AN ASSESSMENT OF A CONTROLLER AID FOR MERGING AND SEQUENCING TRAFFIC ON PERFORMANCE-BASED ARRIVAL ROUTES

Paul MacWilliams and Donald Porter

The MITRE Corporation, McLean, Virginia

Abstract

Controllers managing merges on area navigation (RNAV) arrival routes with high traffic density deal with unpredictable wind and complex speed differentials because of the altitude change along the arrival paths. The topology of a merge (the number of turns and the length of each route prior to the merge) requires more effort and creates a higher workload to identify a potential merge problem early enough to prevent vectoring an aircraft off the RNAV procedure. Furthermore, merges may occur just within the boundary of a control position and may require prior sequencing coordinated by other controllers. To assist in sequencing and merging aircraft on RNAV routes, MITRE has devised an automation aid which takes an aircraft's position on an RNAV route and estimates its position along another RNAV route. This aid allows for an aircraft's position on an RNAV route to be displayed on another route based on defined merge points. The routes can be complex multi-segmented routes defined by non-collinear waypoints and circular arcs defined by Radius-to-Fix (RF) legs.

This aid properly accounts for aircraft flight paths through the turn segments of each route. The aid has been demonstrated to numerous air traffic controllers and traffic management coordinators and has received very positive feedback. Sequencing aircraft for runway configuration changes, Traffic Management Coordinator (TMC) flowing and sequencing, early awareness for building and preserving slots, and allowing aircraft to remain on RNAV routes by using speed control have all been identified as potential uses and benefits during the course of the demonstrations. The use as a training tool for controllers operating in the new required navigation performance (RNP) RNAV terminal environment is also another significant application of the aid.

This paper reports on a specific application proposed by Potomac Consolidated TRACON (PCT) controllers during the course of the demonstrations and operational application development. The operational application is an RNAV arrival procedure involving coordination of the south and west arrival streams at Ronald Reagan Washington National Airport (DCA). The application was adapted, tested, and assessed by PCT controllers. Human-in-the-loop simulations and benefits analyses were conducted and the results are presented in this paper.

Background

Under the Performance-Based Air Traffic Management (P-ATM) concept [1], the Federal Aviation Administration (FAA) is implementing performance-based navigation in the U.S. National Airspace System (NAS). Performance-based navigation is comprised of area navigation (RNAV) and required navigation performance (RNP). During the past five years, the United States has gained significant experience in developing standards for RNAV and RNP, harmonizing those standards with international partners, and implementing procedures based on these standards. The FAA recently published an update to the *Roadmap for Performance-Based Navigation* [2], in which the FAA committed to building RNAV arrivals and departures at the 35 airports of the Operational Evolution Plan (OEP) [3]. Standard Terminal Arrival Routes (STARs) and Standard Instrument Departures (SIDs), based on RNAV, leverage the advanced capabilities of flight deck automation to maintain accurate and repeatable flight track conformance, while also enabling fuel-efficient profiles.

Current terminal operations are changing as more RNAV SIDs and STARs are implemented. Previously, arriving aircraft filing a STAR were cleared into the terminal maneuvering area along the STAR that would direct them toward the downwind leg or more generally toward the airport. Controllers were required to issue headings, speeds, and altitudes to guide flights from this transitional segment to the final approach course. RNAV SIDs and STARs reduce the need for controller vectoring and thereby reduce controller-pilot communications and workload. However, the demand during high traffic periods can cause issues at merges that may require the controller to take aircraft off the RNAV routes for delay vectoring for sequencing. To achieve the additional expected benefits and efficiencies from these terminal routes, controllers may use automation to assist them in managing the traffic where the routes merge.

Description of RPI

The U.S. terminal automation systems (these systems being the Automated Radar Tracking System (ARTS) and the Standard Terminal Automation Replacement System (STARS)) already have algorithms that help controllers synchronize two streams of traffic. This automation aid is called the Converging Runway Display Aid (CRDA). CRDA was specifically designed to assist controllers with arrivals to straight-in converging runways once they are on the final approach segment. However, the aid was implemented with enough generality to allow for the application of this automation aid to converging streams anywhere in the terminal area, not being restricted just to runways. The CRDA applications can be accessed on the automation systems through keyboard commands. The CRDA applications implemented can be toggled on when assistance is needed and its presence is undetectable when it is toggled off.

This foundational CRDA application was expanded recently by MITRE to provide a situational awareness to controllers merging complex flows, where the automation was developed specifically to take advantage of flights on RNAV arrivals. Limitations in the CRDA application and its adaptation necessitated enhancements to be made for sequencing merges on RNAV routes. The tool developed by MITRE for this purpose is called the Relative Position Indicator (RPI) and is intended to be a near-term enhancement to ARTS and STARS. In a previous paper [4], the details of the projection algorithm for RPI, as well as the shortcomings of the foundational CRDA, were presented. RPI is a passive situational awareness aid and does not issue advisories. RPI offers foresight into possible merge issues while relying on the controller to use speed control to achieve sequencing

In RPI, the position of the projected aircraft indicator is based upon the current position of the real aircraft and its radar position. The projection method, which takes into account turns and the lateral offset of the aircraft relative to the RNAV route, is illustrated in Figure 1. When transitioning from one segment to another, there is a course change, and the common waypoint between the segments is generally designed as a flyby waypoint in the terminal area. The projection algorithm computes a nominal turn radius for the flyby based on input parameters for the ground speed and altitude expected for the turn. Projected indicators of aircraft, flying offset of this nominal path, may exhibit slight speed variations. In a previous paper [5], these speed variations were found to be within an acceptable tolerance in accurately projecting the relative location of the aircraft. For flight segments that are connected using an RF leg, aircraft on the RNAV route will follow exactly the turn radius and ground path of the coded procedure. For these circular arcs, nominal speed and altitude parameters are not required, and the projected aircraft indicator will not experience any artificial effects on the speed. An analysis of RPI using RF legs was also presented in the previous paper [5]. This application is shown in Figure 2.

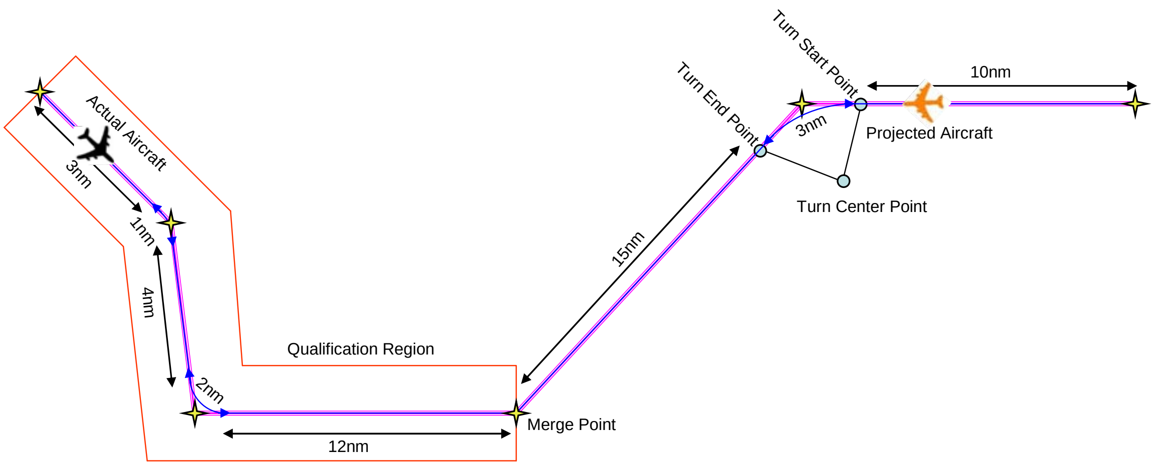

Figure 1. Illustration of RPI Application

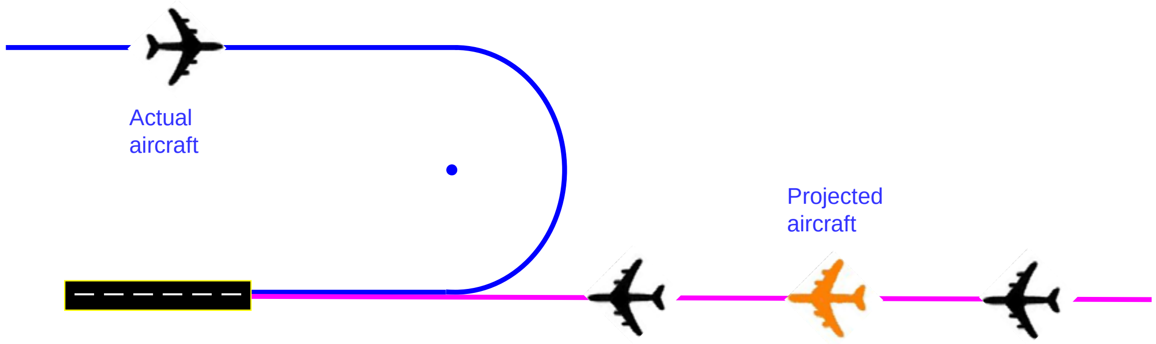

Figure 2. RPI Application with RF Leg

In the tool, a qualification region (terminology borrowed from CRDA) is associated with the RNAV route from which aircraft are being projected. Only aircraft that are within the qualification region will be projected. Additional rules, such as for altitude, heading, runway assignment, heavy indicator, and ground speed, can be applied to determine whether an aircraft qualifies for projection. These rules provide a method for projecting only the desired aircraft, thereby reducing screen clutter. The filtering has been proven effective in the operational CRDA application.

Typically, several different RNAV STARs are used to deliver aircraft to a runway, thus requiring aircraft to merge from multiple flows into a single flow. The structure or topology of the routes prior to a merge makes it challenging for controllers to identify a potential separation problem at a merge point early enough to prevent vectoring aircraft off the RNAV STAR. In addition to the complex topology, control of aircraft along an RNAV STAR is often relegated to numerous controllers—mainly feeder controllers and a final approach controller—throughout its course in the TRACON. In the case of multiple RNAV STARs feeding a single runway, the final controller is normally responsible for the merge onto the final approach. Often there are restrictions on the airspace available to the final controller because of departures, environmental zones, and other factors. When the aircraft are not sequenced prior to the final approach, the controller must often resort to either elongating the final approach or implementing delay vectoring. These control mechanisms are depicted respectively in Figures 3 and 4. While the feeder controllers can assist in sequencing the aircraft for the final controller, it is difficult to accurately determine what control will properly resolve the merge without use of an aid. By using RPI, the feeder controller can have a more accurate and earlier situational awareness of potential merge problems onto the final approach. Earlier identification of merge issues allows the feeder controller to issue speed commands to aircraft to create better sequencing for the final approach controller, thereby mitigating the necessity for elongating the final approach or applying delay vectoring. This results in a reduced workload for the final approach controller and shorter flight paths for aircraft.

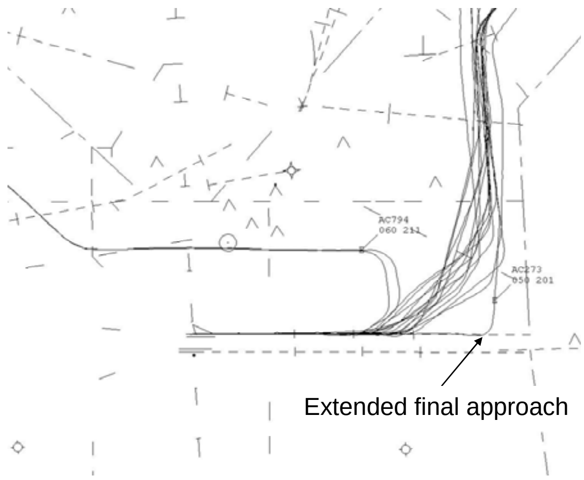

Figure 3. Extended Final Approach

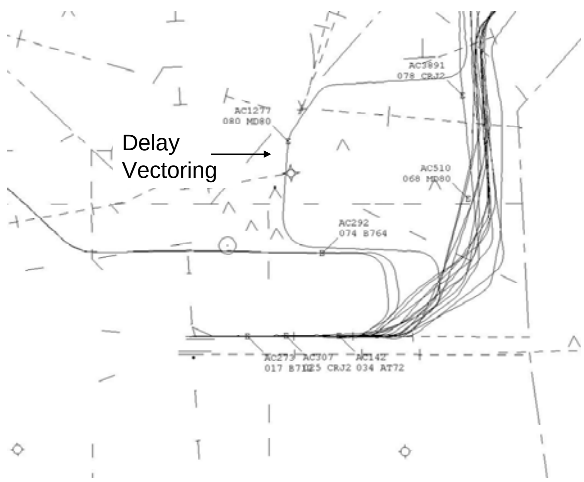

Figure 4. Delay Vectoring

Currently, most RNAV STARS terminate on the downwind. In cases where the application of RPI is used to sequence aircraft merging on final approach towards the Standard Instrument Approach Procedure (SIAP), a nominal path from the downwind to the SIAP must be used.

RPI complements additional proposed enhancements in the P-ATM concept. The planned implementation of runway transitions on RNAV STARS, as designated in the *Roadmap for Performance-Based Navigation* [2], will allow development of procedures that continue to the SIAP. RNAV STARs with runway transitions will allow RPI applications to be adapted accordingly and will no longer rely on nominal paths of traffic overlays for determination of the merge point on final approach for RNAV routes. In the case of improved delivery accuracy and arrival fix coordination in time based metering, the schedule will be more closely met. RPI will allow the controller to monitor the merges in the terminal area with less intervention required to meet the schedule.

A prototype of the RPI application has been implemented in a terminal simulation environment in order to get a better understanding of the site adaptation requirements, to obtain controller feedback by illustrating the use of the aid in different operational scenarios, to explore human factors issues, and to model operational benefits.

Feedback on RPI

Since developing the tool for demonstration and evaluation purposes, MITRE has collected feedback on the use of RPI from supervisors, controllers, and facility managers at Potomac, Atlanta, Chicago, and Houston terminal Air Traffic Control (ATC) facilities. Positive feedback was received on the use of the tool to train controllers for merging RNAV and RNP arrival flows. Furthermore, the supervisors and managers identified two additional traffic management applications that would benefit from using RPI: assisting the TRACON Traffic Management Coordinator (TMC) in flowing and sequencing for runway load balancing, and sequencing flights for runway configuration changes.

One of the responsibilities of the TMC is to make decisions about which aircraft to send to another runway under busy conditions for purposes of runway load balancing. In a typical four corner-post operation, the TMC often has two runway assignment options for arriving aircraft. This would require two adaptations of the RPI application for each corner-post. In the example shown in Figure 7, the TMC is responsible for determining which flow this aircraft (A), arriving from the northwest, should join. By utilizing RPI, the TMC can toggle between these two applications of RPI; one has the

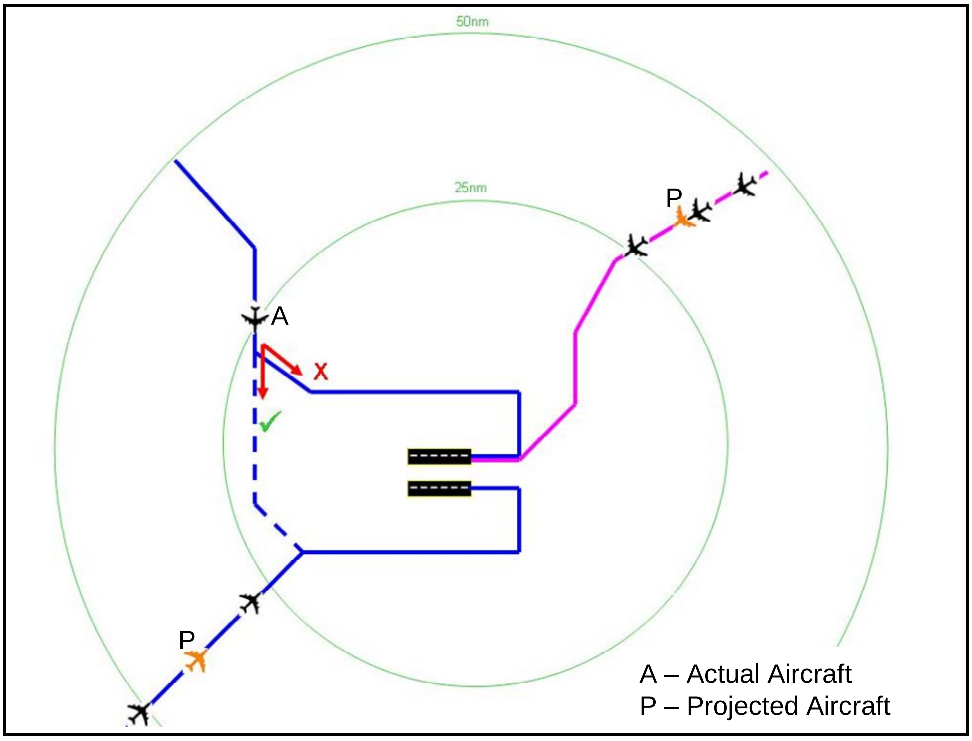

Figure 7. Illustration of TMC Decision to Flow Aircraft Using RPI

aircraft projected onto the northeast flow and the other has the same aircraft projected onto the southwest flow to determine which can better accommodate the aircraft. The TMC identifies the southwest flow as being more suitable for the aircraft and directs the controller to vector and hand off the aircraft to the south. With the assistance of RPI, the TMC is able to more easily identify the appropriate flow, and the resulting merge requires less controller intervention. In this particular example, RPI is configured so that the projected aircraft (P, the lighter aircraft in Figure 7) ties with the actual aircraft (A, the darker aircraft) at the merge. This illustration uses aircraft symbols rather than actual controller radar screen display of aircraft with appropriate controller symbols, leader lines, and data blocks.

Another application of RPI is sequencing aircraft for runway configuration changes. By toggling between different RPI applications, the last expected aircraft for one runway configuration can be identified as well as the sequencing for the new traffic pattern. Figure 8 illustrates the identification of the 'last aircraft' for the west configuration. The two lighter aircraft on the northeast flow are the projected aircraft from the northwest flow. The assumption is that the decision has been made to change the runway configuration and 'last aircraft' has been identified by the feeder controller responsible for that portion of the terminal airspace. After the 'last aircraft' is identified for the west configuration, the RPI application is toggled to the new traffic pattern, and sequencing for the east configuration is determined as depicted in Figure 9.

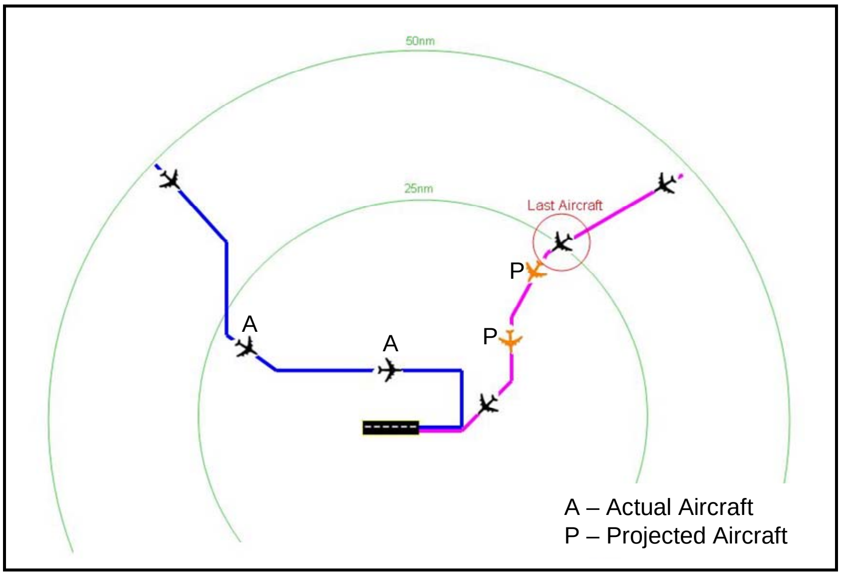

Figure 8. Runway Change Application of RPI: Identification of 'Last Aircraft' in Flow

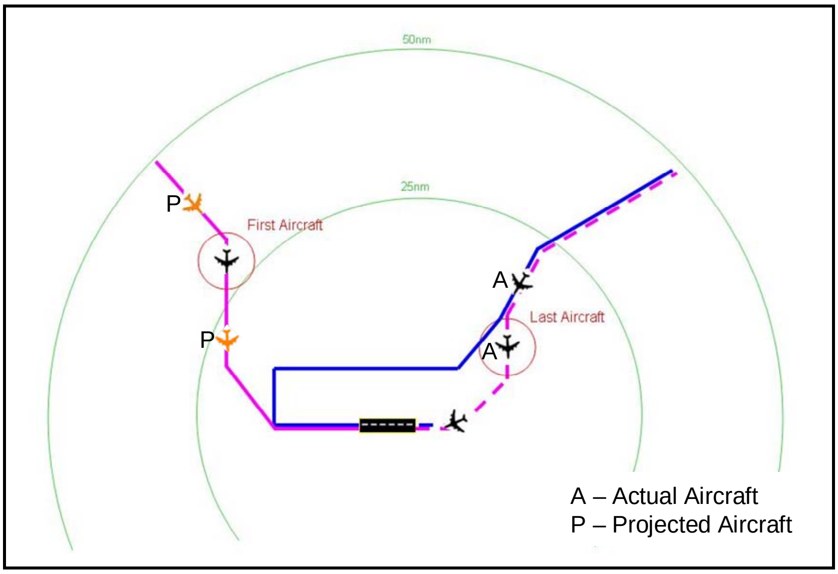

Figure 9. Runway Change Application of RPI: Indication of Relative Sequencing of Flows

The ‘last aircraft’ from the northeast lands to the west, while additional aircraft arriving from the northeast are now projected onto the northwest flow (the lighter aircraft in Figure 9). The controller continues to monitor the projected indicator of the ‘last aircraft’ to ensure that proper time is observed before aircraft begin landing in the new configuration. The controller could continue to use RPI to identify and mitigate sequencing issues much earlier by using speed control while allowing the RNAV aircraft to laterally conform to the route.

In addition to the proposed applications for the RPI application, all existing adaptations and uses of the foundational CRDA application are still encapsulated and can be accomplished using the RPI functionality.

RPI Application for DCA RNAV Arrival Coordination

A specific application for merging and sequencing RNAV arrival flows at DCA was identified by PCT. Figure 10 shows the ELDEE1 and OJAAY1 RNAV STARs at DCA for Runway (RWY) 19 arrivals. On the ELDEE1 arrival, aircraft landing on RWY 19 are to expect vectors to the final approach course after crossing the ELDEE waypoint. Aircraft are to expect to cross ELDEE at 8,000 feet. The expected vectors for aircraft on the ELDEE1 arrival are shown in Figure 10 denoted by the dotted line. The remainder of the ELDEE1 arrival is for arrivals landing on RWY 1, which is not applicable in the configuration proposed for this specific RPI application. Aircraft on the OJAAY1 arrival are to depart the MELOE waypoint heading 325 degrees for vectors to the final approach course. There is an airspace boundary that limits the final airspace, approximately 17.5 nm northwest of the airport because of the proximity of Washington Dulles International Airport (IAD).

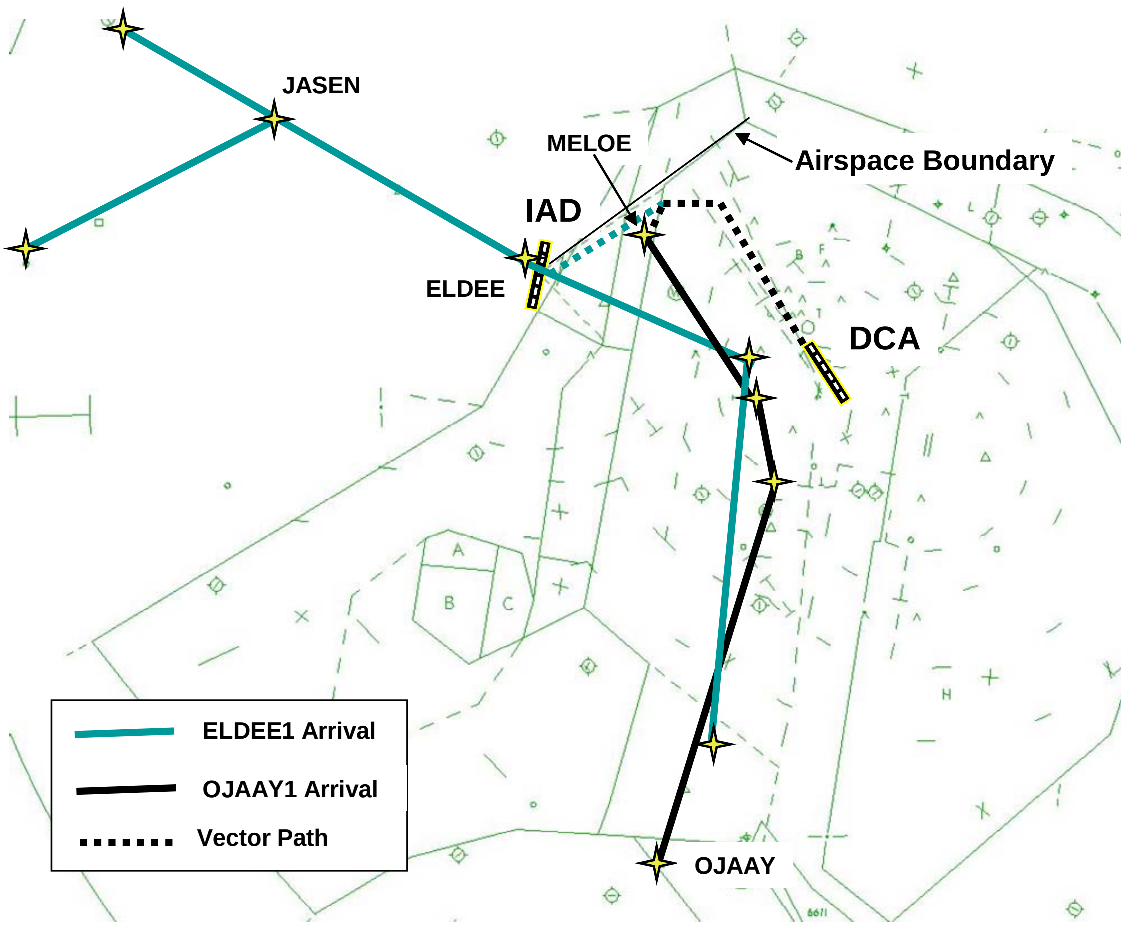

Figure 10. DCA TRACON—ELDEE1 and OJAAY1 Arrivals

Aircraft on the OJAAY1 arrivals are typically given priority at the merge because of the limited controllability prior to the turn towards final approach restricted by the airspace boundary. While OJAAY1 arrivals can be sent east of the airport and brought around to the north downwind to create space for ELDEE1 arrivals, this control method is undesirable due to the longer flight path and is avoided when possible. During periods of lighter traffic, when merges do not require coordination, ELDEE1 arrivals are turned towards the final approach and descended soon after crossing ELDEE. During periods of heavy arrival traffic, the final approach controller frequently has to continue aircraft further along the ELDEE1 arrival than desired as a method of delay vectoring for sequencing. As a gap in the OJAAY1 flow is reached, the aircraft is turned back onto the downwind and then towards the final approach. A 45-minute segment of historic traffic landing on RWY 19 at DCA that illustrates this delay vectoring is shown in Figure 11. This method of achieving sequencing for the merge causes a large number of the aircraft on the ELDEE1 arrival to incur a significant increase in distance flown.

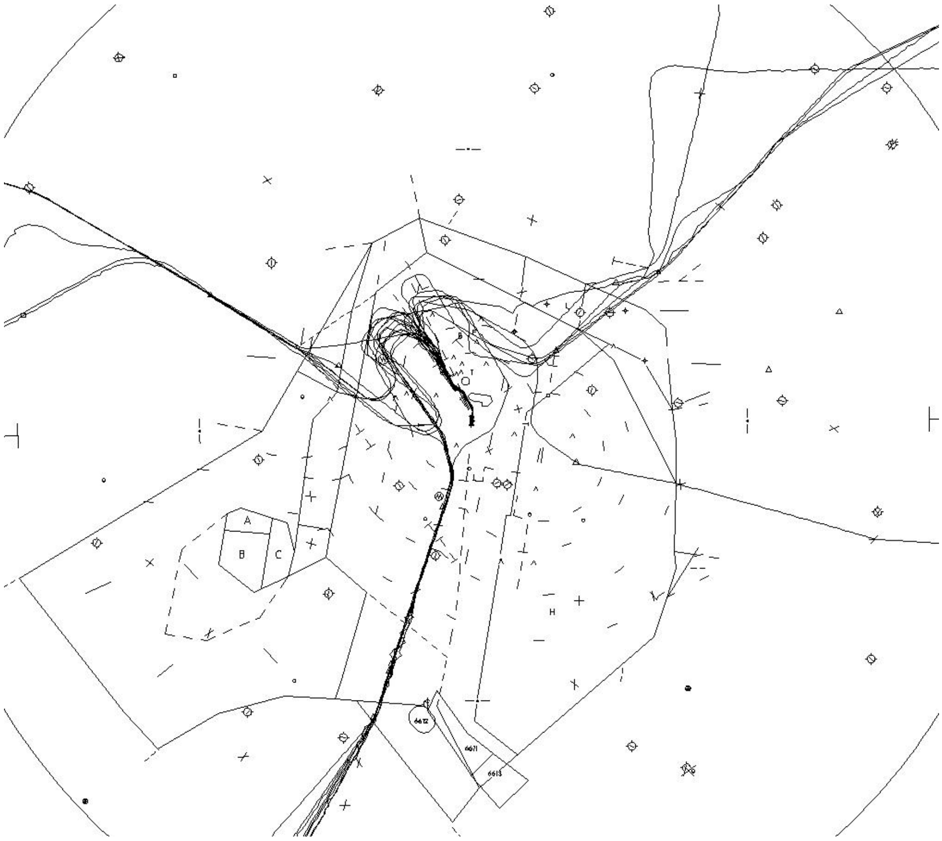

Figure 11. Baseline DCA Traffic

Using RPI, this same 45-minute segment of traffic was reworked by a controller in a human-in-the-loop simulation. The arrival controller observed that it was much easier to recognize the sequence of the aircraft at significantly further distances from the merge point when the RPI aid was present. Using speed control, the feeder controller was able to resolve potential sequencing problems well before the merge point, while leveraging the lateral guidance of the RNAV STARs. With the improved sequencing, the final approach controller was able to turn aircraft on the ELDEE1 arrival towards the final approach soon after crossing the ELDEE waypoint because a gap was created for the aircraft by the feeder controller. Figure 12 shows the reworked traffic segment. The delay vectoring of aircraft on the ELDEE1 arrival is greatly mitigated through the use of RPI for arrival flow coordination.

After reworking the traffic segment, metrics were captured to compare the baseline historic traffic and the traffic controlled using RPI. The distance flown by aircraft on the ELDEE1 arrival was measured from JASEN to a distance 7.5 nm from the runway on the final approach. In the baseline traffic, aircraft on the ELDEE1 arrival flew an average distance of 54.0 nm during this period. In the reworked traffic segment, the aircraft on the ELDEE1 arrival flew an average distance of 38.5 nm. Each aircraft on the ELDEE1 arrival had a reduction in distance flown, with an average of

15.5 nm savings per aircraft through using RPI for arrival flow coordination. The differences in track distances for the OJAAY1 arrivals and the other arrival posts were negligible as expected. In addition to the reduction in distance flown, the flights previously experiencing delay vectoring on the ELDEE1 arrival saw a reduction in flight time of 4.46 minutes on average over the same measurement period.

Historic track data analysis indicates that approximately 20% of the ELDEE1 arrival traffic is subject to delay vectoring during heavy traffic periods as described. This results in 6,000–8,000 aircraft annually that could each realize a significant savings in track distance flown by up to 15 nm and a reduction in flight time of 4.46 minutes.

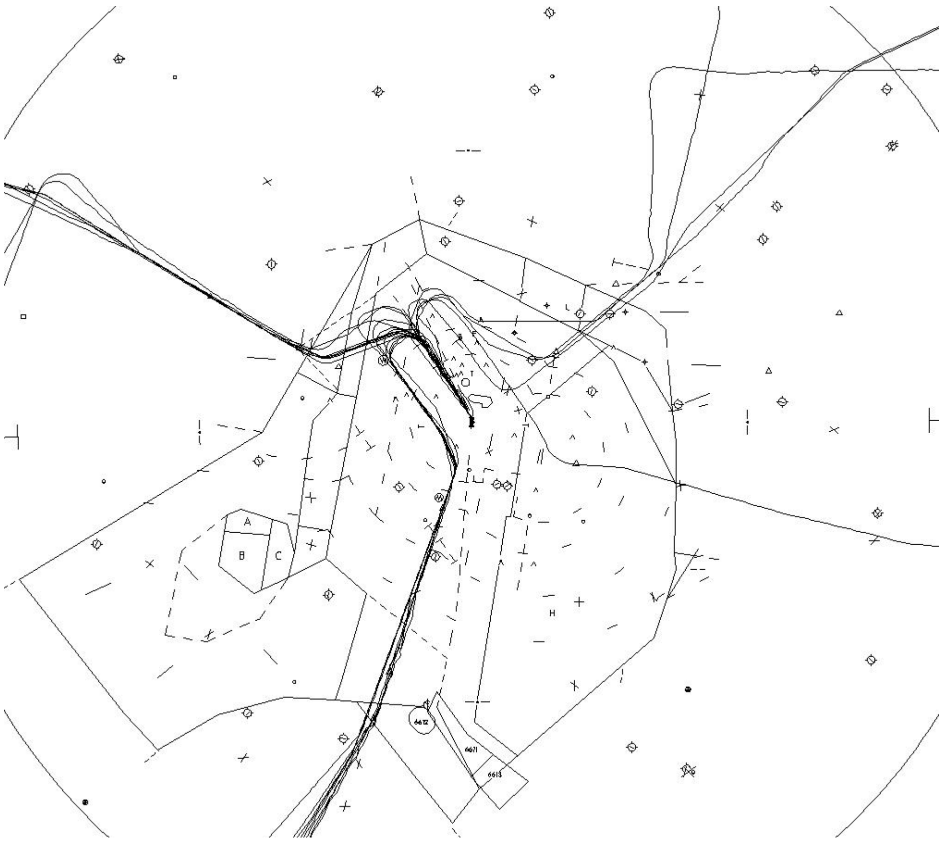

Figure 12. DCA Traffic Reworked Using RPI

Assuming an Airline Direct Operating Cost (ADOC) of $45 per minute, this flight time reduction results in approximately a $1.2–1.6 million reduction in annual cost. These benefits are accomplished while maintaining a constant workload and ensuring safety in the terminal airspace—two key goals of the P-ATM concept [1].

Similar applications for reducing delay vectoring and mitigating elongation of the final approach distance can be applied to numerous other configurations and terminal applications at other OEP 35 airports. A preliminary historic track analysis of a similar application at an OEP top 5 airport shows that an approximately $7 million annual savings in ADOC could potentially be realized through a reduction in delay vectoring and downwind elongation for the merge onto the final approach. This analysis was not coordinated with the site, and further evaluation, testing, and discussion with the facility would be necessary to confirm the benefit. Quantification and verification of specific benefits of RPI adaptations at other airports is a separate analysis beyond the scope of this paper.

Conclusions and Next Steps

Overall, very positive feedback has been received on the use of RPI to assist controllers for merging RNAV and RNP arrival flows. Additional applications that would benefit from using RPI including changes in runway assignments to reduce traffic conflicts and sequencing flights for runway configuration changes have also been identified and will be further explored.

Through human-in-the-loop simulations and analysis of the proposed DCA application of using RPI for merging the ELDEE1 and OJAAY1 arrivals at the final, significant benefits were measured for arrival aircraft. RPI provided the feeder controller with an early situational awareness that allowed speed control to be used to resolve the sequencing at the merge while leveraging the lateral guidance of the RNAV STARs. Aircraft on the ELDEE1 Arrival saw a decrease in distance flown in the TRACON by an average of 15.5 nm and a reduction of flight time by 4.46 minutes each.

MITRE will work with the FAA to move the tool into implementation and will help identify the facilities that will benefit most from the use of this tool in operations and training.

MITRE will continue to pursue development of emerging concepts for managing performance-based arrivals. One such automation concept [6] is an advisory-based application that leverages the Estimated Time of Arrival (ETA) and Required Time of Arrival (RTA) capabilities as shown in Figure 13. Future capabilities, such as Continuous Descent Arrival (CDA) and downlinked weather and intent information, will also be considered and can be used to enhance automation such as RPI and advisory programs. RPI can be used as a ground-based awareness aid complementary to advances in airborne self-separation and other airborne technologies.

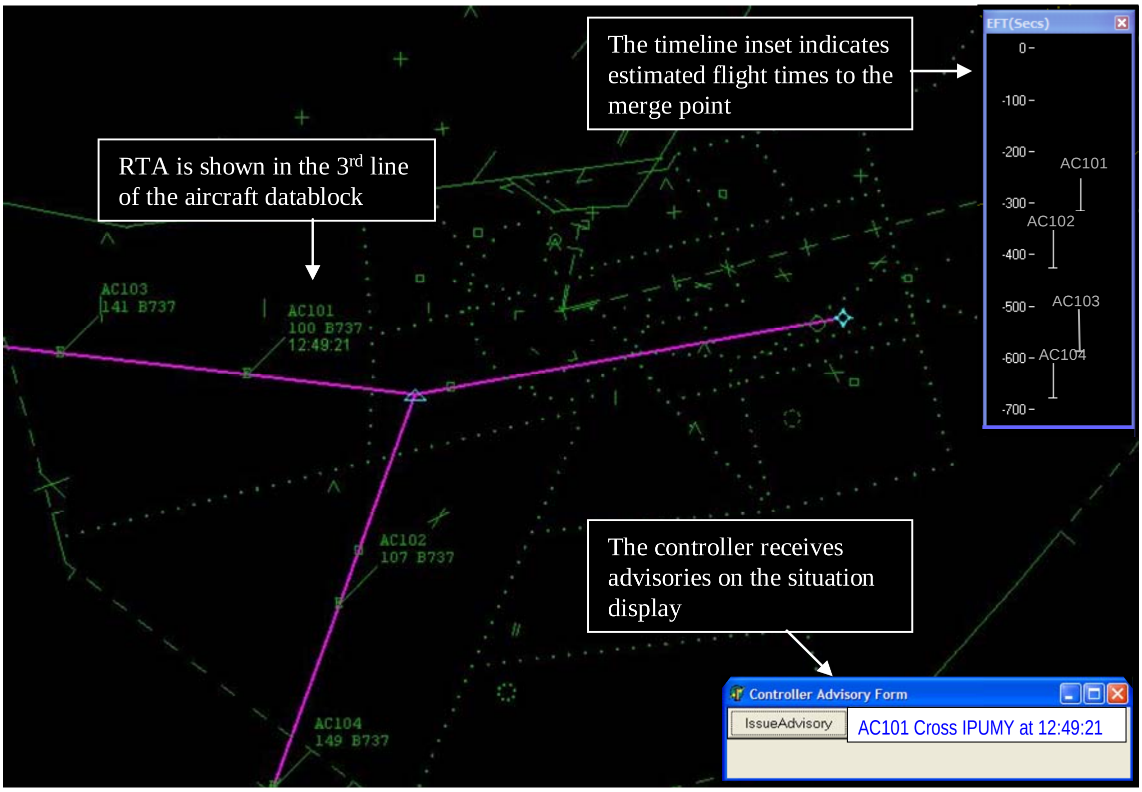

Figure 13. Advisory-Based, Time-of-Arrival Control Application

References

[1] Viets, Karen et al., July 2006, A Mid-Term National Airspace System Concept for Performance-Based Air Traffic Management, McLean, Virginia, The MITRE Corporation.

[2] Federal Aviation Administration, July 2006, Roadmap or Performance-Based Navigation, Washington, DC, Federal Aviation Administration.

[3] Federal Aviation Administration, May 2006, Operational Evolution Plan, Version 8, Washington, DC, Federal Aviation Administration.

[4] Smith, Arthur P. and Thomas A. Becher, October 2005, A Study of SPACR Ghost Dynamics Applied to RNAV Routes in the Terminal Area, Washington, DC, 24th DASC.

[5] MacWilliams, Paul V., Arthur P. Smith, and Thomas A. Becher, October 2006, RNP RNAV Arrival Route Coordination, Portland, Oregon, 25th DASC.

[6] Becher, Thomas A., David R. Barker, and Arthur P. Smith, October 2005, Near Term Solution For Efficient Merging of Aircraft on Uncoordinated Terminal RNAV Routes, Washington, DC, 24th DASC.

Acknowledgements

The authors would like to thank the staff at Potomac Consolidated TRACON for their operational insights, support and feedback. We would like to especially thank Robert Stone and James Bedow for their assistance. We would also like to thank the FAA controllers and supervisors for their feedback and our MITRE colleagues for their guidance.

Keywords

Automation Tools, CRDA, terminal area, situation awareness, Sequencing and Merging Operations

Author Biographies

Paul MacWilliams is a Senior Systems Engineer with The MITRE Corporation's Center for Advanced Aviation System Development (CAASD). He has worked for the last several years on terminal area merging and sequencing R&D at CAASD as well as development of simulation capabilities for the Terminal Area Route Generation Evaluation & Traffic Simulation (TARGETS) application. He has a BSE in Electrical Engineering and a BS in Computer Science from Duke University.

Donald Porter is a Lead Multi-Discipline Systems Engineer, Lead with The MITRE Corporation's Center for Advanced Aviation System Development (CAASD). He had a 24 year career with the FAA including 13 years at Chicago’s O’Hare TRACON and 5 years at the FAA Headquarters serving in the RNAV RNP Division. He is currently working on Terminal Training for Air Traffic, Human-in-the-Loop Simulations for P-ATM, and he chairs or co-chairs the PARC’s RNP Parallel Approach Transition (RPAT) Action Team, PARC's Air Traffic Procedures and Phraseology Action Team, and the PARC's Human Factors Working Group.

Disclaimer