Problem Analysis, Resolution and Ranking (PARR) Development and Assessment

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Abstract

This paper provides an overview of problem resolution capabilities being developed to assist en route air traffic controllers. This function is termed Problem Analysis, Resolution and Ranking (PARR). PARR is envisioned as an enhancement to the User Request Evaluation Tool (URET) Free Flight Phase 1 (FFP1) capability, and has been designated as Priority Research for the follow-on Free Flight Phase 2 (FFP2) effort. PARR is being developed as a series of incremental enhancements to URET, with the Initial PARR capabilities focusing on providing additional support to the Radar Associate (D) controller for the resolution of aircraft-to-aircraft and aircraft-to-airspace problems. Subsequent PARR enhancements address the avoidance of severe weather areas, the implementation of Traffic Flow Management (TFM) flow initiatives, and the integration into a common en route Sector Team Computer-Human Interface (CHI).

This paper provides an overview of the Initial PARR capabilities and a summary of results from ongoing evaluations with active field controllers. An overview of the techniques being developed for the PARR functional performance and benefits assessment is given, along with initial results. Finally, concepts are described for the enhancement of URET and PARR to assist in the avoidance of severe weather areas and implementation of TFM flow initiatives.

1 Introduction

To meet user demands and to accommodate growth in traffic, the FAA and National Airspace System (NAS) users have embarked on an initiative known as Free Flight. Free Flight provides users with as much flexibility of flight as possible, while maintaining or increasing NAS safety and predictability. To implement Free Flight, the FAA has been developing and refining concepts, defining architectures, and developing the decision support capabilities needed to support the concepts. The FAA, supported by MITRE/CAASD, has also been working with industry representatives to develop the NAS Operational Evolution Plan (OEP),[1] which integrates and aligns the FAA's objectives and plans with those of the aviation industry.

The FAA is implementing Free Flight with an incremental development strategy. In the first step - termed FFP1 - a set of existing core capabilities is being deployed to a limited number of sites. One of these capabilities is URET, which is being deployed to seven Air Route Traffic Control Centers (ARTCCs) as part of FFP1. URET will provide en route sector D controllers with automated conflict detection and trial planning capabilities, and a set of tools to assist in the management of flight data. In FFP2, URET will be deployed to additional ARTCCs.

A prototype version of URET has been developed by CAASD and deployed to the Indianapolis and Memphis ARTCCs. As of May 2001, this prototype had been used at these facilities for over one million sector-hours, and over 800 operational personnel have been trained in its use. Evidence from this usage of URET is that it supports a shift away from tactical operations based on radar data towards strategic Air Traffic Control (ATC) planning based on flight plans and associated trajectories. The benefits provided by this shift include less frequent and/or severe maneuvers, more time for negotiation between controllers and pilots to develop clearances that meet the objectives of both, accommodation of pilot requests and user-preferred routing resulting in the reduction of delays and user operating costs, and the relaxation of many of the restrictions currently in place.

The following Free Flight enhancements are expected to provide further support for a shift towards strategic ATC planning, as reflected by FAA and industry consensus in Refs. 2 – 5:

- The addition of tools to the FFP1 baseline to further assist the controller in the development of strategic resolutions for aircraft-to-aircraft and aircraft-to-airspace conflicts, for problems with severe weather, and for complying with TFM flow initiatives.

- The integration of these resolution tools into an ATC Decision Support System (DSS) for the Sector Team, i.e., a DSS that is common to both the D-position and the Radar (R) position, and that allows access to the full range of tactical and strategic information at each position.
- This set of capabilities, under development by CAASD as a series of incremental enhancements to URET, is termed PARR. As with URET, PARR was initially developed for laboratory evaluations using controllers in the late 1980s and early 1990s as part of the AERA (Automated En Route ATC) program.[6-8] PARR has been designated as priority research for FFP2.

The first step of PARR development focuses on the resolution of aircraft-to-aircraft and aircraft-to-airspace problems. These capabilities are described in Section 2, and results from initial evaluations with active field controllers are described in Section 3. Section 4 presents the techniques being developed for the analysis of PARR functional performance, and initial results of this analysis. Finally, Section 5 presents a concept for the extension of these capabilities to the avoidance of severe weather and implementation of TFM flow initiatives.

Because PARR is a URET enhancement and utilizes many components of URET for the creation and display of resolutions, an overview of URET is provided in the following subsection. Further details on URET may be found in Ref. 9.

1.1 URET Overview

URET processes real-time flight plan and aircraft track data from the NAS Host computer. These data are combined with site adaptation, key aircraft performance parameters, and winds and temperatures from the National Weather Service (NWS) in order to build four-dimensional flight profiles, or trajectories, for pre-departure, inbound, and active flights. URET also adapts its trajectories to the observed behavior of aircraft, dynamically adjusting predicted speeds, climb rates, and descent rates based on the performance of each individual flight as it is tracked through en route airspace.

URET uses the predicted trajectories to continuously detect potential aircraft problems for Instrument Flight Rules (IFR) flights up to twenty minutes into the future and to provide a strategic alert to the appropriate sector. In addition, trajectories are the basis for the system's Trial Planning capability. Trial Planning allows the controller to check a desired flight plan amendment for potential conflicts before a clearance is issued. A two-way interface allows the controller to enter the Trial Plan as a Host flight plan amendment with the click of a button.

The URET capabilities include a controller interface for both textual and graphical information. The text-based Plans Display and Aircraft List manage the presentation of flight data (call-sign, route, altitude, etc.), Trial Plans, and conflict information for the sector. Clearance language is also generated for Trial Plans. The Graphic Plan Display (GPD) provides a graphical capability to view aircraft routes and altitudes, predicted conflicts, and results of Trial Plans.

Color coding of Current Plans and Trial Plans is used to reflect the conflict status of each plan. These color codes are as follows: A green plan indicates that the trajectory is predicted to be conflict-free out to twenty minutes. Conflicts with five nautical miles (nm) or less predicted horizontal separation between trajectory centerlines are coded in red. Conflicts with a predicted minimum horizontal separation of greater than five nm between trajectory centerlines, but still within adapted encounter thresholds, are coded in yellow. Blue coding indicates that the trajectory will pass less than a parameter distance from an active Special Use Airspace (SUA).

2 Overview of Initial PARR Capabilities

The initial set of PARR capabilities consists of two components: 1) Assisted Trial Planning, and 2) the Assisted Resolution Tool. Each of these components is discussed in the following subsections.

2.1 Assisted Trial Planning (ATRP)

Assisted Trial Planning (ATRP) is an enhancement to the trial planning menus that are currently available in URET. These menus currently allow the controller to check whether a change of altitude (e.g. per a pilot request due to turbulence) would be free of conflicts, to assess whether a more direct route could be offered, and to determine whether a speed change would resolve an existing conflict. With URET, this process is manual in that, for example, the controller selects an altitude to try, submits the request, and is notified of the conflict status of the resultant Trial Plan. When the controller makes a menu request using ATRP, the conflict statuses of multiple menu option possibilities are returned simultaneously. For example, for an altitude request, the conflict status for a band of altitudes, above and below the currently assigned altitude, is presented on the Altitude Menu.

2.2 Assisted Resolution Tool (ART)

The Assisted Resolution Tool (ART) will provide the controller with another tool to deal with aircraft-to-aircraft and aircraft-to-airspace problems. It is envisioned that this capability will assist the controller in finding solutions to problems in situations where the density or complexity of en route traffic might make it difficult to develop a Trial Plan that resolves the problem, without creating others. As with ATRP, ART will be a closely integrated enhancement to FFP1 URET, and will utilize the same URET user interface.

When initiated for an aircraft, ART generates resolutions that maneuver only that aircraft. When initiated for an aircraft-to-aircraft problem, resolutions for each of the two involved aircraft are generated. For each resolution, only one aircraft is maneuvered (multiple aircraft maneuvers per resolution are anticipated as a future enhancement). For a given aircraft to be maneuvered, PARR searches for conflict-free trajectories to resolve all problems with that aircraft (within a twenty-minute lookahead horizon) in an operationally acceptable manner, without introducing new problems. The search process examines, in turn, maneuvers in each of the following dimensions/directions, thus yielding up to nine resolutions for that aircraft: (a) direct to a fix on the route, (b) reroute to one off-route fix, one left and one right of route, (c) removal of an altitude restriction, (d) altitude maneuvers, one above and one below the conflict, (e) vector maneuvers, one left and one right of route, and (f) an increase or decrease in speed. Each resolution contains only one type of maneuver. (Composite maneuvers are anticipated as a future enhancement, and are currently used for metering resolutions as described in Ref. 10).

The generated ART resolutions are ranked according to estimated airspace user and controller preferences to facilitate the resolution selection process. The top parameter number of resolutions are displayed on the Plans Display, using an abbreviated clearance format to provide a concise, readily interpretable summary of the ART results. At controller option, they are either displayed in their ranked order, or grouped according to maneuver type (e.g., reroute vs. vector maneuvers) and ranked within these groups.

Each ART resolution is a complete Trial Plan; it returns the maneuvered aircraft to its original route, destination, or transition, and in appropriate magnitude increments (e.g., five-degree increments for turns and ten-knot increments for speeds). All maneuvers are within the operational performance limits of the maneuvered aircraft.

2.3 Concept of URET Use with Initial PARR

The addition of the Initial PARR capabilities will neither change the controller's fundamental roles and responsibilities, nor affect specific tasks and activities with URET. With URET, the controller is notified of predicted conflicts and can create a Trial Plan to test a solution. However, URET does not suggest solutions. PARR adds new tools to assist the controller in solving these conflicts, and provides access to a variety of resolutions in the form of URET Trial Plans. As can be done with any URET Trial Plan, a selected resolution can be coordinated with the R controller at the sector or with another sector. Alternatively, controllers can use the proposed resolutions as information in developing a different course of action that better aligns with their plans.

3 Evaluation of Initial PARR Capabilities

The proposed resolution function and CHI have been refined based on CAASD laboratory evaluations with both former controllers and active controllers from URET daily-use ARTCCs. Field evaluations were conducted in January and May 2001 at the Indianapolis ARTCC (ZID). Each evaluation has provided feedback on the initial capability, which has been incorporated into the prototype. This section summarizes the results of the May 2001 evaluation.

3.1 May 2001 Evaluation Overview

Six active controllers participated in this evaluation. Part of the first day was spent on training, which was a combination of lecture and hands-on use of PARR. Each controller had a PARR workstation on which to practice and evaluate.

During training, a list of key evaluation areas (see Section 3.2) was distributed to provide focus for the subsequent use of PARR and for group discussion topics. After training, each controller exercised PARR on a recorded scenario. This configuration allowed for more detailed discussion of resolutions and their ranking.

On the second day, the evaluation moved into the Dynamic Simulation (DySim) Lab, an ATC training laboratory with the same hardware configuration as the control room floor, including a one-way live traffic feed to PARR. The sector was staffed with an R controller and a D controller. This configuration is more realistic and allowed evaluation of communication issues as well as general PARR issues.

As part of the debriefing after the DySim evaluation, a questionnaire was administered. It contained specific questions addressing the evaluation issues that were distributed earlier.

3.2 May 2001 Evaluation Focus Areas

The key areas examined during this evaluation included the following:

- Operational procedures and techniques that may be needed to support the use of PARR at the sector.
- Potential benefits of PARR functionality to the sector team and system.
- Usefulness and acceptability of grouping resolutions by type.
- Specific techniques to implement PARR resolutions.
- Acceptability and usefulness of resolutions.

3.3 May 2001 Evaluation Results

The overall evaluation feedback was exceptionally positive and supported the findings of the January 2001 evaluation. Both evaluations suggest that controllers view PARR as an important enhancement to the URET system. Controllers stated that ART (cf. Section 2.2) provides useful resolutions to problems that a D controller would normally address. They also stated that ART resolutions provided improved situational awareness about the problem, and helped to indicate which problems would be amenable to solution by the D controller. ATRP (cf. Section 2.1) was also perceived to be immediately useful, beneficial, and applicable in current operations.

Controllers indicated that many of the ART resolutions could be issued as presented to solve conflicts. It was noted that ART provides some viable resolutions that might be overlooked due to conventions and habits that do not support unconventional solutions. Controllers agreed that these resolutions would become more accepted as air traffic procedures evolve.

Controllers suggested that some resolutions, e.g. multiple-step and future maneuvers, would be useful as suggestions for problem solving and could be used to enhance situational awareness even if they would not be issued as presented in today's ATC environment. It was noted that these resolutions would become even more useful as procedures and technologies (e.g., air/ground data link) streamline implementation of complex maneuvers.

Controllers agreed that the number of resolutions provided by ART was appropriate, as was the variety of resolutions. Resolutions providing a direct to a fix on the route were considered to be particularly useful and in line with current air traffic control procedures. They stated that these resolutions could be implemented exactly as provided by ART.

Feedback included the following conclusions:

- The CHI is mature and easy to use.
- The presentation of resolutions grouped by maneuver type is an effective support when reviewing the resolutions.
- Resolutions are supportive of the D controller's job (strategic maneuvers that the D controller would coordinate and send to Host).

Controllers identified benefits of Initial PARR to both controllers and airspace users, such as providing the following:

- More options for problem solving, including maneuvers that the controller may not have thought of.
- Better situational awareness.
- Support for increased D controller involvement in problem solving.
- Support for review of several resolution options, even when the sector is busy.
- Presentation of user-preferred resolutions.
- Increased information on the traffic situation to accommodate user preferences while solving problems.
- Support for early resolution of problems, which could lead to increased system capacity.

4 ART Functional Performance and Benefits Assessment

The determination of conflict-free resolutions is a difficult computational problem, in that URET is typically modeling and probing hundreds of aircraft, many of which will be changing speed, direction, and/or altitude within the conflict detection lookahead (twenty minutes). In addition, the effects of wind changes within this period must be taken into account. Given these complexities and the need for a quick response to the controller request for resolutions, ART uses various approximations in the resolution construction process. These algorithms allow ART to generate a resolution with an approximate average of only two conflict detection/trajectory modeling cycles, i.e., only one more than that required to create any Trial Plan.

An effort is underway to verify that ART is constructing acceptable resolutions from the viewpoint of functional performance. Additional goals of this effort are as follows:

- Develop metrics and techniques for benefits analysis.
- Develop functional performance specifications.
- Support on-going ART software development by providing a quantitative baseline for regression testing and automated test capabilities.

To achieve these goals, the following techniques are being developed:

- Determination of statistics for the alerts present in ART resolutions.
- Comparison of ART resolutions with the results of an exhaustive search process.
- Comparison of ART target vs. achieved separation values.
- Analysis of ART resolutions with synthetic aircraft track data.
- Comparison of ART resolutions with controller actions for separation.

An overview of these techniques and their results are presented in following subsections; details may be found in Ref. 11.

4.1 Resolution Alert Statistics

Introduction. A primary goal of ART is to provide conflict-free resolutions, and thus an important component of ART's functional performance analysis is the determination of the extent to which this goal has been achieved. This study addresses this extent from an absolute perspective, i.e., with reference only to the alert status of the resolutions produced, and without reference to the relative number of problems for which a conflict-free solution is actually possible. This latter measurement is a more complex topic (e.g., the number of resolutions possible is specific to a given maneuver type, and requires an exhaustive search mechanism), and is discussed in Section 4.2.

Methods. A four-hour ZID recording from 12:00 to 16:00 (GMT) on April 29, 2001 was chosen as a representative sample of ZID traffic. Using this scenario, an automated testing program selected an aircraft with problems and initiated ART for that aircraft.

Results. The data collected indicate that at three, six, and twelve minutes prior to conflict start, ART was able to generate at least one green (conflict-free) resolution 93.0%, 94.4%, and 94.1% of the time, respectively. This is similar to results previously generated from running ART on earlier scenario data. If both yellow and green resolutions are included, the percentages increase to 98.0%, 97.8%, and 97.1%, respectively.

4.2 Exhaustive Search Comparison

Introduction. This technique addresses the extent to which ART generates conflict-free resolutions relative to those possible from an exhaustive, non real-time search. It compares the ART resolution for a given maneuver type (e.g., maneuvers direct to a downstream fix) with the results of an exhaustive search for that maneuver type.

The exhaustive search process used in this initial study generates a range of Trial Plans with increments in downstream fix distance and altitude, for aircraft with a problem start at least one minute in the future. Subsequent studies will address a more detailed comparison of these results, along with the extension to speed resolutions and more complex maneuver types (e.g., vector maneuvers) involving multiple degrees of freedom. In addition to being important for the specification of ART, the results of these studies will be useful for the continued development of ART, by identifying cases for which ART can be enhanced.

Methods. For the exhaustive search, all plans within the following constraints were generated.

- Direct to downstream fix maneuvers: All possible direct to downstream fix maneuvers within a maximum downstream distance were generated. This distance constraint (300 nm) was the same constraint applied in ART to avoid unacceptably long direct maneuvers.
- Altitude maneuvers: The exhaustive search process generated ten altitude Trial Plans in proximity to the assigned altitude, with the restriction that descent maneuvers were not generated for climbing aircraft, and climb maneuvers were not generated for descending aircraft.

A four-hour ZID recording from 12:00 to 16:00 (GMT) on April 29, 2001 was chosen for this study. An automated testing program was enhanced to initiate both ART and the exhaustive search process for a selected aircraft. In cases for which exhaustive search produced at least one green resolution, an analysis determined the percentage for which at least one green resolution was produced by ART.

Results. For the Direct-to-Fix case, 41 conflict-free maneuvers were found by the exhaustive search process, of which ART found 39 (95%). For the altitude cases, 877 conflict-free altitude maneuvers were found by the exhaustive search process, of which ART found 871 (99.3%). These data support the statement that, for the Direct-to-Fix and altitude maneuvers, the current version of ART is able to find nearly as many conflict-free solutions as found by more exhaustive methods. The cases in which ART did not find a conflict-free resolution, but one was available by exhaustive search, are being studied to determine if enhancements should be included in future versions of ART.

4.3 ART Target vs. Achieved Separation Comparison

Introduction. This technique addresses Resolution Efficiency, which is the extent to which the ART resolutions perturb the aircraft flight relative to the minimum required for separation. It focuses on the efficiency of lateral resolutions, and provides an initial examination of the extent to which ART lateral resolutions deviate from target minimum separation values, i.e., the minimum separation necessary to solve the conflict.

The performance statistics used in this technique compare the separation distances of resolution maneuvers generated by ART (as measured by comparison between the resolution trajectory and that of the avoided aircraft) with target separation values, the separation values that ART attempted to obtain prior to trajectory modeling. Differences between the two are due to the approximations used by ART in constructing resolutions. An assessment of these differences provides an assessment of the accuracy of the ART approximations.

For this initial comparison, predicted minimum separation distance data was collected on the lateral left or right two-legged vector maneuvers that use a minimum off-angle. Future assessments will be specific to the maneuver leg, and analyze the other resolution dimensions.

Methods. ART was modified to provide the target and achieved separation data for each resolution, including the predicted minimum horizontal separation between aircraft, the required minimum horizontal separation and the target horizontal separation. The horizontal minimum separation is the predicted minimum distance between a subject and object aircraft, when vertical separation (including the URET vertical conformance bounds) has been lost.

A four-hour period from 12:00 to 16:00 (GMT) on December 14, 2000 was chosen for this evaluation. These separation data were obtained using an automated testing program with this scenario, which randomly selected an aircraft with notified problems, initiated ART, and then output the resulting separation data. Conflict-free vector maneuvers were then selected for subsequent analysis.

Operationally, ART left and right turn vector resolutions are calculated for increments of five degrees. In the run that was used to collect this data, a one degree increment instead of a five degree increment was selected, to better measure the ability of ART to achieve the target values.

Results. Approximately 90% of the ART lateral resolutions had minimum separation distances between 10 and 15 nm. This range of values appears to be consistent with what is operationally satisfactory/required. Therefore, the primary conclusion was that the parameters that determine the shape of ART's lateral maneuvers are set correctly, and that the ART lateral maneuvers are, in general, efficient maneuvers.

4.4 Testbed Analysis Using Synthetic Track Data

Introduction. This technique studies the sensitivity of the ART resolutions to prediction uncertainty, e.g., for pilot/controller response delays and lateral navigation error. It uses a Monte Carlo simulation technique, in which the ART resolutions are “flown” multiple times using errors sampled from empirically-derived distributions. An initial experiment is described here for a two-aircraft scenario, with the track simulation being performed by software written for a Conflict Probe Testbed.[12]

Methods. Two flights with crossing paths were selected for an initial experiment; FDX146, flying from MEM to PIT, and USA1692, flying from ORD to CLT. Both aircraft were in level flight at FL290 throughout the conflict and the course of the resolution maneuver. The horizontal miss distance for this simulated conflict was calculated as 1.48 nm. When the scenario was input to URET, a red conflict was posted at slightly less than seventeen minutes before the projected point of closest approach. At this point, the simulation was stopped and ART was initiated, first for one flight and then the other. The highest ranked lateral resolution required a left turn of about ten degrees, resulting in FDX146 passing behind USA1692.

Twenty new flight tracks were created for FDX146, representing twenty typical variations in the resolution response. These variations were created by assuming that the controller required 25 seconds to voice the resolution amendment to the pilot, and that the pilot response time was normally distributed with a mean of 30 seconds and a standard deviation of fifteen seconds. (Although these assumptions are reasonably consistent with previous studies of response times,[13, 14] they should not be considered definitive at this time.) The response delays were inserted manually into each scenario, and the existing Testbed software was run to create twenty synthesized tracks. The complete synthesized tracks, along with the original track for USA1692, were then run through a Conflict Analyzer, which determined the minimum miss distance between the sets of track data.

<u>Results.</u> The variations in the resolution path for FDX146 are shown in Figure 1. The measured minimum miss distance varied from 10.6 to 12.8 nm, with a mean value of 11.28 nm. Since all of these miss distances exceed 10.5 miles (the threshold for a yellow alert), it is unlikely that URET would have detected further conflicts between this pair of aircraft. Therefore, the probability of remaneuver is close to zero.

For USA1692, the highest ranked ART lateral amendment was also a left turn of about ten degrees, causing USA1692 to cross in front of FDX146. As before, twenty synthetic tracks were created for USA1692, representing twenty typical variations in the resolution response for this aircraft. The horizontal miss distances reported by the Conflict Analyzer ranged from 10.13 to 11.06 nm, with a mean value of 10.74 nm. Three of the twenty resolution paths resulted in a miss distance of less than 10.5 nm, and may have produced yellow alerts for the same two aircraft at a later time. This suggests a slight possibility of a remaneuver to maintain separation with FDX146.

4.5 Comparison with Controller Actions

<u>Introduction.</u> This technique addresses the relationship between ART resolutions and controller actions for aircraft separation as identified by the analysis of controller voice, track and flight plan data recordings. This relationship is of interest in that it provides an additional operational context in with which to measure ART. For example, while an

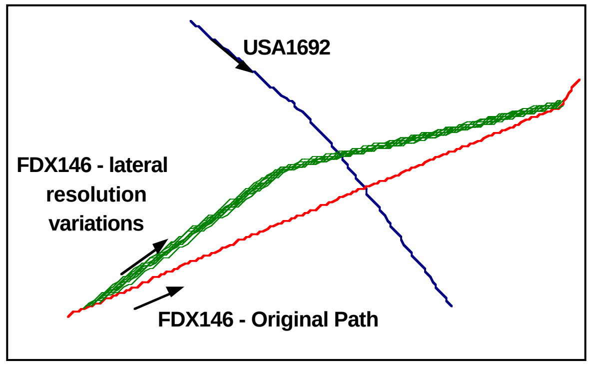

Figure 1. Variations in Resolution Path for FDX146

identity of the strategic ART resolutions and more tactical controller actions is not expected, it is useful to measure the availability of the ART resolutions at the time of controller action. This availability may be characterized both in terms of the proportion of times that a conflict-free resolution is available at the time of controller action, and the proportion of times that such a resolution is available in the dimension matching the controller action. It is also useful to characterize, in relation to the time of controller action, the effect of maneuver start time on ART resolution components such as alert status, initial turn angle and TOA.

<u>Methods.</u> A scenario from 13:00 to 17:00 (GMT), 22 July 1999 was utilized. This scenario consists of ZID aircraft traffic, adaptation, winds aloft forecast data, and a controller voice clearance recording of ZID Sector 82 (LOU HI). URET was not in use at this sector, thus providing a comparison with non-URET ATC operations.

The controller clearances from the voice recording were transcribed, and clearances that occurred when a notified alert was present for the maneuvered aircraft were selected. A total of 85 such alerts were selected. Of these, fifteen alerts were removed from further consideration because they were determined to be a remaneuver for the same problem; in these cases, ART would have produced similar results to the original alert, and their inclusion would have skewed the results.

For the remaining 70 alerts, ART was initiated at the time of controller action, and at five and ten minutes before this time if an alert was present. The type and alert status of each ART resolution was recorded, along with the delta Time of Arrival (TOA) and initial turn angle of each lateral resolution.

<u>Results.</u> In this scenario approximately 66% of the controller actions occurred less than three minutes

before conflict start time. At the time of controller action, 67% of the conflicts had at least one green ART resolution.

When ART was initiated five minutes prior to the conflict start, the median ART lateral delta TOA value was 27 seconds. However, when ART was initiated five minutes later (at the time of controller action), the median lateral delta TOA was 46 seconds (19 seconds longer). The probability of a delta TOA increase correspondingly increased as the maneuver start time was delayed.

Additional data concerned the distribution of initial ART turn angles as a function of invocation time. This data indicates that, in the aggregate, the angles are smaller for earlier actions. For example, sizable proportions of the resolutions at ten minutes before the time of controller action are either in the 5-10 degree or in the 11-30 degree range. Five minutes later, the proportion of resolutions in the 31-90 degree range has nearly doubled, while for the resolutions generated by ART at the time of controller action, the largest turn angles predominate, and there are very few resolutions in the 5-10 degree range.

4.5.1 Comparison of ART and Controller Maneuvers for the Same Conflict

This analysis examined those cases where ART produced at least one green resolution, and determined if at least one of these resolutions was in the same dimension as the controller action. For lateral vector maneuvers, this match was exact, i.e., when the controller vectored the aircraft, it was found that ART also produced at least one green vector maneuver (given that at least one green resolution of any dimension was available). For the altitude maneuvers, the match rate was 78%, i.e., when the controller maneuvered the aircraft vertically, it was found that ART also produced at least one green vertical resolution 78% of the time (again, given that at least one green resolution of any dimension was available).

This analysis also illustrated cases where the aircraft had multiple problems and clearances, and a single PARR resolution and clearance could have been utilized. Such maneuvers should reduce the workload of both controllers and pilots, and enhance flight efficiency.

5 Extensions for Severe Weather and TFM Flow Initiatives

Severe weather areas and congestion Flow Constrained Areas (FCAs) can cause a reduction in NAS resource capacity. In response to a predicted capacity reduction, the TFM personnel in the ARTCCs and in the Air Traffic Control System Command Center (ATCSCC) develop TFM flow initiatives, or strategies, through collaboration with the NAS users. TFM personnel also coordinate with the Operational Supervisors (OSs) and Controllers-in-Charge (CICs) in the ARTCCs for a better understanding of the local situations, as well as for communicating the TFM strategies to be implemented by the sector controllers.

These TFM strategies can contain the following types of flow instructions:

- ***TFM reroutes*** around severe weather areas or congestion FCAs.
- ***TFM flow rate constraints*** to modulate the traffic flows approaching constrained NAS resources (such as airports).
  - A *Miles-in-Trail (MIT) constraint* specifies the desired spacing between aircraft as they cross a fix or boundary.
  - A *Meter Fix Time (MFT) constraint* (also referred to as a time-based metering constraint) specifies an aircraft's TOA at a fix or boundary, as planned by TFM personnel in the ARTCCs.

Today, TFM reroutes and MIT constraints are specified for groups of aircraft and are communicated to the sectors verbally or through General Information (GI) messages. Although MFT constraints are specified for individual aircraft and are communicated to the sectors electronically, these constraints are only available at the R position. The sector capabilities do not yet enable the efficient, strategic application of TFM flow instructions on an aircraft-specific basis.[15, 16] In addition, these capabilities do not yet support the avoidance of forecasted severe weather.

Concepts for extending URET and PARR (collectively termed "URET/PARR") to assist the controller in strategically managing severe weather and related flow initiatives have been prepared for preliminary evaluation.[17, 18] An incremental development approach for implementing the capabilities supporting these concepts is briefly described below.

The capabilities introduced in ***Step 1*** support problem prediction, notification, and resolution for aircraft-to-aircraft and aircraft-to-airspace problems, in addition to traffic flow awareness for group MIT constraints. As described in Section 1.1, URET provides problem prediction, notification, and manual resolution (in the form of manual trial planning) for aircraft-to-aircraft and aircraft-to-airspace problems. As described in

Section 2, Initial PARR capability enhancements provide assisted trial planning in the form of probed URET resolution menus (ATRP), and manually initiated problem resolution (ART). In Step 1, URET/PARR is also enhanced with a traffic flow awareness capability. This capability assists the controller in visualizing MIT constraints that are defined for groups of aircraft and stored in adaptation.

The capabilities introduced in ***Step 2*** begin supporting problem prediction, notification, and resolution ranking for four new types of predicted problems, in addition to traffic flow awareness for MFT constraints. In this step, the National Weather Service (NWS) provides severe weather forecast information for use by URET/PARR and the TFM capabilities. The TFM capabilities electronically communicate TFM reroutes, congestion FCAs, and MFT constraints to URET/PARR. URET/PARR uses this information, along with group MIT constraints in adaptation, to define four new types of problems in Step 2, involving problems between an aircraft and the following:

- Congestion FCAs.
- Areas in which severe weather is forecast.
- MIT constraints.
- MFT constraint.

For these new types of problems, URET/PARR provides the following:

- Problem prediction and notification.
- Manual and assisted trial planning.
- Additional resolution ranking factors; although these new types of problems are not resolved in Step 2, their presence in a resolution acts to lower (towards less preference) the resolution ranking.

In Step 2, URET/PARR is also enhanced with a traffic flow awareness capability that assists the controller in visualizing the MFT constraints received from TFM for aircraft in arrival streams. When air-ground data-link communication becomes available, it is expected to support a subset of controller and pilot messages related to flight plan amendments and pilot requests.

The capabilities introduced in ***Step 3*** support the notification of cancelled TFM reroutes, traffic flow awareness for aircraft-specific distance adjustment constraints (distance to add to aircraft's route before reaching MIT fix or boundary), and the generation of resolutions for the new types of predicted problems. In this step, the TFM capabilities electronically communicate TFM reroute cancellations and aircraft-specific distance adjustment constraints to URET/PARR. URET/PARR provides notification of cancelled TFM reroutes, assistance in visualizing the aircraft-specific distance adjustment constraints for en route and arrival streams, and manually initiated problem resolution for the new types of predicted problems.

The goal for future steps is to integrate the capabilities available for the R and D controllers, making the URET/PARR enhancements available at the R position as well. The URET/PARR prototype system will be used to evaluate the research issues associated with these concepts.

6 Next Steps

CAASD's near-term activities are focused on continued evaluations of the Initial PARR capabilities at URET field facilities, and functional performance assessment as described above. After the successful conclusion of these analyses and approval by the FAA, it is expected that these capabilities will be deployed in a manner similar to URET for FFP1.

Activities related to the extension of the Initial PARR capabilities are currently focused on requirements development, with initial laboratory evaluation in 2002. Additional investigation is also continuing into the evolution of URET and PARR as components of an integrated Sector Team DSS.[19-21]

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