

RNAV Near-Term Terminal Procedures Development

T. Becher and J. Formosa

The MITRE Corporation

Center for Advanced Aviation System Development

1820 Dolley Madison Blvd

McLean VA 22102 USA

E-mail: tbecher@mitre.org, and jformosa@mitre.org

Abstract

Current terminal operations consist largely of vectoring of aircraft by controllers from the terminal radar approach control (TRACON) boundary to the final approach. The nature of vectoring causes large variations in the flight times and paths of aircraft in the terminal area. En route metering functions include planned terminal flight paths. These large variations make it more difficult to meter aircraft efficiently from the en route to the terminal airspace, which often results in aircraft flying extended paths in the terminal area, costing time and fuel. The large variations in flight times also result in poor schedule predictability for users, which can lead to poor on-time performance, disrupted bank schedules, and passenger delays. Defining arrival and departure routes in the terminal airspace can mitigate many of these problems. MITRE's Center for Advanced Aviation System Development (MITRE/CAASD) has been working to develop and assess various near-term terminal area navigation (RNAV) procedures for Philadelphia International Airport (PHL) and Newark International Airport (EWR). These procedures, when implemented, will improve service, reduce required air/ground communications, enhance schedule reliability, improve operational efficiency, reduce flying times, and improve situational

awareness for controllers and pilots. A key component to the RNAV procedure development is the collaborative development of the procedure involving the stakeholders. A repeatable implementation process has been defined for developing RNAV terminal procedures based upon overlays of current flight operations. The process identifies stakeholders, data, steps, and schedules to take a procedure from design to public implementation. To support procedure development, CAASD developed the Terminal Area Route Generation, Evaluation, Traffic Simulation (TARGETS) tool. TARGETS allows procedure designers to use current operations as the starting point for designing an overlay route, to visualize the route, and to evaluate operational aspects of the route. Controllers use the traffic simulation capability to assess impact on current air traffic control (ATC) operations, especially mixed equipage issues. In the paper, we discuss the RNAV procedure implementation process and the tools developed to support the process. Results of applying the process to RNAV procedures at PHL and EWR are presented. Lessons learned are reported and preliminary results on benefits obtained from implementing the routes are also reported.

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Introduction

Current terminal operations consist largely of vectoring of aircraft by controllers from the terminal radar approach control (TRACON) boundary to the final approach. The nature of vectoring causes large variations in the flight times and paths of aircraft in the terminal area. En route metering functions include planned terminal flight paths. These large variations make it more difficult to meter aircraft efficiently from the en route to the terminal airspace, which often results in aircraft flying extended paths in the terminal area, costing time and fuel. The large variations in flight times also result in poor schedule predictability for users, which can lead to poor on-time performance, disrupted bank schedules, and passenger delays. Defining arrival and departure routes in the terminal airspace can mitigate many of these problems.

Area navigation (RNAV) equipped aircraft have the ability to precisely navigate from point-to-point. The majority of aircraft operating at major airports today are RNAV equipped. As carriers continue replacing older aircraft with new equipment, the number of RNAV-equipped aircraft continues to increase. Given the current investment in RNAV equipped aircraft, carriers are interested in getting more return on this investment and seeking new areas of application such as terminal RNAV routes. Since RNAV navigation allows navigation independent of the location of ground-based navigation aids, routes can be designed with other criteria. Operationally, unequipped aircraft (under the assumption that the ratio of unequipped to equipped aircraft is low) would be cleared to fly the same path as the RNAV route through the use of vectors just as today.

There are currently few RNAV routes defined for use in the terminal area environment. For sites where routes have been defined, the facilities developed the routes largely on their own, and each used a different process. As the number of facilities desiring RNAV routes increases, it will be useful to have a set of guidelines in place describing a process for developing RNAV routes so that each new facility will not have to “re-invent the wheel”. Such a process was developed at Philadelphia (PHL) and Newark (EWR) International Airports.

In the remainder of this paper, we discuss the development effort at PHL, the repeatable

implementation process, and the tools developed to support this process. We then include a discussion of efforts at EWR and lessons learned from both route development efforts. Finally, we include a discussion of technology transition and preliminary benefits of implementation of RNAV routes at PHL and EWR.

Philadelphia Route Development

Over the next several years US Airways is forecasting increased domestic hub service and international gateway growth to Europe and the Caribbean at their Philadelphia hub. During these phases of growth, there are plans to maintain a high level of customer service and on-time performance reliability. The Federal Aviation Administration (FAA) with the support of MITRE’s Center for Advanced Aviation System Development (MITRE/CAASD) worked collaboratively with US Airways, the Air Transport Authority (ATA) lead carrier for PHL to develop RNAV routes at PHL. This group put together a team that included themselves and representatives from the PHL TRACON, the FAA Eastern Regional Office, Aviation Systems Standards (AVN), FAA Headquarters, and Jeppesen. This team had two main objectives. The first was to develop and assess various near-term terminal RNAV procedures for PHL. These procedures, when implemented, are expected to improve service, reduce required air/ground communications, increase safety, enhance schedule reliability, improve operational efficiency, and improve situational awareness for pilots and controllers. The team’s second objective was to use the PHL experience to define a step-by-step route-development process that could be repeated at other facilities. Given the large demand for developing RNAV routes, developing a repeatable process that regions and facilities could execute independently was desirable. The process would describe the various tasks, coordination activities, forms to be submitted, and milestones that would be required of any TRACON facility interested in developing RNAV routes. The process would also describe critical path items, task dependencies, and key decision points so that a realistic schedule can be defined.

Constraints in the airspace surrounding the PHL airport result in poor on-time performance and disrupted bank schedules with impact on passengers. These constraints imposed as miles-in-trail

restrictions and holding at the TRACON entry/exit fixes require vectoring of aircraft not only to fly in the airspace where routes are defined, but also to maintain desired separation. US Airways' fleet at PHL is a mix of aircraft types that have sophisticated navigational and Flight Management System (FMS) (hence, RNAV) capabilities. The current fleet is approximately 65 percent FMS-equipped and the percentage is rising as new aircraft are acquired to replace older equipment. US Airways plans to acquire new FMS-equipped Airbus aircraft that will allow the carrier to take advantage of more flexible and efficient terminal RNAV routes. Continental Airlines, the lead carrier at EWR, is between 65-70 percent RNAV-equipped.

Route Definition Process

The initial RNAV route developed for PHL was based upon the desire to overlay the existing OFSHR visual approach to runway 27L with RNAV waypoints so that equipped aircraft could self-navigate all the way to touchdown. The OFSHR visual approach calls for an aircraft to join a radial off the MODENA VOR, which is located northwest of the airport. This allows the aircraft to approach runway 27L at an angle from the south to insure proper radar separation with traffic coming straight in to runway 27R. If the aircraft on the visual approach has the runway 27R traffic in sight when it reaches the 27 DME point on the radial, it is permitted to visually side step over to the runway 27L centerline and land. After overlaying the existing visual approach, the team decided to extend the RNAV waypoints all the way back to the two southern TRACON entry fixes, so that controllers could, if desired, clear an aircraft to the RNAV route immediately after taking the handoff from the en route center. The waypoints defined for the approach were based on historical Automated Radar Terminal System (ARTS) tracking data showing the existing paths that aircraft flew when vectored by controllers.

During development of the PHL procedure, it was found that not all FMS boxes would support more than one procedure to the runway. As a result, the FAA is reevaluating defining routes all the way to the runway. They are considering defining routes to a transition point in space (closer to the runway). This transition point would avoid the limitation of some FMS boxes that allow only one procedure to the runway and promote more flexibility for controllers to assign runways. As part of this reevaluation, the

definition of a transition in the terminal area is being clarified. It will probably be defined as an extension of a STAR to some point closer to the runway where aircraft transition to an approach.

CAASD supported the RNAV procedure development team in several ways. The Terminal Area Route Generation, Evaluation, and Traffic Simulation (TARGETS) software tool was provided to aid in the definition of the proposed RNAV routes, and to perform a medium fidelity flyability check of the routes. Also, PHL used TARGETS during its controller training sessions to assist in familiarizing controllers with the new RNAV routes, and with how the traffic flow might look upon implementation of the routes. Finally, CAASD documented and refined the repeatable implementation process that was developed as a result of the team's effort to define and publish the proposed RNAV routes. The major elements constituting the process used to develop RNAV procedures are outlined below.

Coordination and Collaboration

The right participants are key to the RNAV procedure design process. Each project needs to assemble the proper group of participants. Previous route design efforts suffered from not bringing Air Traffic Control (ATC) and others into the design process early enough. Procedure designers ended up creating a procedure that was not usable to others resulting in rework and longer implementation schedules. The PHL model attempted to include all key players at the start. They included the FAA regional offices, AVN, TRACON/Tower controllers, FAA Headquarters, a lead carrier, Jeppesen, and the engineering support of CAASD. The plan was to evolve this model so that FAA headquarters had a minimal role in the future (if any) and that the engineering support of CAASD was no longer needed. Future projects would use the same process as PHL (tailored to their specific needs) and bring in any additional participants as needed.

Data Requirements

The type of data needed to support RNAV procedure design includes ARTS track data, database of navigation aids, runway information, current procedures, and aircraft performance data for the type of aircraft using the route, wind conditions, and any other airspace or route constraints. ARTS track data allow the procedure planners to use current operations as a starting point for designing the

overlay route by basing the RNAV route on an average track or to compare the designed route with current operations. Current track data also provides input for the determination of TRACON flying times, distances, and estimates of the amount of vectoring that occurs without the implementation of the RNAV route. ARTS data collected after the route is implemented can be compared with previous operations for a benefits analysis. Design of a procedure based upon overlays of tracks ideally means the following. If enough tracks were collected under the operations for which the procedure is being targeted, then the route for the procedure would lie within the two-dimensional region defined by the spatial average of the tracks as the centerline of the region with a 1-3 σ half-width. It is important that designers collect track data that is representative of the operational conditions. Often this poses practical limitations, which is why it is important to have the controllers involved so they can characterize the operations in conjunction with the track data.

Route Design

The design of the route started with early meetings among participants where different RNAV solutions were discussed and then prioritized. The RNAV

route with the highest priority was then designed using TARGETS with initial selection of waypoints, altitudes, and speeds supplied by the PHL TRACON. The team decided to start with the 27L OFSHR Visual that is used during two arrival pushes from the South. This choice would provide a good test bed for refining the process before defining non-overlay routes or more complex arrival routes or routes for use during IFR. Using current operating procedures, an RNAV transition/approach from the TERRI intersection and Cedar Lakes TRACON entry points connecting to the 27L OFSHR Visual Approach was defined. As the project progressed, the name of the RNAV approach changed to the OFSHR Visual Approach. The waypoints were chosen to allow aircraft to make smooth efficient coordinated turns, descents, and slow downs. The route design provided desired separations between departure and arrival paths. TARGETS (discussed in more detail later) was used to convert the hand drawn route on a video map to the latitudes and longitudes for the waypoints. Once the waypoints were determined, the associated altitudes and speeds were entered and the tool was used to adjust the waypoints as needed to meet design constraints. Figure 1 illustrates the OFSHR Visual Approach.

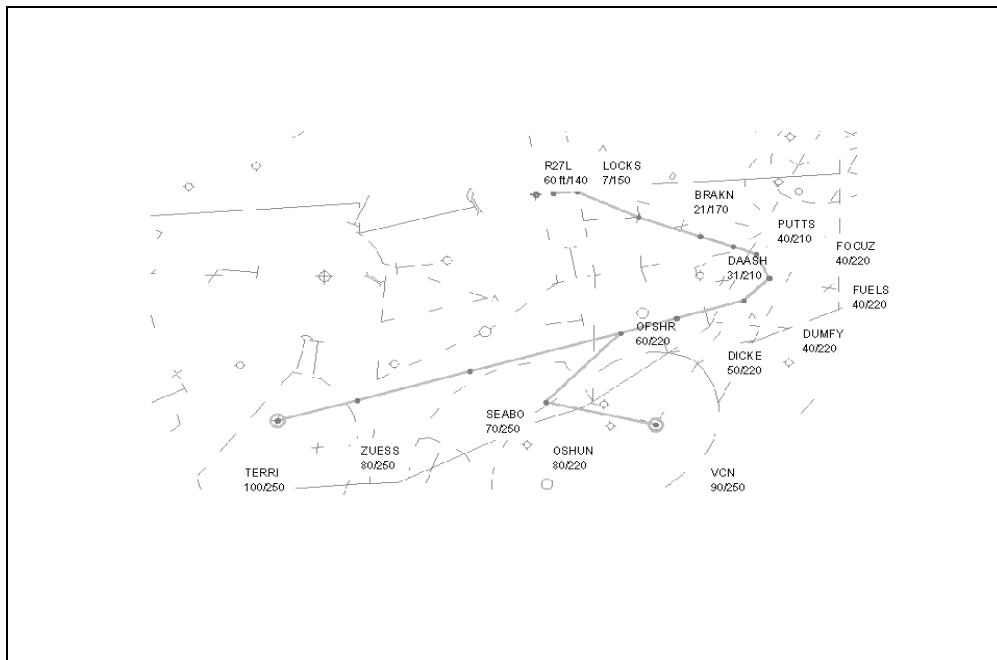


Figure 1. PHL OFSHR Visual Approach

For the OFSHR approach, track data was examined for current operations that reflected aircraft entering from either TERRI or VCN. Since the OFSHR approach was not used that frequently¹, there were not that many tracks available for creating a statistical overlay. Another factor contributing to the difficulty in creating a statistical overlay was the fact that the approach was a visual approach with traffic often cutting the turn from OFSHR to BRAKN (see Figure 1). The existence of intrinsic vectoring (one of the features to be reduced by using the route) also made it inherently difficult to create a statistical overlay. This demonstrated that relying upon controller input to characterize the operation and to aid in waypoint placement is very important.

Flyability of Route

Once the waypoints, altitudes, and speeds of the RNAV route were defined, a medium fidelity flyability check of the route was done. Since it was anticipated that the route would go through a series of early modifications before reaching flight simulator testing, using a medium fidelity flight model to check flyability was cost effective and expeditious. Flyability testing helped eliminate any obvious route problems before the route was tested using the high fidelity flight simulators provided by the lead carrier. Scheduling time on flight simulators is usually competitive and costly. Identifying and correcting route segments that are not flyable during the early iterative stages of procedure development helped procedure designers maintain steady progress without having to wait for other resources to become available. The flyability check done on a route using TARGETS does not preclude the flight checking to be done with high-fidelity flight simulators for a variety of aircraft types by the lead carrier.

High Fidelity Flight Simulation

The lead carrier provided a high fidelity flight simulator to further refine the flyability of the route for particular aircraft types in their fleet under a variety of winds, temperature, and weight conditions. For the PHL effort, US Airways provided flight simulator time to test the route for the Airbus and B737 aircraft types. Additionally, the lead carrier

¹ This was by choice. The procedure designers wanted to start with a simple procedure initially in order to understand the implementation process. One of the primary benefits of the OFSHR procedure was the creation of the implementation process.

used the flight simulator to assess pilot and company acceptance of the approach and procedures.

Controller Familiarization with RNAV Route

Procedure developers can use a tool such as TARGETS to evaluate procedures for all aircraft in traffic scenarios designed around their operations. TARGETS can then be used to familiarize the air traffic controllers with the procedures by allowing them to control traffic over the new routes in a simulation environment. Used in an offline setting, TARGETS is valuable for assisting controllers to become proficient with the use of new routes and procedures. With all routes integrated, controllers can learn to use procedures for both RNAV-equipped and unequipped aircraft.

Live Test of Route

A 60-day live test period is planned to further assess aircraft flyability, pilot issues, and ATC procedures during live operations. During this period, pilot and controller feedback will be analyzed to identify any required or necessary modifications. Upon successful completion of the test period, the lead carrier will continue to analyze the approach and then make the route or Jeppesen special approach plate publicly available for properly equipped users. The procedure can now be used as a special and is ready for going the next steps to become a public procedure.

Terminal Area Route Generation, Evaluation, and Traffic Simulation (TARGETS) Tool

TARGETS is a tool developed by CAASD to help define new RNAV routes and assess alternative route designs for a particular site. TARGETS facilitates the layout and definition of a route structure. It incorporates links to the medium fidelity flight model so that flyability by various categories of aircraft, and under different wind conditions, can be concurrently evaluated. An interactive interface allows online modification of the route data structure. This not only facilitates route design and exploration of related airspace redesign issues, but also provides an opportunity to explore the notion of the dynamic modification of the site route structure for applications such as weather avoidance, path extension, etc. If required, the flight models can be upgraded to higher fidelity.

Route Design Tool

Extensive use was made of TARGETS in developing the waypoints for the RNAV routes. TARGETS functionality includes the display of the site's video map and navigational aids (NAVAIDS) and the ability to create and modify a route by selecting desired waypoints located on the map. The route can be created using a mouse by point-and-click methods to connect these points or the waypoints can be entered directly into a table and then displayed. Speeds and altitudes associated with the waypoints are also entered into a table. Figure 2 is an example of a display from TARGETS showing a user-defined route and ARTS radar tracks both displayed on the video map. The ARTS tracks display helps the procedure development personnel visualize the designed route in relationship to the paths controllers use to vector aircraft.

When a user clicks the mouse on a point on the video map, the latitude and longitude of the point will appear in a table. The user can define speed and altitude constraints associated with any waypoint.

The tool also provides capabilities for users to specify that the next waypoint be located at a specific range and bearing from the current waypoint. Users can toggle display of distances in nautical miles between successive waypoints. There is also a capability to insert and delete waypoints on the route, and to move the location of a waypoint using the mouse to "drag and drop" the waypoint at its new location.

After the route has been created, the tool can be used to run a medium-fidelity check of the flyability of the route. The tool uses the defined waypoints and a bank-angle parameter to create a flight path consisting of a series of flight segments. The segments are classified as either straight segments or turn segments. The segments can then be analyzed based on defined performance parameters such as descent gradient and deceleration rate to determine whether or not the flight path is flyable. This consists of two main tests that are performed on the flight path. The first check examines the initial speed and altitude at a waypoint and the final speed altitude at the next waypoint, and determines whether the



Figure 2. Sample Screen from Route Design Tool

distance between the two waypoints is sufficient to achieve the change in altitude and/or speed that is proposed for that segment. The second flyability check determines where along the current route leg an aircraft should begin to turn toward the next route leg based on the defined bank angle to be used for turns. It then examines successive turns to determine whether the aircraft will be able to complete each turn before having to begin the next turn. A table is created that includes each segment and whether it is flyable. The table is color-coded with flyable segment being green and segments that are not flyable shown as red. Figure 3 illustrates a sample flyability matrix. For the flight segments that are not flyable, the user can then go back and modify the route according to the following options: 1. Change speed and altitude restrictions, 2. Move waypoint locations to achieve greater distance between waypoints, 3. Define less conservative performance parameters (increase descent gradient, decel rate, or bank angle), and check again. After the routes were determined to be flyable, the lead carrier refined the routes by flying the proposed routes in their high-fidelity cockpit simulators. Using TARGETS to perform a flyability assessment while a route is in the early phases provides for efficient use of costly and high in demand resources such as cockpit simulators.

Route Familiarization for ATC Operators

A key component to the FMS/RNAV procedure development is ATC operations. CAASD also provided a human-in-the-loop route-familiarization simulation that allows TRACON and Tower controllers to run desired traffic scenarios using the new RNAV procedure. The familiarization tool can be used to present a real-time simulation of a controller’s radarscope with scripted traffic flying the proposed new RNAV route(s). The tool also has the capability for controllers to interact with various aircraft by issuing vectors or clearing aircraft to fly the RNAV routes. Aircraft can also be cleared to fly direct to a subsequent waypoint on the RNAV route. Interacting with and controlling the simulated traffic enables controllers to familiarize themselves with waypoints along the route and clearances to be given to RNAV equipped aircraft, and to identify operational issues related to the safe use of the procedure. The familiarization tool was used by PHL during controller training briefings.

Lessons Learned

As progress was made toward publication of the PHL RNAV routes, a step-by-step, repeatable



Figure 3. Sample Flyability Matrix

implementation process was developed and tracked to ensure that milestones were met, that tasks were assigned and completed, and that the overall process was critical path observant, streamlined, and efficient. The development of the process uncovered several issues that were incorporated as lessons learned.

For example, the RNAV route began as an overlay to an existing visual approach, and then was extended back to the TRACON entry fixes (TERRI intersection and Cedar Lakes VOR). The issue of how to categorize the proposed route for publication took many weeks of discussions to resolve. Should the route be considered as two separate routes that happened to have some common waypoints? Should the two routes be published as Transitions from different STARS? Could the route be published as a single approach on a single plate? If published as an approach, would clearing aircraft to the approach imply clearance all the way to the runway? And if so, how would this clearance be combined with the requirement that aircraft approaching 27L have traffic for 27R in sight before losing 3 nmi radar separation? All of these issues have to be resolved before publication of the route. The PHL route was published as an RNAV approach, with language on the plate instructing pilots to execute the breakout procedure that was specified on the plate if they didn't have traffic for 27R in sight when they got to a specific waypoint along the route. The approach is a special procedure and will still need to meet TERPS criteria before being made available for public use.

Another issue that was uncovered involved naming of the waypoints along the route. The PHL TRACON staff requested a list of available waypoint names from the Washington En Route Center, and used a subset of those names to define the waypoints for the RNAV route. When the route was finally submitted to Jeppesen for publication as a special approach plate, it was discovered that some of the waypoint names were duplicates of existing waypoints on other RNAV routes. This situation prompted discussion between FAA and Jeppesen personnel regarding improvements that could be made in tracking use of waypoint names, and in reserving names to be used for future RNAV routes. The documented route-development process was also modified as a result of this issue, to indicate that coordination with Jeppesen personnel and checking for duplicate waypoint names

should occur earlier in the process than originally planned.

The PHL route-development effort also revealed some constraints involving the actual FMS avionics. At the time of the route-development, the avionics would only allow a single RNAV approach to be stored for any one runway. This presented a problem for the US Airways fleet, since an RNAV approach had already been defined in the FMS for runway 27L at PHL. US Airways and Jeppesen collaborated to come up with a temporary work-around that would solve the problem, so that the field test of the RNAV route could continue on schedule. A longer-term solution would be handled by the upcoming change 14 to the ARINC 424 standard due in mid 2000.

Newark International Airport (EWR) RNAV Procedure Development

For EWR, the stakeholders designed North and South RNAV arrival routes to runway 29 and a departure route from runway 22. The routes were developed using the same process developed at PHL and using the software support tools developed by CAASD called TARGETS. Figure 4 illustrates the arrival routes prior to some changes made during the procedure design process and after live flight tests. The original waypoint name PRNCE was dropped since a waypoint GRITY already existed. The waypoint CHUMR was dropped completely and replaced with an existing waypoint to the southwest named LIZAH. Using these existing waypoints capitalized upon the existing situational awareness possessed by pilots and controllers. The revised section of the route is indicated with a dashed line in Figure 4 with the original waypoint names marked through with a line. Waypoint duplication has proven to be an important issue to watch during the implementation process. The waypoint LAAZE was found to be a duplicate waypoint three months after live flight testing of the procedure that started in January 2000. It turns out that the name LAAZE was used by a small airport named Farmingdale on a GPS approach. CHUMR will now be the waypoint name.

During flight tests of the procedure, the Tower/TRACON controllers were concerned about how well the aircraft would conform to the 2-D RNAV route because of the proximity of the La Guardia and Statue of Liberty airspace.

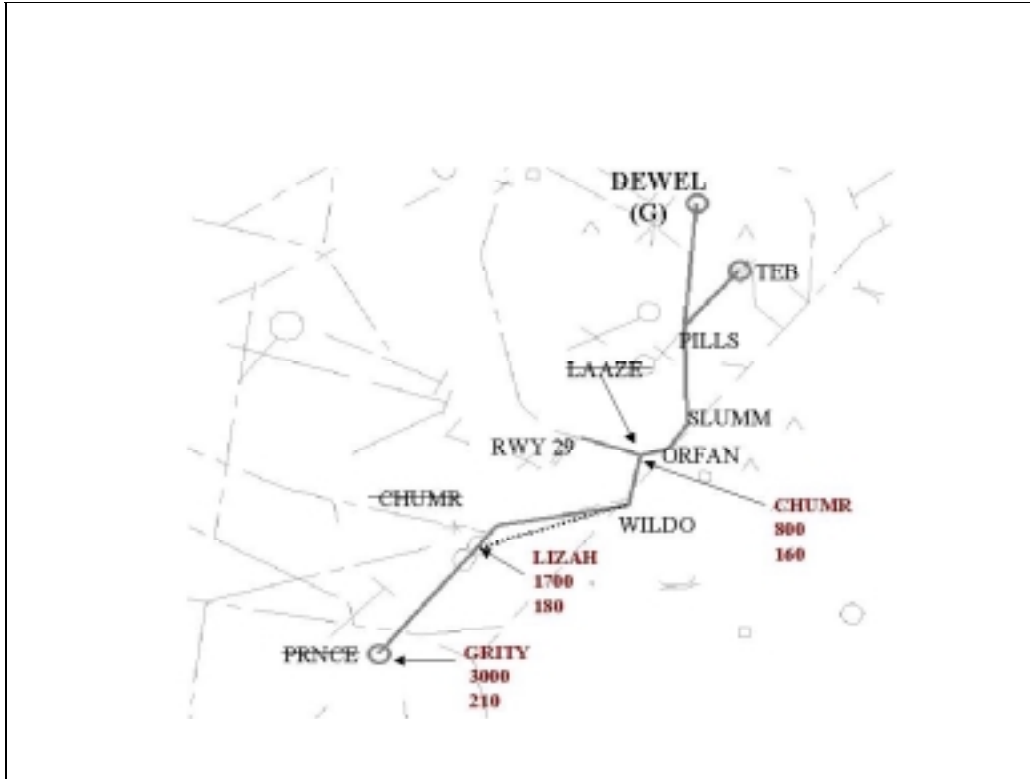


Figure 4. EWR North and South (with iterations) Arrivals to Runway 29

Figure 5 illustrates the difference between the flown track and the planned route. Continental conducted the test flight with a Boeing 737 using a Honeywell FMS. After seeing the live flight test results, controllers were comfortable with aircraft conforming with the route and not getting too close to nearby adjacent airspace.

Benefits

As mentioned earlier, one of the anticipated benefits of implementing terminal RNAV routes is the reduction in required air/ground communications. Preliminary results from PHL have shown that the combined air/ground communications went from 16 (no RNAV procedure) to 6 (using the OFSHR RNAV procedure). It is anticipated that comparable communications reduction will occur for other procedures and other sites.

The magnitude of the total reduction in required air/ground communication is a function of the percent RNAV equipped and the volume of traffic. An order of magnitude calculation was done using a typical

weekday of Enhanced Traffic Management System (ETMS) data for PHL for a 24-hour period. Using the same communication reduction as quoted for OFSHR and for all arrivals, the required communications would go from 14000 (air/ground) to between 8000-11000 (air/ground) for an equipage level of 48 percent (the current level across all carriers at PHL). These back-of-envelope estimates will be validated when additional operational data becomes available.

Technology Transition

There is a large demand for defining RNAV procedures/routes nationally and the FAA needs a means to support this national procedure development. In order to facilitate the procedure/route design process, an implementation process was put together based upon efforts at PHL and EWR. This process will continue to be refined as RNAV procedure development work continues at these sites. In support of this process, the route design and controller route familiarization tool called TARGETS was developed. Technology transition refers to the conveyance of the repeatable process

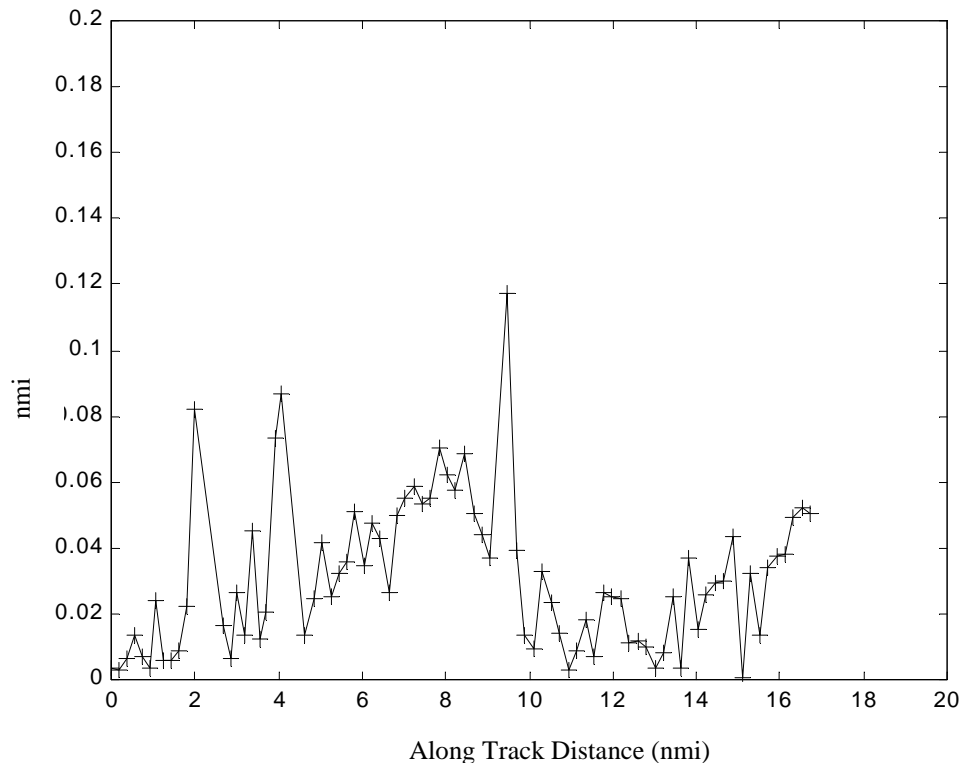


Figure 5. Comparison of Live Flight Ground Track with Planned RNAV Ground Track

and the software tools developed by CAASD to the FAA for support of the national RNAV procedure development. The plan is to use current and future sites to refine and test a reengineered TARGETS running on a desktop computer under Windows. A central requirement is that TARGETS be user-friendly. Once beta testing is complete, CAASD will transition TARGETS to the FAA. The repeatable implementation process will be reflected in a FAA order.

Conclusion

Achieving accurate, predictable, and repeatable flight paths are important to reducing flight time variation due primarily to vectoring in the TRACON. Improved pilot/controller situational awareness, delay reduction, more efficient operations, and reduced required air/ground communications can all be achieved through the implementation of RNAV procedures/routes. Improved position estimation,

path definition, navigational precision, and enhanced user interfaces that are available today on FMS equipped aircraft offer an immediate opportunity to achieve near-term benefits, address user desires, and initiate next generation CNS/ATM concepts.

Advanced RNAV systems are already installed aboard the majority of high performance aircraft. Their current capabilities can be used safely to provide efficiency benefits to the aircraft while easing the workload of the air traffic controller and reducing frequency congestion. Efforts to capitalize on this technology were initiated at PHL where a team was formed to define new terminal RNAV procedures/routes. This team developed a repeatable RNAV implementation process that was used at additional sites. In support of this process, route design and controller familiarization tools were developed with the goal of making the procedure development process easier, clearer, and expeditious. Plans were laid for transferring this process and the

tools to the FAA for national deployment after a period of beta testing using additional sites.

Many important lessons have been learned concerning how to successfully design a procedure that meets the needs of the airspace user, air traffic control facilities, and local communities. The fundamental rule of successful procedure development is that all participants and stakeholders must be involved and committed from the beginning. As procedure development continues to grow and more complex procedures are developed, the methodology outlined here should provide a solid foundation for enhancement.

Biographical Notes

Thomas A. Becher is a Lead Scientist with the Center for Advanced Aviation System Development (CAASD) of the MITRE Corporation. While at CAASD, he has worked on advanced terminal concepts and near term terminal procedures.

Dr. Becher received a Ph.D. in theoretical physics from the University of Houston and an MA in applied mathematics from Indiana University. He is a member of the American Physical Society and IEEE. He has published in Physical Review Letters and Physical Review B.

Jeffery J. Formosa is a Senior Domain Operations Analyst with the Center for Advanced Aviation System Development (CAASD) of The MITRE Corporation. While at CAASD, he has worked as the RNAV Project Lead with respect to RNAV implementation at the Philadelphia, Newark, and John F. Kennedy International Airports. Mr. Formosa is also a CAASD representative to the New York, New Jersey, and Philadelphia Airspace redesign working groups, specifically the RTCA SC-192 working group. Mr. Formosa began his 19 year career in aviation working for US Airways airlines where he held several Air Traffic related management positions, the former as Acting Director of Operations Planning.