZDC were shifted by the tools of the Simulation and Analysis Group to produce conflicts using a method described in (Paglione, et al, 2003b). The GSGT scenario had 126 aircraft to aircraft conflicts above Flight Level 180 and the GSGT/ERIT scenario had 93 conflicts. The process used to induce the conflicts within the simulation attempts to generate a set of conflicts and non-conflict events (referred to as encounters) with certain characteristics or properties. Some of these properties and their quantities are listed in the following tables for the both scenarios.

Table 1 contains the conflict and encounter property counts for the GSGT HCS Simulation run and Table 2 for the GSGT ERIT run. As defined in (Paglione et al, 2006), aircraft to aircraft conflicts are violations of legal separation distances[5]. In the en route airspace, aircraft must be simultaneously separated by less than five nautical miles horizontally and by less than 1000 feet vertically to be considered conflicts by air traffic control. The 1000 foot vertical separation is valid above Flight Level (FL) 290 only for Reduced Vertical Separation Minima (RVSM) certified aircraft; otherwise the minimum vertical separation is 2000 feet. Encounters include the aircraft to aircraft events that are non-conflicts within larger maximum separation distances. For the counts within this section, these were specified at simultaneously less than 25 nautical miles horizontally and less than 5000 feet vertically.

The other conflict and encounter properties are the counts for minimum horizontal separation. For conflicts, this includes 0 to 5 nautical miles but for encounters from 0 to 25 nautical miles. Vertically for conflicts, the bins range from 0 to 2000 feet and for encounters 0 to 5000 feet. Encounter angle is the relative angle between the aircraft's course headings at the minimum horizontal separation. Table 1 and Table 2 have these counts ranging from 0 to 180 degrees, in-trail to head-on, respectively. Phase of flight is the aircraft pair's vertical phase of flight combination at the minimum horizontal separation. This includes both aircraft level, one aircraft level while the other is transitioning (i.e. climbing or descending), and both aircraft transitioning. The distribution of these conflict and encounter properties give insight into the events the conflict probe needs to correctly predict or not predict. Other properties can also be examined such as conflict duration, horizontal phase of flight, flight level, etc. The focus for this study was simply to provide a mix of conflict and encounter properties in the categories listed in Table 1 and Table 2. The methodology is described in detail in (Paglione et al, 2003b).

[5] Again, these are pseudo conflicts induced by the simulation through time-shifting operational recordings of actual flights.

Table 1: Conflict & Encounter Distributions for the GSGT HCS Scenario

	GSGT HCS Scenario			
	Number of Conflicts	126	**Number of Encounters**	7539
Horizontal Separation	**0 to 1 nm**	33 26.19%	**0 to 5 nm**	1407 18.66%
	1 to 2 nm	33 26.19%	**5 to 10 nm**	1250 16.58%
	2 to 3 nm	24 19.05%	**10 to 15 nm**	1377 18.27%
	3 to 4 nm	21 16.67%	**15 to 20 nm**	1588 21.06%
	4 to 5 nm	15 11.90%	**20 to 25 nm**	1917 25.43%
Vertical Separation	**0 to 500 ft**	111 88.10%	**0 to 1000 ft**	2355 31.24%
	500 to 1000 ft	15 11.90%	**1000 to 2000 ft**	1289 17.10%
	1000 to 1500 ft	0 0.00%	**2000 to 3000 ft**	588 7.80%
	1500 to 2000 ft	0 0.00%	**3000 to 4000 ft**	1110 14.72%
			4000 to 5000 ft	442 5.86%
Encounter Angle	**0º to 45º**	100 79.37%	**0º to 45º**	1714 22.74%
	45º to 90º	12 9.52%	**45º to 90º**	500 6.63%
	90º to 135º	1 0.79%	**90º to 135º**	692 9.18%
	135º to 180º	13 10.32%	**135º to 180º**	4633 61.45%
Phase of Flight	**Level-Level**	33 26.19%	**Level-Level**	3690 48.95%
	Level-Trans	69 54.76%	**Level-Trans**	2949 39.12%
	Trans-Trans	24 19.05%	**Trans-Trans**	900 11.94%

Table 2: Conflict & Encounter Distributions for the GSGT/ERIT Scenario

	GSGT/ERIT Scenario			
	Number of Conflicts	93	**Number of Encounters**	5572
Horizontal Separation	**0 to 1 nm**	25 26.88%	**0 to 5 nm**	1075 19.29%
	1 to 2 nm	24 25.81%	**5 to 10 nm**	889 15.95%
	2 to 3 nm	15 16.13%	**10 to 15 nm**	1052 18.88%
	3 to 4 nm	14 15.05%	**15 to 20 nm**	1194 21.43%
	4 to 5 nm	15 16.13%	**20 to 25 nm**	1362 24.44%
Vertical Separation	**0 to 500 ft**	84 90.32%	**0 to 1000 ft**	1577 28.30%
	500 to 1000 ft	9 9.68%	**1000 to 2000 ft**	958 17.19%
	1000 to 1500 ft	0 0.00%	**2000 to 3000 ft**	478 8.58%
	1500 to 2000 ft	0 0.00%	**3000 to 4000 ft**	809 14.52%
			4000 to 5000 ft	395 7.09%
Encounter Angle	**0º to 45º**	76 81.72%	**0º to 45º**	1508 27.06%
	45º to 90º	6 6.45%	**45º to 90º**	364 6.53%
	90º to 135º	2 2.15%	**90º to 135º**	406 7.29%
	135º to 180º	9 9.68%	**135º to 180º**	3294 59.12%
Phase of Flight	**Level-Level**	31 33.33%	**Level-Level**	2825 50.70%
	Level-Trans	45 48.39%	**Level-Trans**	2069 37.13%
	Trans-Trans	17 18.28%	**Trans-Trans**	678 12.17%

3 Analysis Results

This section provides the numerical results of the study of HCS tactical alert processing. These results are based on simulation runs of time shifted field recorded air traffic data in the IIF Lab using the HCS. Future studies will be applied to the ERAM system.

Two simulations were run. The first used the GSGT to simulate both the radar report messages and the non-radar flight messages such as flight plan messages for the aircraft flights in the scenario. The second used recorded radar data to simulate the radar reports and the GSGT to simulate non-radar messages. The radar target data was recorded in the field by the En route Radar Intelligent Tool (ERIT). The first simulation run is referred to as the GSGT scenario and the second as the GSGT/ERIT scenario.

The results are divided into two main areas: overall statistics and sample events. The overall statistics provide the overall error counts and measures[6]. These metrics will be used for the future study on the ERAM system as well. The sample events provide detailed documentation on selected events exhibiting the conflict prediction errors being quantified. They provide a detailed walk through of the errors the metrics are measuring and highlight the complexity of the analysis rules being applied.

The analysis results illustrate the analysis, show the types of errors being measured, and provide a performance baseline for evaluating ERAM.

3.1 Illustration of the Analysis Processing

A pair of aircraft in conflict has been selected to illustrate the processing of the simulation data. The data is shown graphically in Figure 12. The abscissa in the figure is the time line for (1) the aircraft tracks, (2) the aircraft to aircraft conflicts, and (3) the Notification Sets. The events, MA_LATE et cetera are generated by the combination of the conflicts and the Notification Sets. The times of the elements in the diagram of Figure 12 are listed in time sequence in Table 3 .

Both aircraft are descending and converge to the same route. There are no gaps in the track data. There are four conflicts and six alerts for this pair resulting in seven events. The seven events generated are one VA_LATE, two MA_LATE, one MA_STD_A, and three DISCARD. Two of the alerts occur after the end of the track data for the aircraft and are discarded. They are not shown on the figure. Three of the conflicts (C1, C2 and C4) are bracketed by Notification Sets (NS1, NS2, and NS4). The actual warning times are 55, 17, and 31 seconds and the minimum warning time requirements for the three conflicts are 70, 40, and 30 seconds. Therefore the first two conflicts are MA_LATE events and the third conflict is VA_LATE. The remaining alert (NS3) occurs 15 seconds after the start of the other conflict (C3) and therefore the conflict/alert combination is labeled FA_ACST_DISCARD. The alert is discarded and the conflict, for which there is no Notification Set posted at the time of the start of the conflict, is labeled as missed (MA_STD_A). This last conflict has a short duration of approximately 10 seconds.

[6] The counts and measures have been defined in Equation 2 and Equation 3 in (Paglione et al 2006).

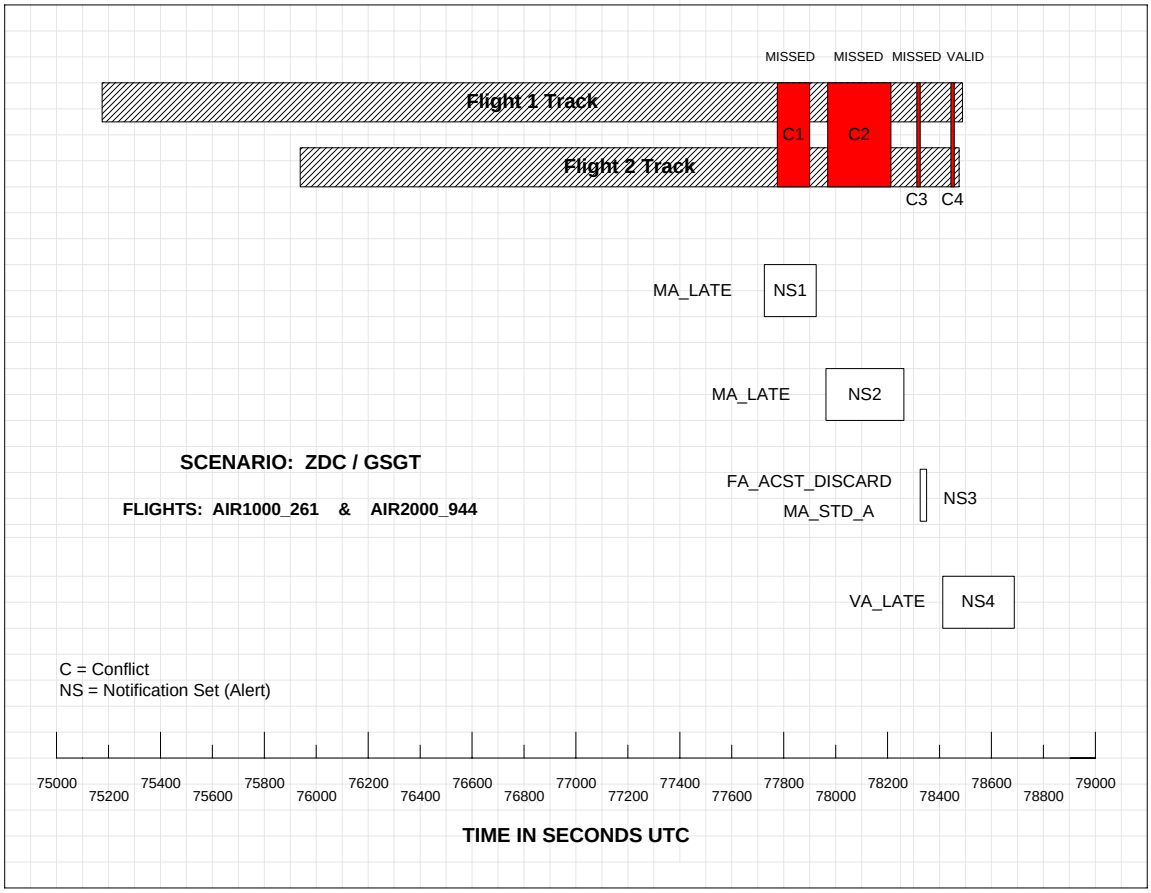

Figure 12: Illustration of Tactical Alert Processing

Table 3: Time Sequence of Events for AIR1000_261 and AIR2000_944

INDEX	TIME IN SECONDS UTC	TIME IN HH:MM:SS UTC	EXPLANATION
1	75180	20:53:00	Start of track for AC1
2	75950	21:05:50	Start of track for AC2
3	77725	21:35:25	NS 1 posted
4	77780	21:36:20	Start of Conflict 1
5	77900	21:38:20	End of Conflict 1
6	77917	21:38:37	NS 1 withdrawn
7	77953	21:39:13	NS 2 posted
8	77970	21:39:30	Start of Conflict 2
9	78210	21:43:30	End of Conflict 2
10	78253	21:44:13	NS 2 withdrawn
11	78310	21:45:10	Start of Conflict 3
12	78320	21:45:20	End of Conflict 3
13	78325	21:45:25	NS 3 posted
14	78349	21:45:49	NS 3 withdrawn
15	78409	21:46:49	NS 4 posted
16	78440	21:47:20	Start of Conflict 4
17	78450	21:47:30	End of Conflict 4
18	78470	21:47:50	End of track for AC2
19	78480	21:48:00	End of track for AC1
20	78685	21:51:25	NS 4 withdrawn

3.2 Results for GSGT HCS Simulation

This section provides results for the GSGT simulation. The real time simulation provides sets of different events – encounters, conflicts, and alerts. These events and their combinations are counted to calculate the metrics which define the performance of the Air Traffic Control system under test on the selected test scenario, the Host Computer System in this case. The next section gives the basic counts from the GSGT scenario simulation. The following sections go into the detail of the events.

3.2.1 Scenario Counts

In the GSGT simulation run, 1106 aircraft were run in the IIF Laboratory using the GSGT simulator to drive the operational HCS within the Lab[7]. The flights were time shifted as described in (Paglione et al, 2003b). The time shifting created 13868 encounter pairs at simultaneous separations less than 40 nautical miles and 8000 feet. 109 of the aircraft pairs had one or more embedded conflicts making a total of 126 aircraft-to-aircraft conflicts. A few of the encounters contain multiple conflicts. One pair had four conflicts, one pair had three conflicts, and twelve pairs had two conflicts. 13759 of the encounters did not result in any conflict. The properties of these conflicts and encounters were presented earlier in Section 2.2. The simulation ran for approximately 4 hours and 8 minutes.

[7] The count of 1106 aircraft does not exactly match the aircraft count listed in Section 2.1.1 due to the additional processing involved, but it is the same flight data.

For this simulation, 14757 conflict alert records were recorded and processed. From these records, 1710 Notification Sets were produced. The processing matched the alerts to the conflicts. After the matching is done there are left over conflicts which had no matching alerts and left over alerts which had no matching conflicts. As mentioned previously any alerts or conflicts below Flight Level 180 were discarded. The processing produced a list of 1726 events to count. There are four main categories of events, described in (Paglione et al, 2006). The counts for these four categories are given in Table 4. As previously described, these four categories have been further subdivided into a total of sixteen categories. The counts for these finer categories are given in Table 5.

Table 4: Event Count Summary for GSGT Scenario

ALERT TYPE	ALERT COUNT
VALID	82
MISSED	44
FALSE	168
DISCARD	1432

Table 5: Detailed Event Count for GSGT Scenario

INDEX	ALERT TYPE	REASON CODE	COUNT
1	VALID	VA_STD	60
2	VALID	VA_LATE	22
3	MISSED	MA_STD_A	14
4	MISSED	MA_STD_B	1
5	MISSED	MA_LATE	29
6	FALSE	FA_STD1	118
7	FALSE	FA_STD2_A	14
8	FALSE	FA_STD2_B	36
9	FALSE	FA_STD3	0
10	DISCARD	MA_DISCARD	0
11	DISCARD	FA_NOTRK_DISCARD1	880
12	DISCARD	FA_NOTRK_DISCARD2	511
13	DISCARD	FA_NOTRK_DISCARD3	4
14	DISCARD	FA_ACST_DISCARD	10
15	DISCARD	FA_EVENT_DISCARD_A	13
16	DISCARD	FA_EVENT_DISCARD_B	14

3.2.2 Performance Metric Values

This section calculates the performance metrics for the scenario described in Section 2.1 in (Paglione et al, 2006).

3.2.2.1 Error Event Rates

The counts produced by the simulation are turned into rates, or estimates of performance probabilities, by dividing them by the appropriate denominator.

3.2.2.1.1 Missed Alert Rate

The missed alert rate has been defined in (Paglione et al, 2006) in Equations 2 and 3. This number quantifies how often the HCS tactical conflict probe does not correctly predict an aircraft-to-aircraft conflict when it does occur.

$$R_{MA} = MA / C = MA / (MA + VA) = 44 / (44 + 82) = 44 / 126 = 0.349$$

where R_{MA} is the missed alert rate, MA is the number of missed conflicts, C is the number of conflicts, and VA is the number of conflicts correctly alerted.

3.2.2.1.2 False Alert Rate – Overall

The false alert rate counts how often the Controller is alerted to a conflict when in fact no conflict occurs. Using Equations 10 and 11 in (Paglione et al, 2006)

$$R_{FA} = FA / A = FA / (FA + VA + MA_LATE) = 168 / (168 + 82 + 29) = 168 / 279 = 0.602$$

where R_{FA} is the false alert rate, FA is the number of alerts which are false, A is the total number of alerts, MA_LATE is the number of conflicts that have been labeled missed because they are late (less than 75 seconds warning time), and VA is number of valid alerts defined above.

A more detailed analysis of the false alerts can be obtained by categorizing the alerts in terms of how close the aircraft came together. The closest point of approach of two aircraft is measured by the min_max factor ρ_m, defined in (Paglione et al, 2006).

Table 6: False Alert Probabilities for GSGT Scenario

BIN NUMBER	MAX_MIN_RATIO RANGE	ENCOUNTER COUNT	FALSE ALERT COUNT	RATE
1	$0 <= \rho_m < 1$	115	28	0.243
2	$1 <= \rho_m < 2$	814	95	0.117
3	$2 <= \rho_m < 3$	887	22	0.0248
4	$3 <= \rho_m < 4$	1775	13	0.00732
5	$4 <= \rho_m < 5$	1777	5	0.00281
6	$5 <= \rho_m < 6$	2632	2	0.000764
7	$6 <= \rho_m < 7$	2617	2	0.000764
8	$7 <= \rho_m < 8$	3215	1	0.000311
9	$8 <= \rho_m$	0	0	0.000000

3.2.2.1.3 False Alert Rate – By ρ_m Value

The false alert rate is expected to be the highest when the aircraft are almost in conflict but not quite and to be quite low when the aircraft are widely separated. The actual behavior of the tactical alert processing for increasing aircraft separation is illustrated in the following table.

In the table the encounters have been subdivided into near encounters and far encounters in between encounters. This has been done using the min_max_ratio (defined in (Paglione et al, 2006). The following table gives the false alert counts and probabilities for the encounters in the scenario.

Note that no encounters with a ρ_m >= 8 are counted. That is, if the value of ρ_m is greater than 8, by definition the aircraft do not have an encounter. A ρ_m value of 8 means the two aircraft were never simultaneously closer than 40 nautical miles and 8,000 feet. Note also that there are no alerts for any aircraft pairs at such a large separation.

The bin values in Table 6 are plotted in the following histogram - Figure 13.

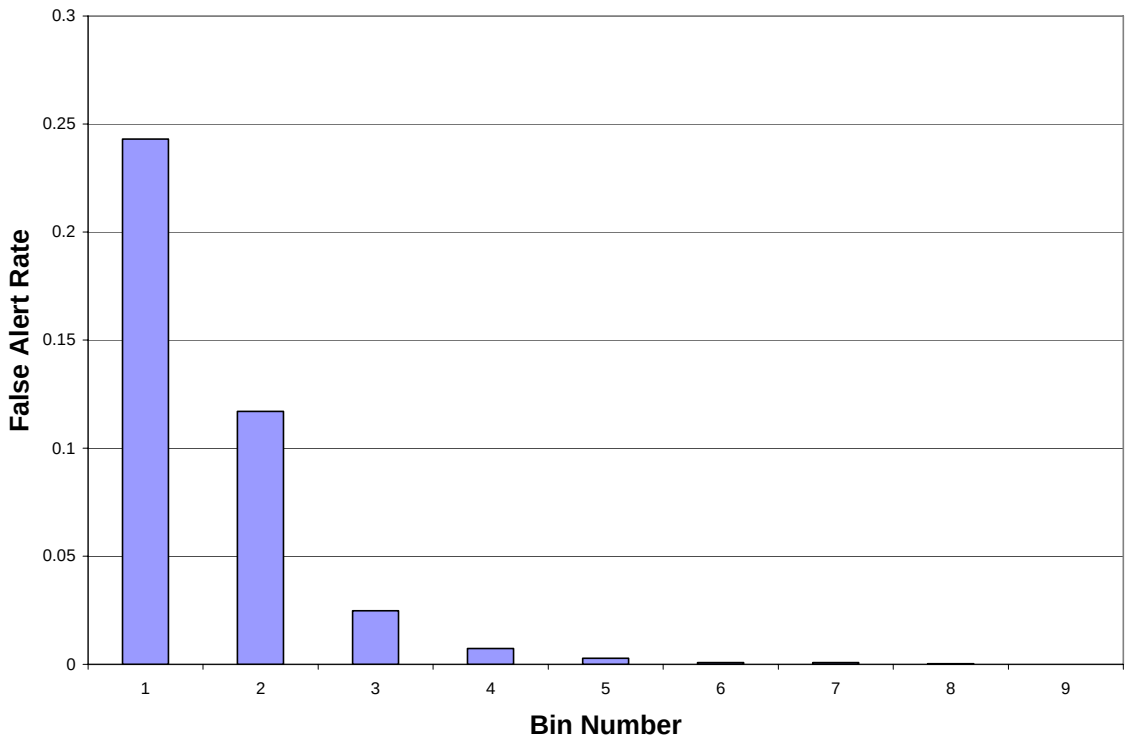

Figure 13: False Alert Rates for the GSGT Scenario

3.2.2.1.3.1 False Alerts for $\rho_m < 1$

An alert is false only if there is no conflict. In general, a value of ρ_m less than one means there is a conflict for the two aircraft; a value of ρ_m greater than or equal to one means there is no conflict between the aircraft. Now, in our processing there are two exceptions to this definition. An alert that is posted before a conflict and then withdrawn before the conflict starts is counted as a false alert even though the conflict did occur later in the flight. Similarly an alert posted after a conflict began is counted as a false alert. It is discarded if posted immediately after the start of the conflict. The second exception involves short duration conflicts. If two aircraft tracks have only one track position report where ρ is less than one, there is no conflict even though ρ is less than one. A minimum of two contiguous track position reports, which have a ρ less than one, is required for a conflict. In the GSGT scenario there are six conflict free encounters which have

ρ_m less than one. As a result of these two factors there are 28 (see Table 6) false alerts for aircraft pairs which have conflicts making ρ_m less than one.

3.2.2.2 Timeliness Metrics

It is required that a tactical alert be posted more than 75 seconds and less than 135 seconds before the start of the conflict. The 75 seconds requirement is relaxed when a conflict in the simulation scenario starts soon after the start of the aircraft track position reports or after gaps in the track data. There are 126 conflicts in the scenario. 15 conflicts are missed and 111 conflicts are predicted but 29 of these are predicted too late. As is listed in the table above 60 alerts (VA_STD) precede the start of the conflict by more than 75 seconds; 22 alerts (VA_LATE) precede the conflict by less than 75 seconds but by more than the adjusted minimum warning time requirement; and 29 alerts (MA_LATE) precede the start of the conflict by less than the adjusted minimum warning time requirement. 12 alerts precede the start of the conflict by more than 135 seconds.

A histogram showing the conflict warning times is given in the following Figure 14. The counts in terms of quantiles and moments are given in Table 7.

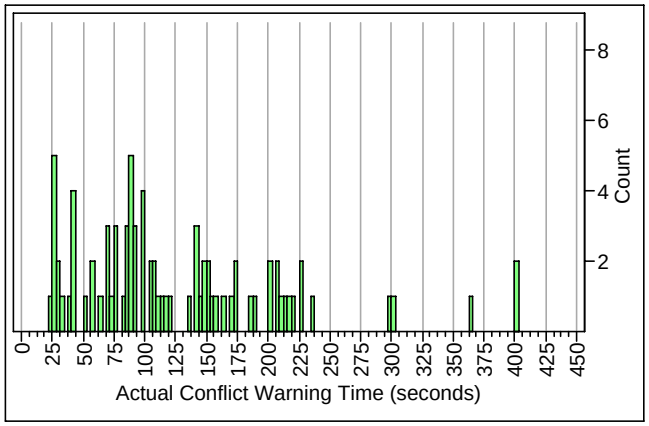

Figure 14: Warning Time Histogram of Valid Alerts for GSGT Scenario

Table 7: Warning Time Counts of Valid Alerts for GSGT Scenario

Quantiles (seconds)

100.0%	Maximum	403.00
99.5%		403.00
97.5%		400.00
90.0%		224.60
75.0%	Quartile	170.00
50.0%	Median	102.00
25.0%	Quartile	70.50
10.0%		31.60
2.5%		25.00
0.5%		23.00
0.0%	Minimum	23.00

Moments (seconds)

Mean	126.19512
Std Dev	83.369687
Std Err Mean	9.2066417
upper 95% Mean	144.51345
lower 95% Mean	107.87679
N	82

3.2.3 Analysis of the Missed Alerts

There are three ways that a conflict can be categorized as missed: (1) there is no alert whatsoever for the aircraft pair, (2) an alert is posted before the conflict starts but is withdrawn before the start of the conflict, and (3) an alert is posted much later than the start of the conflict. Of the 44 missed alerts 6 conflicts have no alerts whatsoever, 9 have alerts but not at the correct time, and 29 have alerts which are late. Not at the correct time means either that an alert was posted and withdrawn before the start of the conflict or it was posted after the start of the conflict.

In the detailed event counts in Table 5 above, the missed alerts have been divided into four categories. (1) MA_STD_A, (2) MA_STD_B, (3) MA_LATE, and (4) MA_DISCARD. A standard missed alert (Type A and Type B) is an aircraft to aircraft conflict for which there was no active Notification Set at the start of the conflict. Type A means that the conflict was not a popup; type B means the conflict was a popup. A late missed alert (MA_LATE) is a conflict for which an alert was posted, but the advance warning time was less than the time required by the ERAM specification. If the conflict is a popup and an alert is posted sufficiently soon after the start of the conflict, both the conflict and the Notification Set are discarded (MA_DISCARD). In this scenario this event does does not occur - MA_DISCARD = 0.

3.2.3.1 Missed Alerts – No Notification Sets

In the scenario there are 6 conflicts between 5 aircraft pairs (1 pair has 2 conflicts) which are totally missed. That is, there are not any Notification Sets for these conflicts. The following table summarizes the nature of these unpredicted conflicts.

Table 8: Missed Alert Conflicts

NO.	HORZ PHASE AC1	VERT PHASE AC1	HORZ PHASE AC2	VERT PHASE AC2	CONFLICTS CPA				CONFLICT DURATION (seconds)
					ρ_m	HORZ SEP (nm)	VERT SEP (ft)	REL HDG (degs)	
1	Str	Lev	Str	Lev	0.66	3.31	600	2	80
2	Str	Desc	Str	Desc	0.69	3.45	400	1	60
3	Str	Lev	Str	Lev	0.87	4.34	800	74	10
4	Str	Lev	Str	Desc	0.40	1.64	400	149	30
5	Str	Desc	Str	Lev	0.53	2.66	300	6	50
6	Str	Lev	Str	Lev	0.26	1.32	0	4	440

The first column is an index to the conflicts, the next four columns give the horizontal and vertical phases of flight for the two aircraft in conflict, AC1 and AC2. The phases of flight are for horizontal – Straight or Turning – and for vertical - Level or Climbing or Descending. The next four columns give the particulars of the closest point of approach (CPA) of the two aircraft in their conflict: the normalized separation ρ_m, the horizontal separation in nautical miles, the vertical separation in feet, and the relative heading of the two aircraft at the CPA time. The last column gives the duration of the conflict in seconds.

A relative heading close to 0° means that the two aircraft are in trail; a value close to 180° means that the two aircraft are flying in opposite directions, either towards each other or away from each other; a value close to 90° means that the flight paths are crossing. Of the six missed conflicts listed above, four are in trail, one is crossing, and one is opposing.

3.2.3.2 Missed Alerts – With Notification Sets

A conflict may be missed even though there is a Notification Set for the aircraft pair. The NS may be posted and withdrawn before the start of the conflict (a false alert), may be posted some time after the start of the conflict (a false alert), or may be discarded. There are 9 missed alerts between 9 aircraft pairs which have Notification Sets, where the Notification Sets do not match the conflicts (overlap in time the starting point of the conflict) resulting in missed alerts. There are 21 NSs for the 9 aircraft pairs. They either start and end before the conflict starts or are posted after the start of the conflict. The alerts which are posted shortly after the start of the conflicts are discarded as FA_ACST_DISCARD and the conflicts, not being matched are labeled missed (MA_STD_A or B).

The illustration in Figure 12 has an example of a conflict which has several NSs with none of them matching the third conflict. This third conflict between the aircraft pair (C3) is missed and there is a NS shortly after the start of the conflict (NS3) which is discarded as FA_ACST_DISCARD.

3.2.3.3 Missed Alerts – Late

The GSGT scenario has 29 late missed alerts between 27 aircraft pairs. These events are conflicts for which an alert was posted but the posting was too late to meet the warning time requirement. The warning is required to be at least 75 seconds before the start of the conflict. If a linear extrapolation of the two aircraft tracks from a point 75 seconds before the start of the conflict does not predict the conflict, the 75 second requirement is reduced to a smaller value. It is

reduced to the time interval before the start of the conflict defined by the point where the linear extrapolation predicts the conflict. In 24 of the 29 cases the minimum warning time requirement (MWTR) was reduced, but the HCS still did not post the alert in time. In two cases the MWTR was reduced to 10 seconds, but the actual warning times were 7 and 9 seconds, making the alerts late (MA_LATE).

The example above (Figure 12) has two MA_LATE events. The Notification Sets NS1 and NS2 are 55 and 17 seconds respectively before their conflicts and their MWTRs are 70 and 40 seconds respectively making them miss their MWTR by 15 and 23 seconds, respectively.

There are no gaps in the tracks data for the flights in this scenario. The MA_LATE conflict alerts are not affected by being close to the start of the track data. The conflict closest to the start of track data is 90 seconds after the start of track data and 15 seconds after the alert. The MWTR is 20 seconds thus making the alert late by 5 seconds. (The MWT linear extrapolation test predicts a conflict 20 seconds before the actual conflict start time.) The alert is 75 seconds after the start of the track data.

3.2.3.4 Missed Alerts - Discard

If an alert is posted shortly after the start of the conflict and the conflict is a popup, both the conflict and the alert are discarded. There are no MA_DISCARDs in this scenario.

3.2.4 Analysis of False Alerts

There are two main types of false alerts – alerts for pairs of aircraft which never come into conflict and alerts for pairs of aircraft which have conflicts but the alerts do not match up to the conflicts. Many potential false alerts are discarded. Most of the discards are due to the mechanics of the simulation – all conflicts and alerts below FL 180 are discarded. In the processing, all false alerts which are posted at a point in time where a linear extrapolation of the flight paths of the two aircraft predicts a conflict are discarded.

There are 168 false alert events for which 147 events have no conflict between the aircraft pair and for which 21 events have a conflict elsewhere. Of the 21 false alerts with conflicts elsewhere 12 alerts are posted and withdrawn before the conflict and 9 are posted and withdrawn after the conflict. The ρ values for the CPA's for the 147 false alerts with no conflicts range from 0.743 to 7.9. Recall that a single track point with a $\rho_m < 1$ does not qualify as a conflict. A conflict requires at least two successive points with ρ values of less than 1.

An examination of the most egregious false alert ($\rho_m = 7.9$) finds that, at the time of the alert, the two aircraft, descending, were separated by over 5 nautical miles horizontally and were diverging with a relative heading of 38°, and were maintaining a vertical separation of over 8000 feet. The alert was up for the minimum time of 12 seconds.

3.2.5 Analysis of Valid Alerts

Two types of valid alerts are possible: Valid Standard (VA_STD), and Valid Late (VA_LATE). A Valid Standard alert is one in which 75 seconds or more warning time has been provided, measured from the issuance of the relevant Host Notification Set until the start of conflict. A Valid Late alert has a warning time less than 75 seconds which is excused because of an unpredictable aircraft maneuver or other event that caused the Host to be unable to predict the conflict sufficiently in advance. If the late warning time is not excused via the extrapolation

method referenced in Section 3.2.4.2 in (Paglione et al, 2006), the alert would be classified as a Missed Alert Late (MA_LATE).

Figure 14 depicts the warning time distribution for Valid alerts in the GSGT simulation. Those warning times less than 75 seconds are for Valid Late alerts and ranged between 23 and 73 seconds. Those warning times greater or equal to 75 seconds are for Valid Standard alerts, and ranged between 75 and 403 seconds. For all Valid alerts, the median (50%) warning time was 102 seconds, the mean warning time was 126 seconds, and the standard deviation was 83 seconds.

3.2.6 Analysis of Discards

An important part of the analysis is the discarding of conflicts and alerts. Because the processing is limited to conflicts above Flight Level 180, all conflicts and their alerts below this altitude are discarded. Conflicts and alerts are discarded for various other reasons as has been detailed in (Paglione et al, 2006). The reason codes for discarding data (and their counts) have been listed above in Table 5.

3.2.6.1 False Alert No Track Discards

A Notification Set predicts a conflict between two specific aircraft. A NS or an alert which does not have a matching conflict is a candidate to be a False Alert. There are three cases where the track data for one or both of the aircraft in the NS is missing. If the track data is missing, the alert is discarded.

3.2.6.1.1 False Alert No Track Discard 1

If either aircraft in the NS is not in the data input to the HCS in the simulation run, that is it is not in the AC_LIST and AC_TRKS database tables, the NS or alert is discarded as FA_NOTRK_DISCARD1. There are 880 Notification Sets labeled FA_NOTRK_DISCARD1 in the GSGT scenario.

3.2.6.1.2 False Alert No Track Discard 2

A second missing track situation occurs when both flights have track data in the scenario, but both flights do not have track data when the alert is posted. This case happens when the alert is posted before the start of the track, after the end of the track, or when there is a gap in the track. The alert is then labeled FA_NOTRK_DISCARD2. There are 511 such alerts in the scenario. In one example (CID 1 = 440, CID 2 = 764), there are four alerts posted after the aircraft have descended below Flight Level 180. No track data below FL 180 is available for the post processing. The four Notification Sets for this aircraft pair are labeled FA_NOTRK_DISCARD2.

3.2.6.1.3 False Alert No Track Discard 3

The third no track case occurs when track data is not available for the duration of the alert. If there is no track data at the end of the alert, it is not possible to use the extrapolation method to determine if a maneuver has removed the conflict. Again the NS is discarded. It is labeled FA_NOTRK_DISCARD3. There are 4 NS's with the FA_NOTRK_DISCARD3 label.

3.2.6.2 False Alert After Conflict Start Time Discard

The Detailed Description of Processing detailed in Section 3.2.4 in (Paglione et al, 2006) requires that VA_STD, VA_LATE, and MA_LATE alerts have a HCS Notification Set posted prior to the start of conflict. If a Notification Set is posted after the start of conflict, it is discarded as a False

Alert, After Conflict Start Time Discard (FA_ACST_DISCARD) result. Note, if a Notification Set is posted without a conflict occurring, it is a considered for a possible False Alert result.

In the GSGT simulation, 10 FA_ACST_DISCARD results were generated, and again, it was verified that for each of these, the Notification Set was issued after start of conflict. Nine of the ten FA_ACST_DISCARD results were paired with a MA_STD_A result. The 10th FA_ACST_DISCARD result was paired with a VA_STD result. This 10th case involved two separate conflicts separated in time by 30 seconds, and was merged into one conflict per the criteria in section 3.1.2 in (Paglione et al, 2006). The HCS generated Notification Sets for each of the two merged conflicts, with the first being utilized as the basis for the VA_STD result, and the second being discarded as occurring after the start of the overall merged conflict.

3.2.6.3 False Alert Event Discard A

An FA_EVENT_DISCARD_A is a False Alert condition that is excused based upon an unanticipated aircraft maneuver that resolved a predicted conflict between two aircraft before the conflict actually occurred. For a Notification Set that is unmatched to a conflict and for which track data for both aircraft is available, extrapolations are made at the time intervals immediately before the NS issuance and continuing through the NS duration. An FA_EVENT_DISCARD_A result is generated if a conflict is extrapolated just prior to the NS generation but not after, and if the NS ends 20 seconds or less following the first extrapolation time interval for which a conflict is not predicted.

In the GSGT simulation, 13 FA_EVENT_DISCARD_A results were generated. Time intervals between the NS end times and the time simulation interval immediately following NS generation ranged between 5 and 15 seconds, averaging 9.9 seconds. Of the 13 FA_DISCARD_A results, 9 were the only event for the aircraft pair involved.

3.2.6.4 False Alert Event Discard B

An FA_EVENT_DISCARD_B is a False Alert condition that is excused based upon an unanticipated aircraft maneuver that resolved a predicted conflict between two aircraft before the conflict actually occurred. For a Notification Set that is unmatched to a conflict and for which track data for both aircraft is available, extrapolations are made at the time intervals immediately before the NS issuance and continuing through the NS duration. An FA_EVENT_DISCARD_B result is generated if a conflict is extrapolated for at least one time interval following the NS generation, and if the NS ends 20 seconds or less following the first extrapolation time interval for which a conflict is not predicted.

In the GSGT simulation, 14 FA_EVENT_DISCARD_B results were generated, each having an extrapolated conflict based on the first simulation time interval following NS generation. Time intervals between the NS end times and the first time simulation interval during the NS duration for which a conflict was not extrapolated ranged between -11 and +19 seconds, averaging 5.3 seconds. 4 of the alerts were withdrawn before the predicted conflict disappeared and 10 were withdrawn after. 14 aircraft pairs result in a FA_DISCARD_B. Five of these aircraft pairs had no other result associated with them.

3.3 RESULTS FOR GSGT/ERIT SIMULATION

The results of the GSGT/ERIT simulation of the HCS alert processing are presented next. The two scenarios are very similar and consequently the results are also quite similar. This scenario has gaps in the radar track data (which was recorded in the field) whereas the radar data in the GSGT scenario is simulated and has no gaps.

3.3.1 Scenario Counts

In the GSGT/ERIT simulation run, 936 aircraft were run in the IIF Laboratory using the GSGT simulator with recorded radar data from ERIT to drive the operational HCS within the Lab[8]. The flights were time shifted as described in (Paglione et al, 2003b). The time shifting created 10429 encounter pairs at simultaneous separations less than 40 nautical miles and 8000 feet. 80 of the aircraft pairs had one or more embedded conflicts making a total of 93 aircraft-to-aircraft conflicts. A few of the encounters contain multiple conflicts. One pair had five conflicts and nine pairs had two conflicts. 10341 of the encounters did not result in any conflict. The properties of these conflicts and encounters were presented earlier in Section 2.2. The simulation ran for approximately 3 hours and 42 minutes.

For this simulation, 11,643 conflict alert records were recorded and processed. From these records, 1149 Notification Sets were produced. The processing matched the alerts to the conflicts. After the matching is done there are left over conflicts which had no matching alerts and left over alerts which had no matching conflicts. As mentioned previously any alerts or conflicts below Flight Level 180 were discarded and not included in these counts. The processing produced a list of 1163 events to count. There are four main categories of events, described in (Paglione et al, 2006). The counts for these four categories are given in Table 9. As has been previously described these four categories have been further subdivided into a total of sixteen categories. The counts for these finer categories are given in Table 10.

Table 9: Event Count Summary for GSGT/ERIT Scenario

ALERT TYPE	ALERT COUNT
VALID	63
MISSED	29
FALSE	104
DISCARD	967

[8] The count of 936 aircraft does not exactly match the aircraft count listed in Section **Error! Reference source not found.** due to the additional processing involved, but it is the same flight data.

Table 10: Detailed Event Count for GSGT/ERIT Scenario

INDEX	ALERT TYPE	REASON CODE	COUNT
1	VALID	VA_STD	51
2	VALID	VA_LATE	12
3	MISSED	MA_STD_A	10
4	MISSED	MA_STD_B	0
5	MISSED	MA_LATE	19
6	FALSE	FA_STD1	83
7	FALSE	FA_STD2_A	4
8	FALSE	FA_STD2_B	15
9	FALSE	FA_STD3	2
10	DISCARD	MA_DISCARD	1
11	DISCARD	FA_NOTRK_DISCARD1	481
12	DISCARD	FA_NOTRK_DISCARD2	445
13	DISCARD	FA_NOTRK_DISCARD3	6
14	DISCARD	FA_ACST_DISCARD	8
15	DISCARD	FA_EVENT_DISCARD_A	4
16	DISCARD	FA_EVENT_DISCARD_B	22

3.3.2 Performance Metric Values

3.3.2.1 Error Event Rates

The rates for this scenario are as follows.

3.3.2.1.1 Missed Alert Rate

The missed alert as above is

$$R_{MA} = MA / C = MA / (MA + VA) = 29 / (20 + 63) = 29 / 83 = 0.349$$

3.3.2.1.2 False Alert Rate – Overall

The overall false alert rate for the scenario is

$$R_{FA} = FA / A = FA / (FA + VA + MA_LATE) = 104 / (104 + 63 + 19) = 104 / 186 = 0.559$$

3.3.2.1.3 False Alert Rate – By ρ_m Value

The false alert rates by ρ_m value are as follows.

Table 11: False Alert Rates for GSGT/ERIT Scenario

BIN NUMBER	MAX_MIN_RATIO RANGE	ENCOUNTER COUNT	FALSE ALERT COUNT	RATE
1	$0 <= \rho_m < 1$	88	22	0.250
2	$1 <= \rho_m < 2$	566	54	0.0954
3	$2 <= \rho_m < 3$	668	17	0.0254
4	$3 <= \rho_m < 4$	1322	7	0.00530
5	$4 <= \rho_m < 5$	1307	2	0.00153
6	$5 <= \rho_m < 6$	1916	1	0.000522
7	$6 <= \rho_m < 7$	2024	0	0.000000
8	$7 <= \rho_m < 8$	2528	1	0.000396
9	$8 <= \rho_m$	0	0	0.000000

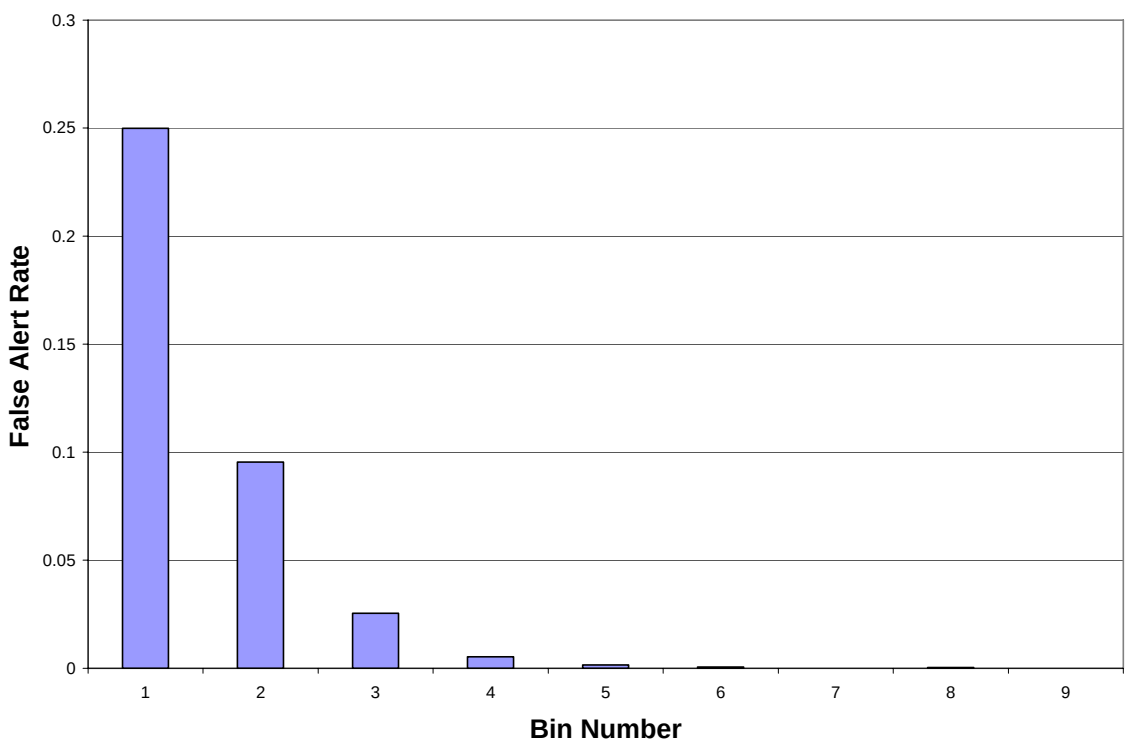

Figure 15: False Alert Rates for the GSGT/ERIT Scenario

3.3.2.2 Timeliness Metrics

There are 93 conflicts in the scenario. 10 conflicts are missed and 82 conflicts are predicted, but 19 of these are predicted too late. One conflict is discarded. 51 alerts (VA_STD) precede the start of the conflict by more than 75 seconds; 12 alerts (VA_LATE) precede the conflict by less than 75 seconds but by more than the adjusted minimum warning time requirement (MWTR), and 19 alerts (MA_LATE) precede the start of the conflict by less than the adjusted minimum warning time requirement. 25 alerts precede the start of the conflict by more than 135 seconds.

A histogram showing the conflict warning times is given in the following Figure 16. The counts in terms of quantiles and moments are given in Table 12.

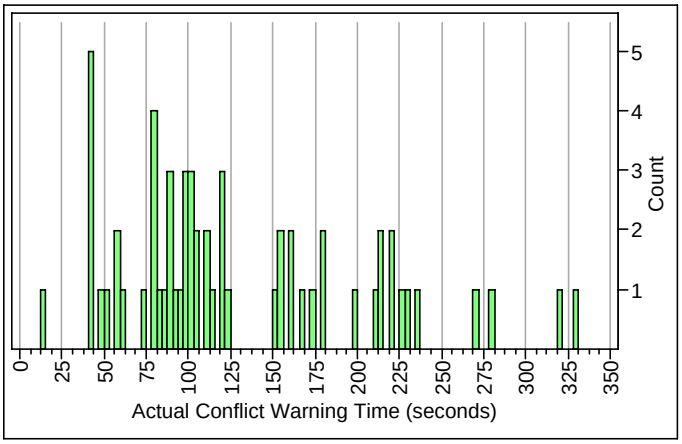

Figure 16: Warning Time Histogram for Valid Alerts of the GSGT/ERIT Scenario

Table 12: Warning Time Counts for Valid Alerts of the GSGT/ERIT Scenario

Quantiles (seconds)

100.0%	maximum	829.00
99.5%		829.00
97.5%		691.00
90.0%		275.00
75.0%	quartile	199.00
50.0%	median	111.00
25.0%	quartile	79.00
10.0%		44.60
2.5%		29.80
0.5%		13.00
0.0%	minimum	13.00

Moments (seconds)

Mean	155
Std Dev	136.23509
Std Err Mean	17.164008
upper 95% Mean	189.31036
lower 95% Mean	120.68964
N	63

3.3.2.2.1 Illustration of the Analysis Processing for Warning Times

A pair of flights has been selected from the scenario to illustrate the application of the warning times. This example shows the limitation of the 135 second maximum warning time requirement when there are multiple conflicts between the same pair of aircraft. One alert is posted and sustained through the entire period that the two flights are in the scenario. The two aircraft are flying in trail on the same route at the same altitude. There are eight separate conflicts which are merged into five conflicts when the short time gaps in the conflicts are ignored.

The pair has one encounter with five embedded conflicts and one Notification Set. The aircraft pair starts in conflict and ends in conflict. The second conflict bridges over two one point gaps where the aircraft are briefly not in conflict. The fifth conflict bridges over one two point gap. The single alert is posted 11 seconds after the start of the first conflict and is sustained until the end of the track data for the first aircraft. The events resulting from the five conflicts and one Notification Set are one MA_DISCARD for the first conflict and four VA_STDs for the other four conflicts. The warning times for the five conflicts are -11, 829, 599, 539, and 119 seconds. The alert falls in the 135 second to 75 second range for only the last conflict.

The 135 second requirement does not apply well to this type of multiple in trail conflicts. Perhaps conflicts like this should be merged into a single conflict.

3.3.3 Analysis of the Missed Alerts

There are 29 missed alerts in this scenario. 19 of the alerts are missed because they are late. 10 conflicts between 9 aircraft pairs are missed. 8 of the aircraft pairs have NS's which, however, do not match up to the conflicts. 1 conflicting aircraft pair has no NS's. The 8 missed alert pairs which have one or more NS's have a total of 28 NS's. 1 missed alert was discarded because an alert was posted shortly (11 seconds) after the start of the conflict which in turn was shortly after a gap in track data (the start of the track for one of the aircraft). In this case the aircraft (the CID's are 290 and 397) actually start in conflict.

3.3.3.1 Missed Alerts – No Notification Sets

In this scenario there is only one conflict for which there are no Notification Sets – a head on encounter. (CID's are 909 and 487)

Table 13: Missed Alert Conflict - No Notification Sets – GSGT/ERIT Scenario

NO.	HORZ PHASE AC1	VERT PHASE AC1	HORZ PHASE AC2	VERT PHASE AC2	CONFLICT CPA				CONFLICT DURATION (seconds)
					ρ_m	HORZ SEP (nm)	VERT SEP (ft)	REL HDG (degs)	
1	Str	Lev	Str	Desc	0.75	2.69	750	169	20

3.3.3.2 Missed Alerts – With Notification Sets

The 8 aircraft pairs with 9 conflicts have 28 Notification Sets. The one aircraft pair that has two conflicts has 9 NS's. The other 7 aircraft pairs which have 1 conflict have 19 NS's. Each of the 9 NS's is compared to both of the conflicts. The start and end times of the NS's are compared to the start times of the conflicts. There are 37 = (19)(1) + (9)(2) comparisons. There are 8

instances of a NS being posted and withdrawn before a conflict and 29 instances of a NS being posted and withdrawn after the start of a conflict.

3.3.3.2.1 Illustration of Missed Alerts – With Notification Sets

The following figure (Figure 17) gives an example of two conflicts which are missed even though there are several alerts. None of the alerts are active at the time of the start of the conflicts. Therefore each conflict is labeled as MA_STD_A (A - because there is no gap in the track data). The first Notification Set is labeled FA_NOTRK_DISCARD2 because there is no track data for the first aircraft when the alert is posted. The second and third NS's are candidate false alerts. The linear extrapolation test is applied to each. The extrapolation of the two tracks from the track points that bracket the posting time of the second alert (NS2) does not predict a conflict. Therefore the NS is labeled a FA_STD1. The extrapolation of the two tracks from the posting time of the third alert predicts a conflict for eight points but on the ninth point no conflict is seen. But the NS is still up for another 39 seconds. The NS is labeled FA_STD2_B. The fourth NS is posted shortly (5 seconds) after the start of conflict and is therefore labeled FA_ACST_DISCARD.

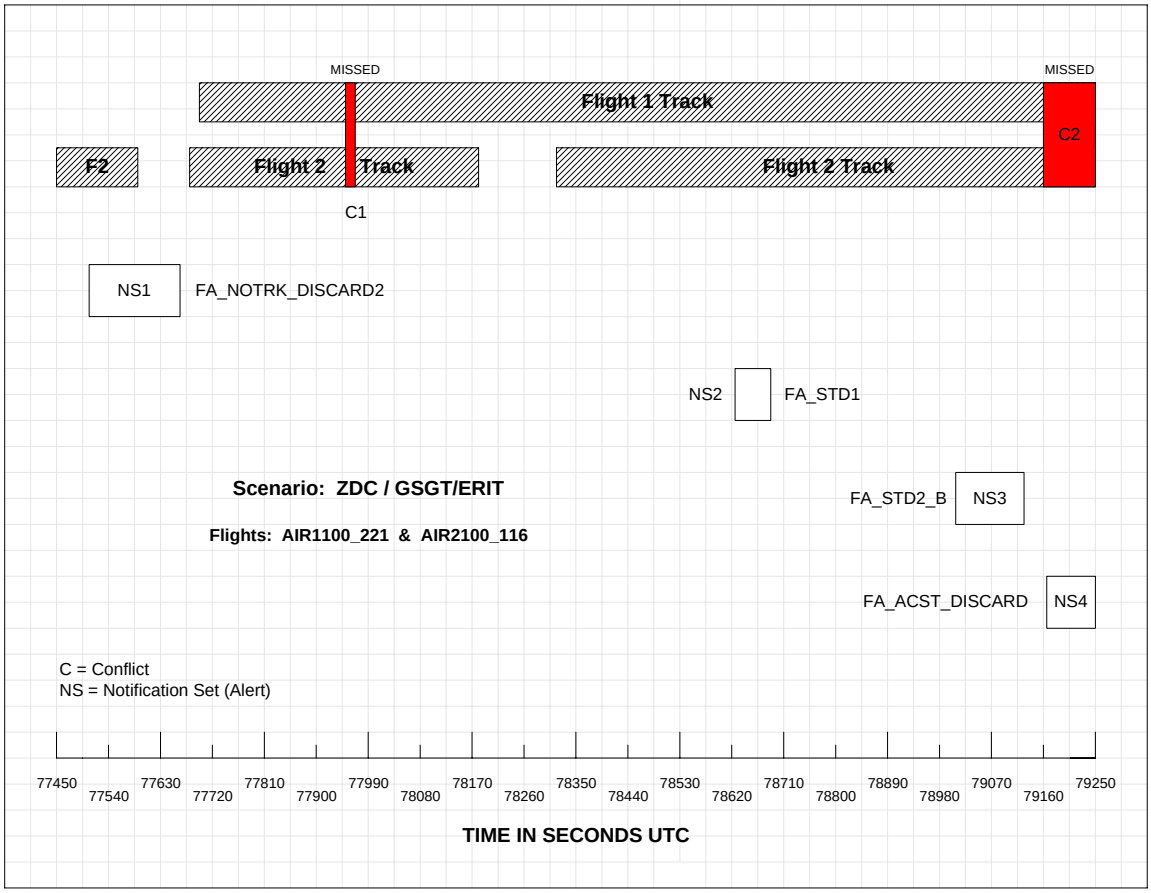

Figure 17: Time Sequence of Track Data, Conflicts, and Notification Sets

Table 14: Time Sequence of Events for AIR1100_221 and AIR2100_116

INDEX	TIME IN SECONDS UTC	TIME IN HH:MM:SS UTC	EXPLANATION
1	77450	21:30:50	Start of track for AC2
2	77509	21:31:49	NS 1 posted
3	77590	21:33:10	Start of Gap 1 in track for AC2
4	77665	21:34:25	NS 1 withdrawn
5	77680	21:34:40	End of Gap 1 in track for AC2
6	77700	21:35:00	Start of track for AC1
7	77950	21:39:10	Start of Conflict 1
8	77970	21:39:30	End of Conflict 1
9	78180	21:43:00	Start of Gap 2 in track for AC2
10	78320	21:45:20	End of Gap 2 in track for AC2
11	78625	21:50:25	NS 2 posted
12	78685	21:51:25	NS 2 withdrawn
13	79009	21:56:49	NS 3 posted
14	79100	21:58:20	End of extrapolation for NS 3
15	79129	21:58:49	NS 3 withdrawn
16	79160	21:59:20	Start of Conflict 2
17	79165	21:59:25	NS 4 posted
18	79250	22:00:50	End of track for AC1
19	79250	22:00:50	End of track for AC2

3.3.3.3 Missed Alerts - Late

The GSGT/ERIT scenario has 19 late missed alerts between 18 aircraft pairs. These events are conflicts for which an alert was posted but the posting was too late to meet the warning time requirement of 75 seconds. If a linear extrapolation of the two aircraft tracks from a point 75 seconds before the start of the conflict does not predict the conflict, the 75 second requirement is reduced to a smaller value. In 16 of the 19 cases the minimum warning time requirement (MWTR) was reduced, but the HCS still did not post the alert in time. In 6 cases the actual warning time missed the minimum required warning time by 3 seconds or less.

There are 4 gaps in the track data for the MA_LATE flights in this scenario. All of the gaps are after the conflicts which were missed by the alerts being late.

The MA_LATE conflict alerts are not affected by being close to the start of the track data. The conflict closest to the start of track data is 220 seconds after the start of track data and 27 seconds after the alert. The MWTR is 30 seconds thus making the alert late by 3 seconds. The alert is posted 193 seconds after the start of the track data. (The CID's are 802 and 303.)

3.3.3.4 Missed Alerts - Discard

There is one MA_DISCARD (CID's are 290 and 397). The conflict is a popup – the aircraft start in conflict. The alert is posted 11 seconds later. Both the conflict and the alert are discarded from the statistics.

3.3.4 Analysis of False Alerts

There are 104 false alerts (89 distinct aircraft pairs) in the scenario, 85 of the alerts (75 distinct aircraft pairs) are for aircraft pairs that have no conflict and 19 of the alerts (14 distinct aircraft pairs) are for aircraft pairs which do have a conflict, but the alert does not match the conflict. Of the 19 false alerts with conflicts, 11 alerts are posted before the start of the conflict and 8 alerts are posted after the start of the conflict.

An alert is excused if (1) a linear extrapolation of the track data predicts a conflict when the alert is posted and (2) a linear extrapolation stops predicting a conflict when the alert is withdrawn. 26 alerts are excused in this way (FA_EVENT_DISCARD_A and FA_EVENT_DISCARD_B).

For 83 of the alerts the linear extrapolation did not predict any conflict (FA_STD1). The linear extrapolation predicts a conflict when the alert is posted for 19 of the alerts but the withdrawal of the alert does not match the stopping of the linear prediction (FA_STD2_A and FA_STD2_B).

For 2 of the alerts the linear extrapolation predicts a conflict when the alert is posted and continues to predict a conflict when the alert is withdrawn (FA_STD3). Both alerts are short – two points. Both aircraft pairs do have one actual conflict. One false alert is posted and withdrawn a minute before the conflict and the other false alert is posted after the conflict.

3.3.5 Analysis of Valid Alerts

Figure 16 depicts the warning time distribution for Valid alerts in the GSGT/ERIT simulation. Those warning times less than 75 seconds are for Valid Late alerts, and ranged between 13 and 73 seconds. Those warning times greater or equal to 75 seconds are for Valid Standard alerts, and ranged between 75 and 829 seconds. For all Valid alerts, the median (50%) warning time was 111 seconds, the mean warning time was 155 seconds, and the standard deviation was 136 seconds.

3.3.6 Analysis of Discards

The logic of the discarding of false alerts, described in (Paglione et al, 2006), has been reviewed in Section 3.2.6.

3.3.6.1 False Alerts No Track Discards

3.3.6.1.1 False Alert No Track Discard 1

There are 481 alerts (Notification Sets) that are classified as FA_NOTRK_DISCARD1 in the GSGT/ERIT scenario.

3.3.6.1.2 False Alert No Track Discard 2

There are 445 alerts (Notification Sets) that are classified as FA_NOTRK_DISCARD2 in the GSGT/ERIT scenario.

3.3.6.1.3 False Alert No Track Discard 3

There are 6 alerts (Notification Sets) that are classified as FA_NOTRK_DISCARD3 in the GSGT/ERIT scenario.

3.3.6.2 False Alert After Conflict Start Time Discard

In the GSGT/ERIT simulation, 8 FA_ACST_DISCARD results were generated. It was verified that the HCS Notification Set was generated after the start of the conflict situation for each of these 8 cases. The false alert discards ranged from occurring 3 seconds after the start of the conflict (the CID's are 257 and 146) to occurring 55 seconds after the start of the conflict (the CID's are 790 and 283). All of the 8 conflicts generating the FA_ACST_DISCARD events also caused a MA_STD_A event. For these 8 events there were no NS's active at the starting times of the conflicts.

3.3.6.3 False Alert Event Discard A

In the GSGT/ERIT simulation, 4 FA_EVENT_DISCARD_A results were generated. Extrapolations for each of these predicted conflicts during the simulation time interval immediately prior to NS generation but not after, and the time intervals between the NS end times and the time simulation interval immediately following NS generation ranged between 3 and 11 seconds, averaging 7.0 seconds. Three of the four FA_EVENT_DISCARD_A results were the only event for the aircraft pair involved, with these encounters having relatively large encounter angles and definitive maneuvers in (at least) the horizontal plane that removed the initially predicted conflict situation. The fourth FA_EVENT_DISCARD_A result occurred early in the encounter between the two aircraft, and these two aircraft then continued into an extended low encounter angle conflict situation that generated several other results, including an MA_LATE.

3.3.6.4 False Alert Event Discard B

In the GSGT/ERIT simulation, 22 FA_EVENT_DISCARD_B results were generated. Extrapolations for each of these predicted conflicts during the simulation time interval immediately following the NS generation, and the time intervals between the NS end times and the first time simulation interval immediately following the first time interval where a conflict was not extrapolated ranged between -17 and +19 seconds, averaging 3.9 seconds. Of the 22 FA_DISCARD_B results, 9 were the only event for the aircraft pair involved.

4 Sample Events from Scenarios

The sample events provide tangible examples of the conflict prediction alert processing. They also highlight the type of errors that are being measured in the overall statistics. The examples presented here are drawn from both the GSGT and the GSGT/ERIT scenarios.

4.1 Valid Alert Examples

This section will present sample flight examples exhibiting valid alerts. Valid alerts can occur either when an alert is presented prior to the specified 75 seconds prior to conflict start, or later than 75 seconds prior to conflict start if justified by events such as an unanticipated aircraft maneuver.

4.1.1 Valid Standard Example

4.1.1.1 Flight Description

In this GSGT simulation example, Flight CPAT01 is a Canadair Regional Jet series 200 aircraft flying from Minneapolis, MN to Richmond, VA, with intermediate fixes at HVQ and FAK. Flight CPAT02 is an Airbus A320 series aircraft flying from Charlotte, NC to Pittsburgh, PA, with intermediate fixes at PSK, IHD, and NESTO2. Figure 18 depicts the flight paths of these two aircraft immediately before and after the Conflict that occurred. The labeled black squares are major airports. Their names are listed in Section 7.

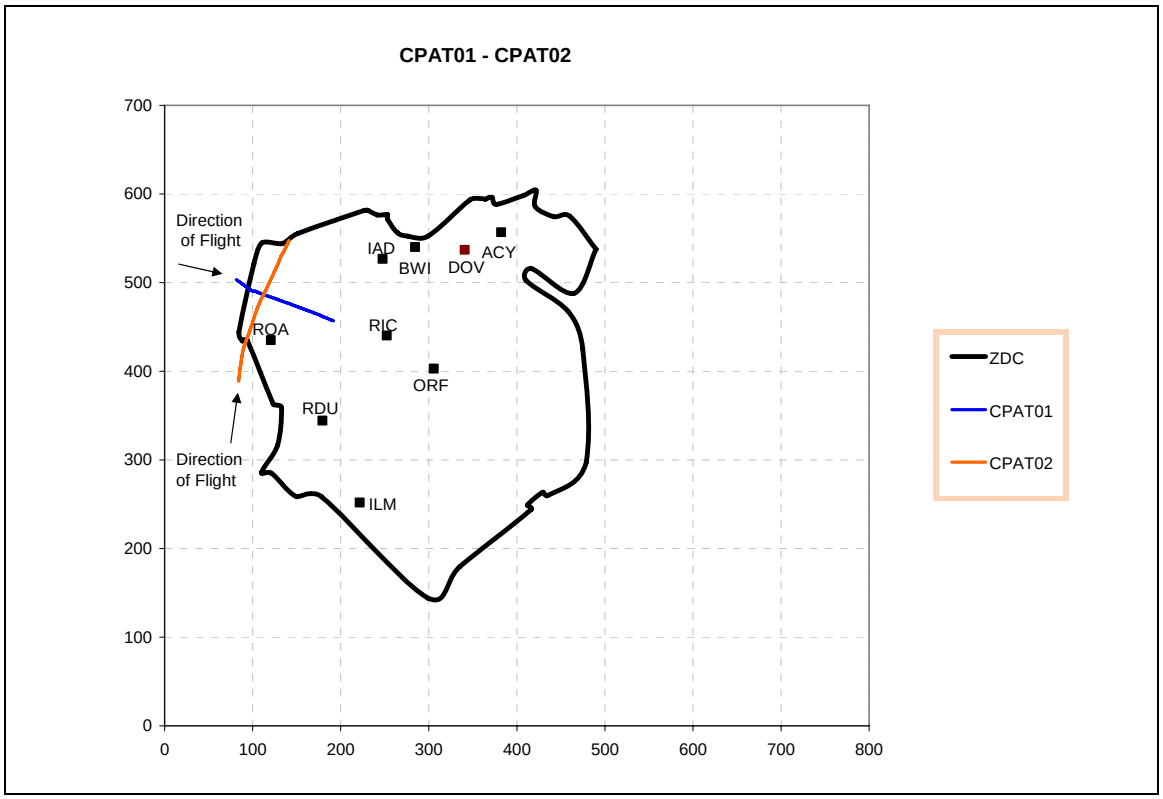

Figure 18: Flight Paths of Flights CPAT01 and CPAT02

4.1.1.2 Conflict Geometry

Track data for these two aircraft within Washington Center airspace started at 78120 seconds into the scenario. At this point CPAT01 was flying on a heading of 127 degrees at an altitude of 31000 feet, and had not yet started a descent to its assigned altitude of 29000 feet. At this same scenario time, CPAT02 was flying a heading of 19 degrees at its assigned altitude of 29000 feet. At 78160 seconds, CPAT01 began its descent, flying a heading of 124 degrees at an altitude of 30900 feet, while CPAT02 remained at 29000 feet on a heading of 18 degrees. At 78270 seconds, CPAT01 had completed its descent to 29000 feet and had completed a slight turn to a heading of 108 degrees, while CPAT02 continued flying at 29000 feet on a heading of 21 degrees. At this point in time, separation between the two aircraft was 19.77 miles and zero feet. By 78290 seconds, CPAT01 began a descent to a new cleared altitude of 26000 feet on a heading of 108 degrees, while CPAT02 began a descent to a cleared altitude of 24000 feet on a heading of 21 degrees. Separation was 16.25 miles and 300 feet, with the aircraft on converging paths horizontally, and both descending. At 78350 seconds, the conflict began when the two aircraft closed to 4.36 miles and 200 feet. Closest approach, horizontally, occurred at 78370 seconds with a separation of 2.34 miles and 600 feet. At this point in time, CPAT01 had slowed its descent rate, allowing vertical separation to start increasing, CPAT01 was at 27400 feet on a heading of 108 degrees, and CPAT02 was at 26800 feet on a heading of 27 degrees. At 78380 seconds, minimum separation requirements were regained when vertical separation increased to 1000 feet at 3.13 miles, ending the conflict.

Scenario track data related to the Conflict was processed graphically using the Wolverine Software Proof graphics animation package. Figure 19 is a Proof screen capture at the time of Conflict start, and Figure 20 is a screen capture at the time of Conflict end.

Briefly, the Proof graphics screen captures are divided into three parts. The upper left section presents the scenario time, referenced to seconds after Midnight, as well as a 24 hour clock. The upper right section depicts the horizontal plane path of the two aircraft. Circles are drawn around each aircraft if they are closer than 5 nm (conflict) or 30 nm (encounter), depending on which data base is being utilized. The lower section of the Proof screen presents state data for each aircraft (lower left/right sections), relative distances and bearings between the two aircraft (lower center sections), and a graphical depiction of the vertical plane path of the two aircraft versus time. For each aircraft, the colored line in the vertical path display represents actual aircraft altitude, and the black line represents assigned altitude.

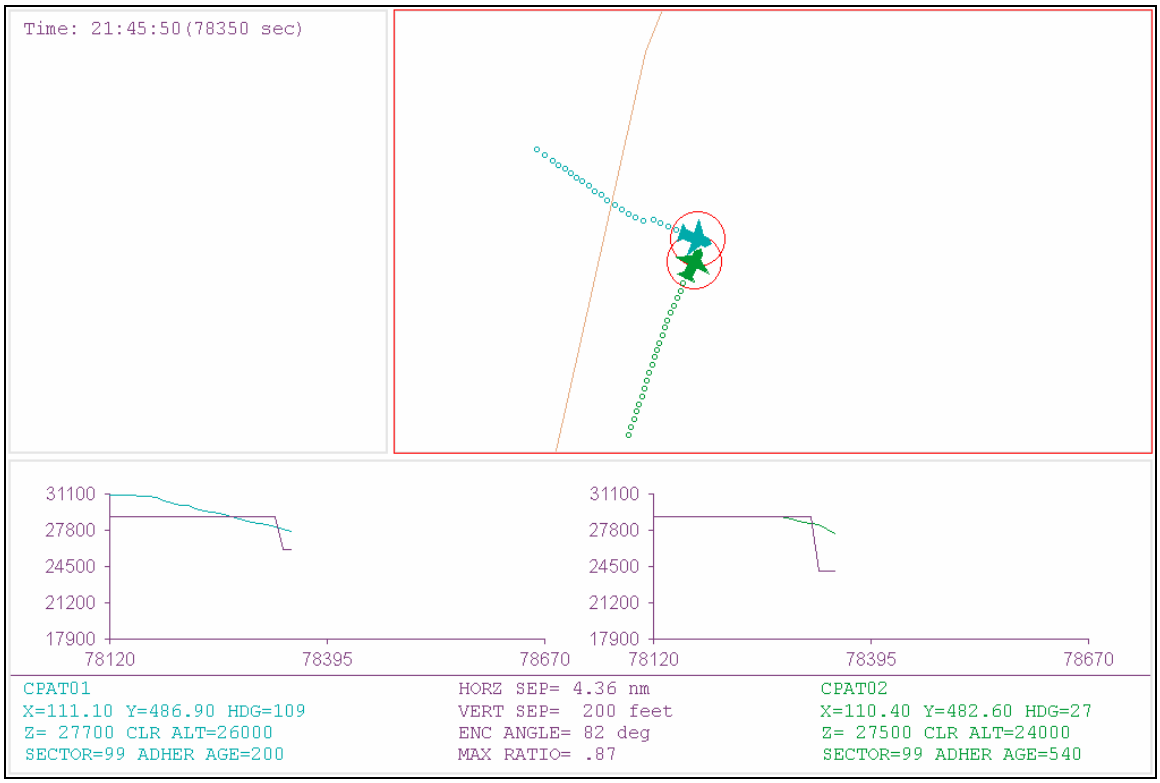

Figure 19: CPAT01 and CPAT02 at Start of Conflict

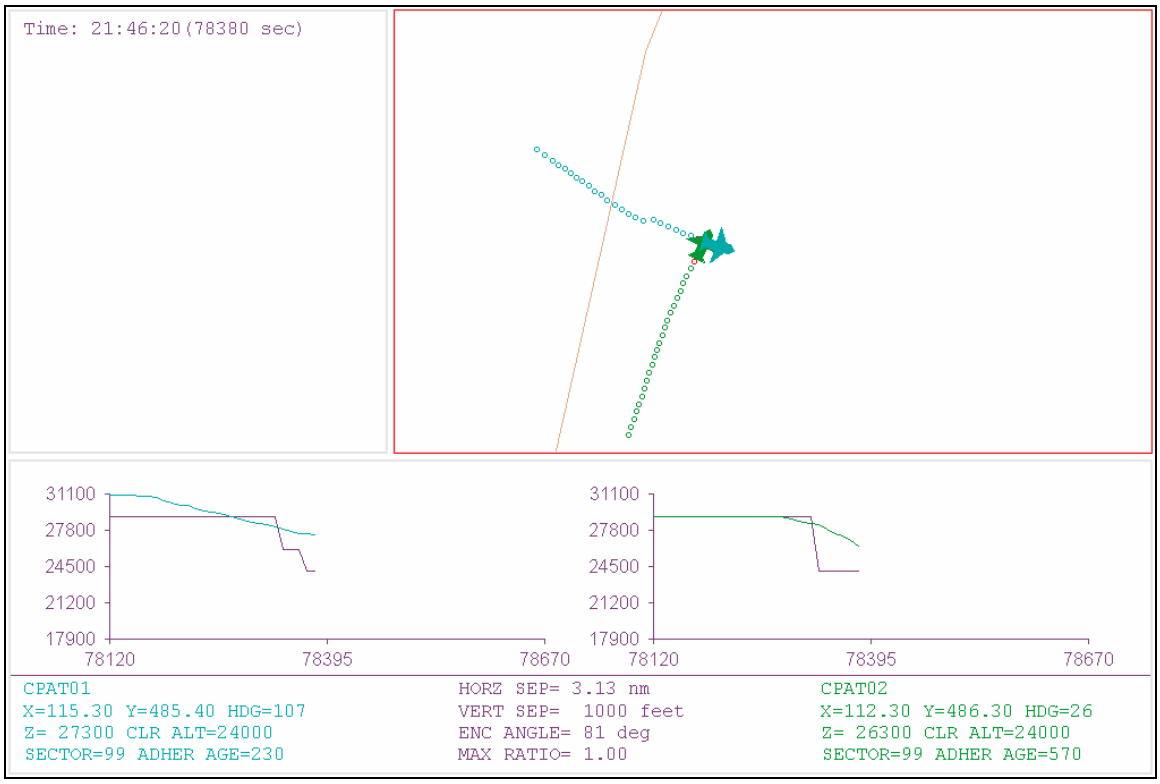

Figure 20: CPAT01 and CPAT02 at End of Conflict

4.1.1.3 Analysis

As a result of this conflict, the HCS generated a Notification Set. The first entry in this NS, the ADD alert, was generated at 78181 seconds into the scenario, and represents the earliest notification by the HCS of the pending conflict. The actual start of the conflict was at 78350 seconds into the scenario, so the actual warning time provided was 169 seconds, or considerably more than the specified minimum warning time of 75 seconds. As sufficient warning time was provided, this alert was placed in the VA_STD, or Valid Standard category.

4.1.2 Valid Late Example

4.1.2.1 Flight Description

In this GSGT simulation example, Flight CPAT21 is a Canadair Regional Jet, flying from Covington, KY to Atlantic City, NJ, via intermediate fixes at BKW, OTT, and SIE. Flight CPAT32 is a Boeing 717 flying from Washington Dulles International Airport to Atlanta, GA via intermediate fixes at FLUKY, MOL, and MACEY2. Figure 21 depicts the flight paths of these two aircraft immediately before and after the Conflict that occurred.

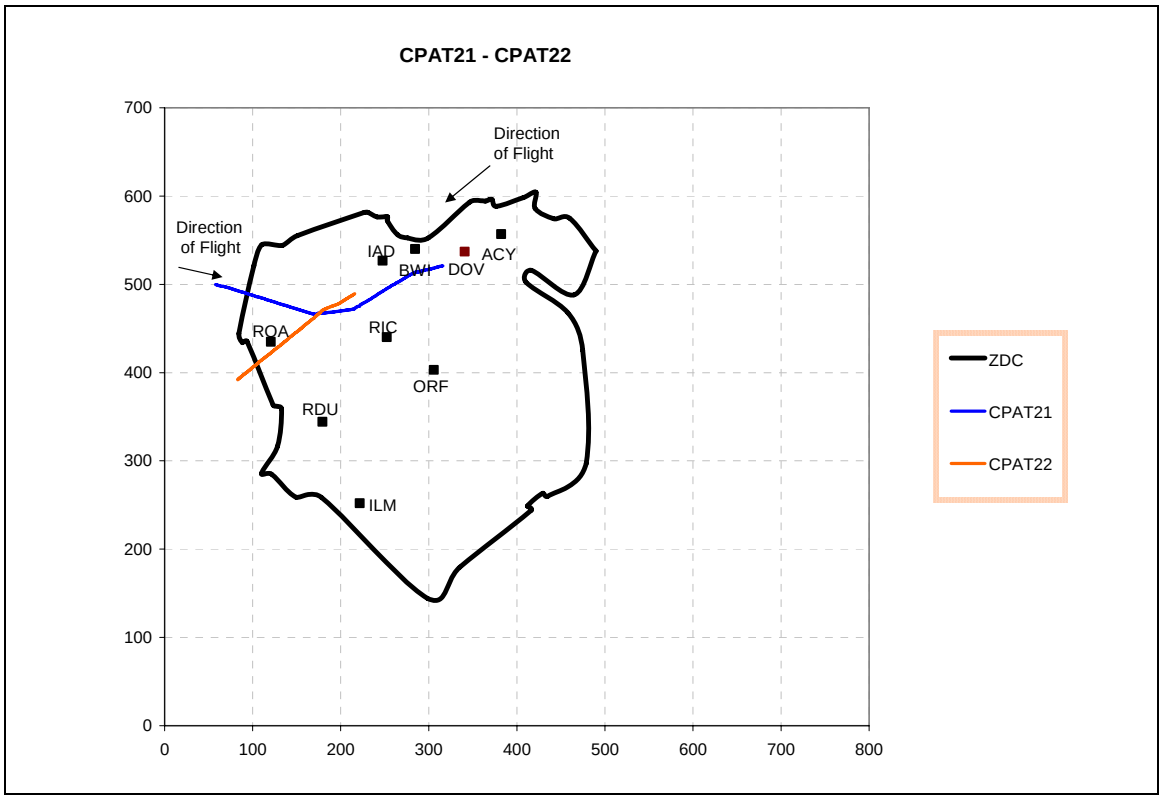

Figure 21: Flight Paths of Flights CPAT21 and CPAT22

4.1.2.2 Conflict Geometry

Track data for both of the aircraft first became available at 75700 seconds into the scenario, with CPAT21 flying at 30400 feet, descending to an assigned altitude of 29000 feet, on a heading of 107 degrees, and with CPAT22 climbing thru 21800 feet, towards an assigned altitude of 27000 feet, on a heading of 238 degrees. By 76016 seconds, CPAT21 had reached its assigned altitude of 29000 feet still on a heading of 107 degrees, and CPAT22 had reached its assigned altitude of 27000 feet and was flying a heading of 249 degrees. At 76016 seconds, CPAT22 was issued a new assigned altitude of 31000 feet, followed 5 seconds later by an assignment to 28000 feet. At 76129 seconds, CPAT21 remained at 29000 feet and 107 degrees, while CPAT22 had climbed to 28000 feet at 243 degrees, and was issued a new altitude clearance to 32000 feet. At this point the aircraft were on a converging path horizontally with CPAT22 about to climb thru CPAT21's assigned altitude, and were separated by 20.93 miles and 800 feet. Over the next 80 seconds, both aircraft turned a few degrees right, with CPAT21 remaining at 29000 feet and CPAT22 climbing, resulting in a situation with the two aircraft converging with decreasing horizontal separation, and with vertical separation remaining below 1000 feet. Finally, at 76210 seconds, horizontal separation decreased to 3.98 miles with 600 feet vertical separation resulting in the start of the conflict situation. By 76250 seconds, both horizontal (6.5 miles) and vertical (1100 feet) separations had increased beyond minimum requirements, ending the conflict.

Scenario track data related to the Conflict was processed graphically using the Wolverine Software Proof graphics animation package. Figure 22 is a Proof screen capture at the time of Conflict start, and Figure 23 is a screen capture at the time of Conflict end. For a brief description of the Proof graphics screen display, see Section 4.1.1.2.

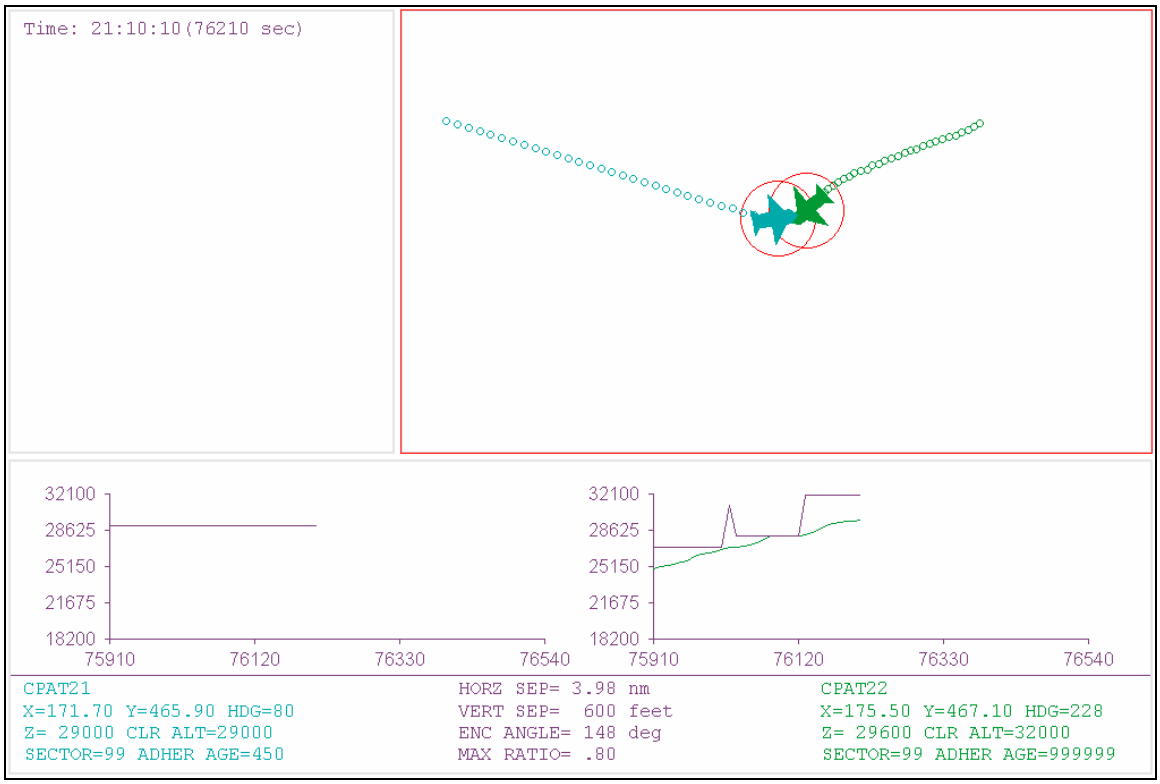

Figure 22: CPAT21 and CPAT22 at Start of Conflict

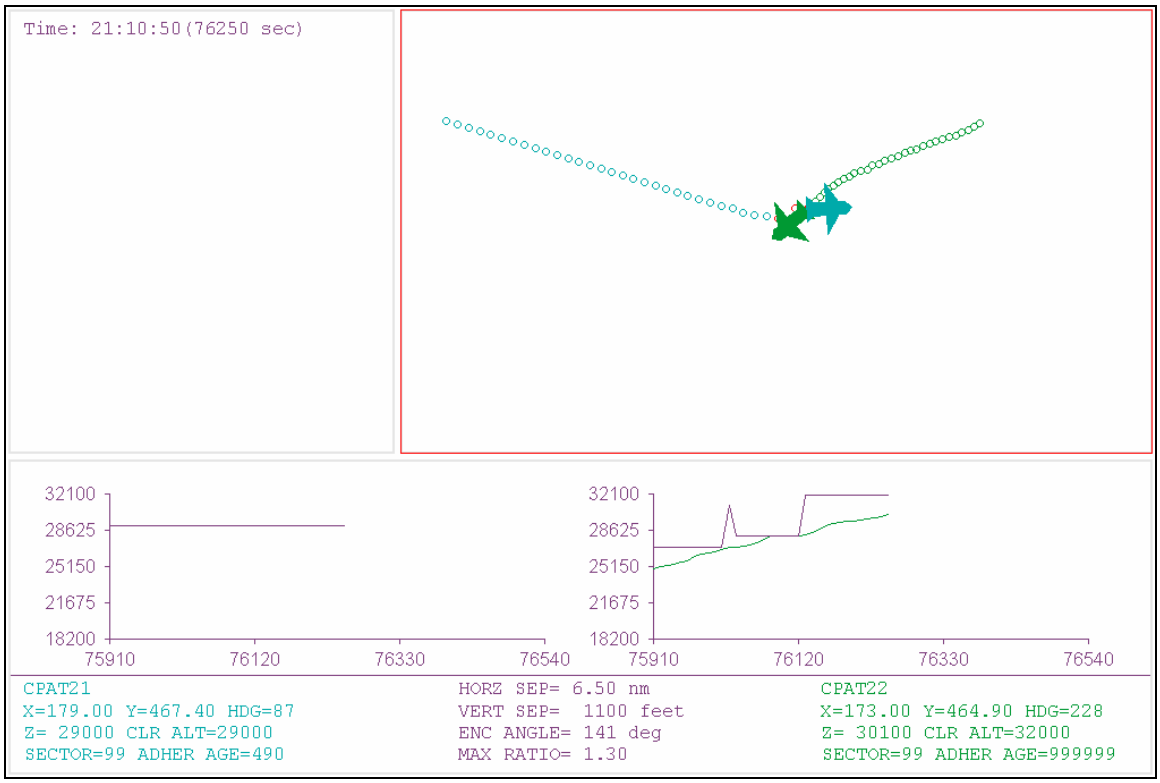

Figure 23: CPAT21 and CPAT22 at End of Conflict

4.1.2.3 Analysis

For this conflict, the HCS issued a Notification Set with an ADD time of 76177 seconds predicting conflict start at 76198 seconds, and with an eventual DEL time of 76249 seconds. As the actual conflict start time was at 76210 seconds, the HCS Notification Set provided a warning time of 33 seconds, below the specified minimum of 75 seconds.

The track data for both aircraft was examined to determine if the late warning time might be excused because of an unanticipated aircraft maneuver or other factor. An extrapolation test was performed on the track data, as described in Section 3.2.4.3 in (Paglione et al, 2006). Starting at a point one track sample interval prior to the actual start of the conflict, and working back one sample interval at a time to a point 80 seconds prior to ACST, straight line estimates were made of each aircraft's track based upon current speed, altitude, and rate of climb. As shown in Table 15, the linear extrapolations were able to predict the conflict back thru 76180 seconds, thus giving a calculated minimum warning time requirement of 30 seconds. As the HCS provided an actual warning time of 33 seconds, this conflict was placed in the VA_LATE, or Valid Late category.

Table 15: Conflict Prediction Results for Flights CPAT21 & CPAT22

Extrapolation Time (sec)	Min-Max-Ratio	Minimum Horizontal Separation (nm)	Minimum Vertical Separation (ft)	Predicted Conflict Start Time (sec)	Warning Time (sec)
76130	0.420	2.100	0	76200	75
76140	0.800	1.634	0	76200	75
76150	1.037	1.546	50	-1	50
76160	1.200	1.695	0	-1	40
76170	1.133	1.385	200	-1	30
76180	0.798	0.935	300	76210	75
76190	0.816	0.912	500	76210	75
76200	0.700	0.769	500	76210	75

4.2 Missed Alert Examples

This section presents sample events that exhibit missed alert errors. Missed alerts can occur either when an alert is never presented or is presented less than the specified 75 seconds prior to conflict start without justification.

4.2.1 Missed Standard Type A Example

4.2.1.1 Flight Description

In this GSGT simulation example, Flight CPAT11 is a Boeing 737 series aircraft flying from Philadelphia, PA to Nashville, TN with intermediate fixes at DPNT4, GVE, GHATS, and HARME. Flight CPAT12 is an Airbus A319 series aircraft flying from San Francisco, CA to Philadelphia, PA, with intermediate fixes at BKW, MOL, GVE, and DPNT4. Figure 24 below depicts the flight paths of these two aircraft immediately before and after the conflict that occurred.

4.2.1.2 Conflict Geometry

Track data for both aircraft became available at 76610 seconds into the scenario with CPAT11 on a heading of 201 degrees climbing from 18100 feet to its assigned altitude of 23000 feet, and CPAT12 assigned to and flying at 35000 feet on a heading of 90 degrees. By 77060 seconds, CPAT11 had climbed to and leveled off at a new assigned altitude of 30000 feet on a heading of 236 degrees, and CPAT12 had descended to and leveled off at a new assigned altitude of 33000 feet on a heading of 83 degrees. From this point until the end of the conflict between the two aircraft, CPAT11 remained at an assigned altitude of 30000 feet on a heading within a few degrees of 236 degrees, and CPAT12 slowly turned left reaching a heading of 51 degrees at conflict end. CPAT12 received a new altitude clearance to 31000 feet at 77092 seconds, and by 77210 seconds had leveled off at that altitude on a heading of 75 degrees. At 76217 seconds, CPAT12 received an altitude clearance to 29000 feet. At this point, the two aircraft were converging horizontally at a near head-on angle, with CPAT12 about to descend thru CPAT11's flight altitude. At 77280 seconds, CPAT12 began its descent, reducing vertical clearance between the aircraft below the minimum required 1000 feet. Horizontal separation at 77280 seconds was 6.66 miles. At 77290 seconds, horizontal separation dropped below 5 miles, and with a vertical separation of 900 feet, the conflict between the two aircraft began. Minimum

horizontal separation between the two aircraft was 3.16 miles at 77310 seconds, and by 77330 seconds, horizontal separation had increased to 6.6 miles, ending the conflict even though the two aircraft were both at 29000 feet.

Scenario track data related to the Conflict was processed graphically using the Wolverine Software Proof graphics animation package. Figure 25 is a Proof screen capture at the time of Conflict start, and Figure 26 is a screen capture at the time of Conflict end. For a brief description of the Proof graphics screen display, see Section 4.1.1.2.

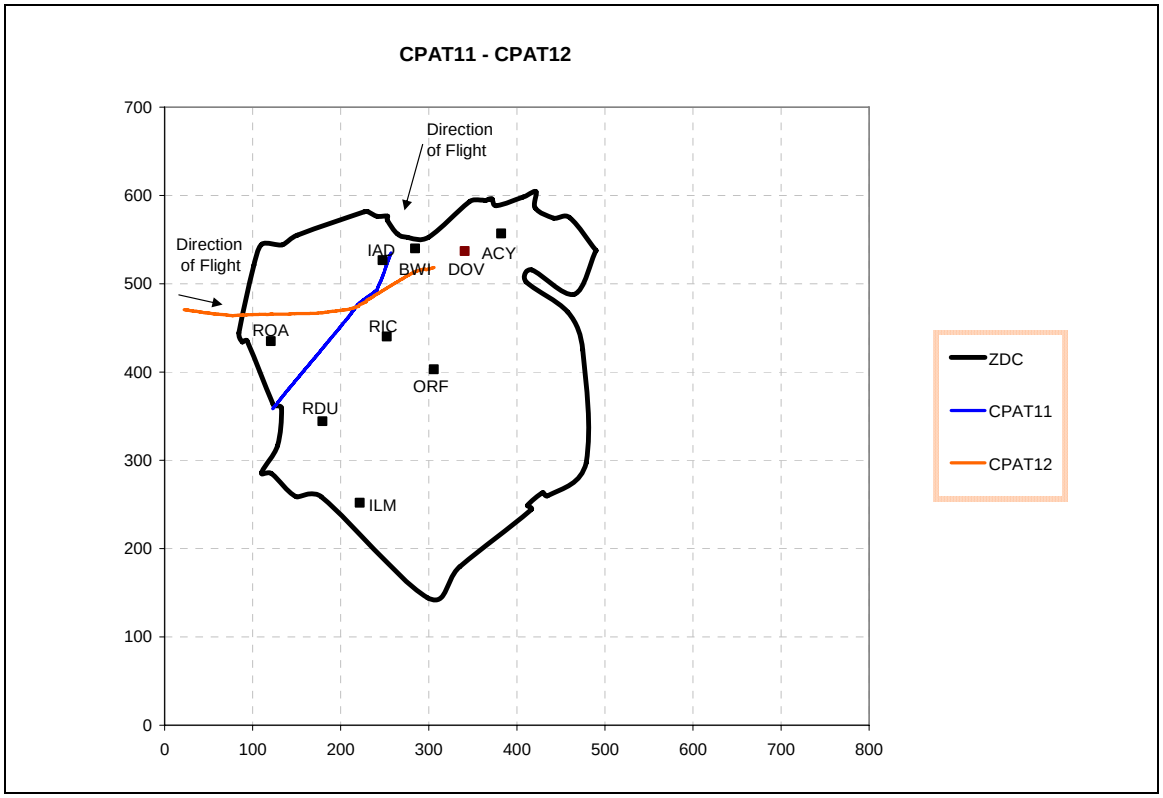

Figure 24: Flight Paths of Flights CPAT11 and CPAT12

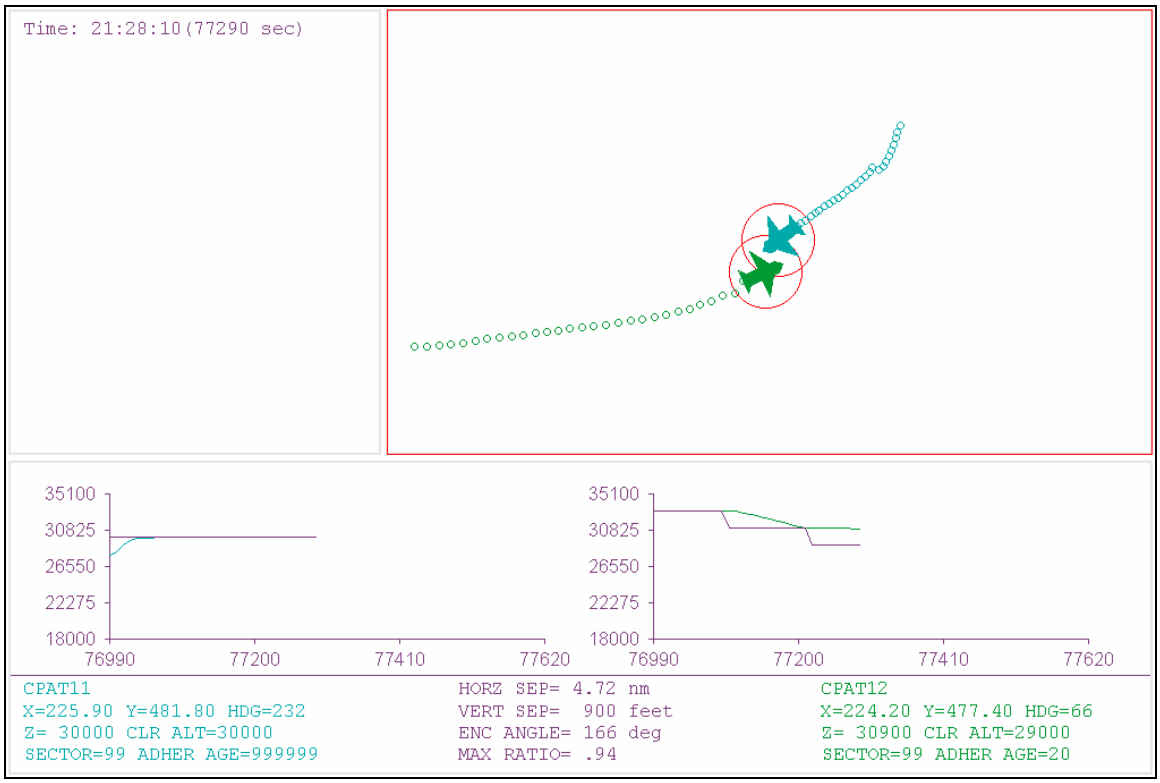

Figure 25: CPAT11 and CPAT12 at Start of Conflict

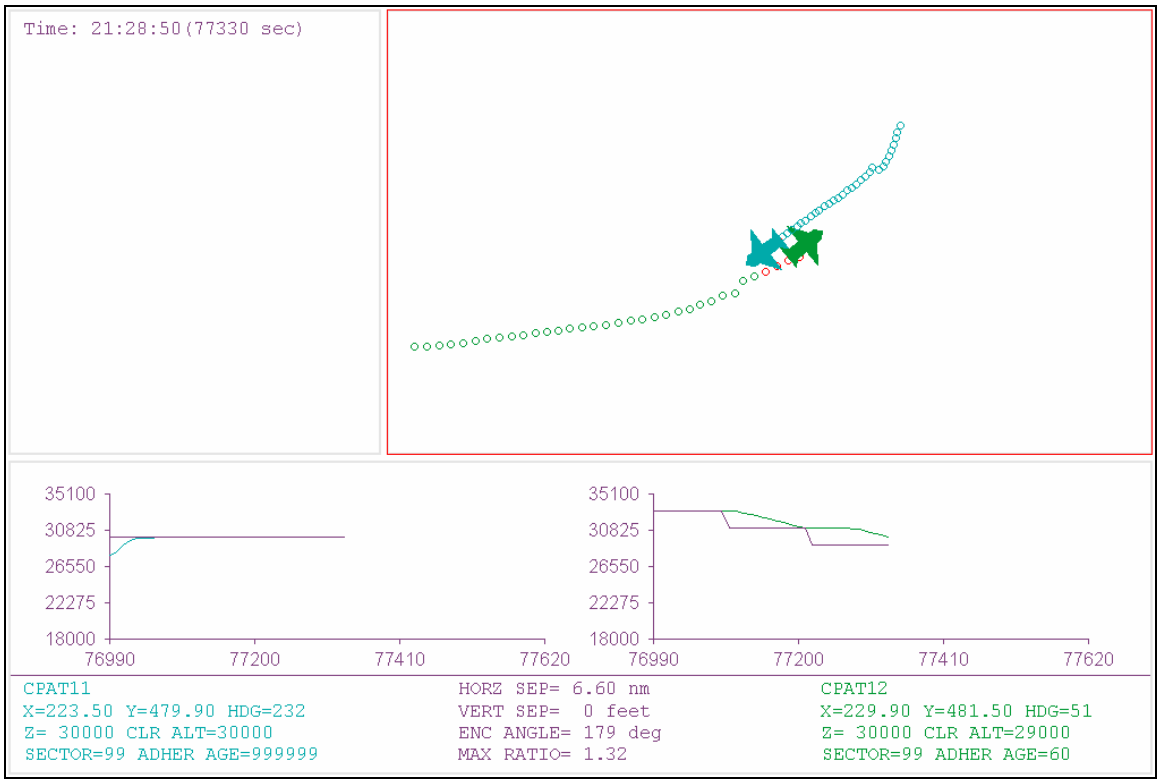

Figure 26: CPAT11 and CPAT12 at End of Conflict

4.2.1.3 Analysis

As a result of this conflict, the HCS did not generate any advisory Notification Sets, despite the 30 second duration of the conflict. As track data for both aircraft was available for a considerable period of time prior to conflict start, this conflict was placed in the MA_STD_A or Missed Standard Type A category.

4.2.2 Missed Late Example

4.2.2.1 Flight Description

In this GSGT/ERIT simulation example, Flight CPAT31 is a Canadair Regional Jet series aircraft flying from JFK Airport in New York to Jacksonville, FL with intermediate fixes at EMJAY, ORF, CHS, and SSI3. Flight CPAT32 is an Airbus A321 series aircraft flying from Fort Myers, FL to Atlantic City, NJ with intermediate fixes at CHS, SWL, and SIE. Figure 27 depicts the flight paths of these two aircraft before and after the conflict that occurred.

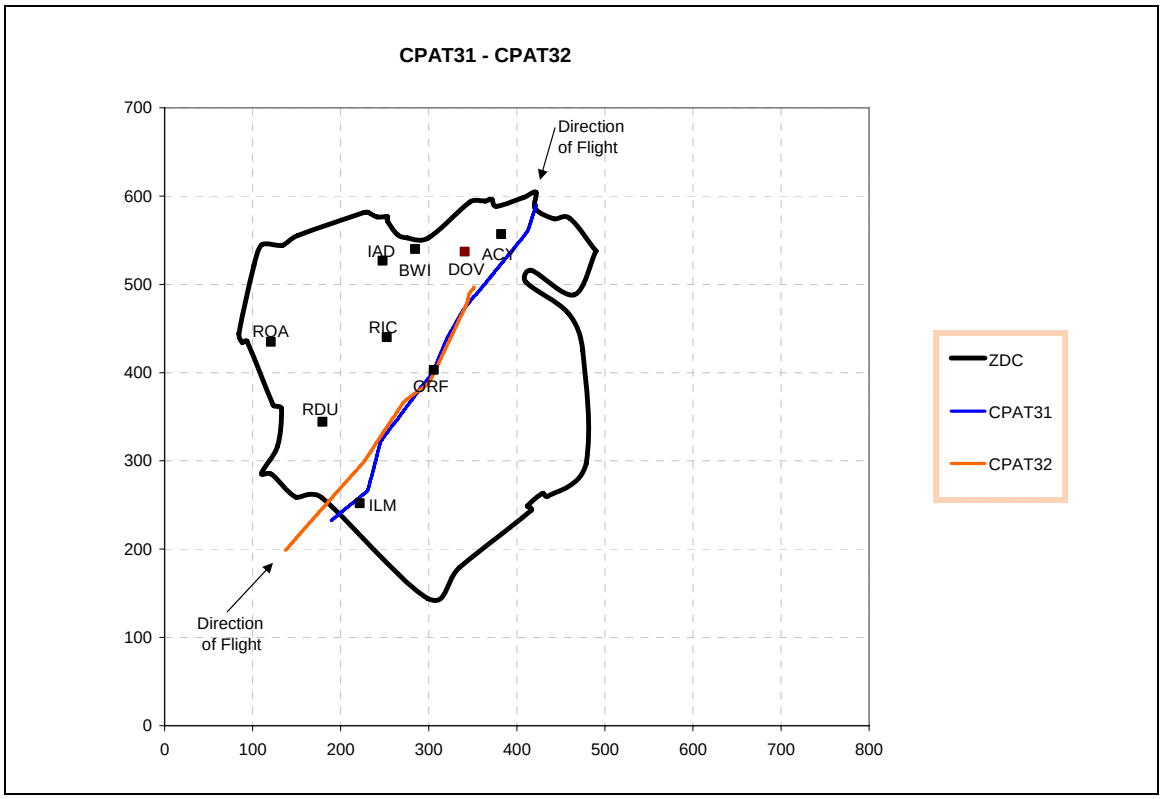

Figure 27: Flight Paths of Flights CPAT31 and CPAT32

4.2.2.2 Conflict Geometry

At 69550 seconds into the scenario CPAT31 was assigned to and was flying level at an altitude of 22000 feet, and was on a heading of 219 degrees. CPAT32 was assigned to and flying level at 29000 feet on a heading of 25 degrees. Over the course of the conflict, CPAT31 remained at 22000 feet and within a few degrees either side of a 220 degree heading. At 69689 seconds, CPAT32 was issued an altitude clearance to 25000 feet, and began a descent. By 69840 seconds, CPAT32 had leveled off at 25000 feet, remaining on a heading of 25 degrees. At 69914 seconds, CPAT32 was issued an altitude clearance to 20000 feet, and began its descent at 69940 seconds. At 69940 seconds, the aircraft were separated by 18.31 miles and 2850 feet, on a near head-on encounter angle, with CPAT32 about to descend thru CPAT31's flight altitude. By 70010 seconds, aircraft separation had decreased to 4.05 miles and 1025 feet, and at 70020 seconds the conflict began, with separation of 2.49 miles and 733 feet. By 70050 seconds, separation had increased to 5.01 miles and 359 feet, ending the conflict situation between the two aircraft.

Scenario track data related to the Conflict was processed graphically using the Wolverine Software Proof graphics animation package. Figure 28 is a Proof screen capture at the time of Conflict start, and Figure 29 is a screen capture at the time of Conflict end. For a brief description of the Proof graphics screen display, see Section 4.1.1.2.

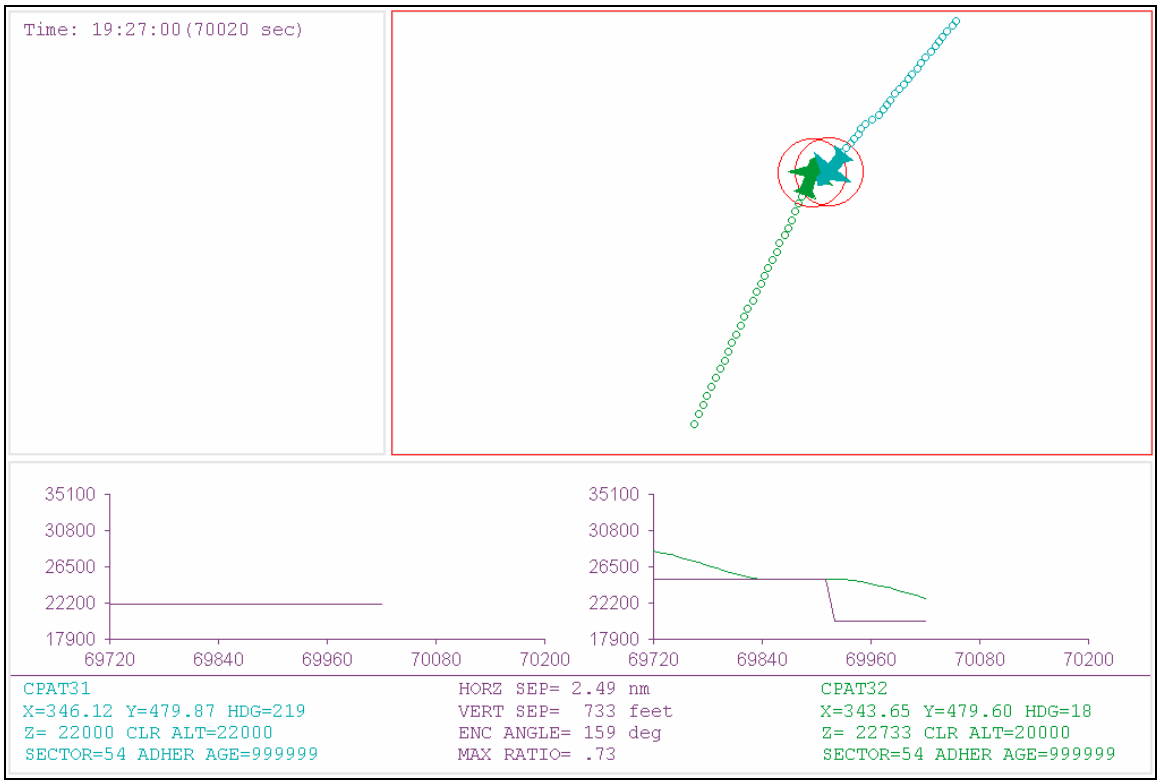

Figure 28: CPAT31 and CPAT32 at Start of Conflict

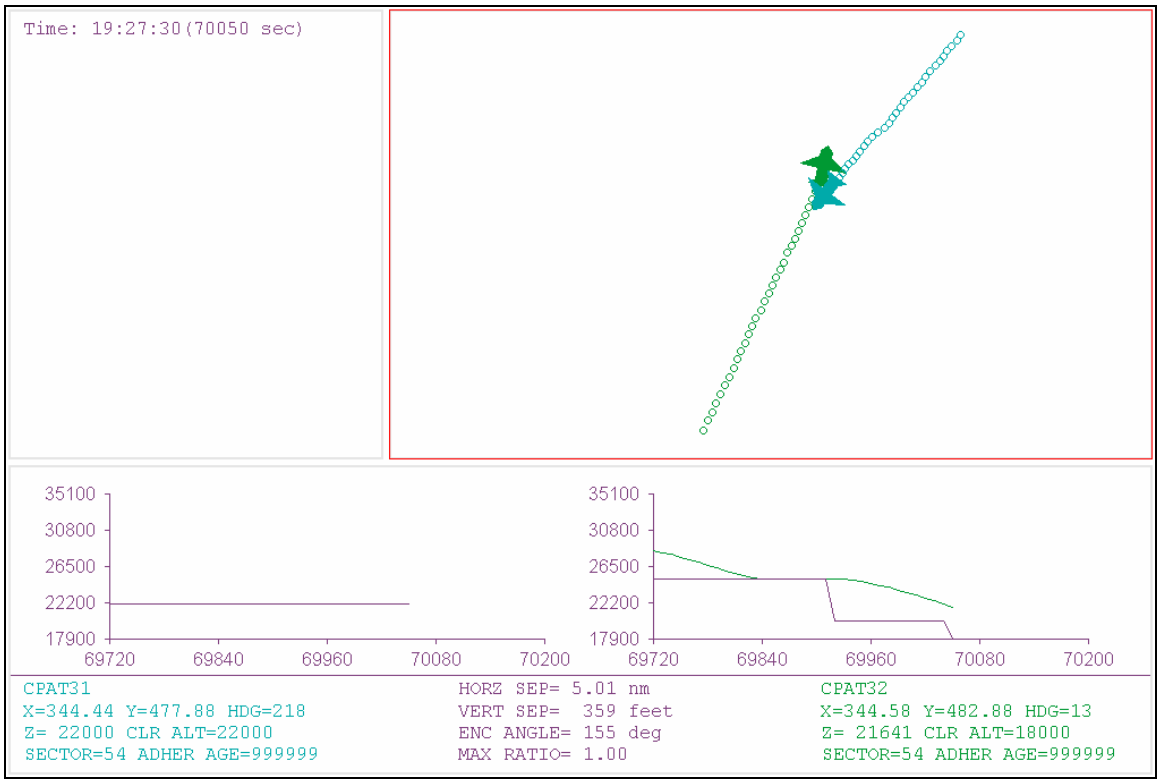

Figure 29: CPAT31 and CPAT32 at End of Conflict

4.2.2.3 Analysis

As a result of the conflict, the Host Computer System posted a Notification Set having an initial ADD entry at 69973 seconds predicting conflict start at 70031 seconds. As the actual conflict start time was at 70020 seconds, the warning time provided by the HCS was 47 seconds, below the minimum specified warning time of 75 seconds.

The track data for the two aircraft involved was examined to determine if the late warning time might be excused. First, it was verified that good track data was present for both aircraft during the time immediately preceding the conflict. Second, an extrapolation test was performed on the track data, as described in Section 3.2.4.3 in (Paglione et al, 2006), to check for the presence of an unexpected maneuver that might impact warning time. Starting at a point one sample interval prior to the actual start of the conflict, and working back one sample interval at a time to a point 80 seconds prior to ACST, a straight-line estimate was made of each aircraft's track based upon current speed, altitude, and rate of climb. As shown in Table 16, the extrapolation detected conflicts back thru 69660 seconds or 60 seconds prior to ACST. Accordingly, a required minimum warning time of 60 seconds was determined.

Although the extrapolation indicated a required minimum warning time below the specified minimum of 75 seconds, the actual warning time provided by the HCS was only 47 seconds. Accordingly, this conflict was placed in the MA_LATE or Missed Late category.

Table 16: Conflict Prediction Results for Flights CPAT31 &CPAT32

Extrapolation Time (sec)	Min-Max-Ratio	Minimum Horizontal Separation (nm)	Minimum Vertical Separation (ft)	Predicted Conflict Start Time (sec)	Warning Time (sec)
69940	1.995	1.590	1650	-1	70
69950	1.256	1.316	147	-1	60
69960	0.988	1.769	37	70040	75
69970	0.851	1.688	65	70030	75
69980	0.693	1.632	70	70020	75
69990	0.449	1.868	143	70020	75
70000	0.460	2.211	32	70010	75
70010	0.491	2.453	113	70020	75

4.3 False Alert Examples

This section presents sample events that exhibit false alert errors. False alerts can occur either when an alert is presented and retracted before a conflict actually starts or when a conflict never occurs and there is no justification for presenting the alert.

4.3.1 False Alert Standard 1 Example

4.3.1.1 Flight Description

In this GSGT/ERIT simulation example, flight CPAT41 is an Airbus A319 series aircraft flying from Mexico City to JFK Airport in New York with intermediate waypoints at GRD, ORF, and SIE. Flight CPAT42 is a Boeing 737 series aircraft flying from Islip, NY to Palm Beach, FL with intermediate fixes at ORF, CHS, and OMN. Figure 30 below depicts the flight paths of these two aircraft throughout the encounter between them. Note that the encounter occurred just to the southwest of Norfolk VA (ORF).

4.3.1.2 Encounter Geometry

Track data for both aircraft first became available at 71300 seconds scenario time. Throughout the encounter, CPAT41 was flying level at an assigned altitude of 39000 feet and was flying a flight path that started on a 53 degree heading at 72430 seconds, gradually turning left reaching a heading of 30 degrees at the time of minimum aircraft separation (72760 seconds). At 72430 seconds, CPAT42 was at an assigned altitude of 38000 feet on a heading of 203 degrees that gradually increased to 216 degrees at the time of minimum separation. The aircraft heading profiles resulted in a gradually decreasing encounter angle between the two aircraft and an eventual offset condition resulting in a closest horizontal approach considerably in excess of minimum separation standards.

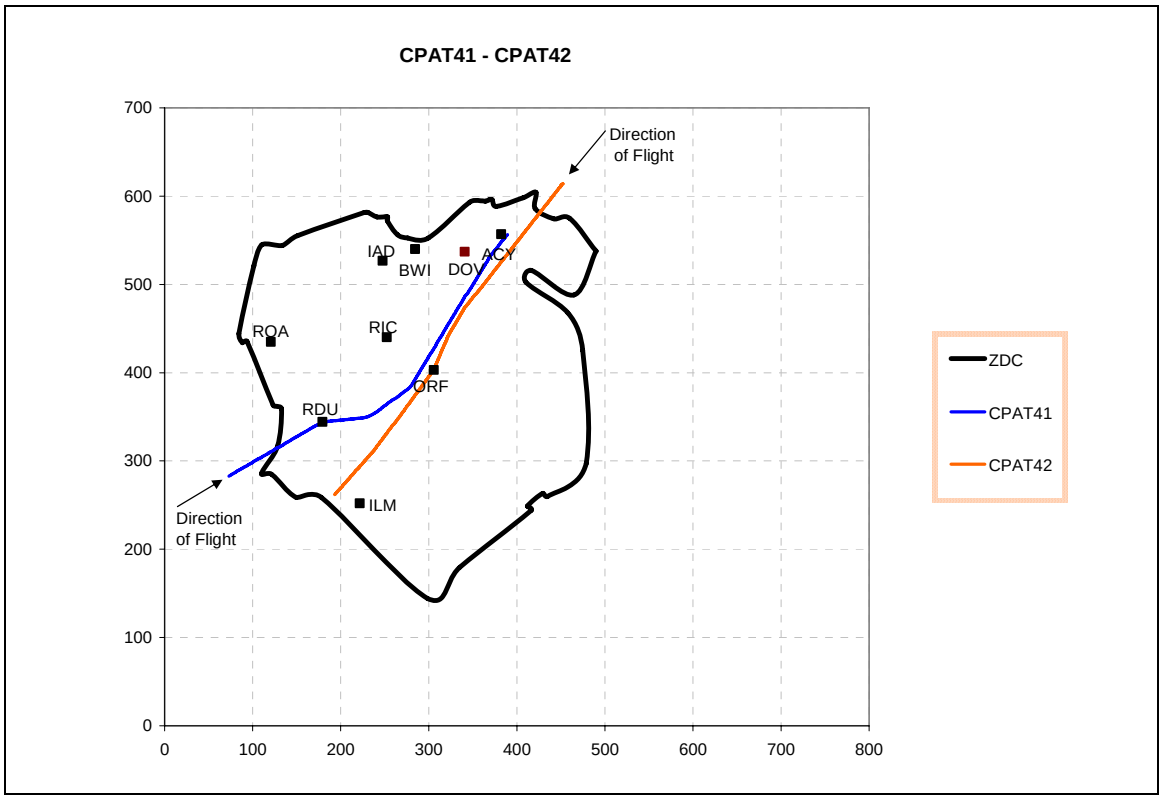

Figure 30: Flight Paths of Flights CPAT41 and CPAT42

At 72601 seconds, CPAT42 was issued a new altitude clearance of 40000 feet, resulting in a condition where CPAT42 would be climbing thru CPAT41's flight altitude. At this time, the aircraft were separated by 41 miles and 1000 feet. Minimum vertical separation was lost between the two aircraft at 72620 seconds when CPAT42 began its climb. As can be seen in Table 17, minimum vertical separation was regained between the two aircraft at 72750 seconds, and the closest horizontal distance between the two aircraft occurred at 72760 seconds. At no time during the encounter was minimum horizontal separation (5 miles) lost, so this incident was classified as an encounter rather than as a conflict.

Table 17: Encounter of Flights CPAT41 and CPAT42

Scenario Time (sec)	Horizontal Separation (nm)	Vertical Separation (ft)
72700	17.59	250
72710	15.72	358
72720	14.11	441
72730	12.81	525
72740	11.70	516
72750	11.12	1000
72760	11.02	1000
72770	11.38	1000
72780	12.18	1000

Scenario track data related to the Conflict was processed graphically using the Wolverine Software Proof graphics animation package. Figure 31 is a Proof screen capture showing the encounter between the two aircraft. For a brief description of the Proof graphics screen display, see Section 4.1.1.2.

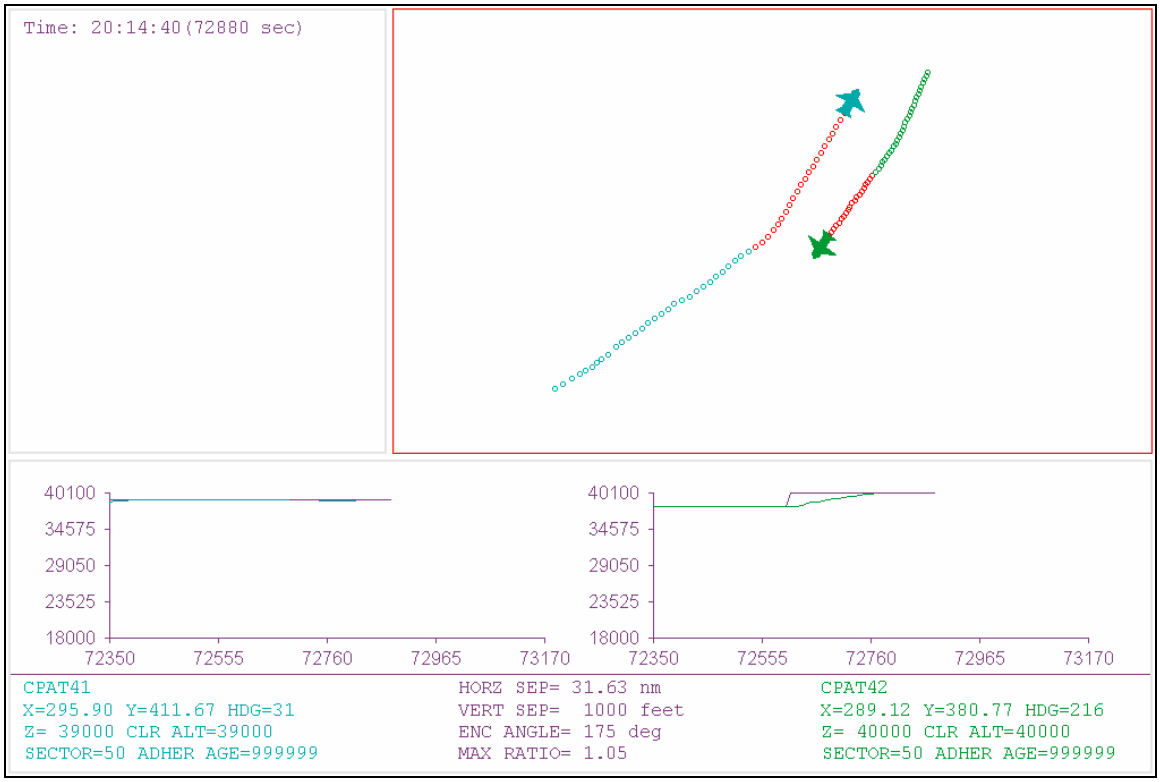

Figure 31: Encounter of Flights CPAT41 and CPAT42

4.3.1.3 Analysis

The HCS posted a Notification Set relative to CPAT41 and CPAT42 with an ADD time of 72673 seconds predicting conflict start at 72673 seconds, and with a DEL time of 72685 seconds. This Notification Set was unmatched against any conflicts as the two aircraft were never in a conflict situation. Following the procedure described in sections 3.2.4.4 and 3.2.4.5 in (Paglione et al, 2006), along with the associated flow charts, it was first determined that track data existed for both aircraft at the Notification Set ADD time. Next, a straight-line extrapolation was made of the position, altitude, and airspeed and heading of both aircraft at the track data point immediately after the NS ADD time to see if a conflict was predicted. When no conflict was predicted from this first extrapolation, a similar extrapolation was made at the track data point immediately prior to the NS ADD time, again looking for a predicted conflict. As no conflict was predicted from this second extrapolation, the incident was placed in the FA_STD1 or False Alert Standard Type 1 category. Table 18 shows the extrapolation results from the two sample points.

Table 18: FA Extrapolations for CPAT41 and CPAT42 Encounter

Extrap Time (sec)	Min-Max-Ratio	Min-Max-Ratio Time (sec)	Minimum Horizontal Separation (nm)	Minimum Horizontal Separation Time (sec)	Minimum Vertical Separation (ft)	Minimum Vertical Separation Time (sec)
72670	1.229	72760	6.144	72760	19	72680
72680	1.550	72760	7.751	72760	8	72680

4.3.2 False Alert Event Discard B Example

4.3.2.1 Flight Description

In this example, flight CPAT51 is an Embraer EMD-145 aircraft flying from Columbus, OH to Reagan National Airport in Washington DC with intermediate fixes at ESL, TRIXY, and AML. Flight CPAT52 is Learjet Model 35 aircraft flying from Wilmington, DE to Louisville, KY via intermediate fixes at FLIRT, YOCKY, and DABY3. Figure 32 below depicts the flight paths of these two aircraft throughout the encounter between them.

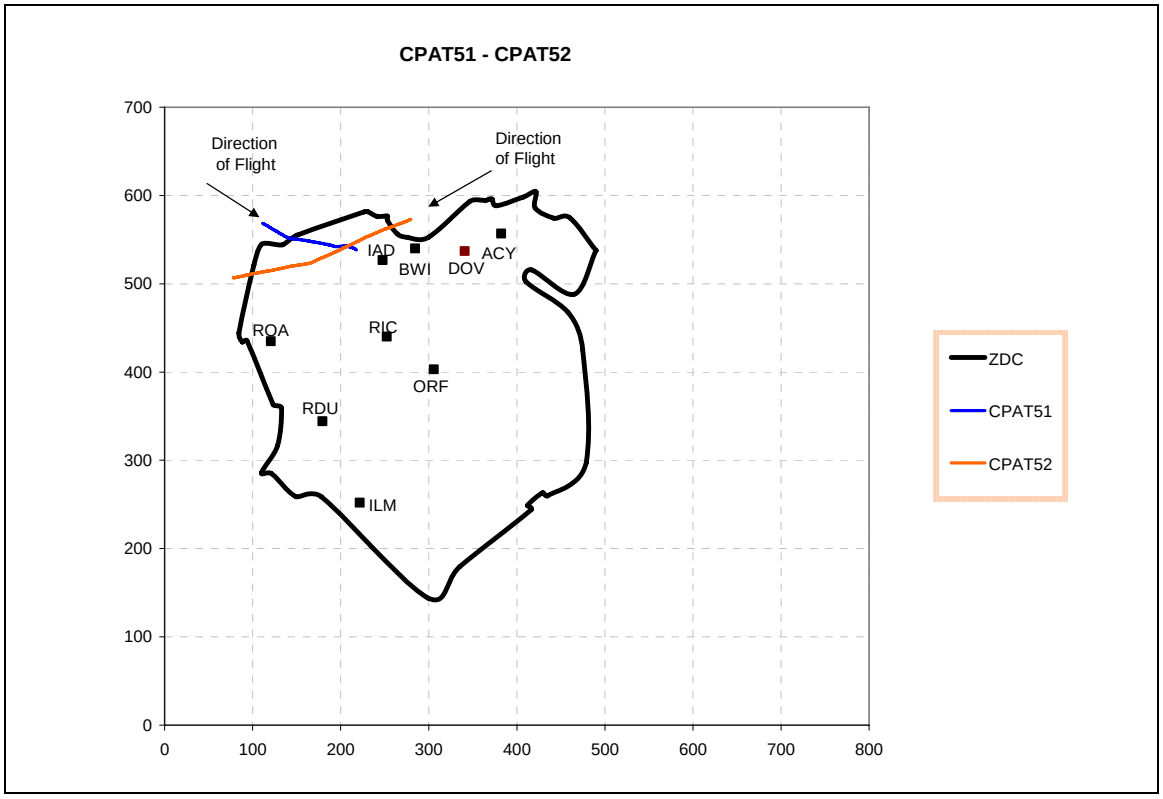

Figure 32: Flight Paths of Flights CPAT51 and CPAT52

4.3.2.2 Encounter Geometry

Track data for both aircraft first became available at 76090 seconds into the scenario. At 76500 seconds, CPAT51 was assigned to and was flying level at 27000 feet on a heading of 100 degrees, and CPAT52 was flying level at an assigned altitude of 24000 feet on a heading of 243 degrees. As can be seen from the altitude profiles in the Wolverine Software Proof graphics Figure 33 below, over the next 100 seconds, both aircraft received new altitude clearances. At 76544 seconds, CPAT51 received an altitude clearance of 25000 feet, and began a descent. At 76559 seconds, CPAT 52 received an altitude clearance of 22000 feet, and likewise began a descent. At 76646 seconds, CPAT51 received an additional clearance to 15000 feet. At this point in time, the two aircraft were on a converging path with CPAT51 descending to 15000 feet and CPAT52 descending to 22000 feet. CPAT52 reached and leveled off at 22000 feet at 76670 seconds. As the two aircraft approached minimum (5 nm) horizontal separation, CPAT51 briefly leveled off at 23000 feet (with a brief undershoot) until the two aircraft closed below, then regained minimum horizontal separation, then resumed its descent. Table 5 shows horizontal and vertical separations between the two aircraft during the closest part of the encounter. At no time was both minimum vertical and minimum horizontal separation lost, so no conflict took place.

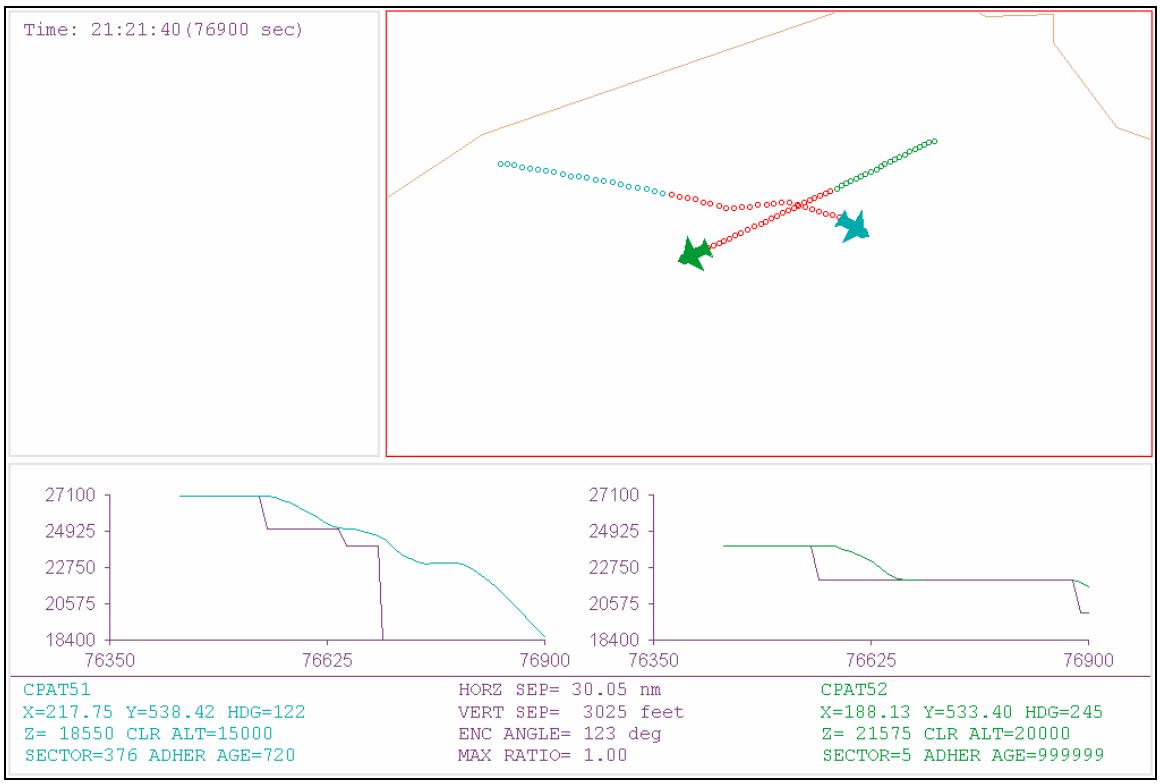

Figure 33: Encounter of Flights CPAT51 and CPAT52

Table 19: Encounter of Flights CPAT51 and CPAT52

Scenario Time (sec)	Horizontal Separation (nm)	Vertical Separation (ft)
76720	12.05	1500
76730	9.66	1283
76740	7.35	1075
76750	5.19	925
76760	3.33	1000
76770	2.94	1000
76789	4.22	1000
76790	6.46	1000
76800	9.01	875
76789	4.22	1000
76790	6.46	1000
76800	9.01	875

4.3.2.3 Analysis

The HCS posted a Notification Set relative to CPAT51 and CPAT52 with an ADD time of 76729 seconds predicting conflict start at 76738 seconds, and with a DEL time of 76789 seconds. This Notification Set was unmatched against any conflicts as the two aircraft were never in a conflict situation. Following the procedure described in sections 3.2.4.4 and 3.2.4.5 in (Paglione et al, 2006), along with the associated flow charts, it was first determined that track data existed for both aircraft at the Notification Set ADD time. Next, a straight-line extrapolation was made of the position, altitude, and airspeed and heading of both aircraft at the track data point immediately after the NS ADD time (76730 seconds) to see if a conflict was predicted. When a conflict was predicted from this first extrapolation, additional extrapolations were made at successive track data points, working towards the Notification Set delete time. As can be seen from Table 20 below, conflicts were predicted for track data points at 76730 thru 76760 seconds (R_MIN_MAX < 1.00), but not at 76770 seconds. As the track data point at which an extrapolated conflict did not exist (at 76770 seconds) was near the Notification Set DEL time (at 76789 seconds), the incident was placed in the FA_EVENT_DISCARD_B, or False Alert Event Discard Type B category.

Table 20: FA Extrapolations for CPAT51 and CPAT52 Encounter

Extrap Time (sec)	Min-Max-Ratio	Min-Max-Ratio Time (sec)	Minimum Horizontal Separation (nm)	Minimum Horizontal Separation (sec)	Minimum Vertical Separation (ft)	Minimum Vertical Separation Time (sec)
76730	0.330	76770	1.650	76770	135	76780
76740	0.465	76770	2.324	76770	12	76790
76750	0.567	76770	2.666	76770	30	76800
76760	0.925	76780	2.984	76770	400	76920
76770	1.000	76770	2.943	76770	1000	76770

5 Conclusion

This study has documented the performance of the HCS to provide tactical conflict alerts to the Air Traffic Control (ATC) Controllers. Two simulations were run in real time without ATC Controllers using field recorded and time shifted air traffic data. The first scenario simulated both the non-radar and radar reports input into the HCS, while the second scenario simulated only the non-radar reports. The radar reports for the later simulation were provided by recorded data, but time shifted as well. The scenarios were run using a standard Host Computer System (HCS), used for testing at the WJHTC. Each scenario lasted about four hours and contained about 1000 aircraft. In both cases, the source of the traffic data simulated was from the same field recording from March 17, 2005 in Washington ARTCC.

The metrics and details of the methodology used in this analysis are described in detail in the companion technical note (Paglione et al, 2006). The basic errors associated with tactical conflict alert predictions are directly noticeable to ATC Controllers, that is whether a conflict is not predicted, referred to as a missed alert, or a non-conflict is predicted, referred to as a false alert. However, many of the detailed issues in regard to the timeliness being measured or rules of determining these errors are not as clearly noticeable but are important nevertheless. As a result, the computation of the metrics, as is illustrated in this report and the companion report (Paglione et al, 2006), required complex processing.

The results for each scenario, since they used essentially the same simulated aircraft flights, were quite similar. The missed alerts rate, defined as the number of missed alert events over number of conflicts, was approximately 0.35 for both scenarios. For the first simulation run, the GSGT HCS version, 126 conflicts were generated and 44 were missed. Of these 44 conflicts, only 15 were actually missed at the actual conflict start time, since the other 29 were called missed alert late because they did not provide the minimum warning time requirement (e.g. 75 seconds) yet were presented before the conflict truly began. Of the 15 missed alerts not designated as missed alert late, only six (between five aircraft pairs being one pair has two conflicts) had no notifications at all. The other nine missed alerts had notifications that were either presented early and withdrawn before the actual conflict start time or presented afterwards. If the timeliness requirement and timing of the notifications were relaxed completely, the missed alert rate would have been approximately 0.05 for the GSGT HCS simulation.

In a similar way as the GSGT HCS simulation, the GSGT ERIT simulation run produced 93 aircraft-to-aircraft conflicts, and 29 were labeled as missed alerts. Analogous to the previous simulation, the timeliness and timing of the alert notifications plays a larger role than the prediction of the conflict itself. Almost two-thirds of the missed alerts predictions, 19, were labeled missed alert late because they violated the minimum warning time requirement. Of the remaining 10 missed alerts, only one had no notification at all, where the other nine were either presented early and withdrawn prematurely or presented late after the conflict began. Thus, if the timeliness and timing of the conflict notifications were relaxed completely, the missed alert rate would have been approximately 0.01.

The false alert rate was the highest, as expected, for encounters which were close to being conflicts and dropped as the minimum separation distances became larger. The overall false alert rates were 0.60 and 0.56 for the two scenarios, respectively. To properly illustrate the spectrum of false alert rates as a function of the aircraft pair's separation distances, the normalizing min-max-ratio metric was used to divide the encounter counts into bins of separation distances. These

bins began within a range zero to one, then one to two times separation distances, then progressively increasing to seven to eight times the legal separation distances. The resulting false alert rates decreased from around 0.12 and 0.10 from the smallest bin to practically zero up to the highest.

The decreasing nature of the false alert curve is exactly as expected. The steepness or sharpness of this performance curve is itself an indication of the performance of the conflict probe. The sharper the curve indicates a more accurate the conflict probe. This is not a metric documented in this report but is documented thoroughly in (Paglione et al, 1999b). The shape of the curve indicates the methodology did correctly capture this phenomenon and will be left for future study.

Both simulation runs complement each other. The GSGT HCS version simulates both radar and non-radar. The GSGT simulator samples the original traffic recording and utilizes these positions to generate a flight path that drives the radar simulator. The ground truth conflicts are based on these generated flight paths input into the radar simulator. For the most part, the flight path is absent of noise, has no time gaps, and is fairly clean[9]. This is in contrast to the second simulation run, GSGT ERIT. It does not simulate the radar data. It simply time shifts and injects the original recorded radar data from the ERIT system. Thus, the ground truth conflicts are based on the resulting HCS track reports. It does contain time gaps and the typical positional errors present in surveillance track reports. These differences did manifest themselves in the sample flights in the form of track report gaps and positional error, but they were not significant enough to exhibit statistical differences in the various accuracy metrics.

In conclusion, the simulation runs and resulting analyses validated the methodology presented in the companion report (Paglione et al, 2006). The development of a methodology and metrics defined in (Paglione et al, 2006) was a significant achievement, but the application of these metrics to the HCS met an even higher challenge due to the exceptional implementation complexity. The results presented in this report on the legacy HCS are also available for future comparison to the new ERAM system's performance when it becomes available. The analysis of HCS results does illustrate that the errors being measured (e.g. missed alert rate of 0.35), even if considered high, are more due to the timeliness of the conflict notifications than the presence of the prediction itself. The minimum warning time requirement used in this HCS study was provided by the associated ERAM requirement. However, it may not have been consistent with the original requirement used in developing the HCS tactical conflict alert function, offering some explanation of the results. Most importantly, the metric's methodology and implementation of the methodology has been tested on the legacy HCS function and is poised for application on the ERAM replacement.

[9] This flight path is generated before the simulated radar noise is added.

6 List of Acronyms/Abbreviations[10]

ACB-330	*Legacy* Simulation and Analysis Group, WJHTC, FAA
ACB-550	*Legacy* ERAM & ECG Group, WJHTC, FAA
ACP	Azimuth Change Pulse
AC1	Aircraft Number 1
AC2	Aircraft Number 2
ACID	Aircraft Identifier (Call Sign)
ACST	Actual Conflict Start Time
AIAA	American Institute of Aeronautics and Astronautics
AIR	Fictitious airline name
AMTWG	Automation Metrics Test Working Group
ARTCC	Air Route Traffic Control Center
ATC	Air Traffic Control
ATCA	Air Traffic Control Association
ATM	Air Traffic Management
AWT	Actual Warning Time
C	Conflict
CID	Computer Identifier
CMS	Common Message Set
COI	Critical Operational Issue
CPA	Closest Point of Approach
CPAT	Conflict Probe Assessment Team
CPT	Conflict Probe Tool
DASC	Digital Avionics Systems Conference
DEL	Delete
DS	Display System
ECG	En route Communications Gateway
ERAM	En Route Automation Modernization
ERIT	En Route Radar Intelligent Tool
FAA	Federal Aviation Administration
FDP	Flight Data Processing
FL	Flight Level
GH	General Information
GPS	Global Positioning Satellite System
GSGT	Graphical Simulation Generation Tool
HADDS	Host Air Traffic Management Data Distribution System
HCS	Host Computer System
HDG	Heading
Host	ARTCC main frame computer
IBST	Interval Based Sampling Technique
IIF	Integration and Interoperability Facility
IRD	Interface Requirements Document
JMP	Statistical software from SAS
JVN	JVN Communications, Inc.

[10] The ACB acronyms are now obsolete due to a re-organization in the FAA. However, they are provided here due to the legacy documents referred to in the study.

JSA	Joseph Sheairs Associates Inc.
MA_LATE	Missed Alert – Late
MA_STD	Missed Alert – Standard
MWT	Minimum Warning Time
MWTR	Minimum Warning Time Requirement
Nm	Nautical Miles
NS	Notification Set
ORR	Online Radar Recording
PC	Personal Computer
PCST	Predicted Conflict Start Time
PROOF	Post processing simulation animation software
RVSM	Reduced Vertical Separation Minima
SAR	System Analysis Recording
SAS	Statistics Analysis System
SDP	Surveillance Data Processing
SDRR	Looped Simulation Drive System Replacement
SEP	Separation
SQL	Structured Query Language
TP	Trajectory Predictor
TPM	Technical Performance Measure
URET	User Request Evaluation Tool
UTC	Coordinated Universal Time (see www.time.gov/about.html)
VA_LATE	Valid Alert – Late
VA_STD	Valid Alert – Standard
WJHTC	William J. Hughes Technical Center
ZDC	Washington ARTCC

7 List of Selected Airport Identifiers

ACY	Atlantic City International Airport
BWI	Baltimore Washington International Thurgood Marshall Airport
DOV	Dover Air Force Base
IAD	Washington Dulles International Airport
ILM	Wilmington International Airport
ORF	Norfolk International Airport
RDU	Raleigh Durham International Airport
RIC	Richmond International Airport
ROA	Roanoke Regional Airport

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