

# Simulation Evaluation of Conflict Resolution and Weather Avoidance in Near-Term Mixed Equipage Datalink Operations

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The pilot- and controller-in-the-loop simulation described in this paper demonstrates the potential benefits of a near-term trajectory-based operations concept with datalink communications. Near-term operations with datalink are characterized by a fleet of which not all aircraft are equipped with datalink communications (i.e., mixed equipage). The objectives of this simulation were to continue to develop capabilities such as the conflict resolution algorithm, as well as evaluate new capabilities and concepts such as tactical conflict detection and trajectory-based weather avoidance with feedback from experienced pilots and controllers. Conflict resolutions and tactical conflict detections were compared to controller actions. The direction of the conflict resolution maneuver advised by the algorithm agreed with controller actions 79% of the time when both chose to apply the same type of resolution maneuver to the same aircraft. Comparing controller actions to conflicts detected by the tactical conflict detection function revealed no missed alerts and a false alert rate of 11%. Trajectory-based weather avoidance functions received high ratings from the controllers for usefulness and ease of use. In particular, controllers noted weather avoidance reroutes originating from a simulated traffic management coordinator position alleviated their concerns about potentially disrupting traffic flow management plans, thus expediting the issuance of the reroutes.

## I. Introduction

RECENT research efforts to improve controller productivity and airspace efficiency have focused on trajectory-based operations (TBO) enabled by datalink communications. Although laboratory studies and simulations have shown the potential benefits of TBO with datalink, realizing these benefits in near-term operations has not been demonstrated. Challenges facing operations in the near-term include mixed datalink equipage. Given the cost of new aircraft equipment, near-term fleet-wide datalink equipage levels are expected to be mixed with fleet-wide equipage projected to reach only 50% by 2025. Since controllers are expected to be responsible for aircraft separation for the foreseeable future, a near-term TBO concept should, ideally, assist controllers in maintaining safety in a mixed equipage environment. One such near-term TBO concept was proposed by McNally.<sup>1</sup> This concept employs trajectory-based controller tools capable of functioning with current datalink communications equipment.

The first pilot- and controller-in-the-loop simulation to begin identifying operational challenges associated with this near-term TBO concept was conducted over a four-week period in September and October 2010.<sup>2</sup> This simulation incorporated R-side controller tools with trajectory-based automation advisories for conflict detection, conflict resolution, and time saving reroute advisories (i.e., Direct-To). Interfaces for these controller tools were enhanced to allow datalink clearances based on standard FANS-1/A messages to be issued to computer generated simulation aircraft as well as two high fidelity flight simulators equipped with actual FANS-1/A communications hardware. During this simulation, controllers and pilots generally had positive feedback with respect to the

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feasibility of the concept in mixed equipage operations. The simulation did reveal some areas in which further study may be needed. In particular, controller/pilot communications while using datalink and some conflict resolution advisories were not operationally acceptable. Controllers and pilots noted datalink communications lacked the immediate feedback inherent with voice communications, not unlike the difference between text messaging and a telephone call. Controllers also noted that some automatic conflict resolution advisories were counter to operational procedures. For example, the conflict resolution algorithm did not consider direction of flight when advising altitude clearances.<sup>3</sup>

This paper documents a follow-on simulation conducted over a two-week period between August 23 and September 2, 2011 at the NASA Ames Research Center. The primary objective of this simulation was to continue developing operational elements of the near-term TBO concept by addressing shortcomings discovered during the previous simulation as well as evaluating new capabilities for the first time. Changes to interfaces and procedures used in the previous simulation intended to improve controller/pilot communications when issuing datalink clearances were evaluated. Logic that would improve operational acceptability of the conflict resolution advisories was added to the previous strategic conflict resolution algorithm. New elements evaluated during this simulation include a tactical conflict detection function known as Tactical Separation Assisted Flight Environment (TSAFE) and trajectory-based weather avoidance concepts.<sup>4,5</sup>

The remainder of this paper includes a description of the simulation design in Section II. The simulation design section is divided into subsections describing the participants, simulation architecture, trajectory-based automation functions, and the test scenarios. Results supporting each of the objectives described above are discussed in Section III, followed by concluding remarks in Section IV.

## II. Simulation Design

### A. Participants

There were two sets of controller and pilot teams participating as test subjects for this simulation. Each controller team consisted of three recently retired controllers from Fort Worth Center (ZFW) with a minimum of 17 year of experience. The two pilot teams were each made up of two flight crews, each from the same airline, with a minimum of 19 years of experience. These flight crews operated the two high-fidelity cockpit simulators.

In addition to the test subjects described above, there were six pseudo-pilots operating three aircraft simulator stations known as the Multi Aircraft Control System or MACS.<sup>6</sup> The pseudo-pilots used these simulators to control all aircraft in the simulation excluding the two aircraft controlled by the high fidelity cockpit simulators. Two additional retired controllers were on staff to assist in training needs as well as operate the Airline Operations Center (AOC) and Traffic Management Coordinator (TMC) positions.

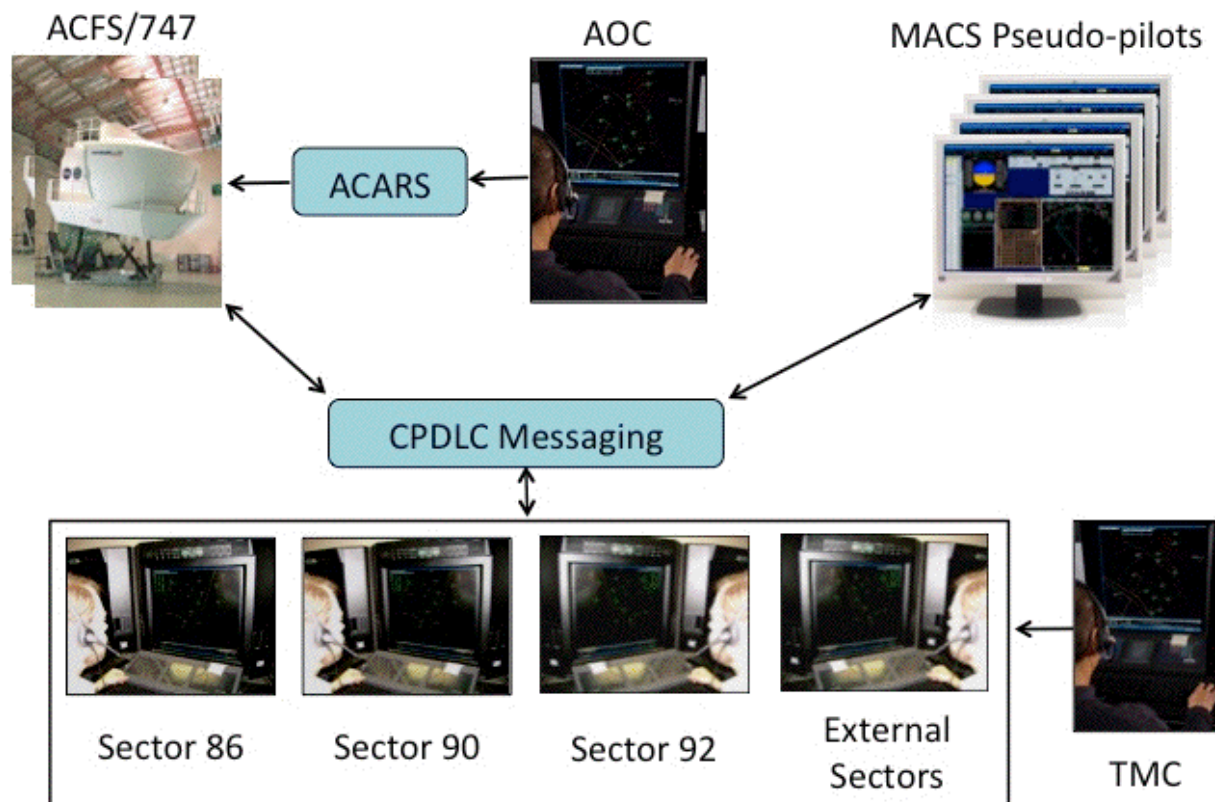
### B. Simulation Architecture

The simulation architecture is shown in Figure 1. There were a total of four Center radar (R-side) controller positions with integrated trajectory-based automation. Key trajectory-based automation features available at each controller position include conflict detection and resolution advisories and a graphical user interface for altitude and route planning referred to as a trial planner.<sup>7-9</sup> Three of these positions were operated by the test controllers to control aircraft in the test sectors (Sectors 86, 90, 92). The fourth position was used to control aircraft external to the test sectors (referred to as the “Ghost” sector). The primary function of the ghost sector was to facilitate transfer of control to and from the test sectors so that the scenarios may run realistically. In addition to voice communications, each controller station was able to send and receive route and altitude clearances via datalink to equipped aircraft. The trajectory-based automation automatically formatted clearances into the appropriate Crew Pilot Datalink Communication (CPDLC) message type.

Two high fidelity cockpit simulators were utilized in this simulation. These simulators were operated by the test flight crews. One of the simulators was a Level D simulator of a Boeing 747-400, and the other was a research simulator known as the Advanced Concepts Flight Simulator (ACFS) which uses a Boeing 737-like flight management system (FMS) and flight dynamics. Both simulators were equipped to process standard CPDLC messages as well as ACARS messages from a simulated AOC.

Two ancillary displays were incorporated into the simulation to represent positions operated by an AOC and a TMC. Each position was equipped with trajectory-based automation tools similar to that of the R-side controller. The AOC position was used to send ACARS formatted reroutes to the two cockpit simulators. Once the pilots received an AOC reroute, they would send a route request to the controller using CPDLC. The TMC position was also used to facilitate reroutes, weather reroutes in particular. The intent of the concept was to unburden the R-side controller by allowing reroutes to be planned by some other person such as a TMC. Once a reroute had been

planned, the TMC would send it to the appropriate R-side controller to issue. This concept is similar to the multi-sector planner position proposed by Prevot.<sup>10</sup>



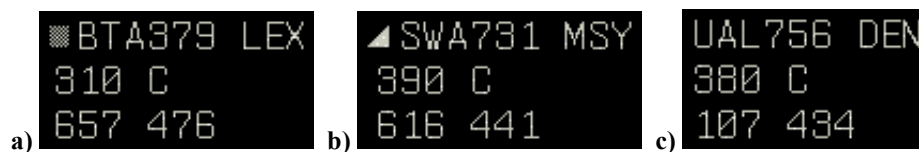
**Figure 1. Simulation Architecture**

### C. Trajectory-Based Automation Functions

This section provides an overview of new or improved trajectory-based automation functions incorporated into this simulation. Details of each particular function can be found in the cited references.

#### 1. Flight Data Block Configuration

Locating key information in the flight data block (FDB) is important as controllers actively manipulate FDBs while controlling traffic. There were two new features added to the FDB for this simulation. These features were intended to improve operations with datalink-equipped aircraft and were based on recent FAA data communication research described in Reference 11. Figure 2 shows FDB symbology added to the left of FDB line 1, prior to the callsign, identifying datalink equipage and sector ownership status. No symbol appeared if the aircraft was unequipped.



**Figure 2. Flight Data Block Datalink Equipage Symbology: a) equipped and owned by sector, b) equipped but not owned by sector, c) unequipped**

The second new FDB feature was intended to improve controller/pilot communication when a datalink clearance was issued. Figure 3 shows the series of color codes indicating the status of a datalink clearance. The previous simulation had no such FDB indicators. When the controller uplinked a datalink route clearance to an aircraft, the destination field, rightmost field on FDB line 1, was highlighted blue indicating a wilco (i.e., will comply) for that clearance was pending (Figure 3a). Similarly, the FDB altitude field would be highlighted blue for a datalink altitude clearance (Figure 3b). If the wilco was not received by the controller within 90 seconds of the clearance uplink, the blue indicator becomes yellow (Figure 3c). This yellow timeout status was an advisory to the controller that action may be required to ensure the clearance was received by the aircraft. Once a wilco was received by the controller, these status highlights would disappear. If the aircraft replies with an unable instead of a wilco, the highlight becomes red. Unable status highlight remained until the controller removed it manually.



**Figure 3. Flight Data Block Datalink Clearance Status: a) route clearance wilco pending, b) altitude clearance wilco pending, c) route clearance wilco not received within 90 seconds, d) route clearance unable by aircraft**

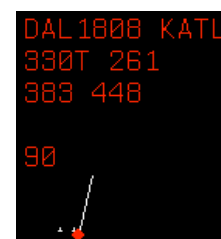
## 2. Strategic Conflict Resolution

The strategic conflict resolution algorithm, or Autoresolver, used in this simulation was based on the algorithm developed by Erzberger.<sup>12</sup> The Autoresolver automatically attempts to generate resolution maneuvers for all detected conflicts with a predicted time to loss of separation between three and twelve minutes. Conflicts involving both aircraft and convective weather are resolved simultaneously. Although the Autoresolver was capable of generating resolution using speed, only altitude and route maneuver types were used in this simulation. For this near-term TBO concept, the conflict resolution algorithm was used in an advisory role. Resolutions were presented to the controllers to be used at their discretion. Changes to the conflict resolution logic since the previous simulation<sup>2</sup> were intended to improve the operational acceptability of the resolution maneuvers and are summarized in the list below. The time at cruise altitude logic was intended to reduce the occurrence of a resolution advising an aircraft to change altitude soon after reaching its cruise altitude (i.e., eight minutes).

- Resolution maneuver for each aircraft of the conflict pair
- Altitude maneuver preference when a climbing aircraft is conflicting with an aircraft in level flight
- Flight direction based altitude resolutions<sup>3</sup>
- Consider time at cruise altitude before advising an altitude maneuver
- User specified turn increments

## 3. Tactical Separation Assisted Flight Environment (TSAFE)

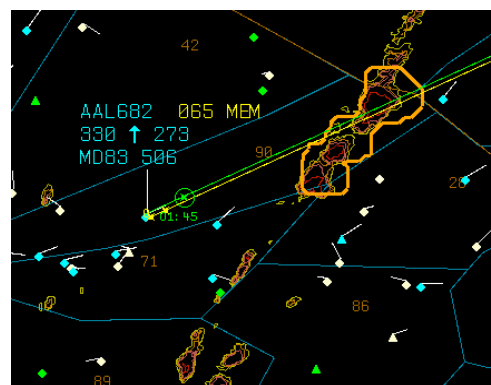
The TSAFE tactical conflict detection function is based on the work presented in Reference 4 and was not implemented in the previous simulation. The purpose of TSAFE was to provide an independent backup conflict detection function for conflicts with a predicted time to loss of separation of less than three minutes. Analysis has shown TSAFE prototypes have outperformed Conflict Alert, the current operational software serving the same purpose. If TSAFE detected a conflict, the flight data blocks of the aircrafts involved with the conflict would flash red (Fig. 4).



**Figure 4. TSAFE conflict alert**

## 4. Trajectory-Based Weather Avoidance

Trajectory-based weather avoidance was another new function evaluated in this simulation. This function was used to detect conflicts with convective weather in a manner similar to trajectory-based conflict detection between aircraft. The convective weather was modeled using the Convective Weather Avoidance Model

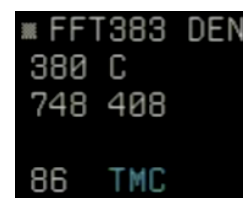


**Figure 5. CWAM weather conflict**

(CWAM) developed by Lincoln Laboratory.<sup>13</sup> CWAM models the probability aircraft will avoid a region of convective weather rather than the convective weather itself. The output of the CWAM model is avoidance regions or polygons that are a function of time (i.e., weather forecast), altitude, and probability of avoidance. An example of the trajectory-based weather avoidance as implemented in the trial planner is shown in Figure 5. The bold orange polygon is the CWAM weather conflict detected along the yellow trial plan trajectory.

#### 5. Traffic Management Coordinator to Sector Controller Communications

Functionality was added to allow the TMC to communicate reroutes directly to the R-side controller. As described above, the TMC uses the trial planner capability to plan a reroute. Once the TMC has completed planning of a specific reroute, the TMC sends the reroute notification to the appropriate R-side controller. This functionality automatically directs the reroute notification to the controller that has control of the aircraft to be rerouted. The TMC reroute notification appears on the bottom line, rightmost field of the FDB of the aircraft to be rerouted (Fig. 6). The TMC suggested reroute could then be viewed in the controller's trial planner by clicking the TMC notification. The TMC reroute could be issued in the same manner the controller would issue any other reroute.



**Figure 6. TMC reroute notification**

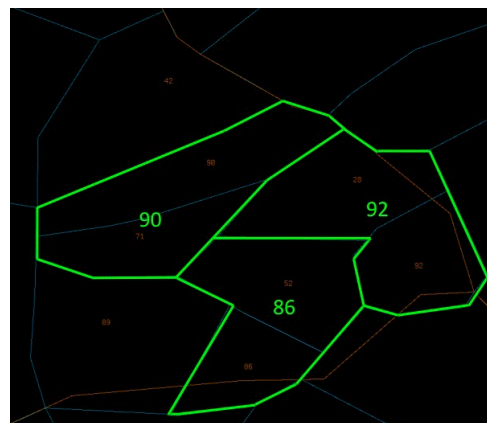
#### 6. Airline Operations Communications

The trial planner located at the AOC position was configured to send reroutes directly to one of the two high fidelity simulators using the Airline Operations Communications datalink interface specified by ARINC.<sup>14</sup> This interface allows uplinking of AOC preferred routes into the Multi-Purpose Control Display Unit (MCDU). The flight crew gets a notification that a route uplink has been received. The flight crew would then review the uplinked route on their navigation display before sending a CPDLC route request for it to the controller.

### D. Test Scenarios

There were two general types of scenarios in this simulation designed to evaluate datalink clearance procedures and weather avoidance (tactical and strategic), all based on actual traffic recordings. All scenarios were developed around three high altitude sectors in southeast Fort Worth Center (Figure 7) with a 50% fleet-wide datalink equipage level. Datalink clearance procedure scenarios had two traffic levels, one at today's traffic level (1.0x) and the other at 1.5 times today's traffic level. The traffic level for weather avoidance scenarios were at today's level.

There were a total of twenty one scenarios for each of the two weeks of simulation (Table 1). Twelve of the scenarios were allotted to the datalink clearance procedures which also encompassed evaluation of the strategic conflict resolution and tactical conflict detection functions. There were six tactical weather scenarios, three with the trajectory-based weather avoidance function, three without (i.e., today's operation). The remaining three scenarios were dedicated to strategic weather avoidance. Controllers were rotated through each of the three sectors in order to provide different presentations for each scenario type and traffic level. The duration of each scenario was 30-45 minutes.



**Figure 7. Fort Worth Center Test Sectors**

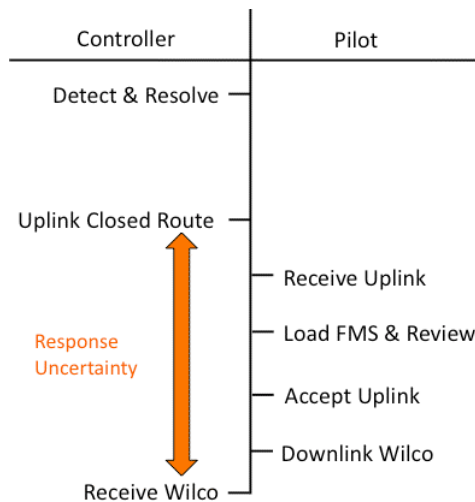
**Table 1. Number of Scenarios Per Week**

Scenario Type	Traffic Level	
	1.0x	1.5x
Nominal Datalink Clearance Procedure	3	3
Voice-Initiated Clearance Procedure	3	3
Tactical Weather with Avoidance Tool	3	-
Tactical Weather without Avoidance Tool	3	-
Strategic Weather	3	-

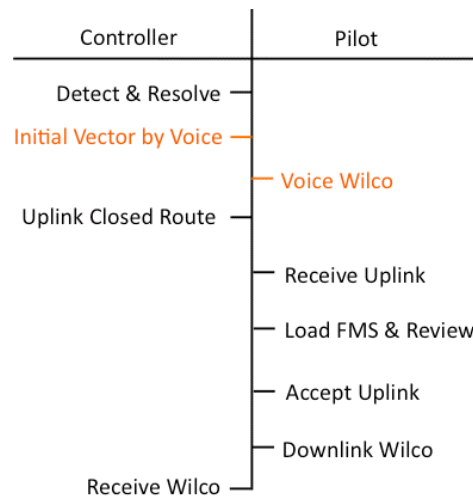
### 1. Datalink Clearance Procedures

Two procedures for issuing clearances to datalink-equipped aircraft were evaluated. The intent of this evaluation was to find an effective combination of voice and datalink clearances for a mixed equipage environment. In the previous simulation conducted in September 2010, it was noted there was some uncertainty with regard to receipt of a datalink clearance. The source of this response uncertainty is depicted in a timeline of events associated with resolving a conflict with datalink route clearances (Figure 8). In this example, the controller first detects the conflict and determines a resolution maneuver for it. The controller would then uplink the resolution to the pilot. Upon receipt of the datalinked resolution, the pilot must go through a series of steps to load, review, and accept the resolution before downlinking a wilco back to the controller. The response uncertainty for this procedure (referred to as the nominal datalink procedure) occurs between the time the clearance is uplinked and the time the wilco is received. Unlike today's voice clearance procedure, the nominal datalink procedure has no equivalent to an immediate pilot read back of a clearance.

An alternate procedure, referred to as a voice-initiated datalink clearance, combines the positive read back of a voice clearance with the ability to send complete route clearances (i.e., returns to original flight plan) with datalink. Unlike "open-ended" vectors, uplinking the complete route via datalink eliminates the need for the controller to issue an additional clearance to return the aircraft to its original flight plan. Comprehensive trajectories can also be defined for complete route clearances, thus, making them more suitable for trajectory-based operations. Figure 9 depicts a timeline for the voice-initiated datalink route clearance. In this procedure, the controller issues an initial turn vector by voice and receives the corresponding voice wilco from the pilot as they do today. The voice portion of the clearance is then followed by an uplink of the complete route clearance. Similar to the "expect further clearance" phraseology used today, the phrase "expect uplink" was appended to a typical voice clearance to indicate further clearance would be sent via datalink. For example, "American one-two-three, turn three-zero degrees left, expect uplink." The intent of this voice initiation is to ensure the aircraft begins the requested maneuver in a timely manner.



**Figure 8. Nominal Datalink Clearance Procedure**



**Figure 9. Voice-initiated Datalink Clearance Procedure**

### 2. Weather Avoidance

There were two types weather avoidance scenarios developed for this simulation, tactical and strategic. The tactical weather avoidance scenarios had convective weather located in and around the test sectors (Figure 10). In order to evaluate the effectiveness of the trajectory-based weather conflict detection capability, these scenarios were divided into two sets of runs, one with the weather conflict detection capability coupled to the trial planner, the other without. In all runs, requests to deviate around weather were made by the pilots. The controllers would then use the trajectory-based trial planner to build routes and fulfill the pilots' requests.



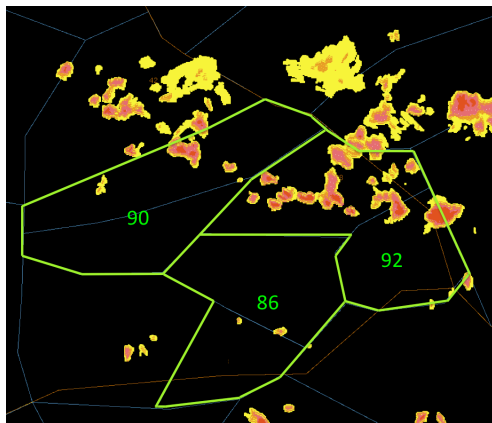


Figure 10. Tactical Weather Scenario

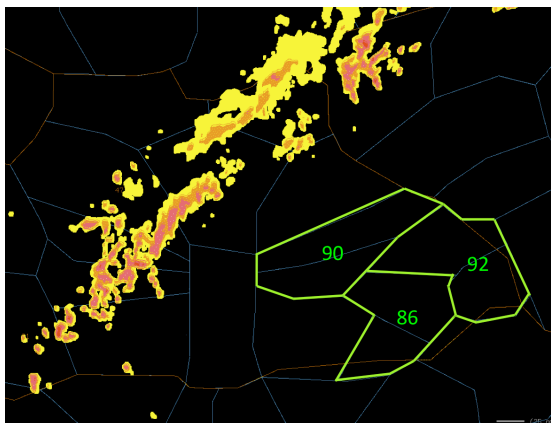


Figure 11. Strategic Weather Scenario

The strategic weather avoidance scenario was intended to evaluate concepts for issuing trajectory-based weather avoidance routes.<sup>5</sup> For this scenario the convective weather was generally located more than fifty nautical miles outside of the test sector (Figure 11). Many flights in this scenario were on weather avoidance routes that may have been planned hours before the flights actually entered the test sector airspace (e.g., Severe Weather Avoidance Program, SWAP, routes). The trajectory-based weather avoidance tools provide a means to update potentially obsolete weather avoidance routes based on the latest weather observations. Strategic weather avoidance routes were initiated from the TMC and AOC positions. Reroutes initiated by the TMC position would be sent directly to the appropriate R-side controller to issue. Reroutes initiated by the AOC position would be sent to the pilots. The pilots would then send a route request to the controller via CPDLC.

### III. Results

#### A. Datalink Clearance Procedures

The first set of scenarios were centered around the evaluation of datalink clearance procedures. Because the strategic conflict resolution and TSAFE algorithms were running, these scenarios provided an opportunity to simultaneously evaluate these functions.

On a scale from one (not effective) to seven (very effective), controller questionnaire results regarding datalink clearance procedures rate the overall effectiveness of the nominal procedure at 6.3, slightly higher than the 6.0 rating received by the mixed voice-initiated clearance. Controller questionnaires also rated the timeliness of the wilco following an altitude or route clearance to be faster at 5.2 for the nominal datalink procedure compared to 4.7 for the mixed clearance. However, subsequent analysis of the maneuver times for each procedure showed the aircraft, on average, began to maneuver sooner for voice-initiated clearances than for the nominal datalink clearances, 12.4 sec versus 15.8 sec, a difference of 3.4 seconds or 21% (Figure 12). Maneuver time was the elapsed time between the time the clearance was issued and the time the aircraft begins the maneuver. Standard deviations for maneuver times were relatively large at 7.9 and 15.1 seconds for voice-initiated and nominal datalink clearances, respectively. As a result of the less favorable questionnaire results and the standard deviations of the measured maneuver times, benefits of the voice-initiated clearances over the nominal datalink clearances were

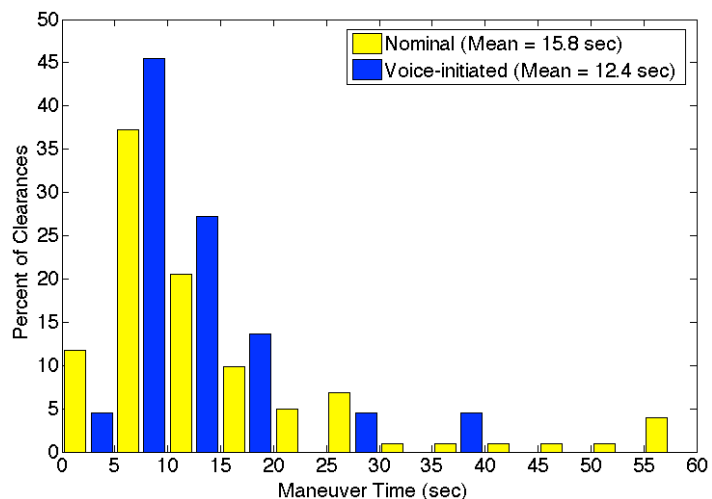


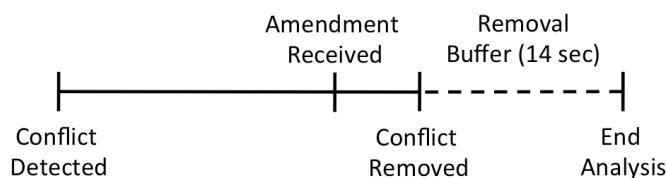
Figure 12. Maneuver time comparison for route clearances

unclear. Moreover, the need for an alternate datalink clearance procedure to address response uncertainty may have decreased with the successful implementation of FDB datalink clearance status indicators.

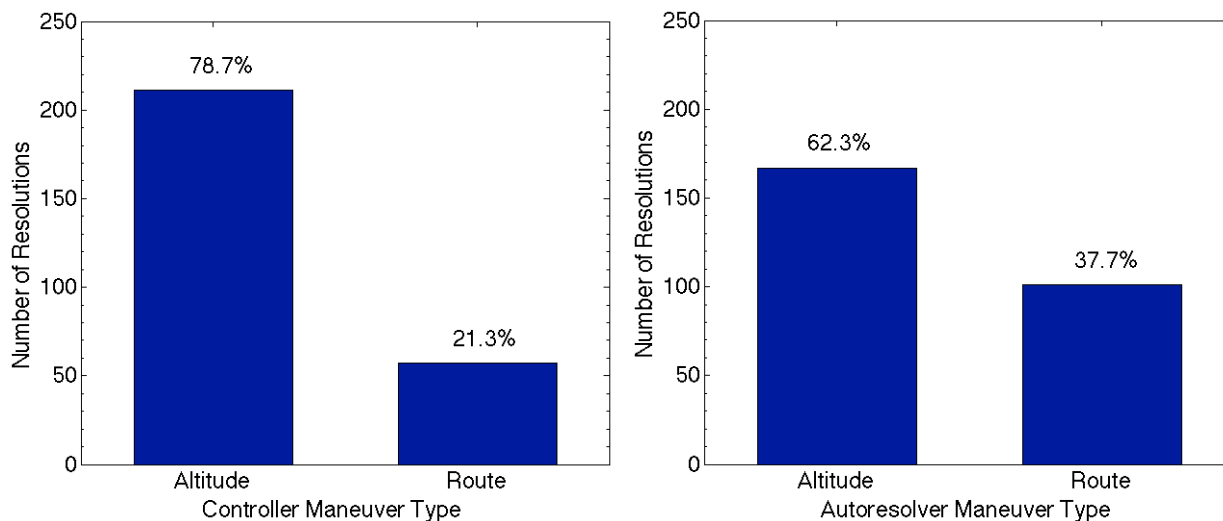
## B. Strategic Conflict Resolution

Since the last simulation in October 2010, changes were made to the strategic conflict resolution algorithm, referred to as the Autoresolver, to consider operational preferences in its advisories. Incorporating logic to consider these operational preferences was intended to produce conflict resolution advisories more like those issued by controllers today. The hypothesis was the strategic conflict resolutions algorithm could likely gain more controller acceptance if it could resolve conflicts like a “real” controller. The types of maneuvers advised by the Autoresolver were compared to those issued by the controllers to resolve the same conflicts. Although there were a number of conflict resolution advisories, only those which could be matched to controller resolution actions were used for the comparison. Moreover, only conflicts from the non-weather scenarios were used for this analysis.

The matching of a controller action to a resolved conflict was accomplished by monitoring the presence and subsequent removal of a conflict from the trajectory-based conflict detection list. This process may be better illustrated with the trajectory-based conflict detection timeline shown in Figure 13. When a conflict is detected, the controller is alerted by the conflict detection algorithm. This algorithm continues to alert the controller of a predicted conflict so long as the aircraft trajectories are in conflict. If the trajectory of one of the aircraft of the conflict pair is changed by an altitude or route amendment, the conflict will be removed. If an altitude or route amendment is logged for one of the aircraft of the conflict pair within fourteen seconds of the removal of the conflict from the conflict detection list, then that amendment or maneuver is considered the matching controller resolution to the conflict. A fourteen second conflict removal time buffer is used to account for the nominal twelve second update rate of the trajectories as well additional time resulting from the asynchronous updating of the planned altitude or flight plan. Examples of conflicts not analyzed include potential false alerts characterized by Autoresolver advisories to conflicts not resolved by the controller and conflicts for which the Autoresolver failed to find a resolution.



**Figure 13. Conflict Detection Timeline**



**Figure 14. Conflict resolution maneuver types**

Of the 503 total conflicts that occurred, 268 were resolved by both the controller and Autoresolver (i.e. matched resolutions), but not necessarily by maneuvering the same aircraft of the conflict pair. Figure 14 shows the general distribution of resolution maneuver types, altitude or route, for these matched resolutions. During these scenarios,



the controllers used altitude maneuvers to resolve conflicts 78.7% of the time, whereas the Autoresolver suggested altitude resolutions 62.3% of the time for the same conflicts.

Further analysis of these 268 matched resolutions revealed the controllers and Autoresolver chose to resolve the conflict by maneuvering the same aircraft 149 or 56% of the time. When agreeing on which aircraft to maneuver, the controllers and Autoresolver used the same maneuver type 101 or 68% of the time. Moreover, agreement of maneuver type was for predominately altitude maneuvers. In only ten cases did the controller and the Autoresolver both choose to resolve the same conflict by maneuvering the same aircraft with a route maneuver. For this limited number of route maneuvers, however, both the controller and the Autoresolver always agreed on the direction of the initial turn (i.e., both left or both right) when the direction of the turn could be determined, i.e., seven out of ten of these route maneuvers. In the other three route maneuver cases, the direction of the initial turn was inconclusive. Although route amendments were logged for these three cases, analysis of the aircrafts' track data showed these aircraft did not begin their maneuver within one minute of the recorded route amendments.

For those conflicts that were resolved by the controller and the Autoresolver with an altitude maneuver to the same aircraft, Figure 15 shows the directions, climb or descend, of each resolution. The controller and the Autoresolver agreed on the direction of the altitude maneuver a total of 79.2% of the time (i.e., 53.9% climbs and 25.3% descents). The Autoresolver advisory differed from the controller by advising a descent 12.1% of the time the controller used a climb maneuver. Further investigation found this difference, in part, could be attributed to a simplified performance constraint in the Autoresolver logic that did not advise climbs for aircraft at or above 35000 ft. The intention of this constraint was to minimize the chances of an Autoresolver advisory that would cause the aircraft to climb above its performance ceiling.

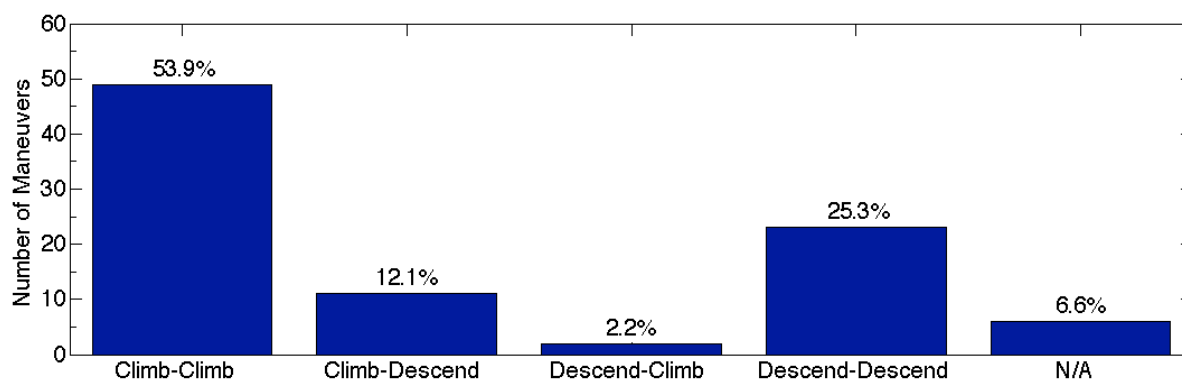


Figure 15. Altitude Resolution Directions, Controller - Autoresolver.

### C. Tactical Conflict Detection

The objective of this evaluation was to assess the false alert rate of the tactical conflict detection algorithm (TSAFE). The TSAFE conflict detection algorithm was running simultaneously with the strategic conflict detection and resolution function. The TSAFE algorithm was evaluated with a method similar to that described above which matched controller actions (i.e., resolution maneuvers) to detected conflicts. If a conflict detected by TSAFE could not be matched to a corresponding controller action or loss of separation, then that detection would be considered a false alert. The assumption was the controller did not take action if they considered the TSAFE alert to be false.

There were a total of 124 TSAFE alerts during the two-week simulation. Approximately half of these TSAFE conflicts were matched with an altitude or route amendment using the method described above. Because conflicts detected by TSAFE require immediate resolution by the controller (predicted time to loss-of-separation less than three minutes), the controller may choose to resolve the conflict with a voice clearance before actually entering the corresponding altitude or route amendment for the resolution maneuver. In these cases, amendments could not be matched with conflicts using the timeline in Figure 13. As result, track data for the 63 TSAFE conflicts not matched with an amendment were analyzed in detail to determine if resolution maneuvers were performed. A summary of the TSAFE false alert analysis is shown in Table 2.

**Table 2. Summary of TSAFE False Alert Analysis**

	TSAFE Alerts	False Alerts	False Alert Rate
<b>Week 1</b>	<b>74</b>	<b>10</b>	<b>13.5%</b>
<b>Week 2</b>	<b>50</b>	<b>4</b>	<b>8.0%</b>
<b>Total</b>	<b>124</b>	<b>14</b>	<b>11.3%</b>

The total TSAFE false alert rate for both weeks of the simulation was 11.3%. The false alert cases were analyzed in detail to determine the potential causes. Of the fourteen false alerts, all but one case involved at least one climbing aircraft where climb rate uncertainty may have played a role. Climb rate uncertainty is a leading cause of trajectory prediction error.<sup>15</sup> The remaining false alert case as well as four others involving climbing aircraft were “in-trail” flights. In-trail flights are pairs of aircraft flying nearly the same heading. In these cases, speed uncertainty can contribute to potential false alerts. It should be noted this TSAFE analysis showed there were no missed alerts. Missed alerts are defined as losses of separation not detected by TSAFE.

#### D. Weather Avoidance

Two types of weather avoidance scenarios were evaluated during this simulation, tactical and strategic. Tactical scenarios were focused on assessing the effectiveness of trajectory-based weather avoidance tools against nearby convective weather encounters. As described in Section II, each controller display was equipped with a trajectory-based trial planner capable of detecting regions of convective weather. The controllers would use the trial planner to build weather avoidance routes as requested by the pilots.

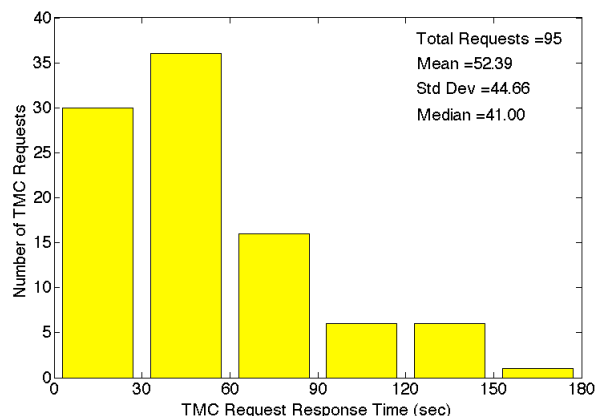
On a scale from one (not effective) to seven (very effective), controllers rated both the ease of use and the usefulness of the tool for coordinating weather avoidance routes as requested by pilots at 6.3. Controllers noted that issuing specific weather avoidance routes for the pilots to follow (i.e., “flat tracking”)<sup>16</sup> makes traffic more manageable than granting pilots permission to deviate up to a specified distance from their filed flight plan to avoid weather (i.e., “free tracking”). Controllers were able to use the trial planner to reroute datalink equipped as well as unequipped aircraft. In the latter case, reroutes were planned with the trial planner, but issued verbally to the aircraft. Controllers and pilots alike noted that full datalink negotiation of weather reroutes (request and issuance) had the most potential. Pilots highlighted the effectiveness of using route building capability inherent to the aircraft Flight Management System (FMS) combined with a datalink route request to avoid weather detected by aircraft’s weather radar. Figure 16 shows an example of a weather avoidance route built by the pilot on the Navigation Display referred to as Modified Route 1 (dashed magenta line) and the corresponding datalinked route request as displayed on the Control Display Unit (CDU) of the FMS.



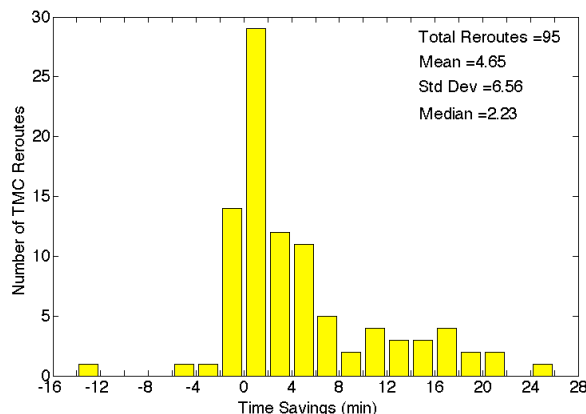
**Figure 16. Weather Avoidance Route Request, Navigation Display (left), Control Display Unit (right)**

The strategic weather avoidance scenarios explored a concept in which weather reroutes were planned from an ancillary position operated by a simulated TMC (Section II.B) before they were sent to the R-side controller for issuance to the aircraft. Figure 17 shows the R-side controller response time to a total of 95 TMC reroute requests.

On average, R-side controllers were able to respond to a TMC request for reroute in approximately 52 sec. In today's operation, reroute response times would likely be longer since there is no direct communications between the TMC and the R-side controller. Coordination of these types of reroutes would typically be done with a phone call from the TMC to the controller's supervisor before they are communicated to the actual controller. Controllers are also cautious about issuing large reroutes that may potentially impact traffic flow management plans. Controllers noted that knowing the reroutes were planned and requested by the TMC alleviated these concerns and expedited the issuance of the reroutes. Potential time savings for the reroutes is shown in Figure 18. The potential time savings for each reroute was the difference between the predicted flight time of the original trajectory and the reroute trajectory. The average potential time savings was 4.65 minutes.



**Figure 17. Controller Response Time to TMC Reroute Request**



**Figure 18. Potential time savings for TMC Reroutes**

#### IV. Conclusions

This paper documents the successful completion of a pilot- and controller-in-the-loop simulation conducted between August 23 and September 2, 2011. This simulation was the second such simulation designed to develop operational elements of a near-term trajectory-based operations concepts enabled by datalink communications. Some elements such as controller/pilot communications when issuing datalink clearances and the strategic conflict resolution algorithms were modified to address shortcomings identified during the initial simulation. The tactical conflict detection function known as TSAFE and trajectory-based weather avoidance were new elements evaluated for the first time in a pilot- and controller-in-the-loop simulation.

Modification to the controller display which added color-coded datalink clearance status indicators to the flight data blocks (patterned after related FAA data communication research) improved controller awareness when issuing datalink clearances. Benefits of an alternate combined voice-datalink clearance procedures intended to reduce wilco response uncertainty proved to be inconclusive.

Logic was added to the conflict resolution algorithm (i.e., Autoresolver) used in the previous simulation in an effort to improve the operational acceptability of the conflict resolution advisories. The hypothesis was the Autoresolver could likely gain more controller acceptance if it could resolve conflicts like a "real" controller. Of the 268 controller-resolved conflicts analyzed, the Autoresolver advised resolving the conflicts by maneuvering the same as aircraft as the controllers 56% of the time. In 68% of these cases, the controller and the Autoresolver used the same maneuver type (altitude or route) and agreed on direction over 79% of the time. However, there were only seven route maneuvers from which to assess turn direction agreement.

The false alert rate for the tactical conflict detection function known as TSAFE was evaluated by comparison to actual controller actions. For this simulation, a false alert was defined as a TSAFE conflict detection which controllers did not take action to resolve. A missed alert was a loss of separation not detected by TSAFE. There was a total of 124 TSAFE conflict alerts during the simulation. The false alert rate was found to be 11.3% (14 cases) with no missed alerts. Of the fourteen missed alert cases, all but one involved at least one climbing aircraft.

A trajectory-based weather avoidance function was evaluated with tactical and strategic scenarios. Controllers gave the functionality high rating for usefulness and ease of use. The functionality was used successfully with both voice and datalink equipped aircraft. However, controllers and pilots alike noted that full datalink negotiation of

weather reroutes (request and issuance) had the most potential. During the strategic weather avoidance scenarios, controllers noted that knowing reroute requests originated from the TMC position alleviated concerns such reroutes would impact traffic flow management plans, thus expediting the issuance of reroutes. Average response time to 95 TMC requests was 52 seconds, resulting in an average potential time savings of 4.65 minutes per reroute.

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