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# Impact of Using Voice-Only Clearances on the Trajectory Modeling and Conflict Probe Performance in Air Traffic Ground Automation

Brian S. Schnitzer
General Dynamics Information Technology

Chu Yao
Federal Aviation Administration, ANG-C41

Robert D. Oaks
General Dynamics Information Technology

Ben Musialek
General Dynamics Information Technology

Mike M. Paglione
Federal Aviation Administration, ANG-C41

Shurong Liu
General Dynamics Information Technology

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William J. Hughes Technical Center
Atlantic City International Airport, NJ 08405

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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 Separation Management and Modern Procedures Project is one of these NextGen initiatives. The FAA's Air Traffic Organization's En Route Program Office (ATO-E) has employed the FAA's Concept Analysis Branch (ANG-C41) to evaluate the impact of including additional intent information due to voice only clearances to the en route automation as part of a research objective to, "*facilitate the entry of clearances and flight plan amendments*." Four different 24-hour baseline scenarios from the Washington en route center were analyzed and voice clearances were introduced to these baselines as part of 6 experimental conditions (Speed, Altitude, Heading, Track Reroute, Heading and Track Reroute, and Combined). 24 experimental conditions were evaluated in total, and trajectory metrics and conflict statistics were investigated. The experiments reported reductions in trajectory errors of 1-2 nautical miles and reduced the conflict prediction false alert rates by more than 5%, with some conditions showing a reduction of 30%.


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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 Separation Management and Modern Procedures Project is one of these NextGen initiatives. The FAA's Air Traffic Organization's En Route Program Office (ATO-E) has employed the FAA's Concept Analysis Branch (ANG-C41) to conduct a series of independent evaluations on performance enhancements to the En Route Automation Modernization (ERAM) Trajectory Modeling (TM) and Conflict Probe (CP) sub-systems. This work is motivated by a Separation Management and Modern Procedures Project's objective of implementing the ERAM strategic conflict probe on the radar controller's display. The strategic conflict probe utilizes the TM and CP sub-systems to notify air traffic controllers when aircraft will violate separation standards as much as 20 minutes in the future. Furthermore, NextGen operational concept envisions a future air traffic environment managed by aircraft trajectory with advances in ground automation like the conflict probe. Thus, ATO-E contracted the ERAM prime contractor under FAA Task Orders 45 and 51 to develop these prototypes within the actual ERAM architecture, so the FAA could evaluate their efficacy.

This report details the impact of including additional intent information due to voice only clearances to the en route automation. Speed, altitude, track reroute, and heading recorded voice only clearances for various sectors in the Washington air route traffic control center (ZDC) were transcribed into text and then converted to clearances that the automation is able to use via special internally developed software. These clearances were then infused into the various baseline scenarios, creating 6 experimental scenarios. Comparisons between the experimental scenarios and their respective baselines yielded results that indicated a reduction in the TP's trajectory error (prediction not matching the aircraft's four dimensional path into the future) and a reduction in the CP's false alerts (prediction that does not match to a potential aircraft violation of separation standards).

The conditions evaluated in this report include the following scenarios:

- Baseline (with no additional voice clearances)
- Speed voice only clearances
- Altitude voice only clearances
- Heading voice only clearances
- Track reroute voice only clearances
- Heading/track reroute voice only clearances
- Combined (all of the above voice only clearances)

Cross track trajectory error (i.e. side to side error) improved by up to 2.6 nm on average when intent information in the form of voice only heading clearances were added to the scenario. Track reroute clearances and the combination of heading and track reroute clearances provided a reduction in error of between 1.3 nm and 1.9 nm. Speed and altitude voice only clearances had little effect on trajectory error. The effect of including voice only clearances on the CP was more consistent. In the majority of the experimental conditions, false alert rate was reduced by more than 5%, with some conditions showing a reduction of 30%. Again, heading scenarios showed the largest reduction overall, while speed and heading/reroute scenarios had a modest reduction in false alert rate.

The results of the study indicate the same trends across all four scenario dates. Specifically, a reduction in cross track error and percentage of false alerts was evident. Voice only clearances that involved the route of a flight (heading and reroute) had the most significant positive impact with respect to the baseline scenarios. Future studies will expand to other facilities and refine the sector selection based on input by subject matter experts.

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# 1. Introduction

This technical note, referred to as the Voice Transcription Study, describes the tools and methodologies developed by the Federal Aviation Administration's (FAA) Advanced Operational Concepts Division, Concept Analysis Branch (ANG-C41) to conduct research studies evaluating transcriptions of air traffic controller voice recordings. The purpose of the Voice Transcription Study is to identify the impact of voice-only clearances on the accuracy of a Conflict Probe (CP). The Voice Transcription Study defines voice-only clearances as clearances given to pilots but not entered into the Host Computer System (HCS). Researchers frequently refer to this lack of clearance information as a lack of aircraft intent information. In the current air traffic control environment, the most common voice-only clearances are for speed, heading, and altitude changes.

Previous studies have indicated that air traffic controllers usually enter altitude changes into the HCS, but seldom enter speed and heading changes[Lindsay, 2000][Rozen and Lindsay, 2001]. Research has also shown that this lack of intent information has a significant negative impact on the En Route Automation Modernization[1] (ERAM) trajectory predictor (TP) and CP[Ryan et al., 2008].

The tools and methodologies documented in this technical note are based on many of the processes and tools utilized in a prior study in which ANG-C41 collaborated with the University of California, Berkeley. This earlier study evaluated the impact that additional clearances had on the accuracy of the CP from information entered by air traffic controllers into the fourth line of the data block[2][Rakas et al., 2011a][Rakas et al., 2011b] but not used by the automation. The study concluded that the additional speed and heading amendments entered on the fourth line of the data block improved the accuracy of the CP. It also recommended that further research be conducted using transcriptions of voice recordings. The tools and methodology described in this technical note are the consequence of that recommendation.

## 1.1 *Scope of the Document*

The scope of this technical note is to describe the tools and methodologies developed by ANG-C41 and to present results based on a set of data for which voice transcriptions were available. Any impact to the TP and the CP will be evaluated, and the implication of the results will be discussed. In addition, this technical note will serve to document the processes and results in order to establish the basis for future studies.

## 1.2 *Background for the Study*

This activity supports the development of mechanisms and methods to improve the entry of air traffic control intent information for use in the trajectory and conflict predictions within ERAM as described in requirements document "*Facilitate the Entry of Clearances and Flight Plan Amendments (19)*"[Exum et al., 2011]. It consists of a joint effort between the FAA's Human Factors (HF, ANG-E25) and Concept Analysis (CA, ANG-C41) branches to analyze the frequency and impact of verbal clearances using data samples obtained from the National Air Space (NAS). The CA Team transformed the voice transcriptions provided by the HF Team and integrated them with automation recorded clearances to perform an impact

[1] ERAM is the replacement for the HCS and User Request Evaluation Tool (URET) in the National Airspace System. URET is a tool that assists controllers with the detection of potential conflicts.

[2] Air traffic controllers sometimes enter clearance information as free form text into the fourth line of the flight's data block that appears on the air traffic controller's radar display. The controllers often use this fourth line as a scratch pad to retain information for later use. When clearances are entered in this manner, the current automation system does not make use of this information.

study by comparing the resulting trajectory and conflict prediction performance before and after the voice transcribed clearances were entered.

This technical note is a follow up report of a previous internal FAA memo [Yao et al., 2012] and documents additional research conducted using a larger data set with the enhanced tools and methodologies described in this document.

## 1.3 Study Objective

This technical note evaluates the potential benefits of including air traffic controller voice-only clearances (speed, altitude, track reroute, and heading changes) along with the intent information already present in the automation. The hypothesis is that additional intent information will improve the accuracy and utility of the Trajectory Predictor (TP) as well as the Conflict Probe (CP).

## 1.4 Document Organization

This technical note contains the following sections:

- Section 1: Introduction - contains background information for the reader.
- Section 2: Methodology - contains a description of the data available for the Voice Transcription Study and the methodologies used to analyze the data. This section also describes the metrics used when evaluating the data
- Section 3: Analysis - contains the results obtained using the tools and methodology.
- Section 4: Conclusion - contains a summary of the results obtained
- Section 5: Appendix
- Section 6: Contains a list of the references used for this study.
- Section 7: Contains a list of acronyms and abbreviations used in this study.

# 2. Methodology

This section provides details regarding how the data was handled in an effort to compare traffic scenarios with and without the inclusion of intent information from voice only clearances. A description of the input data, the data flow, and the algorithms used to convert the voice transcription data into clearances to be processed by ERAM are provided. In addition, the metrics and the analysis approach used are discussed.

## *2.1 Data Processing*

This subsection describes the input data, the data flows, and the algorithms used in this Voice Transcription Study.

### 2.1.1 Input Data

The data used for this Voice Transcription Study includes:

- o Recorded voice transcriptions containing the voice-only clearances provided to the pilots by air traffic controllers
- o Recorded Common Message Set (CMS) messages containing clearances provided to the Host Computer System (HCS)

The following 24-hour scenarios, based on sectors from Washington Air Route Traffic Control Center (ARTCC - ZDC), along with their associated transcribed voice clearances, were used for the current study:

- 1/26/2010, sectors 3, 4, 7, 9, 12, 14, 20, 26, 39, 50, 72
- 1/27/2010, sectors 3, 4, 7, 9, 14, 20, 50, 72
- 10/13/2010, sectors 9, 12, 34, 35, 72
- 10/14/2010, sectors 3, 4, 7, 9, 12, 14, 15, 72

The following subsections describe this input data in detail.

#### 2.1.1.1 Recorded Voice Transcription of Voice-Only Clearances

This Voice Transcription Study uses transcriptions of recorded voice communications to identify the input data provided to the pilots verbally, but not input into the HCS. The FAA's Aviation Research Division, Human Factors Branch (ANG-E25) provided this data, which represents the voice-only clearances given to the pilots[3].The voice transcription files provided by the Human Factors Branch were CSV-formatted (comma-delimited) files that identified the following voice-only commands:

- o Full Data Block (FDB) Heading, Speed, and Free Form Text (QS) messages[4]. A QS message provides an air traffic controller with the capability to create, modify, or delete FDB fourth line heading, speed, or free form text information.
- o Track Reroute (QU) messages[4]. A QU message provides an air traffic controller with the capability to modify the flight plan route of a specified tracked flight.
- o Assigned Altitude (QZ) messages[4]. A QZ message provides an air traffic controller with the capability to change the assigned altitude or flight level for a flight.

[3] A high level description of the Voice Transcription Process developed by ANG-E25 is available in a presentation; see [FAA, 2012].
[4] The FDB Heading, Speed and Free Form Text (QS), Track Reroute (QU), and Assigned Altitude (QZ) messages are defined in NAS-MD-311[FAA, 2007b].

#### 2.1.1.2 Recorded Common Message Set Messages

This Voice Transcription Study used recorded CMS messages to establish the input data provided to the HCS. CMS is the message format used for data exchanged between the HCS and other Air Traffic Management (ATM) applications [FAA, 2007a]. In addition to other information, this data contains the flight plans and clearances entered into the HCS and used by the TP and CP. The recorded CMS messages used for this study were obtained from the FAA's NASQuest system[5].

### 2.1.2 Data Flow

Figure 1 presents the data flow used in this study. The left side of the figure presents the data and the processes used to create the baseline data. This was done once for each 24-hour scenario. The right side of the figure represents the data and processes used to create the treatment data. This was done once for each treatment condition.

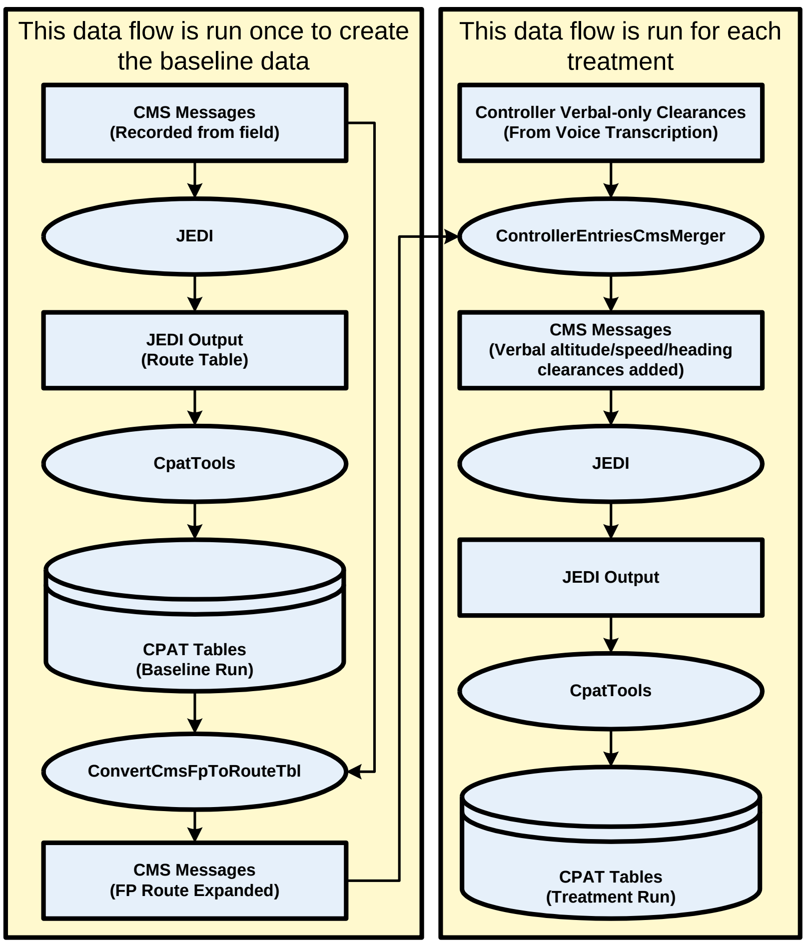



**Figure 1: Data Flow Diagram**

[5]NASQuest is a web interface to a database system used to retrieve CMS data. The NASQuest system receives CMSdata from the Host Air Traffic Management Data Distribution System (HADDS) systems located in all of the 20 Air Route Traffic Control Centers (ARTCC).

#### 2.1.2.1 Baseline Data Flow

The following steps, depicted on the left side of Figure 1, describe the creation of the baseline data for evaluating the accuracy of the baseline TP and the CP:

- The recorded CMS Messages were run through the *Java En Route Development Initiative (JEDI)* system to generate *JEDI* output data. *JEDI* is a simulation software system developed by the MITRE Center for Advanced Aviation Systems Development. It is a research prototype tool based on the current HCS User Request Evaluation Tool (URET).
- The Route Table within the *JEDI* output data was then processed by the *CpatTools*, a suite of tools developed by ANG-C41, which loads the resultant data into Oracle® database tables. This data represents the baseline data for analysis.
- The *ConvertCmsFpToRoute* application, a tool developed by ANG-C41, changes the recorded CMS flight plan routes into CMS messages that contain flight plans containing the converted routes calculated by *JEDI*. The converter routes are a series of fixes (positions in space) or latitude/longitude coordinates representing the planned horizontal path of the flight (eg. "FIXA..FIXB..FIXC..FIXD").[6]

#### 2.1.2.2 Altitude/Speed/Heading Change Data Flow

The following steps (depicted on the right side in Figure 1) describe the process of injecting the voice data, consisting of altitude, speed, and heading changes, into the baseline scenario to create the data for the treatment runs. These steps are repeated for each treatment run. This figure shows:

- The modified CMS Messages and the files containing the Controller Verbal-only Clearances were run through the *ControllerEntriesCmsMerger* application, a tool developed by ANG-C41, which supplemented the CMS messages with additional CMS messages based on the Controller voice-only Clearances obtained from the voice transcription.
- The *JEDI* system was then run using the supplemented CMS-formatted file to provide *JEDI* output data.
- The *CpatTools* were used to process this data and load the *JEDI* output data into Oracle® database tables for comparison with the baseline data

### 2.1.3 Algorithms used to Generate CMS Messages from Voice Clearances

This subsection describes the algorithms used to convert and merge the voice transcription messages into clearances in a CMS-formatted file. These are the algorithms implemented in the *ControllerEntriesCmsMerger* application discussed in Section 2.1.1.1.

#### 2.1.3.1 Speed Change Algorithm (QS Messages)

The *ControllerEntriesCmsMerger* application creates and inserts a Flight Amendment Information Message (AH) into the CMS-formatted file when the application encounters a time stamped QS message in the voice transcription file. This occurs when the air traffic controller issues a voice-only clearance for the pilot to change speed.

[6] The original flight plan messages contain the route with a series of fixes and airways. This is expanded in this study to a series of fixes to facilitate insertion of additional intent into the automation.

### 2.1.3.2 Heading Change Algorithm (QS Messages)

The *ControllerEntriesCmsMerger* application creates and inserts a Flight Amendment Information Message (AH) into the CMS-formatted file when the application encounters a time stamped QS message in the voice transcription file. This occurs when the air traffic controller issues a voice-only clearance for the pilot to change heading.

Figure 2 depicts a typical example that describes the processing of a heading change clearance. In this figure, the current flight plan contains the route string:

    “.A..B..C..D.”

The solid line depicts this route. The dots represent time-stamped track points actually flown by the aircraft; the file represented by *CMS Messages (Recorded from field)* in Figure 1 provides these points.

Figure 2 illustrates the following:

- At time $T_M$, associated with the position point labeled M, a QS message representing a heading change for the pilot to turn is encountered.
- At time $T_S$, a parametric time after $T_M$, it is assumed that the pilot reacts to the verbal clearance.
- At time $T_T$, associated with the position point labeled T, the *ControllerEntriesCmsMerger* application detects that the aircraft turns back towards its original route.
- At time $T_J$, associated with the position point labeled J, the *ControllerEntriesCmsMerger* application detects that the aircraft is close (i.e., within conformance bounds) to its original route.

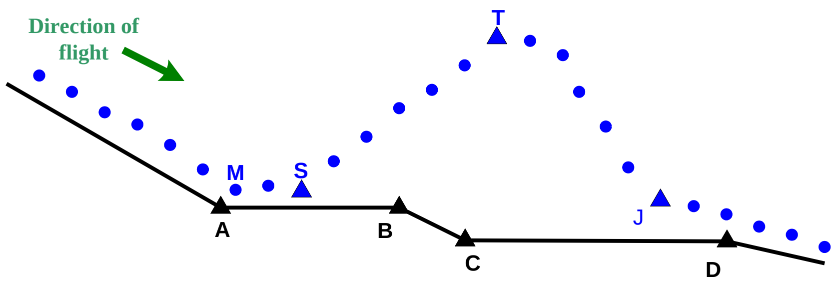



**Figure 2: Heading Change without Flight Plan Amendment**

For this example, the *ControllerEntriesCmsMerger* application creates three artificial fixes:

- S, the first fix, is the latitude-longitude of the track point at time $T_S$. For illustrative purposes this example assumes that this point is at 40° 46"N/96° 41"W.
- T, the second fix, is the latitude-longitude of the track point at time $T_T$. For illustrative purposes this example assumes that this point is at 40° 48"N/96° 40"W.
- J, the third fix, is the latitude-longitude of the track point at time $T_J$. For illustrative purposes this example assumes that this point is at 40° 45"N/96° 39"W.

Each of these artificial fixes is defined using the latitude-longitude format[7] since S, T, and J are not fixes that would be found in the system data. Therefore, the *ControllerEntriesCmsMerger* application creates the following route string reflecting this heading change:

    “.A..4046N/09641W..4048N/09640W..4045N/09639W..D.”.

[7] The latitude-longitude format specifies (1) the degrees and minutes latitude by four digits followed by the character N for north or S for south, and (2) the degrees and minutes longitude by five digits followed by the character E for east or W for west. For example, a fix at latitude 40°48” north and longitude 96°40” west would be formatted as 4048N/09640W.

### 2.1.3.3 Track Reroute Algorithm (QU Messages)

The *ControllerEntriesCmsMerger* application inserts a Flight Plan Amendment Information Message (AH) into the CMS-formatted file when the application encounters a time stamped QU message in the voice transcription file. This occurs when the air traffic controller issues a voice-only clearance for the pilot to change route.

Figure 3 depicts a typical example that describes the processing of a track reroute clearance. In this figure, the current flight plan contains the route string:

“.A..B..C..D.”

The solid line depicts this route. The dots represent time-stamped track points actually flown by the aircraft; the file represented by *CMS Messages (Recorded from field)* in Figure 1 provides these points.

Figure 3 illustrates the following:

- At time $T_M$, associated with the position point labeled M, a QS message representing a heading change for the pilot is encountered.
- At time $T_S$, a parametric time after $T_{M,}$ it is assumed that the pilot reacts to the verbal clearance.
- At time $T_T$, associated with the position point labeled T, a QU message representing a track reroute to downstream fix K is encountered.
- At time $T_K$, associated with the position point labeled K, the *ControllerEntriesCmsMerger* application detects that the aircraft is close (i.e., within conformance bounds) to its original route.

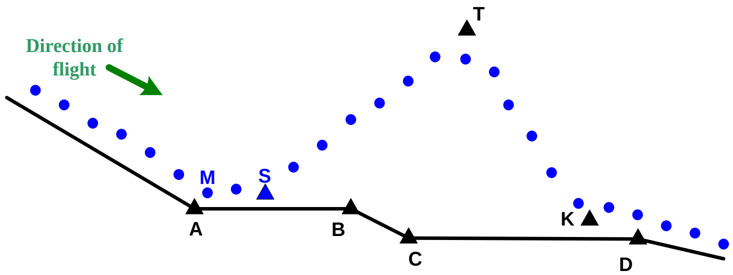



**Figure 3: Reroute Change without Flight Plan Amendment**

For this example, the *ControllerEntriesCmsMerger* application creates an artificial fix S, which is the latitude-longitude of the track point at time $T_S$ and an artificial fix T, which is the latitude-longitude of the track point at time $T_T$. For illustrative purposes, this example assumes that T is at 40° 46"N/96° 41"W. The route following the QU message is known; therefore, the *ControllerEntriesCmsMerger* application creates the following route string:

“.4046N/09641W..K..D.”

### 2.1.3.4 Altitude Change Algorithm (QZ Messages)

The *ControllerEntriesCmsMerger* application inserts an Interim Altitude Information Message (LH) into the CMS-formatted file when the application encounters a time stamped QZ message in the voice transcription file. This occurs when the air traffic controller issues a voice-only clearance for the pilot to change altitude.

## 2.2 Analysis Approach and Metrics

The goal of the Voice Transcription Study's analysis is to quantify the impact of including voice-only clearances on the accuracy of both the TP and CP. The hypothesis is that this additional intent knowledge will improve their accuracy. The following subsections discuss the metrics and analysis techniques to be used in the Voice Transcription Studies.

### 2.2.1 Trajectory Prediction

Accuracy as defined in the Voice Transcription Study is the degree of conformity of a measured or calculated quantity to its actual value [Paglione and Oaks, 2007]. Therefore, any differences in the trajectory predictions made for the baseline data (basic CMS message set) and the treatment data (basic CMS message set infused with the transcribed voice clearances – speed, altitude, or heading) reflect an impact of the voice clearances on TP accuracy. One way to examine this data is to use the Interval Based Sampling Technique, described in detail in [Cale et al., 2001], which pairs time coincident track and trajectory data so that errors for an entire flight can be measured [Paglione and Oaks, 2007].

For this Voice Transcription Study four error metrics, defined in [Paglione and Oaks, 2007], was analyzed. Horizontal error is defined as the magnitude of the vector between a track point and its temporally coincident trajectory point on a horizontal two-dimensional plane. This vector has two components on the horizontal plane: the error along the path of the flight, which is termed along track error; and the error perpendicular to the path of the flight, which is termed cross track error. The fourth metric, vertical error, is simply the difference in altitude between a track point and its temporally coincident trajectory point. Figure 4 illustrates the horizontal, along, and cross track errors in reference to the flight's surveillance track positions.

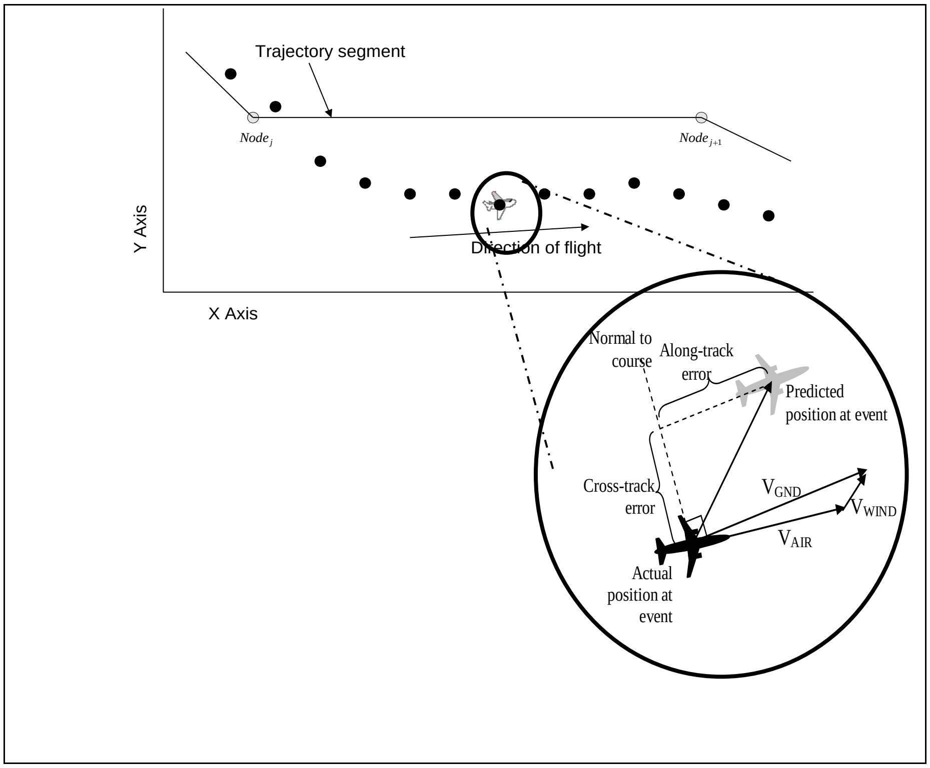



**Figure 4: Diagram of Trajectory Errors**[8]

This resulting set of error data lends itself to a Paired *t*-test [Paglione and Oaks, 2007], which in this case is an evaluation of the mean of the unsigned differences in error between every pair of track-trajectory points for a given flight at a given sample time, as seen in Eq. 1:

$$Err(t) = Err_{baseline}(t) - Err_{treatment}(t) \qquad \textbf{Eq. 1}$$

where

$$Err(t) = Err\ at\ time = t$$

$$Err_{baseline}(t) = \left|Track(t) - Trajectory_{baseline}(t)\right|$$

$$Err_{treatment}(t) = \left|Track(t) - Trajectory_{treatment}(t)\right|$$

### 2.2.1.1 Voice-Only Speed Clearances

The following steps summarize the analysis of flights given voice-only speed clearances:

1. Identify the flights given voice clearances for speed changes.
2. Determine the time of the AH (flight amendment) message in the treatment data associated with the first voice clearance for each flight.
3. For each AH message, determine the critical sample time, which is the time of the first track point after the voice clearance.

[8] Adapted from [Paglione and Oaks, 2007]

4. Calculate trajectory metrics based on the active trajectory, built at or before the critical sample time. This includes all trajectory measurement points where $time - look\_ahead\_time$ is equal to critical sample time. This process is repeated for the baseline and treatment data.
5. Perform a Paired *t*-test using the Matched Pairs Analysis[9] to find the mean difference in the given metrics.

#### 2.2.1.2 Voice-Only Altitude Clearances

The following steps summarize the analysis of flights given voice-only altitude clearances:

1. Identify the flights given voice clearances for altitude.
2. Determine the time of the LH (interim altitude) message in the treatment data associated with the first voice clearance for each flight. This establishes the beginning of the analysis interval.
3. Determine the time of the next LH message, if it exists. This establishes the end of the analysis interval. If none exists, the end of the flight data is used.
4. If the flight did not reach its altitude by the end of the analysis interval, then the new clearance supersedes the old clearance. The effect of the voice clearance, in this case, cannot be determined.
5. For each analysis interval determine the critical sample time, which is the time of the first track point where the flight is within 300 feet of its voice cleared altitude. Note that the applied criterion is strictly "*less than*," and not "*less than or equal to*." Once a flight is within this distance, it is considered to have reached its interim altitude, the LH clearance is interpreted as valid (not interim), and a new trajectory is built.
6. Calculate trajectory metrics based on the active trajectory, built at or before the critical sample time. This includes all trajectory measurement points where $time - look\_ahead\_time$ is equal to critical sample time. This process is repeated for the baseline and treatment data.
7. Perform a Paired *t*-test using the Matched Pairs Analysis to find the mean difference in the given metrics.

#### 2.2.1.3 Voice-Only Heading and Track Reroute Clearances

The following steps summarize the analysis of flights given one or more voice-only clearances:

1. Identify the flights given at least one voice clearance of any type.
2. Determine the time of the AH message in the treatment data associated with the first voice clearance for each flight.
3. Find the critical sample time, which is the first sample just after the time of the voice clearance.
4. Calculate trajectory metrics based on the active trajectory, built at or before the critical sample time. This includes all trajectory measurement points where $time - look\_ahead\_time$ is equal to critical sample time. This process is repeated for the baseline and treatment data.

[9] ANG-C41 frequently uses JMP®, a commercially available software tool, that provides the user with the capability to perform simple and complex statistical analyses. See http://www.jmp.com.

5. Perform a Paired *t*-test using the Matched Pairs Analysis to find the mean difference in the given metrics.

#### 2.2.1.4 Combined Voice-Only Clearances

The following steps summarize an example of the analysis of the combined set of voice clearances:

1. Identify all flights given voice clearances
2. Determine the time of the CMS message in the treatment data associated with the first voice clearance issued for each flight. This establishes the beginning of the analysis interval.
3. Determine the time of the CMS message in the treatment data associated with the last voice clearance issued for each flight. The end of the analysis interval is defined to be 20 minutes after the last voice clearance message or the end of the flight data, in the case where a flight receives only one voice clearance.
4. For each track point in the analysis window, calculate trajectory metrics based on the active trajectory. This includes all trajectory measurement points where $time - look\_ahead\_time$ is equal to the track point sample time. This process is repeated for the baseline and treatment data.
5. Perform a Paired *t*-test using the Matched Pairs Analysis to find the mean difference in the given metrics.

### 2.2.2 Conflict Probe

A conflict probe predicts where and when two aircraft might violate separation standards based on their predicted trajectories. In this study, a conflict is defined by a violation of separation standards based on track data. An encounter is defined as an event where two aircraft come close to each other (less than 20nm) but do not violate separation standards. As documented in [Paglione et al., 1999], [Bilimoria, 2001], [Brudnicki et al., 1998], and [Cale et al., 1998], any conflict probe's performance is not perfect. For example, a CP may miss a conflict (Missed Alert) or may predict a conflict that never occurs (False or Nuisance Alert). The four possible alert classifications are shown in Table 1.

Table 1. CP Alert and Conflict Event Combinations[10]

| | **CONFLICT OCCURS** | **CONFLICT DOES NOT OCCUR** |
|---|---|---|
| **ALERT** | CP predicts conflict and it occurs<br>*(VA – valid alert)* | CP predicts conflict and it does not occur<br>*(FA -- false alert)* |
| **NO ALERT** | CP does not predict conflict and it occurs<br>*(MA -- missed alert)* | CP does not predict conflict and it does not occur<br>*(NC -- correct no-calls)* |
| **Total Number of Alerts** | **Total Number of Conflicts** | **Total Number of Non-Conflicts (i.e. encounters without conflicts)** |

For a real time system, it is important that an alert be given sufficiently in advance of the actual conflict so corrective action can be taken. In other words, an alert must be timely as well as accurate. To ensure timeliness in conflict predictions, a CP alert is required to have a Minimum Warning Time (MWT)

[10] Adapted from [Paglione, 1999]

ranging from one to five minutes (min) depending on the particular type of CP being evaluated. It is of note to point out that there are several types of CPs. A tactical CP requires very little warning time, while a strategic CP, with its longer term objectives, requires larger warning times. This report examines the impact on a strategic CP only. For the Voice Transcription Study, a specified notification lead time is required unless the conflict is determined to be a pop-up event. A pop-up conflict occurs when the CP is not provided with at least MWT of continuous surveillance data or prediction for either flight. Detailed descriptions of the different situations that cause this to occur are described in [Paglione et al., 2004].

For this study, the conflict prediction accuracy metrics consist of counts of the error events, including the false alerts (FA) and missed alerts (MA) in context of the correctly predicted events of valid alerts (VA) and correct no-calls (NC). The CP metrics used in this study are described in detail in [Paglione et al., 2004] and [Crowell and Santiago, 2009]. Three main metrics used in the past are the VA, MA, and FA counts. There are also Missed Alert Rate (MAR) and False Alert Rate (FAR) that use ratios of the main metrics counts. The following Eq. 2 and Eq. 3 describe these ratios as the number of missed alerts over the total missed and valid alert counts and number of false alerts over the number of false alerts and correct no-calls, respectively.

$$MAR = \frac{(MA)}{(MA + VA)}$$ **Eq. 2**

where

$MAR$ is the Missed Alert Rate
$MA$ is the total number of missed alerts
$VA$ is the total number of valid alerts

$$FAR = \frac{(FA)}{(FA + NC)}$$ **Eq. 3**

where

$FAR$ is the False Alert Rate
$FA$ is the total number of false alerts
$NC$ is the total number of non-conflict encounters without associated alerts

In this Voice Transcription Study, what were previously called Missed Alerts will be split into two categories: Late Alerts (LA) and Missed Alerts (MA). Late Alerts occur when an alert is not posted within the minimum warning time of a conflict, but is still posted at least 40 seconds (sec) prior to the start of the actual conflict. Missed Alerts are all conflicts in which an alert is not posted at least 40 sec. prior to the start of the conflict. This includes conflict alerts that are not posted prior to the start of the conflict, sometimes referred to as no-call missed alerts. In the past, a 5 minute minimum warning time requirement was typically used for analysis of a strategic conflict probe. However, after discussions with air traffic controller Subject Matter Experts (SMEs), it was determined that a 3 minute minimum warning time provided a better threshold for defining a Late Alert. The Late Alert Rate (LAR) is an important metric that focuses only on these Late Alerts and does not include the excused popup conflict events. It is summarized in Eq. 4.

$$LAR = \frac{(LA + MA)}{(LA + MA + VA^{*})}$$ **Eq. 4**

where

$LA$ is total number of late alerts that are missed due to warning time less than MWT but greater than 40 seconds warning time

*MA* is the total number of missed alerts that are missing completely or due to a warning time less than 40 seconds, and

$VA^*$ is the total number of standard valid alert conflicts (excludes valid alerts[11] with less than the threshold MWT of warning time associated with pop-up conflicts)

### 2.2.2.1 Comparison of Conflict Prediction Results

The standard approach for detecting an improvement or change in the CP performance is to compare the improved system against the baseline's performance [Ryan et al., 2008]. There are two main limitations to this approach. The MAR and FAR of the baseline system are compared to the new "prototype" system, and since these metrics are themselves random variables, this test tends to underestimate the random variation. Second, and more importantly, this approach summarizes the errors for both systems into a ratio and only net effects are compared. For example, if the ERAM system had two more missed alerts than the legacy URET system, only the net difference is considered. However, in reality, ERAM may have had four missed alerts that the legacy system had correctly predicted, yet two more missed alerts were generated by the legacy system that ERAM correctly predicted. The test only compared the net quantities of missed alert events. A more sensitive test would compare the same conflict and alert events, reporting all mismatches. Furthermore, it is necessary to identify all the specific error events from a practical standpoint, so software corrections can be made. This section will present a method to identify and statistically compare these events.

Table 2 lists the individual reason codes for each run's conflict prediction results. Alerts fall into four categories; missed alerts and false alerts are the two being considered for ths Voice Transcription Study. Valid alerts are the correct prediction of a conflict and discards are events excused due to out of adherence situations or other artifacts of the traffic sample being used. The alert types and reason codes are generated by the *StrategicAlertEvaluator* application written by ANG-C41. It matches the ground truth conflict and non-conflict encounter events and produces a data base table with these codes.

The sets of conflict predictions generated by the legacy system run (referred to as Run A) and a new system (referred to as Run B) are first evaluated separately. The analysis produces a database table with records labeled with the reason codes defined in Table 2. The resulting paired evaluations of the two runs are listed in Table 3, and it is assumed both runs are provided the same input traffic scenario. The first column in Table 3 lists all relevant comparisons of events defined in Table 2. For example, Run A may generate a missed alert that is either a missed alert or valid alert in Run B and vice versa. Of particular interest is when Run A makes an incorrect prediction and Run B makes a correct prediction and vice versa. The light orange shaded rows in the "Conflict Occurs" column indicate that for the same conflict event, one run has a VA and the other an MA. The light green shaded rows in the "Conflict Does Not Occur" highlights where one run has an FA and the other a correct no-call for the same encounter.

[11] Valid alerts in this subset are defined as late valid alerts and listed in Table 2 as LATE_VA.

**Table 2. Conflict Prediction Result - Primary Reason Codes**[12]

| CODE | ALERT TYPE REASON | REASON DESCRIPTION |
|---|---|---|
| STD_VA | Valid Alert | Standard Valid Alert |
| LATE_VA | Valid Alert | Late Valid Alert, Valid since conflict was determined a pop-up |
| NO_CALL_MA | Missed Alert | Missed Alert due to no call (no alert at all before the actual conflict start time) |
| LATE_MA | Missed Alert | Late alert – alert presented with less than the minimum required warning time |
| SHRT_NO_CALL_DISCARD | Discard Alert | Missed Alert no call discarded because conflict duration below a threshold time |
| NO_CALL_DISCARD | Discard Alert | Missed Alert no call discarded since out of adherence |
| SHRT_LATE_DISCARD | Discard Alert | Late alert discard because conflict duration below a threshold time |
| LATE_DISCARD | Discard Alert | Late alert discard since out of adherence |
| NO_TRK_FA_DISCARD | Discard Alert | No post processed track at predicted conflict start time so discard |
| NO_ADHER_FA_DISCARD | Discard Alert | Out of adherence at predicted conflict start time so discard |
| CLR_FA_DISCARD | Discard Alert | Retracted False Alert assigned by an ATC clearance so discard |
| CFL_FA_DISCARD | Discard Alert | False Alert notified beyond last conflict actual start time so discard |
| STD_FA | False Alert | Standard False Alert |
| RETRACT_FA | False Alert | Retracted False Alert, notification end time earlier than predicted conflict start time |
| IN_APDIA_FA | False Alert | False alert generated but predicted conflict start time determined to be inside an automated problem detection inhibited area |

[12] This table summarizes the reason codes into 15 types that capture the essence of the processing involved. The actual processing software produces a total of 19 reason codes.

**Table 3. Comparison of Two Runs - Resulting Alert and Conflict Event Combinations[13]**

| | Conflict Occurs | Conflict Does Not Occur |
|---|---|---|
| **ALERT by both Runs A and B** | Both predicts conflict and it occurs ($V_A$& $V_B$ – valid alerts both) | Both predicts conflict and it does not occur ($F_A$ & $F_B$ – false alert both) |
| **ALERT by A and not B** | A predicts conflict and it occurs ($V_A$– valid alerts by A only) | A predicts conflict and it does not occur ($F_A$– false alert by A only) |
| | B does not predict conflict and it occurs ($M_B$– missed alert by B only) | B does not predict conflict and it does not occur ($NC_B$ – B correct no-call) |
| **ALERT by A and B ALERT or non-ALERT is discarded** | A predicts conflict and it occurs ($V_A$– valid alerts by A only) | A predicts conflict and it does not occur ( ** $F_A$ Continued **) |
| | B does not predict conflict correctly but is discarded (Discard$M_B$-- B discard an MA) | B does not predict conflict correctly but is discarded (Discard$F_B$– B discard an FA) |
| **ALERT by B and not A** | B predicts conflict and it occurs ($V_B$– valid alerts by B only) | B predicts conflict and it does not occur ($F_B$– false alert by B only) |
| | A does not predict conflict and it occurs ($M_A$– missed alert by A only) | A does not predict conflict and it does not occur ($NC_A$ – A correct no-call) |
| **ALERT by B and A ALERT or non-ALERT is discarded** | B predicts conflict and it occurs ($V_B$– valid alerts by B only) | B predicts conflict and it does not occur ( ** $F_B$ Continued **) |
| | A does not predict conflict correctly but is discarded (Discard$M_A$– A discard an MA) | A does not predict conflict correctly but is discarded (Discard$F_A$– A discard an FA) |
| **NO ALERT by both Runs A and B** | Both do not predict conflict and it occurs ($M_A$& $M_B$– missed alert by both) | Both do not predict conflict and it does not occur (NC – correct no-calls by both) |
| **Total Number of Alerts for each/both** | Total Number of Conflicts *(Same for both Runs!)* | Total Number of Non-Conflicts (Encounters that did not have conflicts; *Same for both Runs!*) |

[13] These events are for comparison of Run A and Run B input with identical ground truth scenarios.

**Table 4. Conflict Prediction Comparison Program Evaluation Codes**

| Event (Labels from Table 3) | Evaluation Code | Description |
|---|---|---|
| $V_A$ and $V_B$ | SAME_VA | Both runs have valid alerts for the same conflict |
| $M_A$ and $M_A$ | SAME_MA | Both runs have missed alerts for the same conflict |
| $F_A$ and $F_B$ | SAME_FA | Both runs have false alerts for the same encounter |
| $V_A$ and $M_B$ | VA_MA | Run A has a valid alert and Run B has a missed alert for the same conflict |
| $M_A$ and $V_B$ | MA_VA | Run A has a missed alert and Run B has a valid alert for the same conflict |
| $V_A$ andDiscard$M_B$ | VA_DISCARD | Run A has a valid alert while Run B discards the conflict |
| Discard$M_A$ and $V_B$ | DISCARD_VA | Run A discards the conflict while Run B has a valid alert |
| Discard$M_A$ and $M_B$ | DISCARD_MA | Run A discards the conflict while Run B has a missed alert |
| $M_A$ andDiscard$M_B$ | MA_DISCARD | Run A has a missed alert while Run B discards the conflict |
| $F_A$ and $NC_B$ | FA_NC | Run A has a false alert while Run B has no prediction to match |
| $NC_A$ and $F_B$ | NC_FA | Run A has no prediction to match while Run B has a false alert for the same encounter |
| $F_A$ and Discard$F_B$ | FA_DISCARD | Run A has a false alert while Run B discards the event |
| Discard$F_A$ and $F_B$ | DISCARD_FA | Run A discard the event while Run B has a false alert |
| $Discard_A$ and correct no call B | DISCARD_NC | Run A discards the event while Run B has no prediction to match |
| Correct no call A and $Discard_B$ | NC_DISCARD | Run A has no prediction to match while Run B discards the event |

To determine the various combinations of events defined in Table 3, ANG-C41 wrote a software tool to identify the paired conflict prediction results of two conflict probe runs. The *StrategicAlertComparer* program produces a database table of entries with evaluation codes for each of these events. Table 4 summarizes the evaluation codes used in this study[14].

As implied in Table 3, the most interesting event combinations are when one run correctly predicts an event and the other does not. Comparison of the MAR, LAR, and the FAR metrics only indicate the net magnitude of these differences. To determine the statistical significance of these differences this study utilizes a categorical data analysis technique presented in [Kachigan, 1986]. The difference in alert rates is analyzed rather than the difference between population proportions. For this study, the rates directly relating to the missed and false alerts include the counts of these events. Paired counts that are mutually exclusive and exhaustive, which is required for this test, occur when the error event occurs in one run and the correct event occurs in the other.

For the missed alert analysis, the item of interest is the count of missed alerts in Run A matched with valid alerts in Run B or vice versa. These include the simultaneous counts $V_A$ and $M_B$ compared to the simultaneous counts $M_A$ and $V_B$. Therefore, the count of valid alerts in Run A and simultaneous missed alerts in Run B is statistically compared to the count of valid alerts in Run B and simultaneous missed alerts in Run A. These counts should be equally likely if the two runs are statistically equivalent.

[14] In this study, the scenario inputs of Run A and B are the same. The *StrategicAlertComparer* can also be used where the input scenarios are not identical. Refer to [Crowell et al, 2011].

Calculating the ratio of the squared difference between the expected value of each run and the observed value can test this hypothesis. If the hypothesis is true, this ratio will follow a chi-squared distribution or $\chi^2$ with one degree of freedom. The test statistic is as follows:

$$\chi^2 = \sum_{i=1}^{k} \frac{(O_i - E_i)^2}{E_i} \qquad \textbf{Eq. 5}$$

where

$\chi^2$ is the chi-squared test statistic

$O_i$ is the observed frequency in category *i*

$E_i$ is the expected frequency in category

$k$ is the total number of categories

For this study, *k* is always two, since only paired runs are compared. For example, the observed frequencies are the extracted $V_A/M_B$ and $V_B/M_A$ counts for the two runs. Since the null hypothesis assumes both events are equally likely, both expected frequencies are equal and calculated from the following equation:

$$E_i = \frac{\sum_{j=1}^{2} O_j}{2} \qquad \textbf{Eq. 6}$$

The resulting test statistic in Eq. 5 can be expressed as a probability or P-value[15] by assuming a chi-squared distribution with one degree of freedom. For example, consider $V_A/M_B$= 8 and $V_B/M_A$= 22. The expected frequency from Eq. 6 is 15 for both values, and the resulting test statistic from Eq. 5 is 6.53. Therefore, for this example exercise, the P-value is 0.011. This expresses that the hypothesis that these runs have equivalent missed alerts is only about one percent likely and provides evidence to reject the null hypothesis. For this test in the study, a P-value which is less than 0.10 is considered sufficient to reject the hypothesis.

False alert probabilities can be analyzed in an analogous way. For the false alert counts, the observed frequency of $F_A/NC_B$ and $F_B/NC_A$ are compared.

The preferred method and further simplification to the test above was presented in [Agresti, 2002]. The test is referred to as the McNemar's test and is specifically designed for testing two data sets that are not independent. This is clearly the case in this study where the same flights are examined between two conflict probe runs. An example is illustrated in Table 5.

[15] Devore defines the P-value as the "smallest level of significance at which the null hypothesis would be rejected when a specified test procedure is used on a given data set"[Devore, 1999]. Thus, the P-value is the probability of the null hypothesis has occurred, so a small P-value (less than 0.10) would indicate the null hypothesis unlikely and should be rejected. If the P-value is large (greater than 0.10), the null hypothesis should be assumed correct.

**Table 5. Demonstration of the McNemar's Test**

| Encounters in Treatment System | Encounters in Control System | | |
|---|---|---|---|
| | With False Alert | Without False Alert | Total |
| With False Alert | 47 | 11 | 58 |
| Without False Alert | 37 | 63 | 100 |
| Total | 84 | 74 | 158 |
| | $\chi^2$=14.083, *df*=1; P-value<0.001 | | |

The test statistic, $\chi^2$, is defined generically as follows:

$$\chi^2 = \frac{(n_{21} - n_{12})^2}{(n_{21} + n_{12})} \qquad \textbf{Eq. 7}$$

where

$\chi^2$ is the chi-squared test statistic

$n_{21}$ is the quantity of flights in the second row, first column of the table

$n_{12}$ is the quantity of flights in the first row, second column of the table

Under assumed conditions, the test statistic assumes a chi-squared distribution. The test statistic can be applied directly to the evaluation code quantities listed in Table 4. The following Eq. 8 and Eq. 9 both apply the generic Eq. 7 to these evaluation codes first for missed alert processing and then false alert, respectively.

$$\chi^2_{MA} = \frac{(MA\_VA - VA\_MA)^2}{(MA\_VA + VA\_MA)} \qquad \textbf{Eq. 8}$$

where

$\chi^2_{MA}$ is the chi-squared statistic

$MA\_VA$ is the quantity of Run A missed alerts matching Run B valid alerts

$VA\_MA$ is the quantity of Run A valid alerts matching Run B missed alerts

$$\chi^2_{FA} = \frac{(FA\_NC - NC\_FA)^2}{(FA\_NC + NC\_FA)} \qquad \textbf{Eq. 9}$$

where

$\chi^2_{FA}$ is the chi-squared statistic

$FA\_NC$ is the quantity of Run A false alerts matching Run B correct no-calls

$NC\_FA$ is the quantity of Run A correct no-calls matching Run B false alerts

Note, it can be shown that the methods in Eq. 5 and Eq. 6 will produce equivalent results as those in Eq. 7 through Eq. 9. Also, for the test statistics above to assume a chi-squared distribution the sum of $n_{21} + n_{12}$ in Eq. 7 or equivalently (MA_VA + VA_MA) and (FA_NC + NC_FA) must all be greater than 25. If their sum is less, an exact test can be used to utilize the Binomial Distribution with $n_{21} + n_{12}$ size parameter and 0.5 for the probability of success. Details are provided in [Agresti, 2002].

In addition to the above metrics, Eq. 10 was used to calculate the percentage change in false alerts. This equation calculated the difference in false alerts created by adding voice intent information to a given scenario from the false alerts that were removed by adding voice intent information. This difference was then divided by the total number of false alerts in the baseline scenario, yielding the percentage change from baseline. Negative percentages indicate a reduction in the number of false alerts.

$$NetChange(\%) = \frac{([NC\_FA + DISCARD\_FA] - [FA\_NC + FA\_DISCARD])}{(SAME\_FA + FA\_NC + FA\_DISCARD)} \qquad \textbf{Eq. 10}$$

### 2.2.2.2 Warning Time

Another important metric when evaluating a conflict probe is the timeliness of the conflict notifications. The distribution of warning time taken from these conflict notifications is measured using several point statistics. Warning time is the lead time provided by the predicted notification as defined in Eq. 11.

$$WT_i = ACST_i - NST_i \qquad \textbf{Eq. 11}$$

where

$WT_i$ is the warning time for $i^{th}$ valid alert conflict prediction

$ACST_i$ is the actual conflict start time for $i^{th}$ valid alert conflict prediction

$NST_i$ is the notification start time for $i^{th}$ valid alert conflict prediction

The warning time is calculated on all the valid alerts and late alerts not associated with a popup conflict event (i.e. STD_VA and LATE_MA events from Table 2). A number of point statistics are calculated including average, median, maximum, minimum, standard deviation, 25$^{th}$ percentile, 75$^{th}$ percentile, and inter-quartile range (i.e., the difference between the 75$^{th}$ and 25$^{th}$ percentiles). It was determined that the 25$^{th}$ percentile statistic provides important insight into the warning time distribution, since it is a reasonably sensitive measure of the lower end of the distribution. This indicates how close the tail is to the MWT threshold (three minutes in this study) and the tactical threshold of 40 seconds. Greater values of the 25$^{th}$ percentile reflect that more warning time is provided by the CP; smaller values reflect less warning time, which suggests that the CP is less suitable for strategic operations.

# 3. Analysis

This section presents results for the Voice Transcription Study based on the ZDC data defined above. Section 3.1 presents the trajectory prediction results and Section 3.2 presents the conflict prediction results.

## 3.1 Trajectory Accuracy Analysis

Analysis of trajectory accuracy necessitated filtering flights from the data set for the following reasons, as summarized in Table 6 and Table 7:

- Active trajectory was not affected by including voice clearance intent information
- Flight was past the clearance or past the outbound handoff at the critical sample time and beyond during the look-ahead window
- Flight was classified as general aviation or military
- Flight did not reach cleared altitude prior to receiving another QQ message (altitude and combined scenarios only)

**Table 6. Filtered Flights (without altitude)**

| Scenario | Flights given voice clearances | No trajectories affected by voice clearance | Flights past clearance/outbound handoff during look-ahead window | General aviation or military flights | Flights to analyze |
|---|---|---|---|---|---|
| **Speed** | | | | | |
| **ZDC 01/26/2010** | 113 | 61 | 6 | 4 | 42 |
| **ZDC 01/27/2010** | 67 | 39 | 2 | 3 | 23 |
| **ZDC 10/13/2010** | 13 | 4 | 0 | 3 | 6 |
| **ZDC 10/14/2010** | 109 | 65 | 5 | 1 | 38 |
| **Heading** | | | | | |
| **ZDC 01/26/2010** | 61 | 10 | 2 | 8 | 41 |
| **ZDC 01/27/2010** | 28 | 5 | 2 | 3 | 18 |
| **ZDC 10/13/2010** | 23 | 3 | 0 | 2 | 18 |
| **ZDC 10/14/2010** | 50 | 14 | 1 | 6 | 29 |
| **Reroute** | | | | | |
| **ZDC 01/26/2010** | 265 | 73 | 2 | 10 | 180 |
| **ZDC 01/27/2010** | 222 | 104 | 3 | 10 | 105 |
| **ZDC 10/13/2010** | 91 | 15 | 0 | 12 | 64 |
| **ZDC 10/14/2010** | 161 | 35 | 2 | 22 | 102 |
| **Heading/Reroute** | | | | | |
| **ZDC 01/26/2010** | 291 | 71 | 3 | 17 | 200 |
| **ZDC 01/27/2010** | 232 | 103 | 2 | 13 | 127 |
| **ZDC 10/13/2010** | 104 | 14 | 0 | 14 | 76 |
| **ZDC 10/14/2010** | 185 | 41 | 1 | 27 | 116 |

**Table 7. Filtered Flights (including altitude)**

| Scenario | Flights given voice clearances | Did not reach cleared alt. before next LH | No trajectories affected by voice clearance | Flights past clearance/outbound handoff during look-ahead window | General aviation or military flights | Flights to analyze |
|---|---|---|---|---|---|---|
| **Altitude** | | | | | | |
| **ZDC 01/26/2010** | 48 | 13 | 3 | 11 | 4 | 17 |
| **ZDC 01/27/2010** | 37 | 14 | 0 | 8 | 5 | 10 |
| **ZDC 10/13/2010** | 54 | 17 | 5 | 0 | 6 | 26 |
| **ZDC 10/14/2010** | 86 | 44 | 3 | 4 | 4 | 31 |
| **Combined** | | | | | | |
| **ZDC 01/26/2010** | 360/48 | -/13 | 107/12 | 8/3 | 21/4 | 224/16 |
| **ZDC 01/27/2010** | 277/37 | -/14 | 133/0 | 3/8 | 15/5 | 126/10 |
| **ZDC 10/13/2010** | 108/54 | -/17 | 14/1 | 0/3 | 14/7 | 80/26 |
| **ZDC 10/14/2010** | 257/86 | -/44 | 82/3 | 4/4 | 28/4 | 143/31 |

### 3.1.1 Voice-Only Speed Clearances

The addition of intent information in the form of speed clearances (QS – Speed) had little to no effect on the overall trajectory accuracy. Along track error, the metric of interest for speed clearances, either showed no improvement or improved very little, and in some cases actually increased trajectory error as compared to the baseline. In most cases, even if the differences reached statistical significance, they were insignificant from a practical standpoint.

Figure 5 presents an example of a flight moving from left to right. The recorded track points are interpolated by the tools to be 10 seconds apart. At the time of the first track point, a voice clearance directs the aircraft to reduce speed to 250 knots. The treatment trajectory (denoted in green) reflects the addition of the intent information extracted from the voice clearance, while the baseline trajectory (denoted in red) does not have this intent information. At the time of the last track point shown in the figure (50 seconds later), the treatment trajectory is closer to the track data (with a 0.05 nm along track error) than the baseline trajectory (with a 0.3 nm along track error).

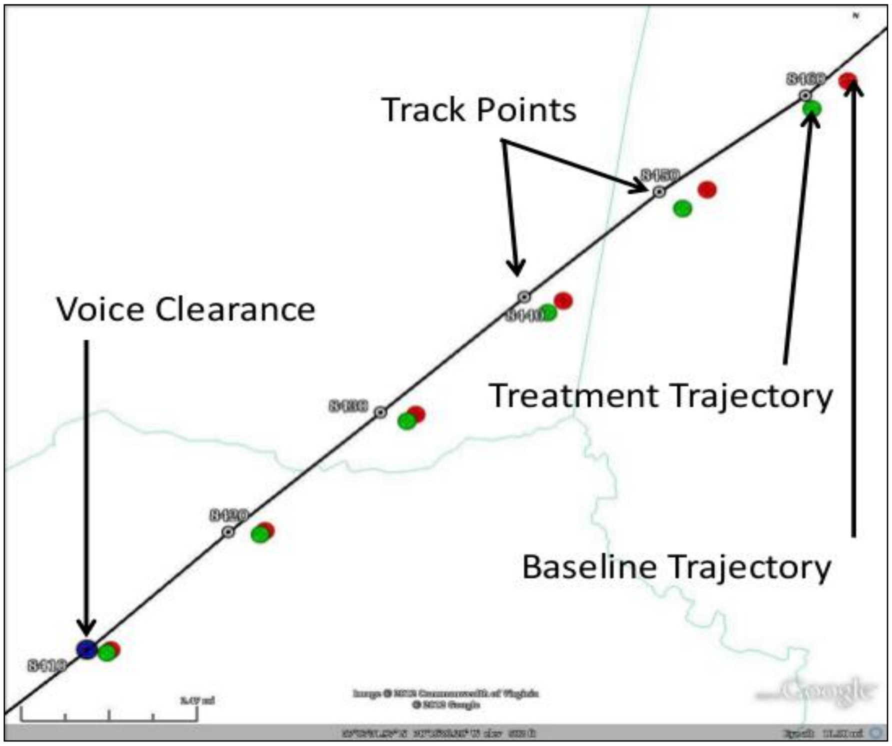



**Figure 5: Trajectory Speed Example**

### 3.1.2 Voice-Only Altitude Clearances

The addition of intent information in the form of interim altitude clearances (QZ – Altitude) had little to no effect on the overall trajectory accuracy. Vertical error, the metric of interest for altitude clearances, either showed no improvement or improved very little, and in some cases actually increased trajectory error as compared to baseline. Even when the differences in vertical error were statistically significant, the magnitude of the difference is generally insignificant from a practical standpoint.

Figure 6 depicts a flight moving from left to right and descending. The recorded track points are interpolated by the tools to be 10 seconds apart. At the time just prior to the Current Position, the flight is operating with an interim clearance to FL270. At the Current Position, an interim altitude voice clearance directs the flight to FL330. The treatment trajectory (denoted in green) contains this additional intent information while the baseline trajectory (denoted in red) does not. The treatment trajectory then merges with the baseline trajectory approximately nine minutes later. For this example, the treatment trajectory more closely represents the track data than the baseline trajectory.

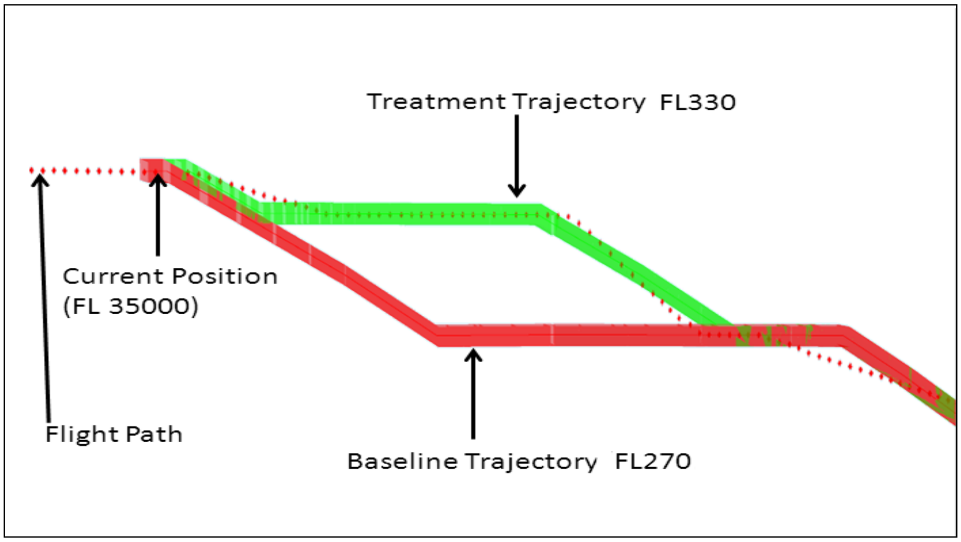



**Figure 6: Trajectory Altitude Example**

### 3.1.3 Voice-Only Heading Clearances

The addition of intent information in the form of heading clearances (QS – Heading) provided the biggest benefit of any treatment condition with regard to trajectory accuracy. Cross track error, the primary metric of interest when route amendments are considered, consistently showed an improvement of about 2 nm or more as compared to the baseline condition across all scenarios. In addition to being statistically significant, 2 nm is of practical interest as well.

An example flight that demonstrates the reduction in trajectory error given additional intent that includes both heading and reroute clearances will be shown in Section 3.1.5.

### 3.1.4 Voice-Only Track Reroute Clearances

The addition of intent information in the form of track reroute clearances (QU – Heading) provided a modest benefit to trajectory accuracy. Cross track error, the primary metric of interest when route amendments are considered, consistently showed an improvement of more than 1.25 nm compared to the corresponding baseline condition across all scenarios. In addition to being statistically significant, a value of 1.25 nm is of interest from a practical standpoint as well.

An example flight that demonstrates the reduction in trajectory error given additional intent that includes both heading and reroute clearances will be shown in Section 3.1.5.

### 3.1.5 Voice-Only Heading and Reroute Clearances

Adding intent information in the form of both heading (QS – heading) and track reroute (QU – Heading) clearances provided a benefit to trajectory accuracy that was better than reroute alone but was less than heading in and of itself. Cross track error, the primary metric of interest when route amendments are considered, consistently showed an improvement of more than 1.4 nm compared to the corresponding baseline condition across all scenarios. In addition to being statistically significant, an average value of 1.4 nm is of interest from a practical standpoint as well.

### 3.1.6 Voice-Only Combined Clearances

Applying intent information from each type of voice clearance in a single treatment condition provided a benefit to trajectory accuracy that was generally worse than the heading clearance (QS – heading, QU – reroute). Cross track error showed an improvement of about 1 nm compared to their respective baseline conditions, while along track error and vertical showed virtually no difference from a practical standpoint.

An example flight that demonstrates the reduction in trajectory error given additional intent information extracted from heading and reroute clearances follows.

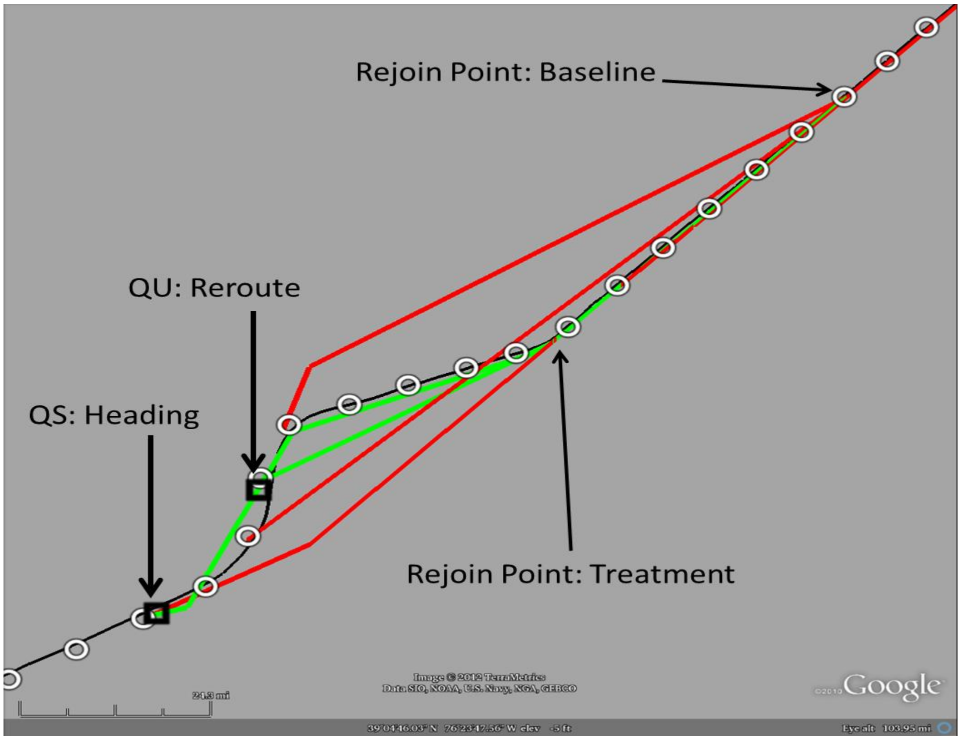



**Figure 7: Trajectory Altitude Example**

Figure 7 depicts a flight moving from left to right. The track points, denoted by the white circles, are 50 seconds apart. Black squares represent voice clearances given to the flight. The first voice clearance (QS: Heading) directs the aircraft to change heading 10 degrees left. The second voice clearance (QU: Reroute) directs the aircraft to return to its previous route at a downstream fix (Rejoin Point: Treatment). The red lines reveal the constant rebuilding of inaccurate trajectories in the Baseline scenario when the CP has a lack of intent information. The green (Treatment) lines illustrate an improvement in trajectory accuracy when the CP receives additional intent information.

The data in Table 8 briefly summarizes the changes in trajectory error over all flights that received voice clearances. The errors presented in this table are the mean unsigned error of the treatment minus the mean unsigned error of the baseline. Values are in nautical miles (nm) except for vertical error, which is in feet (ft)**.** Negative values indicate an improvement in accuracy (i.e., a reduction in error). ***** indicates p<.05, ** indicates p<.01, and *** indicates p<.001. Only flights that passed the filtering described in in Table 6 and Table 7 were included in the trajectory error statistics.

**Table 8. Summary of differences in trajectory error.**

| ZDC | Treatment Condition | Cross Track Error (nm) Mean [StdDev] | Along Track Error (nm) Mean [StdDev] | Horizontal Error (nm) Mean [StdDev] | Vertical Error (ft) Mean [StdDev] | N (Data points) |
|---|---|---|---|---|---|---|
| 01-26-2010 | Speed | .01 [.08] | .24 [2.15]* | .25 [2.09]* | -61 [319]*** | 358 |
| | Altitude | .00 [.00] | -.14 [.61]** | -.13 [.56]** | 57 [1360] | 160 |
| | Heading | -3.40 [4.00]*** | -1.22 [2.29]*** | -3.40 [4.16]*** | -116 [382]*** | 459 |
| | Reroute | -1.37 [3.11]*** | -.34 [1.62]*** | -1.37 [3.10]*** | -25 [203]*** | 1631 |
| | Hdg/Rrte | -1.51 [3.10]*** | -.35 [1.51]*** | -1.46 [3.03]*** | -45 [259]*** | 1884 |
| | Combined | -1.27 [2.90]*** | -.26 [1.68]*** | -1.20 [2.98]*** | -39 [453]*** | 2231 |
| | | | | | | |
| 01-27-2010 | Speed | .01 [.07] | -.62 [2.32] *** | -.50 [2.07]** | -110 [315]*** | 176 |
| | Altitude | .00 [.00] | -.05 [.30] *** | -.05 [.25]*** | 415 [841]*** | 159 |
| | Heading | -1.93 [1.99]*** | -.59 [1.29] *** | -1.92 [1.97]*** | 100 [599]* | 161 |
| | Reroute | -1.61 [3.52]*** | -.17 [2.70] *** | -1.36 [3.18]*** | -37 [164]*** | 1037 |
| | Hdg/Rrte | -1.54 [3.43]*** | -.12 [3.04]* | -1.28 [3.18]*** | -33 [171]*** | 1092 |
| | Combined | -1.21 [3.13]*** | -.12 [1.41]** | -1.02 [2.89]*** | 16 [368] | 1367 |
| | | | | | | |
| 10-13-2010 | Speed | .01 [.10] | .87 [2.56]** | .82 [2.34]** | 20 [316] | 92 |
| | Altitude | .00 [.00]** | -.11 [.76]* | -.10 [.74]* | 375 [1084]*** | 284 |
| | Heading | -2.53 [3.82]*** | -.73 [1.60]*** | -2.44 [3.79]*** | 75 [331]* | 113 |
| | Reroute | -1.87 [4.25]*** | -.33 [2.10]*** | -1.80 [4.32]*** | 20 [262]* | 757 |
| | Hdg/Rrte | -1.90 [4.16]*** | -.44 [2.13]*** | -1.89 [4.25]*** | 11 [272] | 877 |
| | Combined | -1.34 [3.64]*** | -.30 [1.84]*** | -1.32 [3.72]*** | 93 [599]*** | 1206 |
| | | | | | | |
| 10-14-2010 | Speed | .01 [.08] | .01 [1.74] | -.01 [1.66] | -12 [349] | 385 |
| | Altitude | .00 [.00] | .09 [.31]*** | .08 [.29]*** | -14 [127]* | 429 |
| | Heading | -2.34 [3.95]*** | -.01 [1.02] | -2.01 [3.56]*** | -56 [253]** | 217 |
| | Reroute | -1.32 [2.43]*** | -.22 [.97]*** | -1.18 [2.38]*** | -51 [229]*** | 1035 |
| | Hdg/Rrte | -1.43 [2.81]*** | -.13 [2.90]*** | -1.22 [2.70]*** | -46 [238]*** | 1189 |
| | Combined | -.89 [2.33]*** | -.09 [1.02]*** | -.78 [2.31]*** | -30 [249]*** | 1899 |

## 3.2 *Conflict Prediction Analysis*

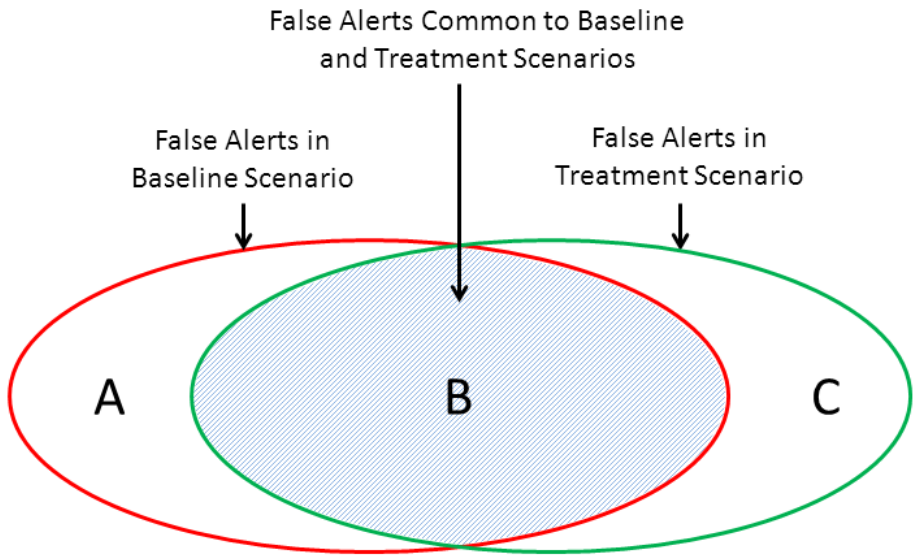
In order to assess the impact of providing additional intent information to the CP, a conflict analysis was performed. The resulting conflict predictions were compared between scenarios with and without adding the transcribed voice-only clearances. Since non-time shifted scenarios were used in this study, no actual conflicts exist because they were resolved by the controllers. In order to induce conflicts so that the analysis could be performed on valid and missed alerts as well as on false alerts, the minimum required horizontal separation was set to six nautical miles in the analysis. This generated between 10-30 conflicts (missed alerts and valid alerts) per scenario. The small number of induced alerts in the 5-6 nm range, while insufficient for analysis, suggests that controllers tend to separate flights by more than 6 nm when resolving conflicts. However, the induced conflicts (in the 5-6 nm range) may be operationally significant. By excluding them from being categorized as false alerts, any analysis performed on the remaining set of alerts is more conservative since the primary goal of providing additional intent information to the CP is to reduce nuisance alerts (alerts that are not of operational significance).

### 3.2.1 Conflict Prediction Comparison Analysis

This section details the conflict alert analysis comparing baseline scenarios with their corresponding treatment scenarios. The results are summarized in Table 12-Table 15 in the Appendix. Each table contains the data for one scenario. Within each table the data are grouped by treatment condition. The column labeled “EVAL_CODE” indicates the alert type formatted as BASELINE_TREATMENT, where the precise nomenclature is described in Table 4. SAME_CODE indicates that the alert of type CODE was identical in baseline and treatment conditions. The left side of each table includes Muted Alerts and the right side excludes Muted Alerts. Muted alerts are important to examine as they are predicted conflicts, based on the aircraft’s flight plan, which can occur when a flight is cleared to an interim altitude. Since the trajectory predictor continues to probe based on the flight plan altitude, not the assigned interim altitude (frequently referred to as the uncleared portion of the flight), any conflicts that are predicted will be presented as muted alerts until the aircraft reaches the assigned interim altitude. Controllers frequently clear aircraft to interim altitudes to avoid conflicts or while waiting for clearances from higher/lower altitude sectors. A muted alert is presented to the controller in a faded color to make it easily distinguishable from standard alerts.

Data were filtered so that only events involving at least one flight that was given a voice only clearance were considered. Of these events, only the cases in which a false alert was called in either the baseline or the treatment scenario were of interest. Specifically, the following alert codes were considered in the alert comparison:

- NC_FA
- DISCARD_FA
- FA_NC
- FA_DISCARD
- SAME_FA




| Symbol | Represents Alerts: |
|---|---|
| A | FA_NC and FA_DISCARD |
| B | SAME_FA |
| C | NC_FA and DISCARD_FA |

Baseline False Alerts = A + B
Treatment False Alerts = C + B

**Figure 8: Subset of False Alerts**

The sum of the FA_NC and FA_DISCARD codes (‘*A*’ in Figure 8) represents the false alerts that were called in the baseline scenario but were not called in the treatment scenario. The sum of the NC_FA and DISCARD_FA codes (‘*C*’ in Figure 8) represents the false alerts that were not called in the baseline scenario but were called in the treatment scenario. The number of SAME_FA codes (‘*B*’ in Figure 8) represents the false alerts that were called in both the baseline and the treatment scenario. A visual representation of this can be seen in Figure 8, where the red ellipse represents all false alerts in the baseline scenario and the green ellipse represents all false alerts in the treatment scenario. These counts were converted into a percentage difference between baseline and treatment as detailed in Eq. 10, where the percentage improvement in false alerts *NetChange(%)* is equal to (*Treatment False Alerts – Baseline False Alerts*)/(*Baseline False Alerts*). Positive values indicate an increase in the percentage of false alerts with respect to baseline while negative values indicate a decrease in false alerts (i.e. an improvement).

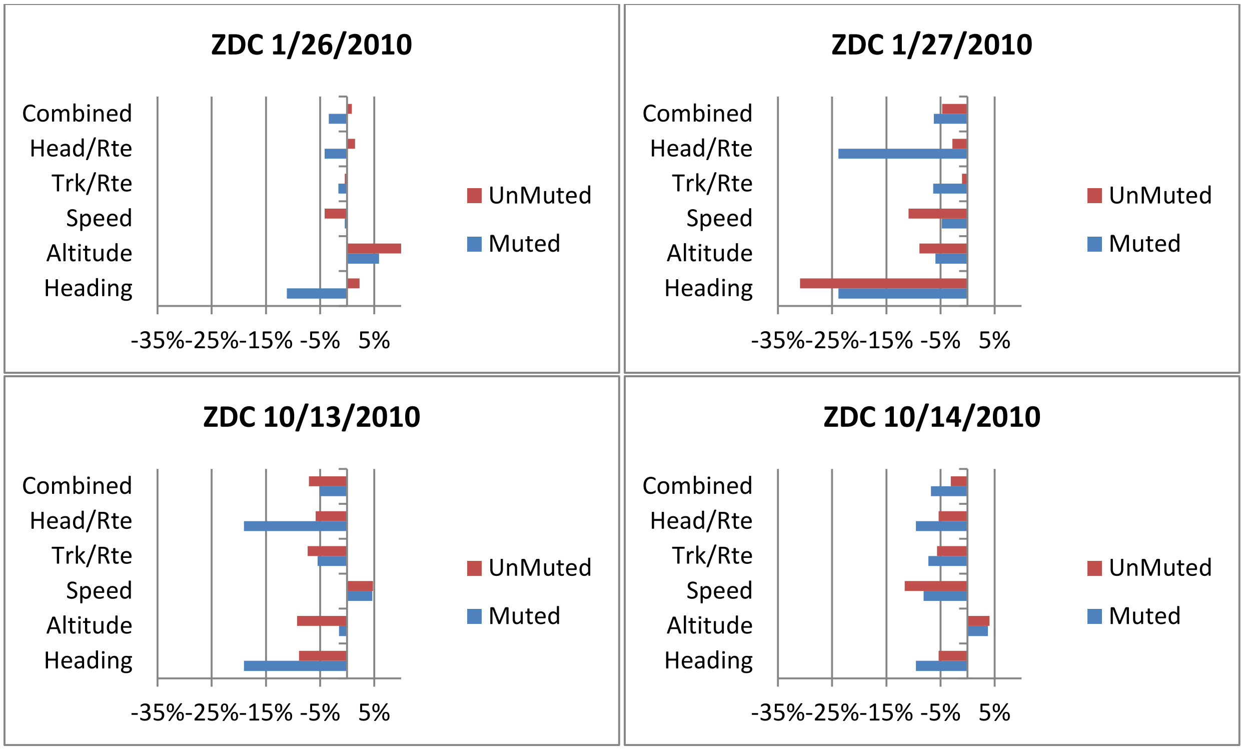



**Figure 9: Net Change in False Alert Rate (voice affected flights only)**

Figure 9 depicts *NetChange(%)* as described in Figure 8. Red bars represent cases where muted alerts were not included in the counts and blue bars represent cases where muted alerts were included in the counts. The inclusion of additional intent information caused an overall reduction in the percentage of false alerts. This can especially be seen in the heading and heading/reroute conditions, where the reduction was between 25-30% in the 1/27 heading scenario and between 10-20% in the 10/13 scenario.

Table 9 contains the absolute counts (rather than percentage change) of these alerts. The values marked in green (reduction) and red (increase) are another representation of the change in false alert rate for each experimental condition. These values are averaged across the 4 scenario dates and separated by treatment condition. In 11 of the 12 cases, a reduction in the false alert rate was observed.

Additionally, all changes in the classification of individual alerts between baseline and treatment scenarios (Table 12- Table 15) as well as Late Alert Rates (LARs) and False Alert Rates (Table 16 and Table 17) are included in the appendix.

**Table 9: Count of False Alerts (voice affected flights only)**

| | | With Muted Alerts | | | | | Without Muted Alerts | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Condition | Alert Type | 1/26 | 1/27 | 10/13 | 10/14 | Average | 1/26 | 1/27 | 10/13 | 10/14 | Average |
| Combined | FA_NC | 73 | 32 | 48 | 56 | -5% | 33 | 21 | 20 | 29 | -3% |
| | NC_FA | 70 | 36 | 36 | 45 | | 42 | 23 | 9 | 28 | |
| | FA_DISCARD | 57 | 49 | 37 | 60 | | 20 | 19 | 7 | 20 | |
| | DISCARD_FA | 29 | 5 | 15 | 19 | | 14 | 4 | 5 | 11 | |
| | SAME_FA | 789 | 559 | 587 | 652 | | 288 | 239 | 158 | 273 | |
| Heading - | FA_NC | 62 | 29 | 48 | 42 | -6% | 28 | 15 | 20 | 24 | -3% |
| - Reroute | NC_FA | 56 | 31 | 32 | 27 | | 35 | 19 | 7 | 18 | |
| | FA_DISCARD | 50 | 40 | 32 | 46 | | 16 | 14 | 5 | 14 | |
| | DISCARD_FA | 25 | 5 | 16 | 14 | | 13 | 4 | 5 | 8 | |
| | SAME_FA | 634 | 438 | 472 | 458 | | 230 | 185 | 121 | 186 | |
| Reroute | FA_NC | 47 | 27 | 46 | 34 | -5% | 26 | 12 | 14 | 16 | -3% |
| | NC_FA | 46 | 30 | 31 | 18 | | 24 | 20 | 8 | 8 | |
| | FA_DISCARD | 32 | 37 | 28 | 32 | | 10 | 14 | 6 | 9 | |
| | DISCARD_FA | 22 | 4 | 15 | 14 | | 11 | 4 | 3 | 6 | |
| | SAME_FA | 600 | 408 | 442 | 405 | | 211 | 173 | 104 | 170 | |
| Speed | FA_NC | 20 | 2 | 0 | 15 | -4% | 7 | 5 | 0 | 7 | -7% |
| | NC_FA | 16 | 2 | 5 | 11 | | 6 | 1 | 1 | 4 | |
| | FA_DISCARD | 9 | 6 | 1 | 20 | | 4 | 2 | 0 | 8 | |
| | DISCARD_FA | 2 | 0 | 1 | 4 | | 1 | 0 | 0 | 0 | |
| | SAME_FA | 234 | 118 | 106 | 211 | | 85 | 48 | 21 | 80 | |
| Altitude | FA_NC | 0 | 3 | 4 | 6 | 0% | 0 | 2 | 5 | 5 | -1% |
| | NC_FA | 4 | 3 | 1 | 10 | | 1 | 3 | 2 | 7 | |
| | FA_DISCARD | 0 | 6 | 3 | 1 | | 0 | 5 | 3 | 1 | |
| | DISCARD_FA | 3 | 0 | 1 | 4 | | 3 | 0 | 0 | 2 | |
| | SAME_FA | 119 | 92 | 323 | 179 | | 40 | 38 | 57 | 68 | |
| Heading | FA_NC | 24 | 14 | 5 | 22 | -12% | 7 | 10 | 6 | 14 | -11% |
| | NC_FA | 10 | 2 | 1 | 15 | | 11 | 1 | 0 | 11 | |
| | FA_DISCARD | 21 | 10 | 8 | 21 | | 6 | 4 | 2 | 9 | |
| | DISCARD_FA | 8 | 1 | 2 | 6 | | 4 | 0 | 0 | 4 | |
| | SAME_FA | 197 | 64 | 91 | 166 | | 74 | 28 | 34 | 61 | |

Once again, the events counted in Table 9 refer to the combination of false alert, correct no call, and discard events. However, more information is available that explains the mechanisms by which the additional intent information being studied may improve the conflict predictions. In particular, the reason codes described in Table 2 explain the logic used by the evaluation software making these determinations and helps describe the operational mechanisms involved. Therefore, the alternate hypothesis being evaluated is attempting to prove that the differences caused by the improved intent in the treatment run produce a significant number of discards or correct no-call (i.e. correct rejection) events as illustrated in Figure 8.

For discard events, two reason codes are of particular interest, including the clearance discard and no track discard. The clearance discard represents an event when an alert is presented, probably correctly, and then removed coincident upon the posting of a clearance. This event is likely to occur when a conflict notification is presented, agreed upon by the air traffic controller, and acted upon through a verbal clearance on the aircraft involved, maneuvering them to avoid the predicted conflict. This verbal clearance may be entered into the automation in some instances but not in others and is precisely the subject of this study. More specifically, if the difference associated with the FA_DISCARD versus the DISCARD_FA counts can be attributed to the clearance discard events, it illustrates that these events are significant. The other discard reason code is the no track discard. It occurs when the conflict notification presents an alert that predicts the conflict start time where either flight involved has no track present in the traffic sample under study. The authors do not expect this to be a significant occurrence but possible as the improved intent from the verbal only clearances improve the longitudinal trajectory prediction accuracy (see Section 3.1 for this analysis). To illustrate this, two of the four scenarios were examined in more depth. For results with muted alerts for 1/27/2010 and 10/13/2010, the following counts were compared and tabulated in Table 10. It was easily shown that the dominating mechanism is the clearance discard event that increases with improved intent in the heading treatment runs. This occurred in 1/27 scenario 10 to 1 and in the 10/13 scenario 8 to 2, respectively.

**Table 10: Example Comparison of Reason Codes**

| Run Date: 1/27/2010 - Heading | | |
|---|---|---|
| FA_DISCARD : 10 | False Alert to Clearance Discard | False Alert to No Track Discard |
| | 10 | 0 |
| DISCARD_FA : 1 | Clearance Discard to False Alert | No Track Discard to False Alert |
| | 1 | 0 |
| Run Date: 10/13/2010 - Heading | | |
| FA_DISCARD : 8 | False Alert to Clearance Discard | False Alert to No Track Discard |
| | 7 | 1 |
| DISCARD_FA : 2 | Clearance Discard to False Alert | No Track Discard to False Alert |
| | 1 | 1 |

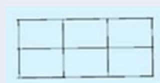
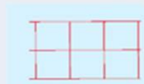
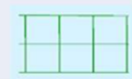
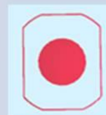
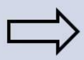
For the correct no-call events, a false alert event changes from being predicted to correctly not being predicted. This can occur for a number of reasons. The authors believe this occurs predominately when the conflict notification is truly a nuissance case and not operationally of interest. Thus, the alternate hypothesis being examined in this study postulates that the improved intent provided by the additional clearances in the treatment run improves the trajectory accuracy and resulting conflict predictions, and then significantly reduces the false alerts by correctly removing them. This is illustrated by the results. In the counts in Table 9, for the same 1/27 run above, for false alerts to correct no-calls versus correct no-calls to false alerts, the counts go from 14 to 2, respectively. For the same heading run for 10/13, the false event counts go from 5 to 1, respectively. In both runs examined as well as the others not discussed, there are a signficant reduction in false alerts by being allocated as a clearance discard when the original alert was potentially operational significant and correctly removed when it was truly a nuissance.

## *3.3 Flight Examples*

This section contains several flight examples that portray flights that were given a voice-only clearance. Each figure depicts a pair of flights where the detected conflicts varied between the baseline run (where the voice clearance was not provided to the system), and the treatment run (where the voice-only clearance was input into the system).

Table 11 contains the legend that was used in the figures to graphically depict the geometry of the example flights.

**Table 11: Legend used in Flight Examples**

| | Flight 1 (non-voice) | Flight 2 (w/o voice) Baseline | Flight 2 (w/ voice) Treatment |
|---|---|---|---|
| Track |  |  | N/A |
| Trajectory |  |  |  |
| Conformance Box plus Min Separation based on Trajectory |  |  |  |
| Current Position |  |  | N/A |
| Direction of flight |  |  | N/A |
| Point of predicted conflict |  |  |  |

### 3.3.1 Example 1 – False Alert to No Call

Flight example 1 (Figure 10) examines a conflict between Flight 1, an A320 flying at FL360 en route from Boston to Fort Lauderdale and Flight 2, a Boeing 737 climbing from 11,000 ft to its cleared altitude of FL400, en route from Baltimore to the Bahamas.

In this example, the controller issued a voice-only clearance to Flight 2 to turn left 15°. This resulted in a slight deviation in its track position (red track). Since the clearance was not entered into the automation, the baseline system predicted a conflict based on the active flight plan route (red wire-frame path). The prediction resulted in a conflict being detected (intersection of black and red conformance). After including the voice clearance into the automation in the treatment run, the system produced a trajectory (green wire-frame path) that correctly predicted no conflict (No Call). Clearly in this example, if the controller had entered the voice clearance into the system, the False Alert would have been eliminated.

It should be noted that an LH (interim altitude) for FL 370 was given at the time of the false alert notification (baseline scenario, red wire-frame), which caused a trajectory rebuild for the non-voice flight (black wire-frame). This rebuild is what produced a false alert with short notification in the baseline scenario.

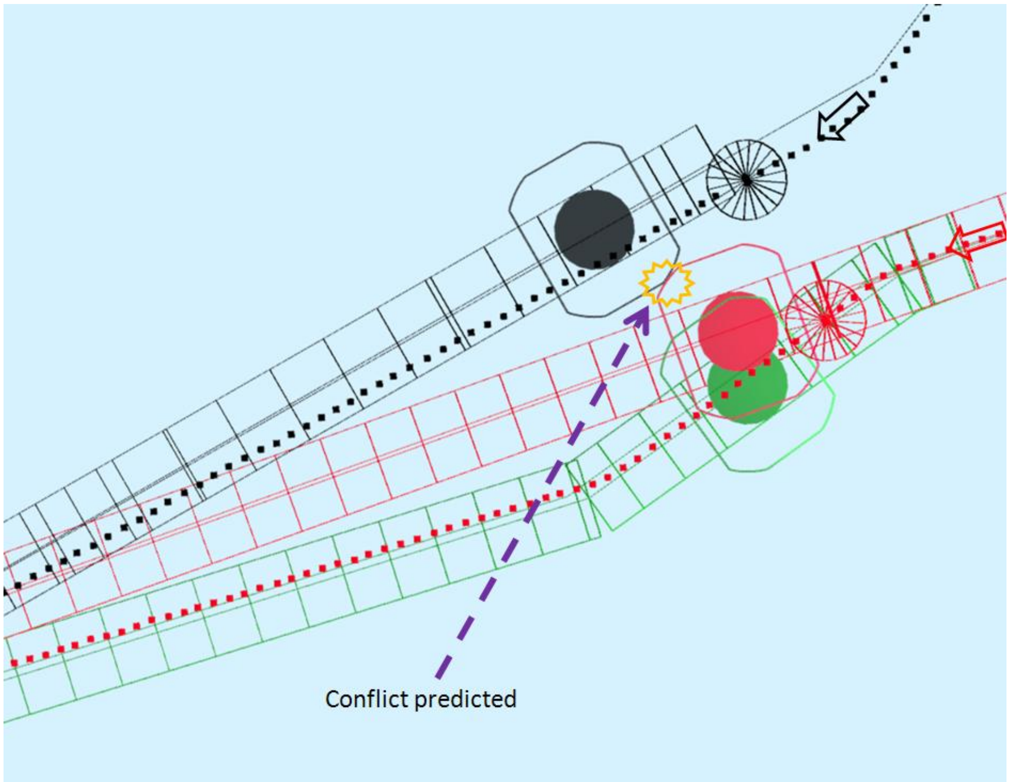



**Figure 10: Flight Example 1**

### 3.3.2 Example 2 – No Call to False Alert

Flight example 2 (Figure 12) examines a conflict between Flight 1, an Embraer 145 flying at FL310, en route from Louisville, KY to LaGuardia, NY and Flight 2, an Embraer 135 climbing from 8,100 ft to its cleared altitude of FL290, en route from Raleigh/Durham, NC to LaGuardia, NY.

In this example, the controller issued a voice-only clearance to Flight 2 to turn to a 360° heading, resulting in the track positions shown (red track, Figure 11). Without the intent information from the voice clearance, the automation creates the baseline trajectory (red wire-frame, Figure 11). This trajectory does not lead to a predicted conflict. The second trajectory for Flight 2 (green wire-frame path, Figure 11) is a result of including the voice-only clearance into the automation. In addition to a change in predicted horizontal position, the intent information allows the automation to recognize that Flight 2 turns, which increases the size of the conformance box by 1 nm laterally and 1 nm longitudinally in order to accommodate uncertainties in the turn modeling. The two flights are predicted to be in vertical transition as well (Figure 12) which increases the size of the conformance box for each flight by 1,000 ft vertically. These two factors contribute to the prediction of a conflict in the treatment scenario which results in a False Alert.

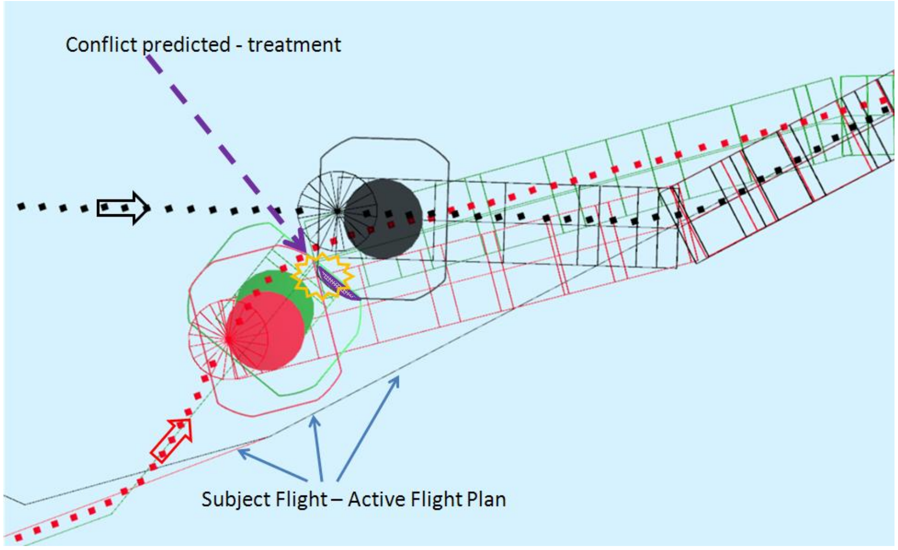



**Figure 11: Flight Example 2 – horizontal**

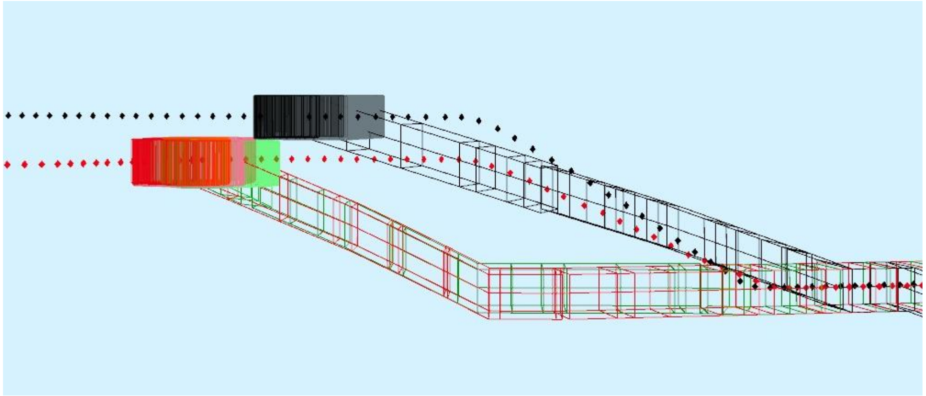


**Figure 12: Flight Example 2 – vertical**

### 3.3.3 Example 3 – No Call to False Alert

Flight example 3 (Figure 13 and Figure 14) examines a conflict between Flight 1, an A321 flying at FL350, en route from Tampa, FL to Philadelphia. PA; and Flight 2, a Boeing 752 flying at FL390 en route from Atlanta, GA to Philadelphia, PA.

In this example, the controller issued a voice-only clearance to Flight 2 to turn to a heading of 010°, resulting in the track positions shown (red track). Without the intent information from the voice clearance, the automation creates the baseline trajectory (red wire-frame, Figure 13). This trajectory does not lead to a predicted conflict. The second trajectory for Flight 2 (green wire-frame path, Figure 13) is a result of including the voice-only clearance into the automation. In addition to a change in predicted horizontal position, the intent information allows the automation to recognize that Flight 2 is in close proximity to a turn, which increases the size of the conformance box by 1 nm laterally and 1 nm longitudinally in order to accommodate uncertainties in the turn modeling. Flight 2 is predicted to be in vertical transition as well (Figure 14) which increases the size of the conformance box for Flight 2 by 1,000 ft vertically. These two factors contribute to the prediction of a conflict in the treatment scenario which results in a False Alert.

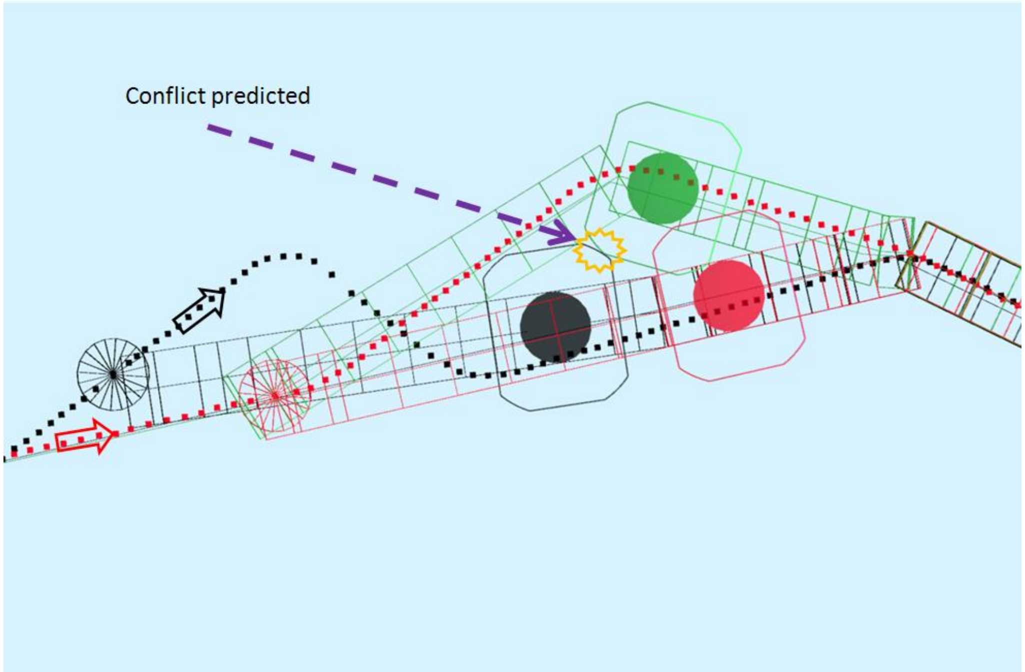



**Figure 13: Flight Example 3 - horizontal**

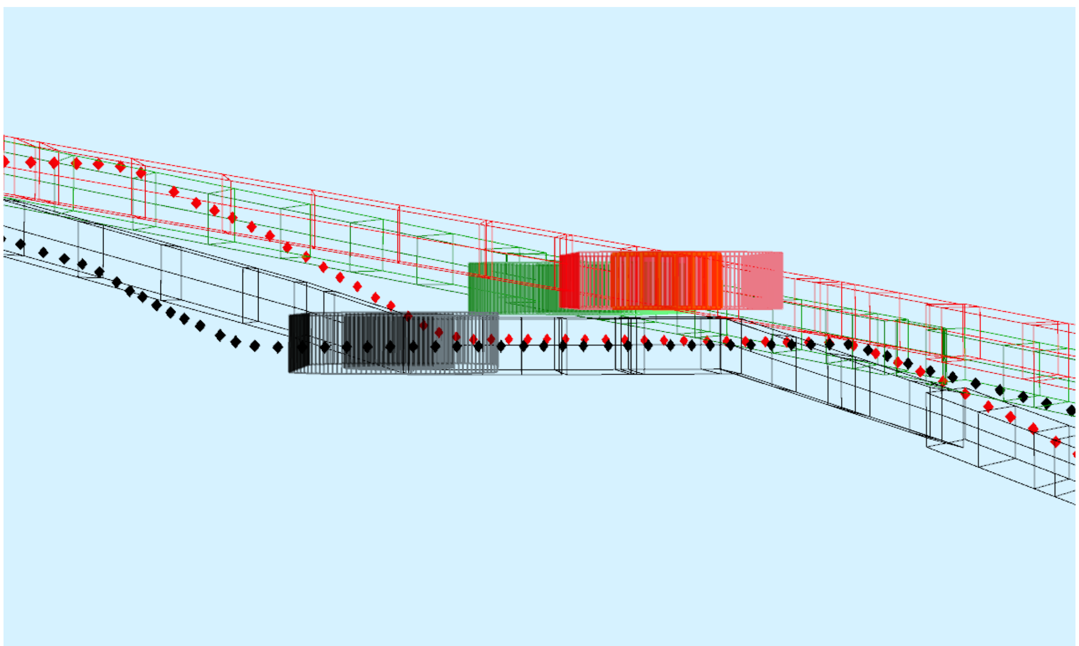


**Figure 14: Flight Example 3 - vertical**

# 4. Conclusion

The voice transcription study analyzed TP and CP performance when additional intent information transcribed from controllers' voice commands was utilized. This report describes the effects on trajectory accuracy when information transcribed from dates 1/26-27/2010 and 10/13-14/2010 in the ZDC ARTCC are infused into the CMS data for each respective day.

Adding intent information related to the heading of a flight, in the form of QS and QU messages provided a significant improvement in overall trajectory accuracy. While there were some flights that showed little to no effect, most flights that received this information showed a sizeable improvement. It can be seen in Table 8 that the cross track error in the Heading treatments (QS – Heading) showed the largest reduction in trajectory error, between 1.9 nm and 3.4 nm This reduction was significantly greater than the Reroute and Heading/Reroute treatments, which showed a reduction of between 1.3 nm and 1.9 nm. While it seems counterintuitive that the Heading condition produces better results than the Heading/Reroute condition (which contains more intent information), the reason for this can be seen in the algorithm used to construct the clearance from the transcribed Heading information (Figure 2). When creating a heading amendment (AH) from voice transcribed data the divergence point, turn point, and rejoin point are calculated based on the original route and track of the flight. This implicitly results in a two-part maneuver, based on the track of the flight, which consists of a heading change and a subsequent reroute to a downstream fix. This is used to produce an AH message that gets inserted into the original CMS as a single amendment to the route of the flight. This compound-amendment differs from the Heading/Reroute condition, where the initial heading message is produced in an identical manner but the amendment message becomes overridden by the addition of a reroute message a short time later (Figure 3). This reroute message is by definition based on an assumption that the flight reacts to the verbal clearance a parameter time after receiving the voice clearance, and the only interaction with the track of the flight is its location at position S in the algorithm example.

In contrast, the intent information provided by adding speed and altitude clearances had a minimal effect on overall trajectory accuracy for each scenario. Although a few flights that received this additional information showed improvements in along track and vertical trajectory error, these effects were offset by the lack of benefit to the majority of the flights. As seen in Table 8, along track error improved in only one scenario and the magnitude of the improvement was less than .75 nm. Vertical error was generally less accurate by several hundred feet after voice intent information was added. Determining the specific reasons why speed and altitude do not improve trajectory accuracy is beyond the scope of this report. However, several possibilities include:

- Speed
    - High levels of noise in speed data with a corresponding noise in along track error
    - QS+ and QS- messages provide a minimum/maximum speed, and not a specific speed that the flight must maintain
    - Flights have some discretion in the speed that they fly

- Altitude
    - High levels of noise in vertical position with a corresponding noise in vertical error
    - Lack of corresponding QZ (altitude) clear messages that remove interim altitude clearances
    - Intent can be assumed at or near arrival, even when clearances are not provided to the flight, due to sector altitude restrictions/arrival flight paths

Finally, the Combined condition had a modest overall improvement in trajectory error, a reduction of between .9 nm and 1.3 nm. Again, while it seems that providing more of the missing intent information should produce trajectories with maximally improved accuracy, the lack of improvement found in the Speed and Altitude conditions is averaged along with the results of the Heading and Reroute conditions to mitigate any improvement in trajectory accuracy.

Based on the discussion above, improvements in trajectory accuracy based on providing more intent information to the HCS should focus on route amendments. While utilizing future track information, as in the heading algorithm described in Figure 2, is not possible in an operational environment, the ability to implement a multi-part maneuver could provide enough intent information to significantly increase trajectory accuracy.

When considering effects of additional intent information on the Conflict Probe, this study finds measurable improvements in the bulk of the treatment conditions across all four scenarios (Figure 9, Table 9). Reduction in the percentage of False Alerts across the 4 scenarios was around 5%, though they reached as high as 12% in the Heading condition, However, the authors believe that the magnitudes of the effects were reduced as a consequence of the sector selection. Many of the sectors used in this study were arrival sectors. Controllers in these sectors usually try to align flights in trail which reduces or eliminates the potential crossing traffic and also reduces the chance of having conflicts. In addition, the controllers generally don't issue a voiced command that would cause a conflict.

In order to more effectively measure the benefits to the CP, the authors recommend making the following changes for future voice transcription studies.

- Use high and ultra high sectors, which contain mainly en-route traffic and have different geometric traffic patterns
- Use time-shifted scenarios which contain induced conflicts

In summary, the study processed four scenario dates of voice-only clearances, concluding that the heading amendments had the most impact on the performance of the TP. In addition, heading had the greatest impact on the CP. The selection of more appropriate (high altitude) sectors as well as the induction of conflicts is expected to better illustrate the impact of voice clearance information to the CP.

# 5. Acronyms

| | |
|---|---|
| **AH** | CMS Flight Amendment Information Message |
| **ANG-C41** | Advanced Operational Concepts Division, Concept Analysis Branch |
| **ANG-E25** | Aviation Research Division, Human Factors Branch |
| **ARTCC** | Air Route Traffic Control Center |
| **ATM** | Air Traffic Management |
| **CMS** | Common Message Set |
| **CP** | Conflict Probe |
| **CSV** | Comma-Separated Values |
| **FA** | False Alert |
| **FAA** | Federal Aviation Administration |
| **FAR** | False Alert Rate |
| **FAV** | Fixed Airspace Volume |
| **FDB** | Full Data Block |
| **Feet** | Feet |
| **FL** | Flight Level |
| **HADDS** | Host Air Traffic Management Data Distribution System |
| **HCS** | Host Computer System |
| ***JEDI*** | Java En Route Development Initiative |
| **LA** | Late Alert |
| **LH** | CMS Interim Altitude Information Message |
| **MAR** | Missed Alert Rate |
| **Min** | Minutes |
| **MWT** | Minimum Warning Time |
| **NC** | Correct No-call |
| **NAS** | National Air Space |
| **nm** | Nautical Miles |
| **QS** | HCS Heading, Speed, and Free Form Text Message |
| **QU** | HCS Track Reroute Message |
| **QZ** | HCS Assigned Altitude Message |
| **sec** | Seconds |
| **SME** | Subject Matter Expert |
| **TP** | Trajectory Predictor |
| **URET** | User Request Evaluation Tool |
| **VA** | Valid Alert |

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# 7. Appendix

**Table 12: Conflict alert comparison for 01/26/2010**

| ZDC 1/26/2010 | With Muted Alerts | | | | | | Without Muted Alerts | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EVAL_CODE | Heading | Altitude | Speed | Trk/Rte | Head/Rte | Combined | Heading | Altitude | Speed | Trk/Rte | Head/Rte | Combined |
| DISCARD_FA | 8 | 3 | 1 | 20 | 23 | 26 | 4 | 3 | 1 | 11 | 13 | 14 |
| DISCARD_MA | | | | | | | | | | | | |
| DISCARD_NC | 59 | 11 | 37 | 123 | 158 | 172 | 17 | 1 | 10 | 53 | 55 | 61 |
| FA_DISCARD | 21 | | 9 | 32 | 49 | 55 | 5 | | 4 | 9 | 14 | 18 |
| FA_NC | 21 | | 20 | 45 | 57 | 68 | 7 | | 7 | 26 | 28 | 33 |
| NC_DISCARD | 23 | 3 | 37 | 108 | 124 | 154 | 7 | 7 | 11 | 43 | 51 | 61 |
| NC_FA | 10 | 4 | 16 | 46 | 55 | 69 | 11 | 1 | 6 | 24 | 34 | 41 |
| SAME_DISCARD | 9645 | 9698 | 9674 | 9569 | 9531 | 9514 | 4970 | 4987 | 4980 | 4927 | 4923 | 4916 |
| SAME_FA | 4844 | 4886 | 4857 | 4809 | 4780 | 4763 | 2148 | 2160 | 2149 | 2125 | 2118 | 2109 |
| SAME_MA | 5 | 5 | 5 | 5 | 5 | 5 | 6 | 6 | 6 | 6 | 6 | 6 |
| SAME_VA | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 2 |
| VA_DISCARD | | | | | | | | | | | | |
| VA_MA | | | | | | | | | | | | |

**Table 13: Conflict alert comparison for 01/27/2010**

| ZDC 1/27/2010 | With Muted Alerts | | | | | | Without Muted Alerts | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **EVAL_CODE** | **Heading** | **Altitude** | **Speed** | **Trk/Rte** | **Head/Rte** | **Combined** | **Heading** | **Altitude** | **Speed** | **Trk/Rte** | **Head/Rte** | **Combined** |
| **DISCARD_FA** | 1 | | 1 | 5 | 6 | 6 | | | | 4 | 4 | 4 |
| **DISCARD_MA** | | | | | | | | | | | | |
| **DISCARD_NC** | 16 | | 8 | 51 | 57 | 64 | 6 | 2 | 6 | 16 | 20 | 26 |
| **FA_DISCARD** | 9 | 6 | 5 | 32 | 36 | 43 | 4 | 5 | 2 | 12 | 13 | 18 |
| **FA_NC** | 11 | 3 | 2 | 25 | 26 | 29 | 7 | 2 | 4 | 10 | 12 | 17 |
| **NC_DISCARD** | 5 | 2 | 14 | 36 | 42 | 55 | | 4 | 6 | 10 | 11 | 19 |
| **NC_FA** | 2 | 3 | 1 | 28 | 29 | 33 | 1 | 3 | 0 | 19 | 18 | 21 |
| **SAME_DISCARD** | 9280 | 9297 | 9288 | 9241 | 9234 | 9227 | 5088 | 5092 | 5088 | 5074 | 5070 | 5064 |
| **SAME_FA** | 4555 | 4566 | 4568 | 4518 | 4513 | 4503 | 2081 | 2085 | 2086 | 2070 | 2067 | 2057 |
| **SAME_MA** | 14 | 14 | 14 | 14 | 14 | 14 | 16 | 16 | 16 | 16 | 16 | 16 |
| **SAME_VA** | 8 | 8 | 8 | 8 | 8 | 8 | 6 | 6 | 6 | 6 | 6 | 6 |
| **VA_DISCARD** | | | | | | | | | | | | |
| **VA_MA** | | | | | | | | | | | | |

**Table 14: Conflict alert comparison for 10/13/2010**

| ZDC 10/13/2010 | With Muted Alerts | | | | | | Without Muted Alerts | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EVAL_CODE | Heading | Altitude | Speed | Trk/Rte | Head/Rte | Combined | Heading | Altitude | Speed | Trk/Rte | Head/Rte | Combined |
| DISCARD_FA | 2 | 2 | 0 | 14 | 15 | 15 | | | | 3 | 5 | 5 |
| DISCARD_MA | | | | | | | | | | | | |
| DISCARD_NC | 19 | 4 | 8 | 54 | 62 | 72 | 9 | 3 | 2 | 17 | 19 | 21 |
| FA_DISCARD | 8 | 4 | 1 | 27 | 31 | 36 | 2 | 3 | | 6 | 5 | 7 |
| FA_NC | 5 | 4 | | 45 | 47 | 47 | 6 | 5 | | 14 | 20 | 20 |
| NC_DISCARD | 7 | 7 | 4 | 50 | 53 | 65 | 2 | 5 | 1 | 16 | 16 | 20 |
| NC_FA | 1 | 1 | 4 | 31 | 32 | 36 | | 2 | 1 | 8 | 7 | 9 |
| SAME_DISCARD | 10528 | 10543 | 10541 | 10481 | 10472 | 10462 | 5813 | 5819 | 5820 | 5802 | 5798 | 5796 |
| SAME_FA | 5583 | 5588 | 5595 | 5524 | 5518 | 5513 | 2348 | 2348 | 2356 | 2336 | 2331 | 2329 |
| SAME_MA | 61 | 61 | 61 | 61 | 61 | 61 | 83 | 83 | 83 | 83 | 83 | 83 |
| SAME_VA | 37 | 37 | 37 | 37 | 37 | 37 | 15 | 15 | 15 | 15 | 15 | 15 |
| VA_DISCARD | | | | | | | | | | | | |
| VA_MA | | | | | | | | | | | | |

**Table 15: Conflict alert comparison for 10/14/2010**

| ZDC 10/14/2010 | With Muted Alerts | | | | | | Without Muted Alerts | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EVAL_CODE | Heading | Altitude | Speed | Trk/Rte | Head/Rte | Combined | Heading | Altitude | Speed | Trk/Rte | Head/Rte | Combined |
| DISCARD_FA | 1 | 4 | 3 | 3 | 4 | 18 | 4 | 2 | | 3 | 7 | 10 |
| DISCARD_MA | | | | | | | | | | | | |
| DISCARD_NC | 11 | 16 | 17 | 33 | 41 | 123 | 10 | 5 | 10 | 33 | 24 | 35 |
| FA_DISCARD | 2 | 1 | 10 | 1 | 4 | 58 | 8 | 1 | 7 | 1 | 12 | 18 |
| FA_NC | 4 | 6 | 4 | 14 | 14 | 55 | 13 | 5 | 7 | 14 | 23 | 28 |
| NC_DISCARD | 4 | 13 | 13 | 10 | 12 | 88 | 13 | 8 | 15 | 10 | 18 | 38 |
| NC_FA | 1 | 10 | 6 | 2 | 2 | 45 | 11 | 7 | 4 | 2 | 18 | 28 |
| SAME_DISCARD | 1937 | 10907 | 2096 | 2080 | 2071 | 10786 | 6119 | 6126 | 6123 | 2080 | 6102 | 6088 |
| SAME_FA | 957 | 5317 | 986 | 985 | 982 | 5211 | 2215 | 2230 | 2222 | 985 | 2201 | 2190 |
| SAME_MA | 4 | 50 | 68 | 68 | 68 | 50 | 61 | 61 | 61 | 68 | 61 | 61 |
| SAME_VA | 7 | 24 | 6 | 6 | 5 | 24 | 13 | 13 | 13 | 6 | 13 | 13 |
| VA_DISCARD | | | | | | | | | | | | |
| VA_MA | | | | | 1 | | | | | | | |

**Table 16: LAR-FAR 1/26/2010 and 1/27/2010**

| ZDC 1/26/2010 | With Muted Alerts | | | Without Muted Alerts | | |
|---|---|---|---|---|---|---|
| Condition | NC | LAR | FAR | NC | LAR | FAR |
| BL-Rate | 28865 | 0.769 | 0.155 | 31353 | 0.846 | 0.069 |
| BL-Count | | 41195 | 5292/34157 | | 41226 | 2339/33692 |
| AL - Rate | 28865 | 0.769 | 0.155 | 31352 | 0.846 | 0.07 |
| AL - Count | | 41195 | 5299/34164 | | 41226 | 2343/33695 |
| AO - Rate | 28876 | 0.769 | 0.154 | 31361 | 0.846 | 0.069 |
| AO - Count | | 41195 | 5261/34137 | | 41226 | 2342/33703 |
| HD - Rate | 28880 | 0.769 | 0.154 | 31357 | 0.846 | 0.069 |
| HD - Count | | 41195 | 5265/34145 | | 41226 | 2341/33698 |
| HR - Rate | 28881 | 0.769 | 0.154 | 31362 | 0.846 | 0.07 |
| HR - Count | | 41195 | 5261/34142 | | 41226 | 2343/33705 |
| SP - Rate | 28868 | 0.769 | 0.155 | 31354 | 0.846 | 0.069 |
| SP - Count | | 41195 | 5281/34149 | | 41226 | 2335/33689 |
| TR - Rate | 28870 | 0.769 | 0.155 | 31363 | 0.846 | 0.069 |
| TR - Count | | 41195 | 5281/34151 | | 41226 | 2338/33701 |

| ZDC 1/27/2010 | With Muted Alerts | | | Without Muted Alerts | | |
|---|---|---|---|---|---|---|
| Condition | NC | LAR | FAR | NC | LAR | FAR |
| BL-Rate | 27739 | 0.688 | 0.151 | 30009 | 0.893 | 0.07 |
| BL-Count | | 22/32 | 4925/32664 | | 25/28 | 2242/32251 |
| AL - Rate | 27739 | 0.688 | 0.151 | 30008 | 0.893 | 0.069 |
| AL - Count | | 22/32 | 4919/32658 | | 25/28 | 2238/32246 |
| AO - Rate | 27747 | 0.688 | 0.15 | 30030 | 0.893 | 0.069 |
| AO - Count | | 22/32 | 4885/32632 | | 25/28 | 2229/32259 |
| HD - Rate | 27745 | 0.688 | 0.15 | 30020 | 0.893 | 0.069 |
| HD - Count | | 22/32 | 4904/32649 | | 25/28 | 2229/32249 |
| HR - Rate | 27744 | 0.688 | 0.15 | 30023 | 0.893 | 0.069 |
| HR - Count | | 22/32 | 4892/32636 | | 25/28 | 2236/32259 |
| SP - Rate | 27743 | 0.688 | 0.151 | 30016 | 0.893 | 0.069 |
| SP - Count | | 22/32 | 4919/32662 | | 25/28 | 2236/32252 |
| TR - Rate | 27744 | 0.688 | 0.15 | 30019 | 0.893 | 0.069 |
| TR - Count | | 22/32 | 4895/32639 | | 25/28 | 2240/32259 |

**Table 17: LAR-FAR 10/13/2010 and 10/14/2010**

| ZDC 10/13/2010 | With Muted Alerts | | | Without Muted Alerts | | | ZDC 10/14/2010 | With Muted Alerts | | | Without Muted Alerts | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Condition** | **NC** | **LAR** | **FAR** | **NC** | **LAR** | **FAR** | **Condition** | **NC** | **LAR** | **FAR** | **NC** | **LAR** | **FAR** |
| **BL-Rate** | 33049 | 0.786 | 0.151 | 35494 | 0.968 | 0.066 | **BL-Rate** | 34805 | 0.862 | 0.141 | 37434 | 0.972 | 0.061 |
| **BL-Count** | | 66/84 | 5873/38922 | | 90/93 | 2492/37986 | **BL-Count** | | 56/65 | 5716/40521 | | 70/72 | 2437/39871 |
| **AL - Rate** | 33052 | 0.786 | 0.151 | 35500 | 0.968 | 0.065 | **AL - Rate** | 34799 | 0.862 | 0.141 | 37434 | 0.972 | 0.061 |
| **AL - Count** | | 66/84 | 5868/38920 | | 90/93 | 2486/37986 | **AL - Count** | | 56/65 | 5723/40522 | | 70/72 | 2440/39874 |
| **AO - Rate** | 33062 | 0.786 | 0.15 | 35507 | 0.968 | 0.065 | **AO - Rate** | 34822 | 0.862 | 0.14 | 37438 | 0.972 | 0.061 |
| **AO - Count** | | 66/84 | 5839/38901 | | 90/93 | 2479/37986 | **AO - Count** | | 56/65 | 5664/40486 | | 70/72 | 2427/39865 |
| **HD - Rate** | 33060 | 0.786 | 0.151 | 35501 | 0.968 | 0.065 | **HD - Rate** | 34803 | 0.862 | 0.141 | 37437 | 0.972 | 0.061 |
| **HD - Count** | | 66/84 | 5863/38923 | | 90/93 | 2484/37985 | **HD - Count** | | 56/65 | 5694/40497 | | 70/72 | 2429/39866 |
| **HR - Rate** | 33063 | 0.786 | 0.15 | 35502 | 0.968 | 0.065 | **HR - Rate** | 34820 | 0.862 | 0.14 | 37443 | 0.972 | 0.061 |
| **HR - Count** | | 66/84 | 5841/38904 | | 90/93 | 2479/37981 | **HR - Count** | | 56/65 | 5669/40489 | | 70/72 | 2425/39868 |
| **SP - Rate** | 33048 | 0.786 | 0.151 | 35495 | 0.968 | 0.066 | **SP - Rate** | 34814 | 0.862 | 0.141 | 37434 | 0.972 | 0.061 |
| **SP - Count** | | 66/84 | 5878/38926 | | 90/93 | 2493/37988 | **SP - Count** | | 56/65 | 5696/40510 | | 70/72 | 2426/39860 |
| **TR - Rate** | 33055 | 0.786 | 0.15 | 35498 | 0.968 | 0.065 | **TR - Rate** | 34821 | 0.862 | 0.14 | 37438 | 0.972 | 0.061 |
| **TR - Count** | | 66/84 | 5845/38900 | | 90/93 | 2483/37981 | **TR - Count** | | 56/65 | 5682/40503 | | 70/72 | 2426/39864 |

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