

Problem Resolution Support for Free Flight Operations

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Abstract—The MITRE Corporation’s Center for Advanced Aviation System Development (CAASD) has been conducting research into new automation capabilities to support free flight operations. One of these capabilities is a problem resolution function to assist the en route sector controller team in handling the more complex traffic patterns that can result from a less structured free flight environment. This function is termed Problem Analysis, Resolution and Ranking (PARR). PARR is envisaged 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, with the first step focusing on the resolution of aircraft-to-aircraft and aircraft-to-airspace problems. Follow-on enhancements include resolutions for metering and other traffic flow management (TFM) flow initiatives, resolutions for the avoidance of severe weather areas, and the integration into a common en route Sector Team CHI. A Research Management Plan has been prepared by the Federal Aviation Administration and MITRE/CAASD to support this development process. This paper describes the initial PARR capabilities, along with an extension to incorporate assigned metering time constraints.

Index Terms—AERA, conflict probe, conflict resolution, free flight, PARR, problem resolution, trial planning, URET.

I. INTRODUCTION

TO MEET user demands and to accommodate growth in traffic, the Federal Aviation Administration (FAA) and National Airspace System (NAS) users have embarked on an initiative known as free flight. Free flight provides users with as much flexibility in 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 is implementing free flight with an incremental development strategy. In the first step—termed Free Flight Phase 1 (FFP1)—a set of existing core capabilities are being deployed to a limited number of sites. One of these capabilities is the User Request Evaluation Tool (URET), which is being deployed to seven Air Route Traffic Control Centers (ARTCCs) as part of FFP1. URET will provide en route sector radar associate position (D-Position) controllers with automatic problem detection and trial planning capabilities, and a set of tools to assist in

the management of flight data. In Free Flight Phase 2 (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 ARTCC’s. As of February 2001, this prototype had been used at these facilities for over 900, 000 sector hours, and over 800 operational personnel had been trained in its use.

A set of FFP1 enhancements for which there is a clear consensus in both the FAA and industry [1]–[4] is the following.

- 1) 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 problems, for problems involving severe weather, and for TFM initiatives.
- 2) The integration of these resolution tools into an air traffic control (ATC) decision support system (DSS) toolset that supports the Sector Team, i.e., a DSS that is common to both the D-Position and the radar position (R-Position) and 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 Problem Analysis, Resolution, and Ranking (PARR). PARR has been designated as priority research for FFP2. As with URET, PARR was initially developed with laboratory controller evaluations in the late 1980s and early 1990s as part of the Automated En Route ATC (AERA) program [5]–[7].

The first step of PARR development focuses on the resolution of aircraft-to-aircraft and aircraft-to-airspace problems. This paper describes these initial capabilities, along with an extension to incorporate assigned metering time constraints. As PARR is a URET enhancement and utilizes many components of URET for the creation and display of resolutions, an overview of URET is also provided. Further details on URET may be found in [8].

A. URET Overview

URET processes real-time flight plan and track data from the NAS Host computer. These data are combined with site adaptation, key aircraft performance data, and winds and temperatures from the National Weather Service in order to build four-dimensional flight profiles, or trajectories, for pre-departure, inbound, and active instrument flight rules (IFR) 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.

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URET uses the predicted trajectories to continuously detect potential aircraft problems up to 20 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 problems 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 graphic information. The text-based Plans Display and aircraft list manage the presentation of flight data (aircraft call-sign, route, altitude, etc.), Trial Plans, and problem information for the sector. Clearance language is also generated for Trial Plans. The Graphic Plan Display (GPD) provides a graphical capability to view Current and Trial Plan routes, altitudes and problems.

Color coding of Current Plans and Trial Plans is used to reflect the problem status of each plan. These color codes are as follows. A green plan indicates that the trajectory is problem-free. Problems with less than or equal to five nautical miles (nm) predicted horizontal separation between trajectory centerlines are coded in red. Problems with a predicted minimum horizontal separation of greater than 5 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.

II. RESOLUTIONS FOR AIRCRAFT-TO-AIRCRAFT AND AIRCRAFT-TO-AIRSPACE PROBLEMS

On controller initiation, PARR provides a set of candidate problem resolution advisories in the form of URET Trial Plans. This set of resolutions is presented to the controller in one of two ways depending on whether PARR is initiated 1) for a selected type of maneuver (to assign a new speed, altitude, or direct-to-fix maneuver) or 2) for a specified aircraft or problem. Each of these presentation methods and the underlying processing are discussed in the following sections.

A. PARR Initiated for a Selected Maneuver Type

PARR may be initiated for a selected type of maneuver, i.e., to assign a new speed, altitude, or direct-to-fix maneuver. This initiation occurs automatically when a Trial Plan menu for the corresponding maneuver type is displayed. For example, when displaying the URET Trial Plan Altitude Menu as illustrated in Fig. 1, PARR is automatically initiated to generate a range of Trial Plans for new assigned altitudes, with this range being dependent on the current and assigned altitude of the aircraft, and its phase of flight. The color code of each resulting Trial Plan is then used to color-code the menu entry. In this way, the controller can determine which entries are problem-free by simply viewing the menu (as illustrated in Fig. 1, green entries are also underlined to provide a redundant coding).

As with the current URET menus, selection of the menu entry causes the corresponding trial plan information to be displayed in the URET Plans Display, where it can be cleared and then sent as a

Host flight plan amendment with the click of a button. It may also be selected for graphical presentation on the URET GPD.

Since a range of Trial Plans is generated even if no problem is present in the selected aircraft's current plan, PARR may be used to quickly check the problem status of a desired action, e.g., to change an assigned altitude due to turbulence, or to send the aircraft direct to a downstream fix. The concept of use is that PARR not only supports problem resolution but also the granting of user requests.

Controller evaluations to date have indicated that these PARR capabilities are quite beneficial for assisting with air traffic control operations. Similar conclusions regarding color-coded entries on altitude menus were also found in [9].

B. PARR Initiated for a Selected Aircraft or Problem

In addition to the PARR capabilities described above for a specific maneuver type, PARR may also be initiated for a specified aircraft with one or more problems, or for a specific problem. In these cases, PARR will examine a variety of resolution dimensions and directions, and the resolutions may have multiple clearance components, e.g., a step climb maneuver consisting of a climb to a level-off altitude, followed by a resumption of climb.

If initiated for an aircraft, PARR will generate resolutions which maneuver only that aircraft. If initiated for an aircraft-to-aircraft problem, resolutions for each of the two involved aircraft will be generated. As with the PARR capabilities for a specific maneuver type, controller evaluations to date have indicated that these PARR capabilities are quite useful for assisting with air traffic control operations.

For each resolution, only one aircraft is maneuvered. (Multiple aircraft maneuvers are anticipated as a future enhancement.) For a given aircraft to be maneuvered, PARR will search for problem-free trajectories to resolve all problems with that aircraft (within URET's 20-min lookahead horizon) in an operationally acceptable manner, without introducing new problems. The search process examines, in turn, maneuvers in each of the following five dimensions/directions, thus yielding up to five resolutions for that aircraft: 1) above the problem; 2) below the problem; 3) left of route; 4) right of route; and 5) an increase or decrease in speed. Each resolution will contain only one maneuver. (Composite, multiple-dimension maneuvers are anticipated as a future enhancement for aircraft-to-aircraft problem resolution and are currently used for metering as described below.)

The completed PARR resolutions are ranked and displayed on the URET Plans Display as described below. Typically, one of these resolutions would be selected and implemented by the controller. Alternatively, the controller may use the resolution set to estimate which maneuver dimensions/directions are candidates for further inspection. Finally, the number of successful resolutions available may be used by the controller as an ongoing indicator of when maneuver options are becoming limited, and positive action should be taken to resolve the problem.

Each PARR 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).

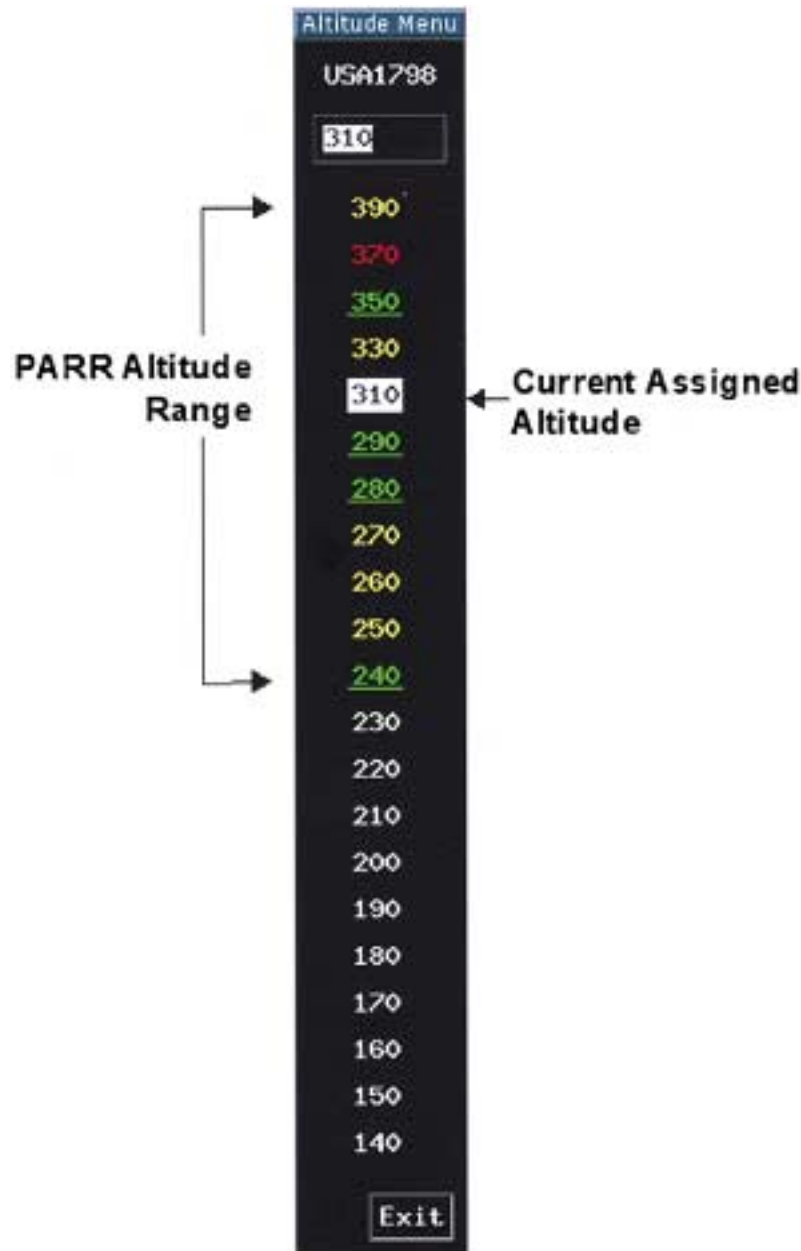


Fig. 1. URET Altitude Menu with PARR assigned altitude maneuvers.

All maneuvers are within the operational performance limits of the maneuvered aircraft. Parameter, maximum turn angle constraints are also applied.

1) *Algorithm Description:* When initiated for a selected aircraft or problem, the PARR processing consists of three steps: Problem Analysis, Resolution Generation, and Resolution Ranking. Each of these steps is described below.

a) *Problem Analysis:* The first step in the PARR processing is Problem Analysis. For each aircraft to be maneuvered, data are collected for use in the resolution process, such as:

- 1) aircraft headings, speeds, and transitioning states at the current time;
- 2) problem start and end times, and the predicted aircraft headings, speeds, and transitioning states at those times;

3) aircraft minimum and maximum altitudes and true airspeeds;

4) sector and facility currently controlling the aircraft.

This information is collected and stored in a problem summary structure and is used throughout the resolution and ranking components of PARR.

b) *Resolution Generation:* The second step in the PARR processing is Resolution Generation. This step calls lower level functions to create the resolution planned actions and build resolution trajectories within URET. The resolution algorithm iterates for the maneuvered (subject) aircraft, the other maneuvered aircraft (if PARR was initiated for a specified problem), and all dimensions/directions for each aircraft. Each dimension further calls aircraft and airspace problem resolution routines to model resolutions. If the problem is solved, the current iteration limit is

adjusted and the current direction will be skipped in subsequent iterations. Otherwise, the current best resolution (according to ranking criteria described below) is saved in a data structure for the next iteration.

Resolution Generation is terminated when at least one of the following conditions is satisfied:

- 1) For each aircraft and each dimension/direction, one of the following conditions holds:
 - a) A problem-free resolution has been found.
 - b) All problems remaining are tactical problems with the current plan, and PARR has made them no worse (i.e., PARR has not increased the alert severity, or decreased the problem start time). “Tactical” is defined here as having a start time earlier than a parameter time in the future (e.g., three minutes).
 - c) The system has determined that a resolution (in the given dimensions/direction) would exceed the operational performance limits of the aircraft.
- 2) An initial iteration limit (counting all iterations for each maneuvered aircraft and resolution dimensions/directions) has been reached, and at least one resolution satisfying conditions 1a) or 1b) above has been generated.
- 3) A second iteration limit has been reached.

In the unlikely event that no resolutions are generated—either because there is no URET notified problem that starts greater than a parameter time in the future, or the system has determined that a resolution would exceed the operational performance limits of the aircraft—the controller is notified that no resolutions are available.

The following sections describe the three maneuver dimensions.

i) *Vertical maneuver description*

PARR vertical maneuver generation calculates a block of airspace that the aircraft must avoid. The algorithms are rule-based using aircraft transitioning status, planned maneuver times and problem start/end times to generate resolutions using pre-defined maneuver shapes. These shapes are categorized according to whether the maneuvered aircraft passes above the original problem region (termed “above-problem” maneuvers), or below the original problem region (“below-problem” maneuvers).

As illustrated in Fig. 2, the above-problem maneuver shapes are Increase Altitude, Extend Climb, Early Climb, Early Extend Climb, and Step Late Descent (which includes the case of late descent with no step maneuver). As illustrated in Fig. 3, the below-problem maneuver shapes are Decrease Altitude, Step Climb, and Step Early Descent (which includes the case of an early descent, when there is a future level-off prior to the arrival airport). In each figure, MSP is the Maneuver Start Point, TOC is the Top of Climb, BOD is the Bottom of Descent, and BOC is the Bottom of Climb. These maneuvers were derived on the basis of extensive evaluations and analysis as part of the AERA effort [7]. While other maneuver shapes are technically possible (e.g., an early

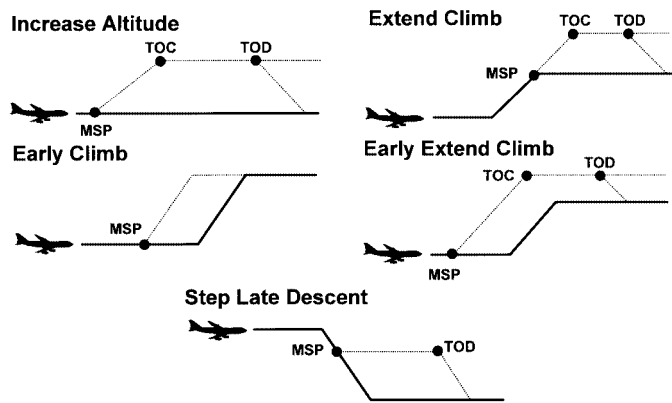


Fig. 2. Above-problem maneuver shapes.

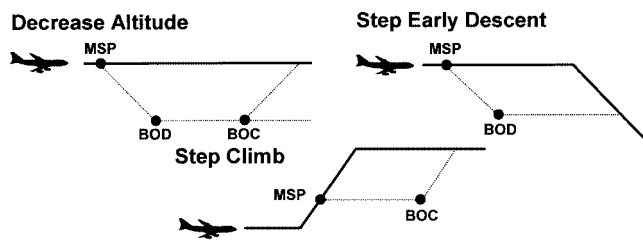


Fig. 3. Below-problem maneuver shapes.

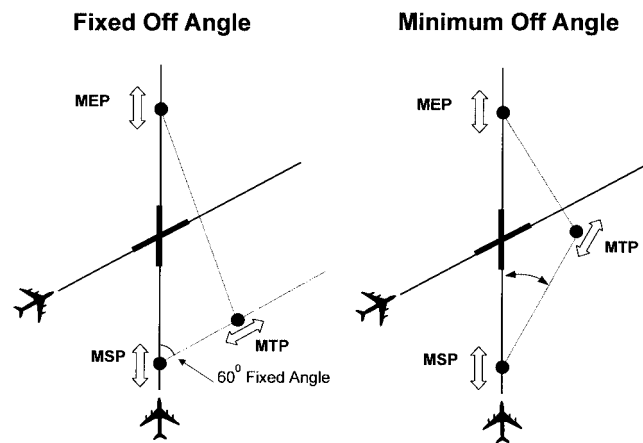


Fig. 4. Fixed Off-Angle and Minimum Off-Angle lateral maneuvers.

TABLE I
ABBREVIATED CLEARANCE INFORMATION

Standard Form	Abbreviated Form
turn left	L
turn right	R
deg	0
fly present heading	fph
at HHMMZ(ΔMM) . . .	[ΔMM. . .]

climb combined with a step maneuver), these types of maneuvers are currently not implemented in PARR due to issues with operational acceptability and restricted applicability to unusual, multiple problem encounters.



Fig. 5. URET Plans Display with PARR resolutions.

After an appropriate maneuver shape has been selected, the algorithms will vary the maneuver transition points indicated in Figs. 2 and 3, using problem information obtained from the previous attempt.

ii) *Lateral maneuver description*

Lateral maneuvers are categorized according to whether the maneuvered aircraft initially turns left or right of route; PARR attempts both of these maneuvers for a given aircraft. Each lateral maneuver is further classified as one of three different maneuver types: Direct to Maneuver End Point (MEP), Minimum Off-Angle, and Fixed Off-Angle.

A Direct-to-MEP maneuver occurs when an aircraft proceeds directly from the MSP to the MEP and there are no intermediate turns. The Minimum Off-Angle maneuver uses the minimum angle necessary to pass around the object aircraft, i.e., the other aircraft involved in the problem. The Fixed Off-Angle maneuver has a first maneuver leg with a fixed initial turn angle (typically 60 degrees); this is a maneuver in which it is either inefficient or not possible (with the given left or right turn) to pass around the object aircraft on the first maneuver leg. Fixed Off-Angle and Minimum Off-Angle maneuvers are illustrated in Fig. 4. (MTP is the Maneuver Turn Point.)

iii) *Longitudinal maneuver description*

Longitudinal maneuvers consist of either a speed increase or decrease, followed by the time at which the currently planned speed may be resumed. At most, one speed change maneuver for a given aircraft is presented to the controller.

c) *Resolution Ranking:* The third step in the PARR processing is Resolution Ranking. In this step, the completed resolutions are sorted according to anticipated airspace user and controller preferences, to facilitate the resolution selection process. Resolution Ranking is determined by a numerically weighted combination of factors. The following are the main factors that influence ranking:

- 1) the resolution dimension/direction and phase of flight (e.g., to reflect preferences for descent maneuvers in the arrival phase of flight);
- 2) the removal of an existing altitude restriction;

- 3) the change in the time of arrival (TOA) caused by the resolution;
- 4) the number of flight levels changed in the resolution;
- 5) the coordination required with another sector;
- 6) the number of additional sectors entered by the resolution;
- 7) the number of resolution problems, their problem status, and predicted time to the start of problem;
- 8) the recurrence of a current plan problem in the resolution, and whether PARR was initiated for this problem.

Resolutions with a rank value exceeding a parameter value (with a higher value indicating a less-preferred resolution) are inhibited from display.

Computer Human Interface (CHI): Displayed clearance information, which does not assume any particular aircraft equipage, is specified in terms of heading changes, VORs, VOR radials, altitudes, and speeds. The clearance information on the Plans Display is abbreviated as described in Table I. Evaluations by controllers have found the abbreviated clearance information useful in conveying the intent of each resolution in a concise manner, allowing the controller to quickly find a resolution in the desired dimension and direction.

As illustrated in Fig. 5, the abbreviated clearance information is presented on the URET Plans Display, in rank order below (and indented from) the display of the Current Plan(s) on which the resolutions are based. In this figure, PARR has been initiated for DAL198, which is climbing from 7800 ft to FL370. As illustrated in Fig. 6, DAL198 has one red problem, with VGD101, which is cruising at FL260.

PARR has generated three resolutions which maneuver DAL198. The highest ranked resolution is illustrated graphically in Fig. 6, and is a 10° turn right to intercept a radial from the DJB VOR, and then proceed direct to DJB to rejoin the route. The second-ranked resolution presented in Fig. 5 is to level DAL198 when reaching FL250, and then resume the climb to FL370 when past VGD101 (at 11 minutes from current time). The third resolution in Fig. 5 is to turn DAL198 left 25° to intercept a radial from the DJB VOR, and then proceed direct to DJB. Buttons to the left of each entry allow the optional display of Host flight plan amendment information on each plan (and problem information, as applicable). Any of the PARR resolution Trial Plans may be displayed graphically,

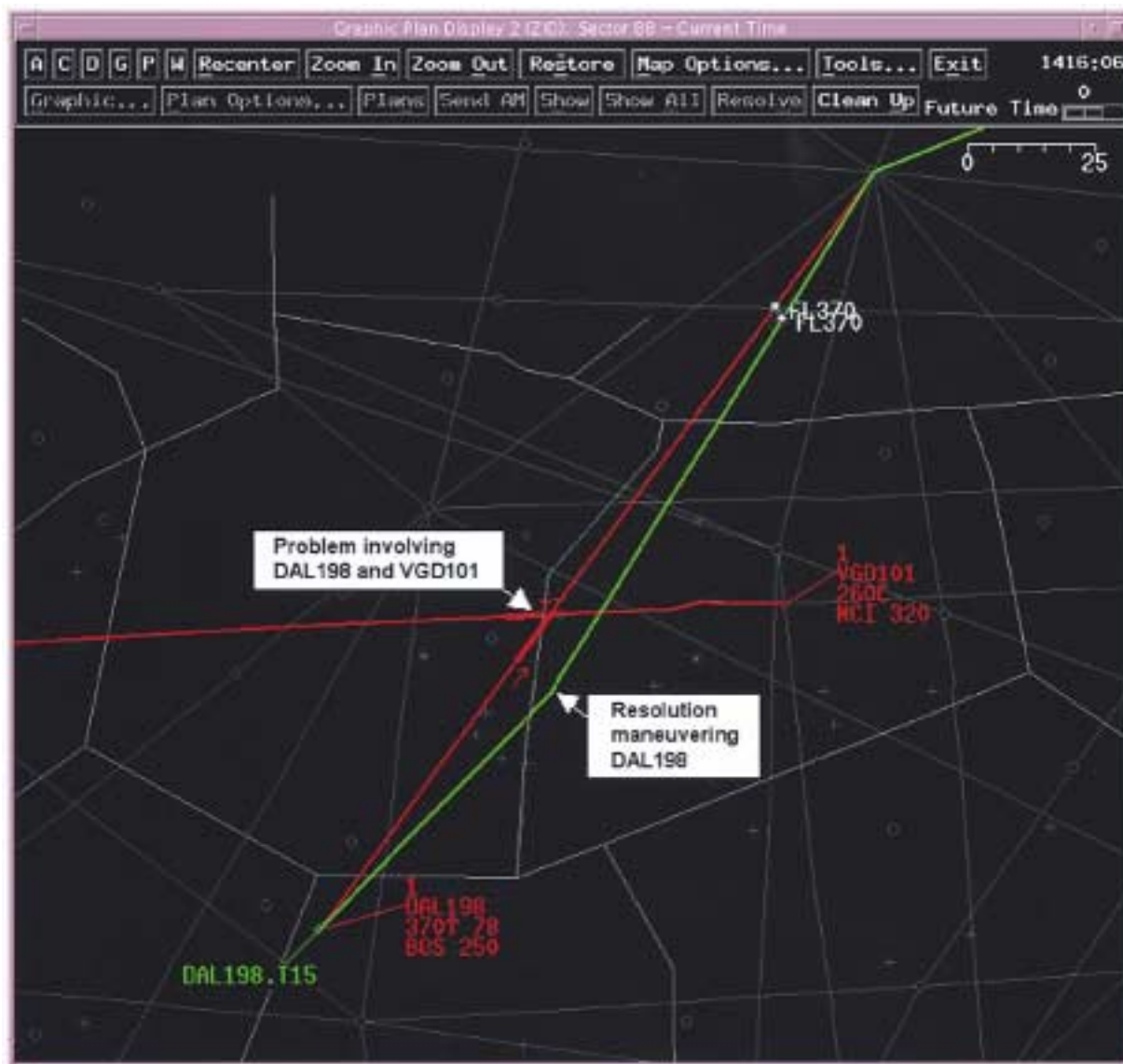


Fig. 6. GPD of a Current Plan problem and PARR resolution.

TABLE II
RESOLUTION COUNT SUMMARIES

Indianapolis Center	
Total Conflicts--Tactical and Non-Tactical	2299
Non-Tactical Conflicts--Conflict Start > 3 min	1794 (78.0%)
Green Resolutions from Non-Tactical	4201 (72.2%)
Red Resolutions from Non-Tactical	616 (10.6%)
Yellow Resolutions from Non-Tactical	784 (13.5%)
Blue Resolutions from Non-Tactical	221 (3.8%)
Non-Tactical Conflicts with At Least One Green	1634 (91.1%)

coordinated, or implemented in the same manner as any other URET trial plan.

Resolution Generation summaries: To help quantify PARR resolution results, an automated test program was created. A recorded scenario of approximately five hours of real-world data from Indianapolis (ZID) Center (date: 4-17-98)

were run in URET. The test program scanned the URET database at predetermined intervals looking for problems. If a problem was found, PARR was initiated for an aircraft involved in the problem, and the results of the PARR execution (number of resolutions with red, yellow, blue, and green color codes) were collected and tabulated. The results from this run are shown in Table II. While they are preliminary, the results indicate that in over 90 percent of nontactical problem situations (i.e., the problem begins at least three minutes after PARR is invoked), PARR is able to construct at least one green resolution for a given aircraft.

III. RESOLUTIONS TO COMPLY WITH ASSIGNED METERING TIMES

A PARR enhancement is being developed to generate maneuverers that meet a specified meter fix time (MFT) constraint, in addition to avoiding aircraft-to-aircraft and aircraft-to-airspace problems. This concept is much the same as for the initial PARR capabilities; however, instead of initiating PARR to generate



Fig. 7. GPD of a PARR metering resolution.

resolutions for a separation problem, PARR would be initiated for a MFT problem (i.e., an aircraft is predicted to miss the assigned MFT). The procedures for implementing and displaying the metering resolution are similar to those described above. Once initiated, PARR will search for maneuvers that meet the MFT with a trajectory that is free of problems with nonmetered aircraft (e.g., crossing traffic), and with metered aircraft that are predicted to meet their assigned MFT.

If delay to meet an MFT is required, the PARR resolution first reduces the aircraft's speed to an acceptable minimum (for fuel efficiency and to reduce the size of vector maneuvers) and then adds lateral delay as needed. In the event an earlier arrival time is required, the route is shortened when possible, with a speed increase added as necessary to meet the MFT. Where applicable, lateral maneuvers for both left and right of route are generated.

In the example shown in Fig. 7, AAL1317 is being metered into DFW and requires 1.5 min of delay to meet the assigned MFT at the meter fix (SOUSA). PARR creates a problem-free, fuel-efficient resolution to meet the MFT by delaying a turn to SOUSA and reducing speed once the aircraft is below FL290.

IV. ANTICIPATED BENEFITS

It is expected that PARR will make significant contributions to the attainment of the key ATM system goals: safe, orderly, expeditious air traffic flow, and increased controller productivity. These contributions are summarized below:

Enhanced safety—Safety enhancements are important since the relaxation of ATC restrictions can lead to more complex traffic patterns. PARR can assist in maintaining or enhancing safety in two ways. First, PARR provides tools with which controllers can obtain an improved,

strategic situational understanding, e.g., by quickly indicating which altitude, speed, or direct-to-fix alternatives are problem-free. Second, the resolutions provided by PARR can allow the controller to more easily implement strategic, problem-free resolutions. The strategic nature of these resolutions will allow increased time for decision-making and coordination.

Controller workload reduction—PARR can reduce controller workload in the problem resolution process by: 1) suggesting specific resolutions; 2) indicating successful and failed resolution dimensions/directions; and 3) generating resolutions that will be less likely to cause downstream problems than tactical resolutions.

Improved flight information for use in trajectory modeling—PARR increases the potential for flight plan amendments to be entered into the Host computer (e.g., by providing route modifications that may be entered into the Host, versus incomplete vector clearances which cannot be entered). Since trajectory modeling accuracy is in part a function of the degree to which flight plan data represent the intended path of the aircraft, this increased potential can improve modeling accuracy.

Resolution efficiency—PARR can compute efficient maneuver parameters using detailed aircraft performance and atmospheric data, and examine a variety of dimensions and directions for increased resolution efficiency. Additionally, the efficiency of these parameters is independent of the amount of traffic in the sector. PARR can also facilitate a strategic problem resolution approach that can reduce the number of large, tactical maneuvers.

Increased user benefits—PARR can be expected to increase user benefits by enabling the accommodation of

greater numbers of aircraft operating in less structured airspace. Strategic planning and problem solving will also allow more time for controllers to address requests from the airspace users, and the PARR capabilities can facilitate the granting of these requests. Finally, the efficiency of the PARR resolutions will reduce deviations from the user-preferred flight profile when maneuvers are required.

In consideration of the above benefits, a cost/benefits study done for the Advanced Automation System [10] estimated the incremental benefits for a full "AERA 2" problem resolution capability (as would now be realized in the full set of PARR enhancements to URET) to be \$2.5 billion in constant 1988 dollars, for a 20-year life cycle span.

V. NEXT STEPS

Near-term activities are focusing on limited evaluations of the above PARR capabilities at a URET field facility. A number of issues will be addressed during these evaluations:

- 1) The Concept of Use for each resolution enhancement, and the plan for transitioning to this Concept of Use from current operations in a phased, operationally acceptable manner.
- 2) Roles and responsibilities of Sector Team members, and coordination with other sectors.
- 3) The overall acceptability of the integrated URET/PARR CHI, clearance representation, and Resolution Ranking.
- 4) The ability of PARR to generate operationally acceptable resolutions, particularly in complex and/or heavy traffic.
- 5) Implementation of resolutions with future maneuver actions.
- 6) Training requirements.

Additional activities are focused on the definition of metrics for the functional performance and benefits assessment of PARR. Methodologies for the measurement of these metrics are also being defined and implemented.

After the successful conclusion of these activities and approval by the FAA, it is expected that the initial PARR capabilities described in Section II (for aircraft-to-aircraft and aircraft-to-airspace problem resolution, as modified on the basis of evaluation results) will be deployed in a manner similar to URET FFP1. As noted above, follow-on enhancements which are being planned include resolutions for metering and other TFM flow initiatives, resolutions for the avoidance of severe weather areas, and the integration into a common en route Sector Team CHI.

VI. CONCLUSION

A free flight concept has been formulated for the 2003–2005 time frame [1]–[4]. This concept includes the provision of enhanced problem resolution support tools to assist the en route sector controller in handling more complex traffic patterns that can result from a less structured environment. Evaluations to date indicate these capabilities are capable of being implemented as an enhancement to the URET FFP1 system and can yield significant benefits to both the controller and the airspace user.

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