technical note technical note

Evaluation of Updates to Aircraft Characteristic Tables

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16. Abstract

The Federal Aviation Administration (FAA) is currently implementing a number of improvements to the National Airspace System (NAS) in the United States under a multi-agency initiative called the Next Generation Air Transportation System (NextGen) Program. The NextGen operational concept envisions a future air traffic environment managed by aircraft trajectory with advances in ground automation like the En Route Automation Modernization (ERAM) strategic conflict probe. The FAA's Concept Analysis Branch (ANG-C41) has been conducting a series of independent evaluations on proposed performance enhancements for ERAM. This paper describes an experiment designed to evaluate the effect of updating aircraft performance characteristics tables, which are referenced when calculating the predicted path of every aircraft. The experiment consists of simulated runs using an ERAM prototype system in a laboratory environment, and focuses on trajectory accuracy and conflict probe performance. Historical traffic scenarios are taken from two centers, the Chicago (ZAU) Air Route Traffic Control Center (ARTCC) and the Washington (ZDC) ARTCC, and the data is time-shifted in order to induce conflicts. Initial results indicate a slight overall improvement in trajectory accuracy when using the updated aircraft performance characteristics tables. While this improvement may be too small to make a practical difference in many cases, use of the updated tables does not appear to degrade the trajectory performance. The benefit is more pronounced in certain aircraft types, and in some select cases conflict probe alerts are improved. The recommendation is to adopt the updated tables, perform further analysis, and continue efforts to improve the tables.

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Executive Summary

The Federal Aviation Administration (FAA) is currently implementing a number of improvements to the National Airspace System (NAS) in the United States under a multi-agency initiative called the Next Generation Air Transportation System (NextGen) Program. The NextGen operational concept envisions a future air traffic environment managed by aircraft trajectory with advances in ground automation like the conflict probe. The Separation Management and Modern Procedures Project is one of these NextGen initiatives and its objective is to implement the En Route Automation Modernization (ERAM) strategic conflict probe on the radar controller display. The strategic conflict probe utilizes ERAM's Trajectory Modeler (TM) and Conflict Probe (CP) sub-systems to notify air traffic controllers when aircraft will violate separation standards as much as 20 minutes in the future. The FAA's Concept Analysis Branch (ANG-C41) has been conducting a series of independent evaluations on proposed performance enhancements to the TM and CP sub-systems. These various prototypes have been developed by Lockheed Martin, the development contractor of ERAM, within the ERAM architecture.

This paper describes an experiment designed to evaluate the effect of updating aircraft performance characteristics tables, which provide parameters such as climb and descent rates and adapted true airspeed of distinct aircraft types at varying temperatures and flight levels. These tables are referenced by the TM in calculating the predicted path of every aircraft. The current table values are based on empirical flight data, and the proposed updates to the tables take advantage of a recent analysis of additional flight data by Lockheed Martin. The question being evaluated is whether the updated tables result in improved trajectory accuracy and conflict probe performance.

The experiment consists of simulated runs using an ERAM prototype system in a laboratory environment. The TM and CP performance in treatment runs, which use the updated tables, is compared to the performance in baseline runs, which represent the current state of the live ERAM system. This experiment uses baseline traffic scenarios from two centers, the Chicago (ZAU) Air Route Traffic Control Center (ARTCC) and the Washington (ZDC) ARTCC. The flight data from each center consists of track points and route clearances from 2010 recordings of live traffic during peak hours. The data is time-shifted to induce conflicts, which are useful for testing the CP but rarely occur in recorded data. The metrics applied to the results have been used in previous studies and are thoroughly documented.

The initial results indicate a slight overall improvement in trajectory accuracy when using the updated aircraft performance characteristics tables. The decrease in vertical and along track trajectory error, while statistically significant, is too small to make a practical difference in many cases. However, use of the updated tables does not appear to degrade the trajectory performance. The benefit is more pronounced in certain aircraft types, and in some select cases conflict probe alerts are improved. Further analysis is needed with data that covers various temperature profiles and flights that include all of the updated aircraft types. The recommendation is to adopt the updated tables and continue efforts to improve the tables.

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1. Introduction

Task Order 85 of the Separation Management and Modern Procedures Project involves the development and validation of a data tool with the objective of upgrading the aircraft performance characteristic tables used in trajectory modeling in ERAM. To this end Lockheed Martin (LM) developed the ACZR aircraft data tool and used it to generate updated performance characteristic tables. These updates are discussed in more detail in the next sub-section.

The FAA Concept Analysis Branch (ANG-C41) conducted an experiment to evaluate the impact of the table updates on ERAM's trajectory modeling and conflict probe alert performance. The experiment consists of simulated runs in the ERAM system using two separate flight traffic scenarios based on data collected from the Chicago (ZAU) and Washington (ZDC) Air Route Traffic Control Centers (ARTCCs). The flight data was collected from 2010 recordings and has been time-shifted to induce conflicts for testing purposes; this time-shifting technique is described in [Paglione et al., 2003].

This paper details the experiment and related analysis to determine whether the updated tables result in improved trajectory accuracy and conflict probe performance. This work is one in a series of independent evaluations on proposed performance enhancements to the ERAM TM and CP sub-systems.

1.1. Aircraft Characteristics Table Updates

The operational ERAM system references aircraft characteristics tables which provide performance data such as adapted aircraft altitude transition rates and true airspeed. The adapted values are used in modeling the flight plan trajectory and aircraft trajectories for conflict detection [Torres et al., 2013]. The existing tables are based on a combination of published data and empirical data from traffic recordings made prior to 2000, with some limited updates made in response to problem reports. Aircraft types that did not have either of these sources were assigned a cloned profile from another aircraft type.

Torres et al. argued that problems with these current tables include limited empirical data, many aircraft types being clones instead of having an individualized profile, and the fact that new aircraft types have been introduced since 2000. Lockheed Martin developed a tool, ACZR, that updates the existing tables based on analysis of new flight data. The process is described in URET SIG2280, and the analysis infrastructure is presented in Figure 1.

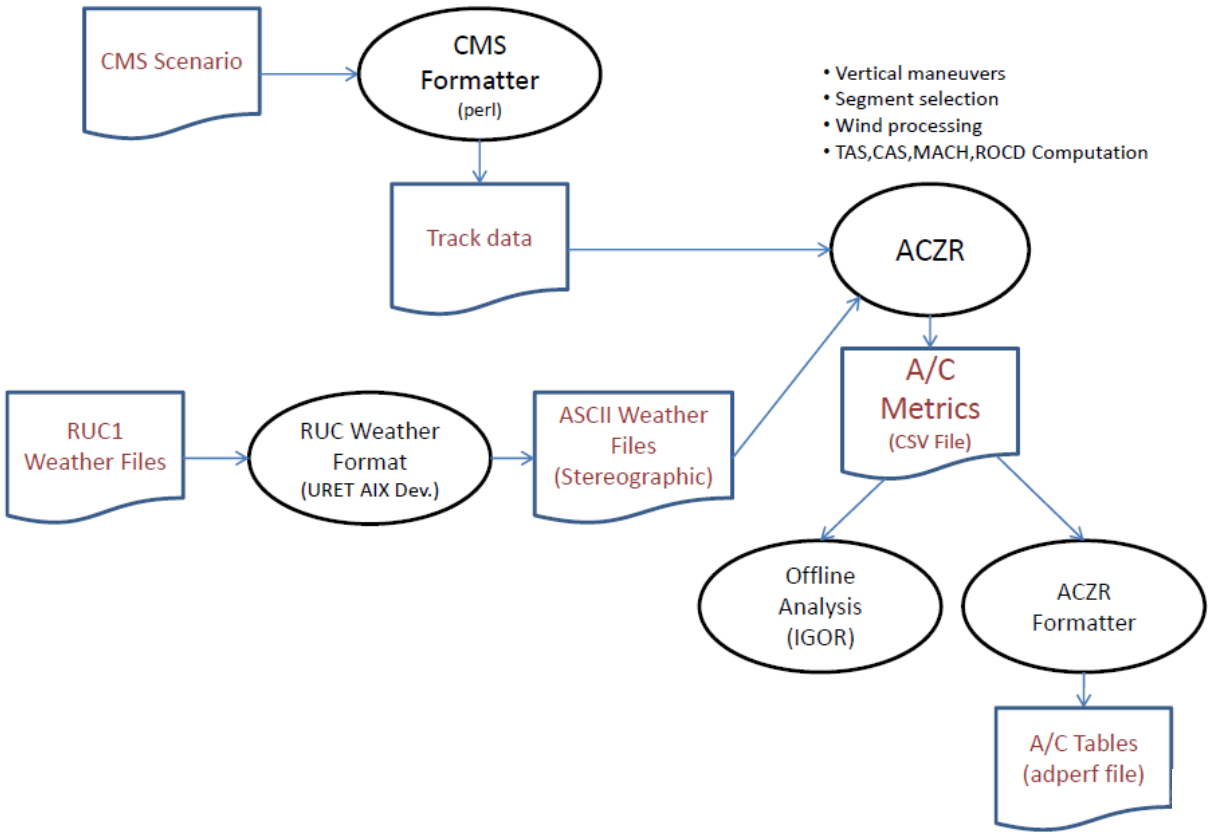

Figure 1. Aircraft characteristics analysis infrastructure [Torres et al., 2013]

The process depicted in Figure 1 involves analyzing data for distinct aircraft types at varying temperatures and flight levels and generating updated values for the performance parameters under these conditions. These proposed table updates are used in the "treatment" scenarios of the experiment, as explained in the following section. The aircraft characteristics tables were updated for both "master" and "clone" designators. Masters are designators whose aircraft characteristics tables are directly populated with empirical data for that aircraft type. Clones have tables that are copied from another designator.

2. Experiment Methodology

The objective of the study is to evaluate the impact of updates to aircraft performance characteristic tables. To this end, an experiment is introduced which allows a comparison of the automation system's performance when using the existing tables (in what is referred to as a "baseline" scenario) to its performance when using the updated tables in a "treatment" scenario. Lockheed Martin carried out the required runs, using a laboratory version of ERAM to simulate the ground automation system.

Flight data recordings from two centers were used to make the experiment more general by capturing potential differences in air traffic characteristics. In addition, using multiple centers increases the variety of aircraft types and temperature profiles observed. However, since one 8-hour period of recordings at each center was used as input, only a few temperature profiles were likely sampled. The observable effects are limited to those profiles that were sampled and therefore had a chance to affect the performance of the simulated ERAM. For the purposes of this initial analysis, any designator that has updates to some parameter values is considered to be "updated".

The actual recorded radar data from Feb 11, 2010 (ZAU) and April 30, 2010 (ZDC) is used as input to a track data generator for each scenario. Some small random error is generated to emulate radar noise, which causes the track data to vary slightly for each run in a given center. Preliminary analysis compared time-coincident track positions from the two scenarios and found the 3-dimensional distance between the points to have an average value of 0.11nm.

TM and CP performance are of interest in this study and the chosen metrics reflect trajectory accuracy and conflict probe alert comparison. The metrics for trajectory accuracy, as well as a technique for sampling relevant, unbiased error values, are detailed in [Paglione and Oaks, 2007]. Trajectory and CP performance metrics are discussed in [Crowell et al., 2011]. The process of collecting the historical air traffic data and converting it for use in simulated runs has been used in several previous studies and the data sample was time-shifted using the methodology documented in [Paglione et al., 2003].

2.1. Updated Designators

The proposed table updates were used in the treatment scenario runs, and a list of the aircraft types with updated performance values was provided to ANG-C41. Table 1 lists the "master" aircraft type designators for which the aircraft characteristics tables were updated.

Table 1. Updated designators: Masters

A306	B738	C130	CRJ7	FA20	P180
A319	B739	C17	DC10	FA50	P46T
A320	B744	C208	DC93	GLF4	PA31
A321	B752	C340	DC95	GLF5	PA46
A332	B753	C414	DH8A	H25B	PC12
A333	B762	C421	DH8B	K35R	SF34
AT72	B763	C525	DH8C	LJ31	SW4
B190	B764	C550	E120	LJ35	T38
B350	B772	C560	E135	LJ45	TEX2
B712	BE20	C56X	E145	LJ60	
B722	BE30	C650	E170	MD11	
B733	BE35	C750	E190	MD82	
B734	BE40	CL60	E45X	MD83	
B735	BE58	CRJ1	F2TH	MD88	
B737	BE9L	CRJ2	F900	MD90	

The updated "clone" designators are listed in Table 2, along with their current mapping. For example, the first entry indicates that the current aircraft characteristic table for designator A318 is a copy of the table for A319. A proposed updated table for A318 has been directly populated with data specific to the A318. The presence or absence of a flight's aircraft type in one of the lists in Table 1 and Table 2 (in other words, its update status) is applied in interpreting the results.

Table 2. Updated designators: Clones

A318 →A319	DH8D →CRJ2
A343 →DC95	E50P →C500
A346 →DC95	EA50 →C501
B736 →B739	FA7X →FA50
B77L →B772	G150 →C750
C25A →C525	GALX →GLF5
C25B →C750	GL5T →GLF5
C30J →C130	HA4T →H25B
C510 →C500	HAWK →A10
C680 →C650	LJ40 →LJ45
CL30 →CL60	LNC4 →C182
COL4 →C182	PRM1 →BE40
CRJ9 →CRJ7	SR22 →BE36
DC91 →DC95	TBM8 →C208
DC94 →DC95	

There are 84 masters and 29 clones listed as designators with updated tables. Most, but not all of these appear in the traffic scenarios available for this study. A categorization of the flights that

appear in the ZAU and ZDC scenarios, including which update status category they belong to, is presented in Table 3.

Table 3. Aircraft types and flights found in data sample

		Masters	Clones	Not updated	Total
ZAU	Aircraft types	76	19	52	147
	Total flights	1987	134	113	2234
ZDC	Aircraft types	78	23	64	165
	Total flights	2349	151	164	2664

Including the traffic data of both centers, 80 out of 84 masters and 26 out of 29 clones are observed. Only 7 designators in total are not found in either the ZAU or ZDC scenario. These aircraft types are listed in Table 4.

Table 4. Seven updated designators not found in data sample

Designator	Class
AT72	Master
C130	Master
T38	Master
TEX2	Master
DC91	Clone
HAWK	Clone
LNC4	Clone

Since flights with these designators were not present in the traffic data sample, they cannot be included in the experiment and therefore no information is available about the effect of the updated tables on trajectory modeling for these flights in ERAM.

3. Analysis and Results

The data from LM was processed through custom-built software tools in order to smooth the track data and run trajectory and conflict probe diagnostics. Statistical analysis was carried out with the goal of answering the objective. To complement the overall statistical view of the results, several flight examples were selected to give a focused, anecdotal illustration of how the updated tables affected trajectory and conflict probe performance. The following three subsections present the results for trajectory accuracy, conflict probe performance, and flight examples.

3.1. Trajectory Accuracy

Changes to the rates of climb and descent (ROCD) in the performance tables are anticipated to affect the vertical trajectory error, and changes to the adapted true airspeed (TAS) are anticipated to affect the along track error. Therefore these two error metrics in particular are examined, although cross track and horizontal error metrics are also collected. Figure 2 illustrates the trajectory error metrics that are used in this study.

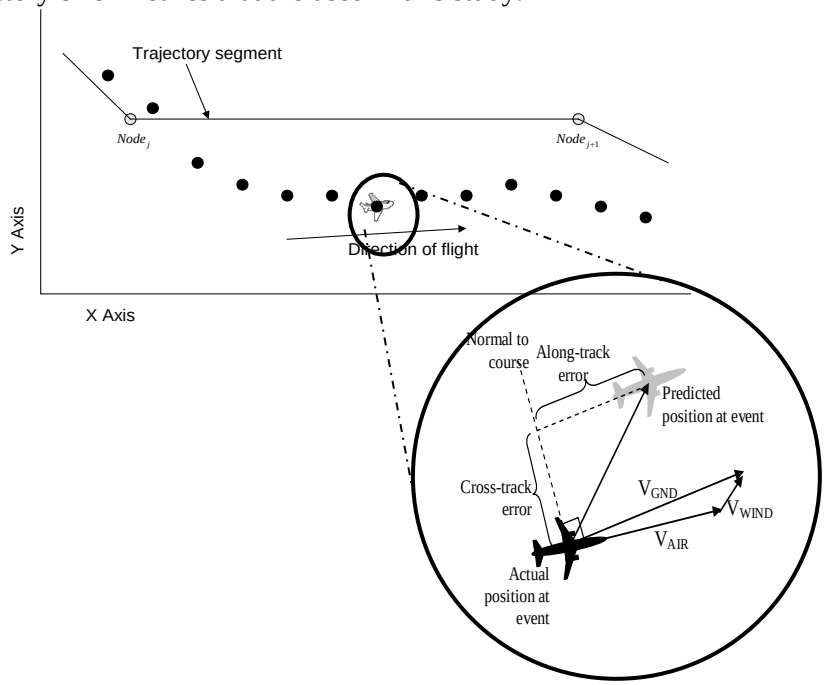

Figure 2. Diagram of trajectory error metrics

Following the technique presented in [Paglione and Oaks, 2007], at every sampling time predicted positions along the active trajectory are compared to corresponding track position reports. Trajectory errors are calculated at the current sampling time (look ahead time of 0) and at future times along the trajectory (e.g., look ahead time of 5 minutes). To get a general idea of overall trajectory accuracy for scenario comparison, the four metrics are sampled at 0, 5, 10, 15, and 20 minute look ahead times and the average value of each metric is calculated for each flight in a scenario. Note that cross and along track error are perpendicular components which comprise horizontal error. The average of absolute error values is used because the distance from centerline (zero) is of primary interest, and sign can be disregarded. A paired *t*-test is applied, which compares the average error for a given flight between a baseline and treatment scenario to

determine whether a statistically significant difference exists between the two. The flights are grouped by update status: master, clone, or not updated.

In the group of flights whose aircraft characteristic tables were not updated, no significant difference in trajectory errors is found for either center. This corresponds with the expectation that there is no underlying difference between the baseline and treatment scenarios for these flights.

In the Clone group of flights (Table 5), the data indicates a statistically significant difference in average vertical and along track error between the baseline and treatment scenarios for ZAU. When updated aircraft characteristic tables are used, the predicted aircraft trajectories are closer to the reported track positions by an average of 34 ft in the vertical dimension and 0.06 nm along the track for ZAU. In the ZDC data, the only difference that is statistically significant is in along track error, for which the average improvement is 0.09 nm.

In the Master group, a significant difference is found in average vertical, along track, and cross track errors. The vertical error is found to decrease by an average of 9 ft, and along track error decreases by 0.04 nm. However, the difference in cross track error indicates an increase of less than 0.01 nm in trajectory error in the treatment scenario for ZAU. While the magnitude of this increase is very small, there is no clear explanation for the increase. The pattern in ZDC is identical, although with smaller magnitude differences: 6 ft decrease in vertical error, 0.02 nm in along track error and an increase of 0.003 nm in cross track error.

The results of the matched pair tests are provided in Table 5. The mean difference in average trajectory error between the baseline and treatment runs is listed along with the *p*-value from the statistical test for each of the four types of trajectory errors. Negative values indicate a decrease in error from the baseline scenario, which uses the existing tables, to the treatment scenario, with updated tables. Each *p*-value presented in Table 5 is the probability of observing a discrepancy in means at least as large as that observed, even if there is no underlying difference in the means. A *p*-value less than 0.05 is typically considered statistically significant and these cases are indicated in Table 5 by boldface.

Table 5. Paired *t*-test results for trajectory errors

		Clone		Master	
	Center	Difference	*p*-value	Difference	*p*-value
Horizontal (nm)	ZAU	**-0.0478**	0.0204	**-0.0274**	<.0001
	ZDC	**-0.0850**	0.0001	**-0.0142**	0.0032
Vertical (ft)	ZAU	**-34.4310**	0.0059	**-9.0981**	0.0003
	ZDC	-8.7662	0.2481	**-5.5676**	0.0013
Cross Track (nm)	ZAU	0.0063	0.2017	**0.0061**	0.0007
	ZDC	0.0012	0.7749	**0.0033**	0.0340
Along Track (nm)	ZAU	**-0.0578**	0.0069	**-0.0360**	<.0001
	ZDC	**-0.0941**	<.0001	**-0.0177**	0.0015

The impact of using the updated tables may be more evident in some aircraft types than others. To capture this, trajectory results for each flight are grouped by aircraft type, and the

overall observed effect on trajectory error is plotted. Figure 3 displays the mean difference in trajectory error between the treatment and baseline scenario, by aircraft type for ZAU.

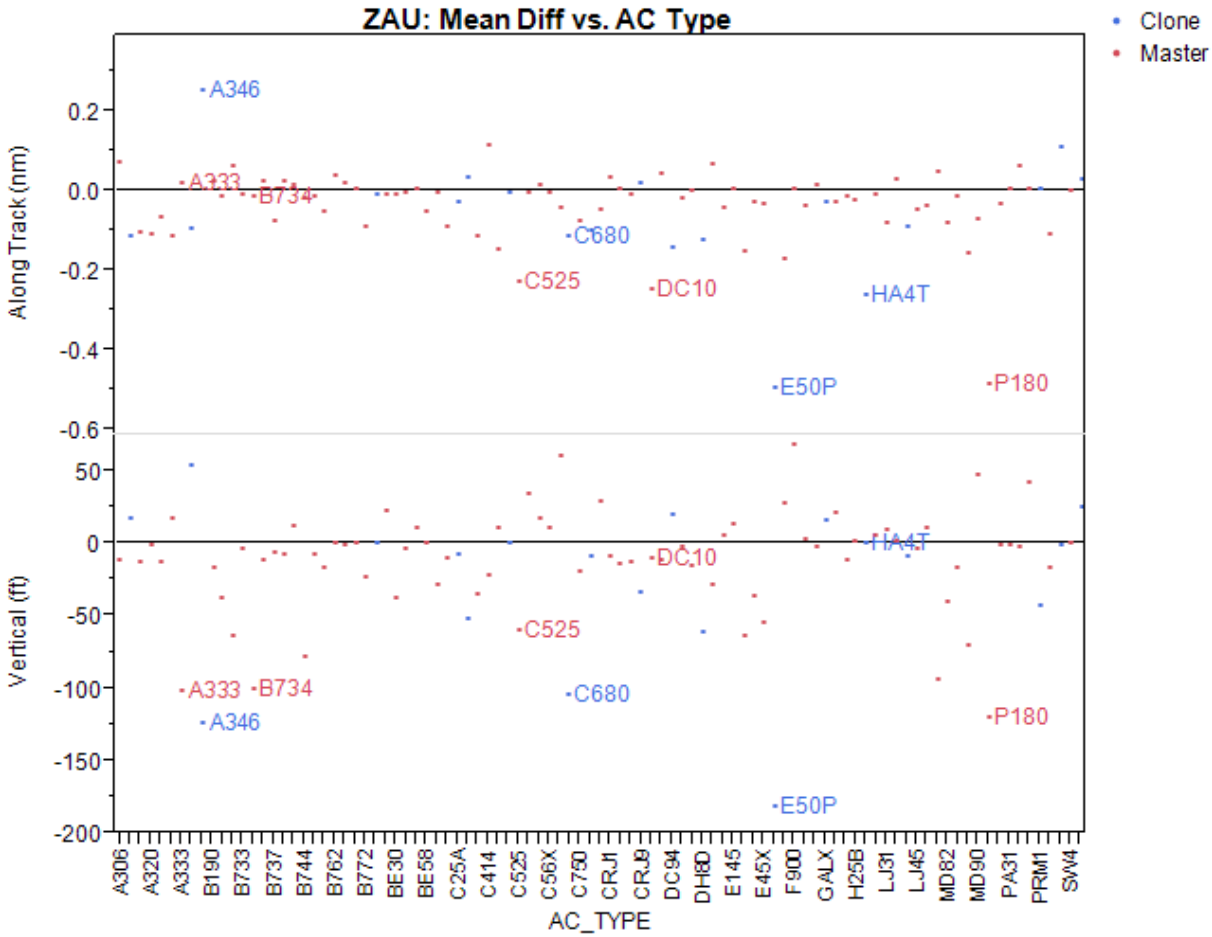

Figure 3. Mean difference vs. aircraft type for ZAU

The top section of the graph in Figure 3 presents the difference in along track error and the bottom presents the difference in vertical error, averaged over all flights of a particular aircraft type. Negative values denote lower trajectory error in the treatment than in the baseline (i.e., improved accuracy). Clones are represented by blue points and masters by red. Aircraft types whose performance tables were not updated tend to fall along the zero line and are excluded from the graphs. Note that there are too many aircraft types to be able to list them all on the horizontal axis, however each is represented by a data point. Aircraft types that exhibit an accuracy improvement of more than 0.2 nm in along track error or 100 ft in vertical error are labeled with the designator (9 total). Figure 4 displays the same information for the ZDC data, although the scale is slightly different.

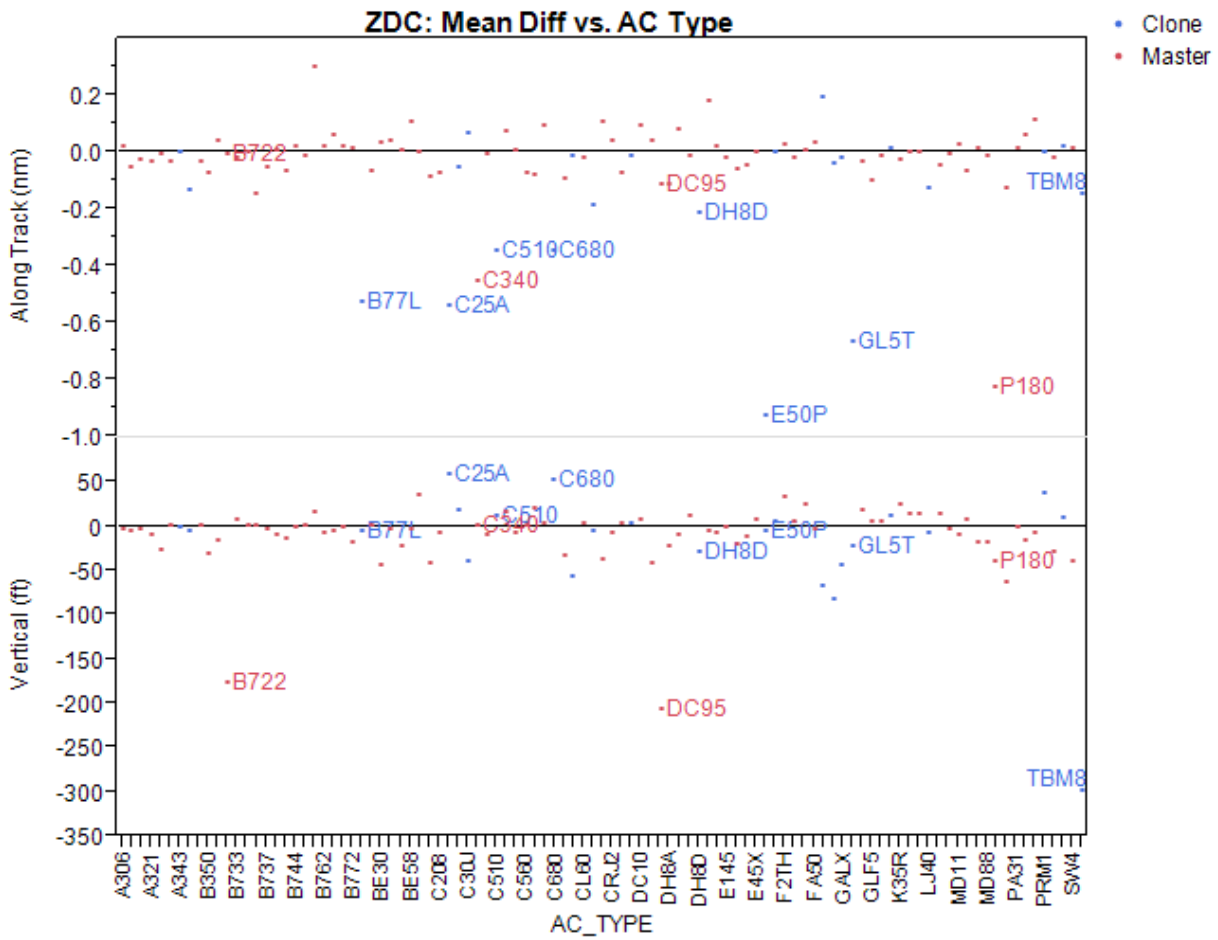

Figure 4. Mean difference vs. aircraft type for ZDC

Again, aircraft types that exhibit accuracy improvement of more than 0.2 nm in along track error or 100 ft in vertical error (12 total in ZDC) are labeled with their designator in Figure 4. Aircraft types that have a notable increase in accuracy in both centers are C680, E50P, and P180.

3.2. Conflict Probe Performance

The conflict probe alerts generated by the ground automation are processed with the *Strategic Alert Evaluator*, part of a suite of applications referred to as *CPAT Tools* and developed by the Conflict Probe Assessment Team (CPAT) in ANG-C41. The simulated track reports are processed to identify instances where a loss of separation (LOS) occurred, and these are matched to the alerts using an algorithm documented in [Crowell et al., 2011] and [Paglione et al., 2004]. The result is that every time-coincident instance of an alert or encounter is labeled as one of the following:

- Valid Alert (VA), an alert given more than 3 minutes before a simulated LOS
- Late Alert (LA), an alert given less than 3 minutes before a simulated LOS
- Missed Alert(MA), no alert before a simulated LOS
- False Alert (FA), an alert occurring with no simulated LOS

Another category, “Discard,” is a method of excusing situations where exceptions in the data made it impossible for a correct alert to be produced. For instance, these would include a conflict

with duration less than a stated threshold, or periods of missing track data. Finally, an encounter with no loss of separation that is correctly not alerted is termed a No Call (NC).

By matching up the encounters from the track data a comparison of alert evaluations can be made. This comparison demonstrates differences between the baseline and treatment scenarios and is provided in Table 6 (ZAU) and Table 7 (ZDC). For instance, FA_NC gives the count of aircraft encounters that were categorized as False Alerts in the baseline scenario and became correct No Calls in the treatment scenario. Codes with "SAME_" present the count of matching alert categorizations.

Table 6. Conflict alert comparison for ZAU

Evaluation Code	Count
DISCARD_FA	73
DISCARD_NC	194
FA_DISCARD	87
FA_NC	256
NC_DISCARD	182
NC_FA	247
SAME_DISCARD	790
SAME_FA	1111
SAME_MA	7
SAME_VA	187
MA_VA	3
VA_MA	2
VA_NOMATCH	1

Table 7. Conflict alert comparison for ZDC

Evaluation Code	Count
DISCARD_FA	54
DISCARD_NC	259
FA_DISCARD	58
FA_NC	214
NC_DISCARD	183
NC_FA	180
SAME_DISCARD	1017
SAME_FA	1150
SAME_MA	5
SAME_VA	202
MA_VA	1
VA_MA	1

A chi-square test for statistical significance in CP comparison is adapted from [Kachigan, 1986] and applied in [Crowell et al., 2011]. The test is applied for three main categories of potential improvement and the results are presented in Table 8.

Table 8. Chi-square test for significant difference in alert performance

	Comparison	Chi-Square	*p* value
ZAU	DISCARD_FA	1.225	0.268382
	FA_NC	0.161034	0.688207
	MA_VA	0.2	0.654721
ZDC	DISCARD_FA	0.142857	0.705457
	FA_NC	2.93401	0.086732
	MA_VA	0	1

The data in Table 6 and Table 7 suggests a trend towards improvement, but the difference is not statistically significant according to the chi-square test.

3.3. Flight Examples

The flight examples depicted below are provided to visually demonstrate the effects of the aircraft characteristics table updates on trajectory accuracy and the Conflict Probe. Figures 5-8 are screen captures from *FliteViz4D*, an interactive 4D visualization tool developed by ANG-C41 and capable of presenting many different types of data [Crowell et al., 2012]. Dotted lines represent the track of each aircraft, which is almost identical in both of the scenarios that are compared. Wireframes represent the trajectories for each flight and small hollow cylinders represent the current position of the flight. In the examples demonstrating the impact to CP, large boxes represent the future time along the trajectory at which the conflict in question is predicted to occur. Blue and green coloration represent baseline conditions, while red and gold represent data from the treatment scenario.

3.3.1. Example 1 – Trajectory Improvement

Figure 5 depicts an Embraer E170 (E170) on its initial climb from Chicago O'Hare International Airport (KORD). The dotted line represents the flight's track data, which is identical for the two scenarios. The aircraft trajectories are represented by two wireframes, blue for the baseline and red for the treatment scenario.

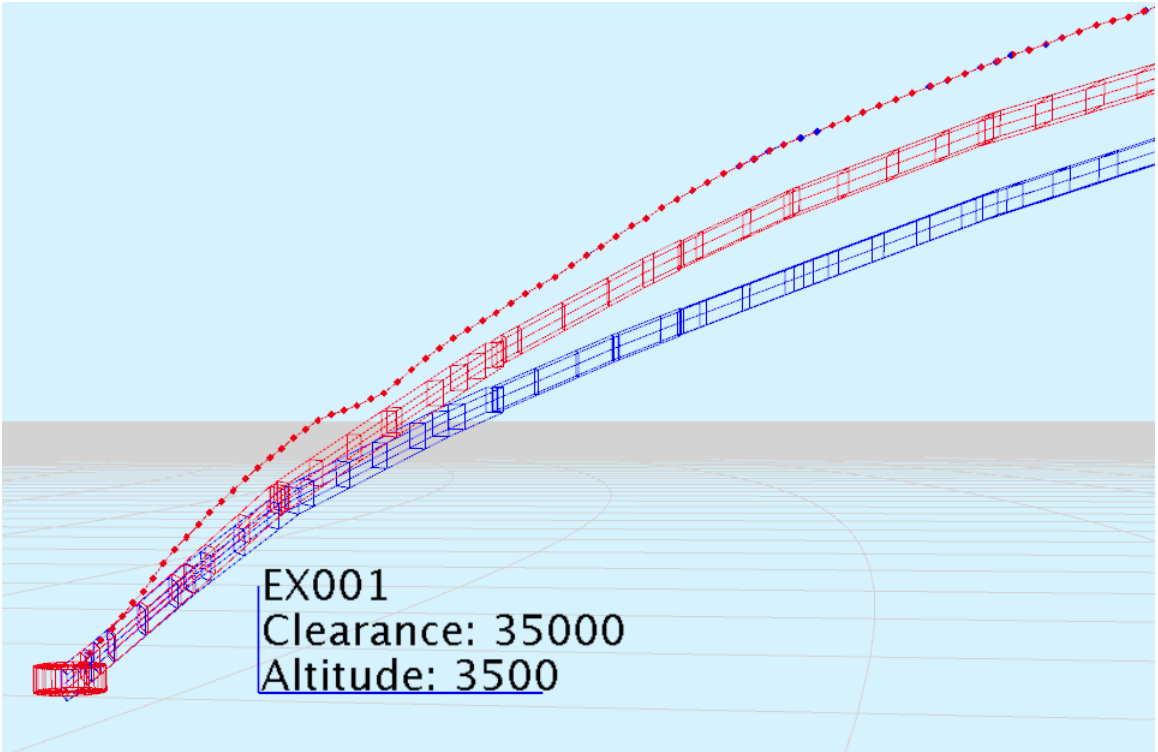

Figure 5. Trajectory improvement during a climb from KORD

The treatment (red) trajectory has a steeper climb segment which more closely matches the actual track data and leads to a maximum improvement in vertical accuracy of about 4000 feet compared to the analogous baseline (blue) trajectory. Since the scenarios contain the same clearances and track data and since the trajectories are built at the same time, it can be inferred that the same information was available to the Trajectory Modeler for each scenario. This suggests that any difference between the trajectories is due to the performance table upgrade for this aircraft type.

3.3.2. Example 2 – Trajectory with Minimal Improvement

Figure 6 depicts a Canadair RJ200 Regional Jet (CRJ2) on its initial climb from Quad City International Airport (KMLI, Moline). The dotted line represents the flight's track data, which is identical for the two scenarios. The aircraft trajectories are represented by two wireframes, blue for the baseline and red for the treatment scenario.

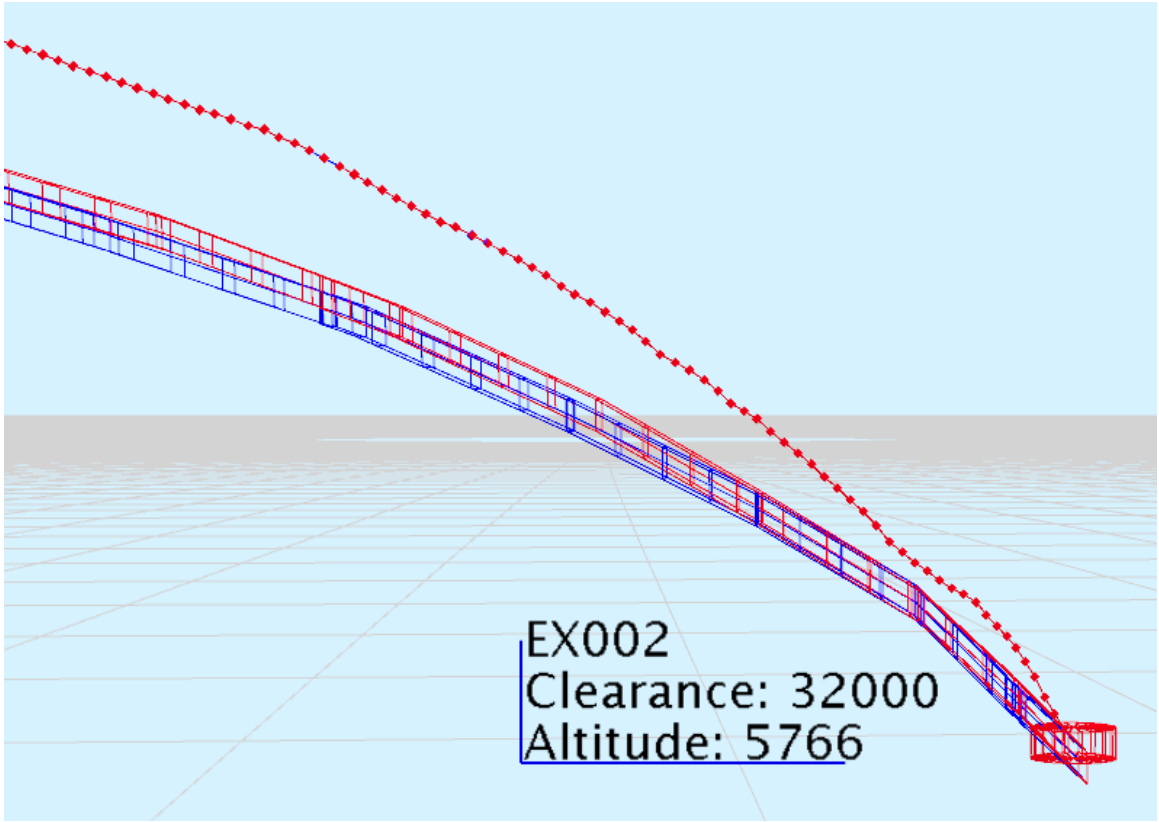

Figure 6. Minimal trajectory improvement during a climb from KMLI

The treatment (red) trajectory has a slightly steeper climb segment which leads to a maximum improvement in accuracy (that is to say, a reduction in error) of about 800 feet when compared to the analogous baseline (blue) trajectory. Since the scenarios contain the same clearances and track data and since the trajectories are built at the same time, it can be inferred that the same information was available to the TM for each scenario. This suggests that any differences between the trajectories are due to the performance table upgrade. However, the rate of climb predicted by the TM is significantly less than path actually flown by the aircraft, and the trajectory error reaches a maximum of about 4000 feet.

3.3.3. Example 3 – Removal of a False Alert

Figure 7 depicts a predicted conflict between two flights, EX003_A and EX003_B, that are both in vertical transition. EX003_A, an Embraer 135 (E135) is on an initial climb from General Mitchell International Airport (KMKE, Nashville) while EX003_B, an Embraer 170 (E170) is climbing out of Chicago Midway International Airport (KMDW).

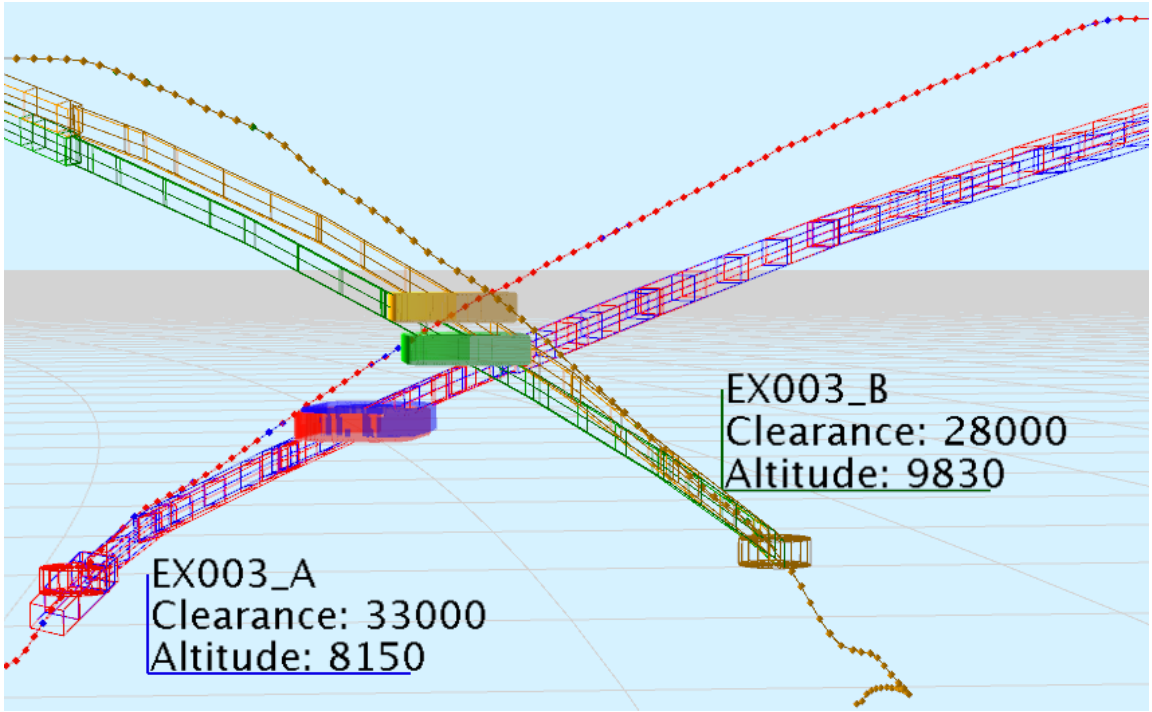

Figure 7. More accurate trajectory leads to removal of a false alert

The baseline (blue wireframe) and treatment (red wireframe) trajectories are virtually identical for flight EX003_A at its current position. For flight EX003_B, an improvement in the treatment trajectory (gold wireframe) as compared to the baseline (green wireframe) results in a steeper climb prediction, and both trajectories are built at the same time.

In the baseline scenario (blue large box, green large box) a conflict is predicted based on increased conflict probe bounds and a trajectory separation of about 2900 ft. Note that the probe bounds shown in Figure 7 are the standard bounds for level flight and not the expanded bounds that are actually applied for this encounter pair. Since the predicted loss of separation never materializes, the alert in the baseline scenario is considered to be a False Alert (FA).

With the application of the updated tables in the treatment scenario, the trajectory points to a predicted separation of 4600 ft., which falls outside of the conflict probe bounds (again, expanded in this case because of the vertical transitioning). No conflict is predicted and no alert is issued in the treatment scenario, therefore the FA in the baseline becomes a correct no-call with the benefit of the updated tables.

3.3.4. Example 4 – Introduction of a False Alert

Figure 8 depicts a predicted conflict between two flights. EX004_A, an Airbus 320 (A320), is flying level en route from Lyden Pindling International Airport (MYNN, Bahamas) to Lester B. Pearson International Airport (CYYZ, Toronto). EX004_B, a Cessna Citation Sovereign (C680), is climbing out of Baltimore/Washington International Thurgood Marshall Airport (KBWI).

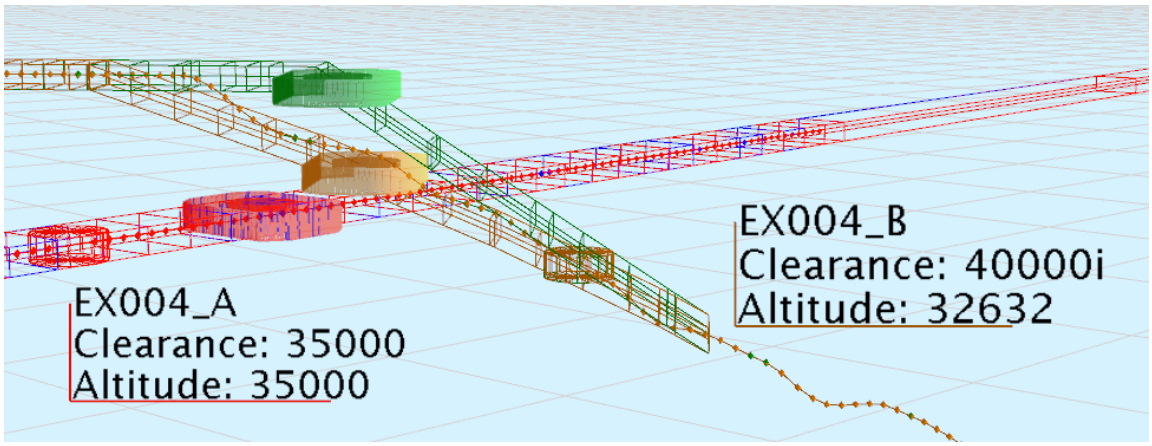

Figure 8. More accurate trajectory leads to an additional false alert

The baseline (blue wireframe) and treatment (red wireframe) trajectories are virtually identical for flight EX004_A at its current position. However, for flight EX004_B, an improvement in the treatment trajectory (gold wireframe) as compared to the baseline (green wireframe) results in a shallower and more accurate climb prediction. Both trajectories are built at the same time.

In the treatment scenario, with future positions marked by the large red and gold boxes, the predicted separation is 1200 ft. which is within the expanded conflict probe bounds, and a conflict is predicted. Again note that the probe bounds shown in the diagram are for level flight and do not represent the expanded bounds which are applied for conflict prediction in this case. When considering the baseline scenario (large blue and green boxes) the predicted separation is 4600 ft. and no conflict is predicted. While the loss of separation predicted in the treatment scenario never materializes and the resulting alert is termed a False Alert (FA), the improvement in trajectory accuracy is still considerable. This example illustrates that improved trajectory accuracy in the along and vertical dimensions may cause additional false alerts, but the authors speculate that a reduction in conformance bounds as illustrated in [Crowell et al., 2011] would integrate with the improvement in prediction accuracy and provide a better overall performance.

4. Discussion

Air traffic from ZAU and ZDC was collected and time shifted to create two flight traffic scenarios in which to test the impact of updates to the aircraft performance characteristic tables in ERAM. Experimental runs are performed by Lockheed Martin using an ERAM simulator, first with the existing tables and then again with updated tables. Established trajectory accuracy metrics are applied to the predicted aircraft trajectories to measure the impact of updated tables on the trajectory modeling capabilities. The flights are assigned to one of three categories based on their aircraft type designator belonging to a list of masters, clones, or neither.

The initial results indicate that the overall impact from updating tables is a statistically significant decrease in some types of trajectory error. While this decrease is too small to make a practical difference in many cases, it is more pronounced for certain aircraft types. The table upgrades do not appear to degrade the accuracy of the trajectory modeling, although some of the results -particularly for cross track error- were inconsistent. Further analysis is required to determine the cause of the very slight apparent increase in cross track error.

This study provides evidence that the updated aircraft characteristics tables provide a modest improvement in the accuracy of aircraft trajectory predictions in ERAM. Perhaps more importantly, the updates do not degrade trajectory accuracy, and further application of these methods should continue to improve predictions in a cumulative manner. And while the impact to the CP was not found to be statistically significant, there are some situations in which the updated tables result in better alert performance and they slightly outnumber the cases in which the alert performance may be degraded. Based on this analysis we recommend that the updated tables are used, and that further work is done to collect data to upgrade the tables. Additional analysis is also recommended to collect data to enable evaluation of the table parameters at varying temperature profiles and for the 7 aircraft types that were not found in this particular data sample.

5. List of Acronyms and Abbreviations

ANG-C41	FAA Concept Analysis Branch
ARTCC	Air Route Traffic Control Center
CAS	Calibrated airspeed
CP	Conflict Probe
CPAT	Conflict Probe Assessment Team
ERAM	En Route Automation Modernization
FA	False alert
FAA	Federal Aviation Administration
ft	Feet
LA	Late alert
LM	Lockheed Martin Corporation
LOS	Loss of separation
MA	Missed alert
NAS	National Airspace System
NC	No-call
NextGen	Next Generation Air Transportation System
nm	Nautical miles
ROCD	Rates of climb and descent
TAS	True airspeed
TM	Trajectory Modeler
VA	Valid alert
ZAU	Chicago center
ZDC	Washington center

6. References

Crowell, A., Fabian, A., Young, C.M., Musialek, B., and Paglione, M.M. 2011. *Evaluation of Parameter Adjustments to the En Route Automation Modernization's Conflict Probe*. FAA Technical Note, DOT/FAA/TC-TN12/2.

Crowell, A., Fabian, A., and Nelson, N. 2012. *An Interactive 4D Visualization System for Air Traffic Concept Analysis*. 31st Digital Avionics Systems Conference (DASC), Williamsburg, Virginia.

Kachigan, S.K. 1986. *Statistical Analysis: An Interdisciplinary Introduction to Univariate and Multivariate Methods*, Radius Press.

Paglione, M.M. and Oaks, R.D. 2007. *Implementation and Metrics for a Trajectory Prediction Validation Methodology*. American Institute of Aeronautics and Astronautics (AIAA) Guidance, Navigation, and Control Conference, Hilton Head, South Carolina.

Paglione, M.M., Oaks, R.D., and Bilimoria, K.D. 2003. *Methodology for Generating Conflict Scenarios by Time Shifting Recorded Traffic Data*. Proceedings of the American Institute of Aeronautics and Astronautics (AIAA) Technology, Integration, and Operations (ATIO) Technical Forum.

Paglione, M.M., Oaks, R.D., and Ryan, H.F. 2004. *Methodology for Evaluating and Regression Testing a Conflict Probe*. 23rd Digital Avionics Systems Conference (DASC), Salt Lake City, Utah.

Torres, S., Little, J., and Mckay, E.G. 2013. *ERAM TO-85 AC Characteristics Updates Summary of Activities and Results*. Lockheed Martin IS&GS-Civil briefing slides, May 30.