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DESIGN CONCEPT AND DEVELOPMENT PLAN OF THE EXPEDITE DEPARTURE PATH (EDP)

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Abstract

Air traffic management decision support tools have shown the capability to increase arrival traffic throughput of congested Terminal Radar Approach Control (TRACON) facilities without significantly impacting air traffic controller workload. NASA Ames Research Center, in cooperation with the Federal Aviation Administration (FAA), is playing a leading role in identifying air traffic management problems, developing and prototyping concepts, and performing field trials for such decision support tools. The Center-TRACON Automation System (CTAS) is a suite of decision support tools developed by NASA Ames Research Center, and is included in the FAA's Free Flight Program. This paper describes the concept and development plan of the Expedite Departure Path (EDP) component of CTAS. EDP is a decision support tool aimed at providing TRACON Traffic Management Coordinators (TMCs) with pertinent departure traffic loading and scheduling information, and radar controllers with advisories for tactical control of TRACON departure traffic. EDP employs the CTAS trajectory synthesis routine to provide conflict-free altitude, speed and heading advisories. These advisories will assist the TRACON departure controller in efficiently sequencing, spacing and merging departure aircraft into the en route traffic flow. The anticipated benefits of EDP include a reduction in airborne delay for departure aircraft, reduced fuel burn and reduced noise impact due to expedited climb trajectories. EDP will eventually share information with both surface and arrival decision support tools to form an integrated decision support system capable of planning, coordinating and executing highly efficient terminal airspace operations.

Introduction

During the first half of 2001, nearly 1 out of 4 flights was canceled, delayed, or diverted in the United States National Air Space (NAS).[1] Among the major reasons were weather, lack of airport capacity, and outdated technologies and equipment of air traffic control (ATC) systems. Demand in passenger air transportation is still growing. Recent forecasts issued by the FAA predict that, beginning in 2004, the number of passengers is expected to grow at a rate of 4.2 percent annually and reach one billion per year by 2013.[2] In an effort to solve the problems of delay and congestion, the FAA initiated a plan to modernize the existing ATC system more than two decades ago. In 1998, the FAA, in collaboration with industry, revisited its approach to NAS modernization and proposed a gradual move from the traditional system of ATC, with heavy reliance on procedures, to a more collaborative system of air traffic management known as Free Flight. NASA and the FAA have worked together on the development of decision support tools (DSTs) for the Free Flight Program. The main objective of such DSTs is to provide controllers with the necessary information to perform their duties more effectively in the operation of the NAS.

NASA Ames Research Center (ARC) has been developing ATC algorithms and DSTs for more than twenty years. NASA ARC created the Center-TRACON Automation System (CTAS)[3], which is a suite of DSTs for both en route and terminal area ATC. CTAS is designed as an open architecture system, so that a new tool can be prototyped and developed without significant changes in the existing software. Among the CTAS tools are the Traffic Management Advisor (TMA), the Passive Final Approach Spacing Tool (pFAST), the Direct-To (D2), and the Expedite Departure Path (EDP) tool.[4] TMA provides en route controllers and traffic managers with an arrival schedule based on highly accurate trajectory predictions, allowing more efficient transition into the terminal airspace around capacity-constrained airports. TMA has been used on a daily basis since it was installed at Fort Worth Air Route Traffic Control Center (ARTCC or Center) in 1996. Since then, the FAA has deployed TMA at 6 additional Centers. pFAST provides TRACON controllers with runway assignments and landing sequences to balance runway loading and reduce inter-arrival spacing. pFAST was shown to reduce terminal area arrival delay and increase arrival throughput by 9-13%.[5] D2 is a DST for en route radar controllers that automates the evaluation and input of route and altitude options. D2 analyzes all aircraft for potential conflicts and for wind-favorable direct routing opportunities. Conflict advisories and direct-to route advisories are displayed on the controllers' display.[6]

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The EDP project was initiated in the late 1990s as part of NASA's Advanced Air Transportation Technology (AATT) program and its operational concept was reported in 1999.[7] EDP is a decision support tool aimed at providing TRACON Traffic Management Coordinators (TMCs) with pertinent departure traffic loading and scheduling information, and radar controllers with advisories for tactical control of TRACON departure traffic. EDP employs the CTAS trajectory synthesis routine to provide conflict-free altitude, speed and heading advisories. Four-dimensional departure trajectories are built for aircraft which have received their initial TRACON track hit.

This paper describes the design concept and development plan of the EDP tool. First, a brief discussion of previous research and development work done on DSTs for terminal area ATC is presented with emphasis on departures. Next, a TRACON airspace and climb trajectories of departure aircraft are described, using Dallas-Fort Worth (DFW) TRACON airspace as an example. In the subsequent section, the paper focuses on the design concept of EDP in five categories: 1) climb trajectory prediction, 2) generation of departure routes, 3) algorithms for sequencing and conflict resolution, 4) departure issues, such as unrestricted climb and noise abatement procedures, and 5) proposed graphical user interface design for departure radar controllers and TRACON TMCs. Lastly, the system architecture of EDP in the CTAS environment and future development plan are presented.

Previous Research and Development

The research and development of DSTs addressing departure traffic management is still immature compared to the development of arrival traffic management tools. The departure-related DSTs currently in operation focus on the management of aircraft departure queues and departure runway load balancing, employing simplistic trajectory models to coordinate departures among airports sharing departure airspace.

Eurocontrol developed an integrated ATC simulation environment named PHARE (Program for Harmonized Air Traffic Management Research in Eurocontrol) and performed a demonstration in 1998.[8] The Departure Manager (DM) component of PHARE organizes the terminal area airspace by optimizing the departure sequence and planning climb trajectories of aircraft before takeoff. While flights are in taxiing phase, the controller has two options: 1) select the best climb trajectory or 2) follow the standard climb procedure defined in SID (Standard Instrument Departure) initially allocated. Four-dimensional trajectory prediction and conflict probe functionalities are utilized in finding the best trajectory among all the possible climbing procedures for pre-departure flights. The DM approach of optimizing departure profiles prior to takeoff requires knowledge of aircraft departure time well in advance. This approach is practical for the departure slot-driven system in place in Europe, but is not easily adapted to the first-come-first-served queuing system in place at most U.S. airports, where departure time is difficult to predict to the level of precision required for optimal trajectory planning.

NASA, in coordination with FAA, is developing the Surface Management System (SMS), a DST to help controllers and air carriers collaboratively manage the movements of aircraft on the surface of busy airports.[9] SMS is designed to perform near-term prediction of departure sequences, times, queues, and delays for each runway to support tactical control of surface movement. Proposed future capability of SMS includes interoperability with a departure DST such as EDP and TMA.

NASA has performed extensive research on DSTs to assist terminal area traffic controllers in the management and control of arrival traffic. NASA developed the concept of the Final Approach Spacing Tool (FAST) in the early 1990s. Later, a prototype system known as passive FAST was developed and operationally tested at DFW TRACON.[10] Passive FAST advises landing sequence and runway assignment to balance runway loading and reduce inter-arrival spacing. Further NASA efforts are focused on the development of an enhanced version known as active FAST (aFAST).[11] Active FAST generates tactical heading and speed advisories (in addition to runway assignments) to further reduce inter-arrival spacing and increase arrival throughput. Active FAST's sequencing and deconfliction algorithm was designed generically enough, so that it can be applied for scheduling departure traffic.

NASA first outlined the operational concept of EDP through a series of operational scenarios documented in Reference 7. Issues of unrestricted climb and merging of multiple aircraft over a departure fix were identified through these operational scenarios. The scenarios illustrated how the new operational concept could safely and optimally expedite the climb of departure aircraft, and merge departures into the en route streams through the use of speed, heading, and altitude advisories.

TRACON Airspace and Departure Trajectories

After a pilot receives a clearance to takeoff from a local controller in the ATC tower, a departure controller at the

TRACON facility assumes control of the aircraft. The TRACON airspace is divided into sectors assigned to multiple controllers. Departure controllers are responsible for separating, sequencing, and merging departure aircraft. The TRACON departure controller provides pilots with heading, speed, and altitude advisories within his/her designated airspace to achieve safe, manageable and expeditious departure flow. Each departure controller's responsible airspace boundaries and altitude ranges vary depending on the airport's runway configuration. Figure 1 depicts the DR1's (i.e., Departure Radar 1 controller) delegated airspace for the north flow configuration (aircraft departing to the north) for DFW TRACON, with runways at the center of the figure.[12] Numbers shown in a fraction form tells the range of airspace in terms of flight level (FL). For example, DR1's delegated airspace close to the runways starts from the surface up to FL80 (i.e., 8000 ft MSL) in a north flow configuration, whereas it covers the altitudes between FL130 and FL170 in a south flow configuration (not shown in the figure).

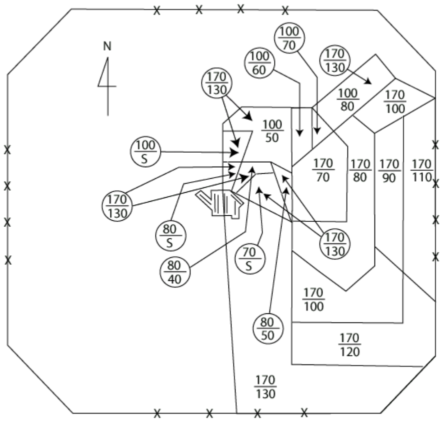

Figure 1. DR1 (Departure Radar 1) Airspace in North Flow Configuration (DFW)

SID procedures along with the terms specified in the Letter of Agreement between Center and TRACON facilities determine high-level heading and altitude restrictions on departure paths. The departure route of an aircraft extends through a departure fix specified in the SID procedure in most cases. Similar to arrival metering fixes, which enable approach controllers to meter inbound traffic, departure fixes are used to separate outbound streams and meter departure aircraft efficiently into an en route traffic stream, especially during peak departure operations. Several departure fixes are grouped into a departure gate. Figure 2 shows the diagram of DFW TRACON with the arrival and departure fixes marked. By having arrival and departure fixes separated as shown in the diagram, controllers can manage both arrival and departure flows with minimal interference.

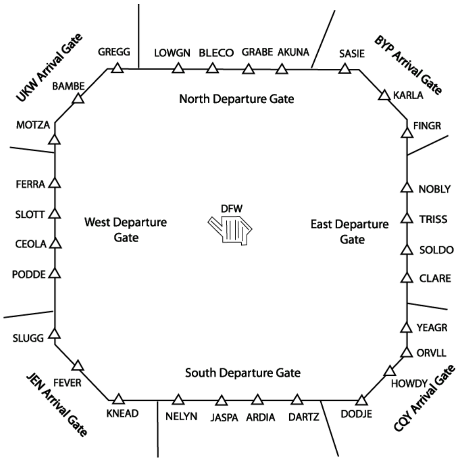

Figure 2. Fixes and Gates (Arrival and Departure) of DFW TRACON

While TRACON airspace is designed to procedurally separate arrival and departure traffic, efficiency may be compromised. For example, aircraft A in Figure 3 is an arrival aircraft, which has entered from the HOWDY arrival metering fix in the southeast corner of DFW TRACON and is assigned to land on runway 17C. Aircraft B is a departure aircraft, which has departed runway 17R heading for the SOLDO departure fix of the East departure gate. The projected routes of two aircraft are intersected in the vicinity of a waypoint called DIETZ. To ensure required separation in today's environment, the air traffic controller directs aircraft A to descend and maintain 11,000 ft MSL while aircraft B is directed to climb and maintain 10,000 ft MSL. Once the courses of the two aircraft are divergent, the departure aircraft is allowed to continue climbing to a higher altitude and will be handed off to a sector controller at the Center. Figure 4 shows the actual altitude and true airspeed change of an MD80 jet recorded along its flight path during the course of ascending. The rate of climb slows down around 10,000 ft MSL while the aircraft accelerates its airspeed to a climb speed.

With current radar control procedures, even when aircraft are far apart, controllers do not generally anticipate that the departure aircraft will cross behind or climb above the arrival aircraft prior to the route intersection. As outlined in the following section, EDP will provide departure controllers with the necessary information to expedite the climb of departing aircraft where conflict with arrival aircraft is not predicted.

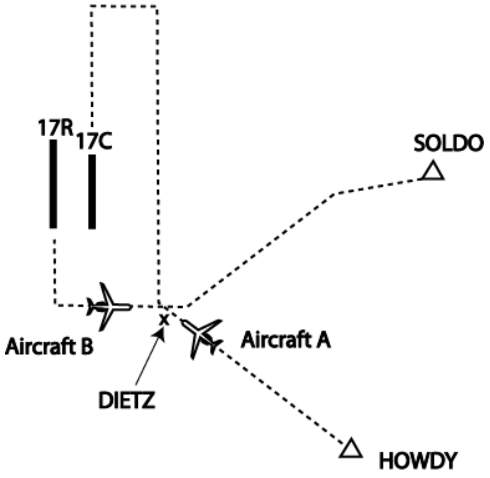

Figure 3. Intersecting Arrival and Departure Aircraft

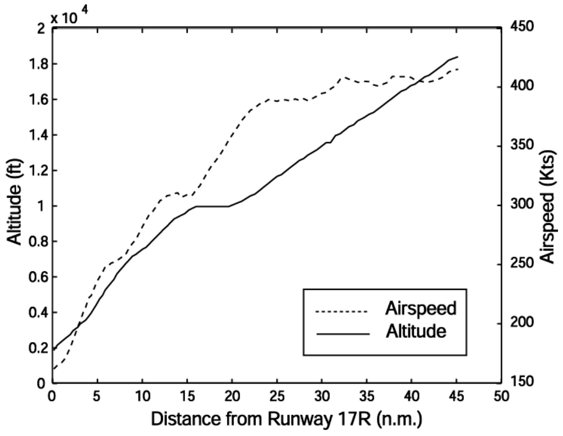

Figure 4. Altitude and Airspeed Change of a Jet Inside TRACON

Design Concept of EDP

EDP is a ground-based DST intended to provide optimized schedules and advisories to departure controllers, while meeting constraints from flow control and ensuring the efficient and safe flow of outbound traffic from airports into en route control sectors. EDP is designed to provide climb profiles as well as lateral path guidance that should allow efficient, uninterrupted climb-out, and safe merge of the flight into en route traffic.

The goal of EDP is to provide automation that will allow controllers eventually merge traffic directly into en route streams as opposed to funneling them through a departure fix. As an interim step, the system is being designed to operate within the current model. This section describes the key concepts and functionalities of EDP.

Climb Trajectory Prediction

It is essential to have an accurate and reliable trajectory synthesis capability in order to perform the sequencing and scheduling functions required to manage departure aircraft safely and efficiently. The accuracy of estimated times of arrival (ETAs) at departure fixes and other waypoints along the route will be the key metric of performance and reliability for EDP. For example, the amount of time an aircraft should be delayed on the ground cannot be computed with any degree of precision if the airborne aircraft's estimated flight time to departure fix is not accurate. Likewise, in a scenario where both arrival and departure aircraft's paths are crossing at some point in the future, the accurate prediction of ETAs and altitudes of two aircraft at the crossing point is essential to determine if an unrestricted climb can be safely advised.

EDP employs the CTAS Trajectory Synthesizer (TS) module to generate climb trajectories. The TS module uses a point-mass aircraft model to generate climb trajectories using aircraft state, wind aloft, speed and altitude restrictions, temperature and pressure profiles, and a series of waypoints depicting the intended route of flight. The outputs of the TS analysis are 4-dimensional (i.e., x, y, h, and time) aircraft state information at closely spaced discrete points along the trajectory. The accuracy of climb prediction depends on the aircraft's aerodynamic model data, weight, and thrust as can be seen in the climb rate equation (Equation 1).

$$\frac{dh}{dt} = V\left[\frac{(T-D)}{W} + \frac{dV/dt}{g}\right] \qquad (1)$$

where
h = Altitude,
T = Thrust,
D = Drag,
W = Weight (assumed constant),
V, dV/dt = Velocity and acceleration along the flight path, respectively
g = Gravity constant.

In the above equation, weight and thrust of the aircraft are two very important factors in the computation of climb rate. Currently, the thrust is calculated from the aircraft engine properties, and a typical takeoff weight for the aircraft type is used for the weight of the aircraft. The accuracy of real-time estimation of thrust and weight will significantly affect the accuracy of the trajectory prediction and further affect the overall performance of EDP.

Generation of Departure Routes

To perform scheduling, merging and conflict resolution, EDP must generate a set of trajectories for each aircraft that represent the group of all likely flight paths for that aircraft. The route analyzer (RA) produces this set of trajectories by constructing each aircraft's nominal route using airspace-specific adaptation and perturbing this route to generate the entire set. The nominal route starts at the aircraft's current position and ends at a departure fix or an en route fix along the aircraft's flight plan. A departure fix is assigned to each aircraft when either the flight plan route or Host computer converted route is received.

To separate and sequence aircraft in compliance with the departure procedures, controllers vector aircraft along a series of trajectory segments. A typical departure trajectory consists of the following segments: INITIAL (or UPWIND), CROSSWIND, DOWNWIND (or RADIAL_INTERCEPT), and RADIAL. Figure 5 shows an example of the departure trajectory segments.

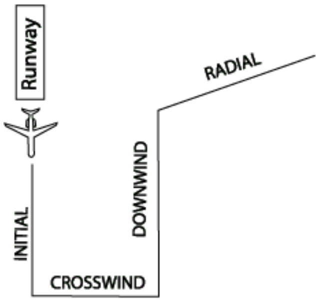

Figure 5. Departure Trajectory Segments

The route is constructed beginning with the determination of an aircraft's analysis and route segment categories based on the aircraft's flight plan and current state. Among the criteria used for determining these categories are origin airport, airport configuration, engine type (e.g., JET), current departure trajectory segment, and assigned departure fix. Each category defines a detailed instruction for route building for that particular situation. Table 1 shows an example of a category definition for a given analysis category (e.g., DFW_JET_NOBLY_INITIAL) and Table 2 shows a route definition associated with a route segment category (e.g., DFW_NOBLY). In these examples, the **initial_route** in the category definition instructs the route analyzer to begin constructing the route by intercepting the crosswind route segment (found in the route definition) starting from the current position of the aircraft. The table of the route definition dictates the segments following the initial route segment until the stop point, which is a departure fix (NOBLY) in this example.

Keyword	Value
INITIAL_ROUTE	intercept_crosswind_route
START_POINT	current_location
STOP_POINT	departure_fix

Table 1. Sample Category Definition (DFW_JET_NOBLY_INITIAL)

Segment	Waypoint 1	Waypoint 2
INITIAL	17R	XWND.1
CROSSWIND	XWND.2	DWND.1
DOWNWIND	DWND.1	FNFST.064
RADIAL	FNFST.064	NOBLY

Table 2. Sample Route Segment Definition (DFW_NOBLY)

In addition to the previously discussed route building information, each category definition prescribes a set of available degrees-of-freedom (DOFs), which define the set of all likely trajectories for the aircraft. The DOFs for departure routes include: crosswind extension, fanning, speed adjustments, and altitude changes (see Table 3). Once a nominal departure route is completed, all likely perturbations of the nominal route are constructed by applying DOFs to the route. Each DOF can further specify both slow and fast limits. Figure 6 shows an example variation of the route shown in Figure 5 produced by applying the **crosswind_extension** and **fan_from_waypoint** degrees-of-freedom.

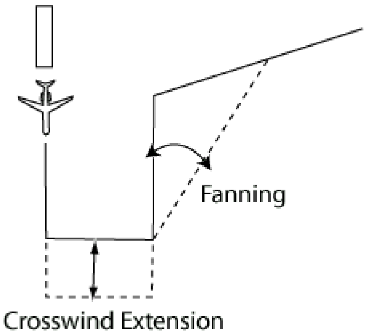

Figure 6. Waypoint Fanning and Crosswind Extension Degrees-of-Freedom

Lastly, RA employs TS to compute the four-dimensional trajectories for the set of all likely routes.

Degree-of-freedom	Criteria
	Values: fast(slow)
crosswind_extension	set_crosswind_extension
	5.0 n.m. (9.0 n.m.)
fan_from_waypoint	fan_to_waypoint
	radial_intercept_waypoint (FNSLW.064)
speed (350kts)	distance_value
	25.0 n.m. (20.0 n.m.)
altitude (15000 ft)	altitude_waypoint
	DINIT1 (BRADBY)

Table 3. Sample Route Degrees-of-freedom

EDP Scheduling Algorithm

The key functionality of EDP is to schedule departure traffic by sequencing aircraft flying on the trajectory segments and resolving future conflicts among them. EDP employs the same concurrent sequencing and conflict resolution algorithm developed for FAST.[11] The sequencing portion of this algorithm combines the precise 4D trajectory prediction of the TS and fuzzy reasoning to determine the order in which aircraft should fly over a specified scheduling constraint (i.e. runway threshold for arrivals or departure fix for departures). The sequencing task is accomplished in two steps: ordering and merging. Ordering determines the relative sequence of aircraft on a particular trajectory segment and merging determines the order of aircraft as 'ordered' flight segments converge to a common flight segment. The conflict resolution component of the concurrent algorithm predicts possible conflicts between aircraft and adjusts the trajectories via additional application of the aforementioned DOFs. The resulting trajectories are employed by the sequencing component to determine the 'spatial acceptability' of a given sequencing option. The outcome of the sequencing and conflict resolution is a set of efficient, conflict-free trajectories for all aircraft constrained to the scheduling needs of the airspace operators (i.e., controllers and TMCs). From this set of trajectories, EDP extracts the Scheduled Time of Arrival (STA) for each aircraft at the scheduling constraint (departure fix), and presents controllers with tactical advisories to assist in meeting this STA without conflict or excessive workload. The detailed description of the fuzzy reasoning-based sequencing algorithm can be found in Reference 13.

Spacing aircraft on different routes flying toward a common departure fix and merging into an en route stream is an important task of EDP's scheduling algorithm. In the existing operational environment, controllers restrict aircraft by altitude and speed and/or use miles-in-trail (MIT) restrictions to ensure safe separation at the airspace boundary and to meet traffic load restrictions of downstream facilities. MIT restrictions have at least two inefficiencies regarding departure operations. First, it is difficult for controllers to meet MIT restrictions when aircraft are converging on the MIT location (e.g., departure fix) from multiple origin airports or from different controllers. This leads to last-minute sequencing decisions, increased workload and inefficient airspace usage. Consequently, larger restrictions than necessary are often imposed to assure the desired flow at the fix is achieved with acceptable workload. Second, controlling aircraft by altitude and speed may prevent the pilots from performing unrestricted climb, especially when merged aircraft do not have sufficient spacing and the trailing aircraft is at a lower altitude than the leading aircraft. (The scenarios of these situations are detailed in Reference 7.) EDP's scheduling algorithm considers the situation concurrently and finds a conflict-free solution to present to the controller well in advance of the restriction location. Compared to the merging of arrival traffic streams, merging aircraft on departure trajectories seems to be a bit simpler problem in terms of computational complexity. This stems from the fact that departure operations are divergent while arrival operations are convergent and there is generally more demand in the runway threshold during an arrival rush than on a departure fix during a departure push. Figure 7 illustrates the merging of four aircraft departing DFW and DAL (Dallas Love Field) airports over a departure fix (marked with a triangle). Aircraft A and C are on the flight segment being merged (RADIAL) and Aircraft B and D are currently on their RADIAL_INTERCEPT flight segments. Reference 11 provides additional details of the merge process in this example.

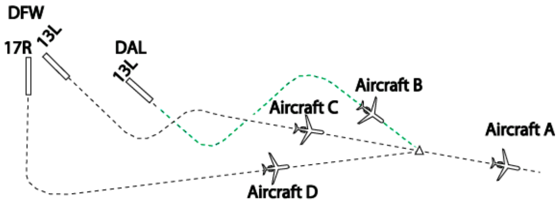

Figure 7. Merging Over a Departure Fix

Issue of Unrestricted Climb

In the process of procedurally separating departure and arrival streams in the terminal area, it is often necessary to restrict departure aircraft altitude on climb-out until the departure aircraft is clear of the arrival traffic stream. A typical restriction on departure aircraft's climb profiles observed in DFW TRACON airspace is that aircraft are initially allowed to climb to 10,000 ft MSL and wait for a clearance to climb to the next altitude, for example, 17,000 ft MSL. The main purpose of this altitude restriction is to procedurally separate climbing departure aircraft from descending arrival traffic; departures are, by default, separated from arrivals. Permitting departures to climb to their cruise altitudes without any intermediate altitude restrictions would be desirable in terms of efficiency, congestion, and in some cases noise impact.

Observations of live air traffic within DFW TRACON airspace suggest that, regardless of the absence or existence of arrival traffic in the vicinity of departure aircraft's routes, most departure flights have shown a similar pattern for their climb profiles. (Readers are referred to Figure 4 to see the pattern.) This observation suggests that controllers are not expediting climbs for departure aircraft when they could safely do so. Advisories based on EDP's accurate departure trajectory prediction and conflict prediction algorithm will enable controllers to allow more aircraft to climb safely without restrictions. By explicitly accounting for uncertainties in trajectory prediction for both arrivals and departures, EDP will advise unrestricted climbs for departure aircraft that meet a predefined criterion for low conflict probability and/or predicted minimum separation.

A typical day of DFW TRACON live traffic data was recorded and analyzed to assess the potential for unrestricted departure profiles in DFW TRACON airspace. For simplicity, a flight was considered eligible for unrestricted climb if lateral separation from all arrival aircraft exceeded three nautical miles at all times. Only East gate departures in a south flow airport configuration were considered in the analysis. Figure 8 shows the number of departure flights counted for each hour and the number of flights considered eligible for unrestricted climb. Roughly half (49%) of the flights were considered to be eligible for unrestricted climb.

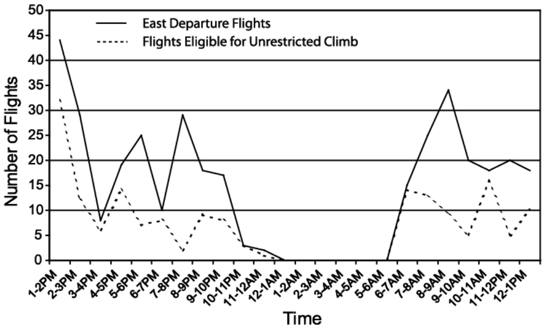

Figure 8. DFW East Departure Flights (data were not available during 2:30 – 6:00 AM)

To illustrate the difference in vertical profiles between restricted and unrestricted climbs, four aircraft heading for TRISS departure fix were selected and their climb profiles were compared. Figure 9 shows the climb profiles of two restricted climbs and two unrestricted climbs in a heavy traffic hour. AC1 and AC2 maintained the altitude of 10,000 ft MSL for about one minute before they resumed climbing, whereas AC3 and AC4 did not slow their ascent at 10,000 ft MSL. It is interesting to notice that although AC1 and AC4 departed only 16 minutes apart, they had shown significantly different climb profiles.

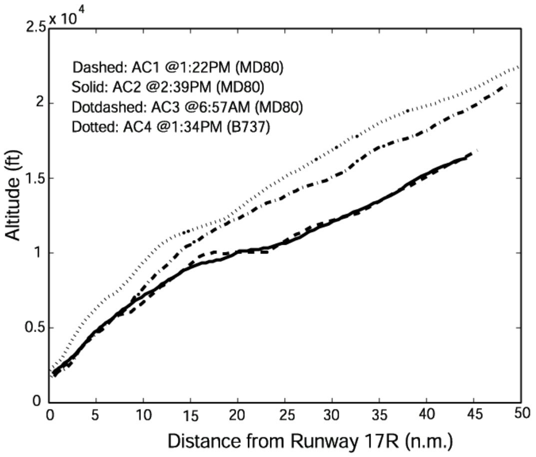

Figure 9. Restricted vs. Unrestricted Climb Profiles

Integration with Noise Abatement Departure Procedures

The noise impact on the community caused by air transportation has received increased attention recently, at significant cost to the FAA and municipalities.[14] Recent studies have focused on analyzing aircraft noise from different perspectives and finding solutions to reduce the noise impact on heavily populated areas around major airports.[15,16] Further efforts to reduce noise impact by means of enhanced operational noise abatement procedures would be beneficial to both communities and the air transportation industry. Visser, et al. developed a concept to design noise abatement procedures for departure flights at any given airport. The proposal combines a noise model, a geographic information system, and a dynamic trajectory optimization algorithm.[17] Augustine, et al. reported in their benefit analysis of noise mitigation via ATM operational procedures that DSTs can provide substantial benefits at airports where noise impact is an issue.[18] EDP is an ideal platform for the efficient execution of the noise abatement procedures described in the above studies. Site adapted noise abatement departure procedures can be utilized when necessary. Furthermore, by computing the noise impact of route perturbations during the scheduling process, tradeoffs in DOF usage can be employed to achieve conflict free trajectories with the lowest community noise impact possible given operational safety and throughput requirements. Details of the design concept of this functionality will be refined and reported as work continues.

EDP Graphical User Interface

EDP will provide TRACON air traffic controllers with tactical advisories on their displays, so that controllers can issue advisories to the pilots in a timely manner. Heading, speed, and altitude advisories in textual format will be displayed under the current Full Data Block (FDB) for each aircraft. In addition, graphical symbols will be displayed at locations where controllers are to issue the commands. Figure 10 shows an example of advisories for three departure aircraft with heading, speed, and altitude advisories. For example, the controller is directed to issue an altitude advisory for DAL568 to ascend and maintain 17,000 ft MSL when the aircraft's target reaches the diamond symbol (yellow). Similarly, the aircraft AAL2370 and AAL760 will be advised to increase the speed to 350 kts and change the heading to 80 deg respectively when the aircraft's targets reach the circle (red) and triangle (blue) symbols respectively. The color codes and shapes of the advisories will be consistent with those of the aFAST tool.[19]

The TMC will view the planview graphical user interface, which displays timelines in addition to the information displayed to the controllers. The timelines display each departure aircraft's predicted ETA and STA at the departure fix. The timeline enables the controller to monitor the load at departure fixes and spacing among aircraft.

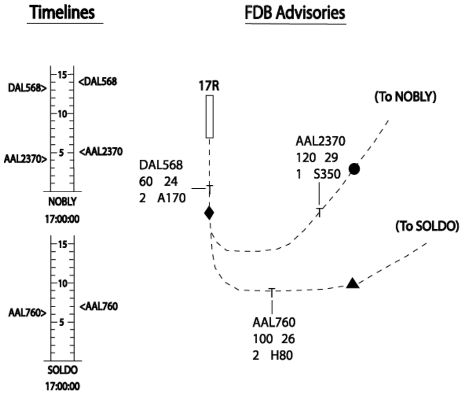

Figure 10. An Example of EDP Graphical User Interface

Software Architecture of EDP

EDP software is composed of nine separate modules running on UNIX workstations communicating with each other via TCP/IP: Communication Manager (CM), Input Source Manager (ISM), Route Analyzer (RA), Profile Selector (PFS), Trajectory Synthesizer (TS), Planview GUI (PGUI), Timeline GUI (TGUI), Weather Data Acquisition Daemon (WDAD), and Weather Data Process Daemon (WDPD).[4] (Figure 11 illustrates the organization of the EDP software components.) The CM manages communication among all of the processes, and controls the start-up and termination of the entire CTAS system. The ISM filters and mosaics the live air traffic data fed from the Center Host and TRACON ARTS computers and transmits the processed data to the CM. The RA generates multiple routes for each aircraft by applying degrees-of-freedom on a nominal departure route. The RA sends trajectory analysis requests to the TS together with speed and altitude restrictions. Upon receiving the trajectory analysis results from the TS, the RA repackages the analyses and passes them to the PFS for scheduling and advisory generation. The PFS generates an efficient conflict-free schedule and the corresponding advisories required to meet this schedule. This is accomplished in coordination with the arrival scheduler (aFAST), insuring the departure schedules are not in conflict with arrival schedules. The PFS sends STAs and advisories to the PGUI and the TGUI for display.

The TS generates 4-D trajectories, including both horizontal route and climb profile, and returns the results to the requesting module (RA or PFS). Each RA-TS and PFS-TS pair is running on the same workstation and data communication is accomplished via a shared-memory interface. The WDAD process is responsible for gathering weather data files by the National Oceanic and Atmospheric Administration's (NOAA) Rapid-Update Cycle (RUC) processing, and making them available to other processes. The WDPD is responsible for converting raw weather data files provided by WDAD into binary weather files usable by CTAS. The PGUI provides TMCs with a planview display of the TRACON airspace and CTAS advisories. Timelines of aircraft ETAs at departure fixes are also displayed. For TRACON radar controllers, the FDB advisories are displayed on their workstations. The majority of the CTAS software has been implemented in the ANSI C language and runs under the Unix operating system: roughly 20 percent of the software has been written in C++. The primary platform for CTAS is the Sun Microsystems workstation running the Solaris operating system.

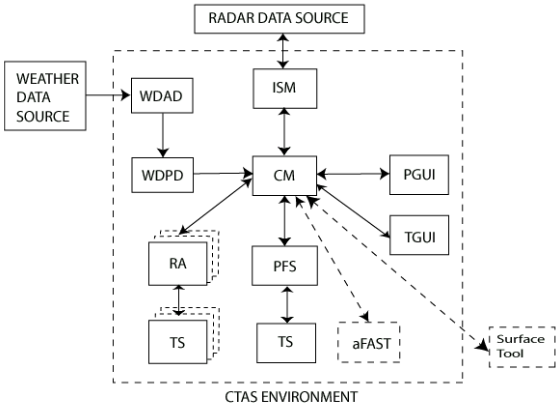

Figure 11. Organization of EDP Software

Development Plan

Currently, NASA Ames Research Center is developing a research prototype system of EDP under the Advanced Air Transportation Technology program. Simulation of ascent and merging algorithms will be completed by the spring of 2003. Evaluation of the prototype software will be performed in three stages as a short/mid-term plan. First, basic functionality tests will be performed using the closed-loop testing method.[20] The basic functionalities include route generation, trajectory prediction, and scheduling/merging. The closed-loop testing method, also known as trajectory feedback testing, will be used to verify that EDP maintains the desired separation when all aircraft follow the system's solution trajectories. This testing method is ideal for evaluating the performance of the core EDP algorithms because it allows the developer to test a variety of scenarios varying from single runway, single departure fix situations to multiple runway, multiple fix situations without requiring human controllers' involvement.

In the second stage, controller-in-the-loop simulations will be performed in a "shadowing" mode to evaluate the physical characteristics of the advisories. The scripted scenarios will be generated from live traffic or from Pseudo Aircraft Systems (PAS)[21] generated simulations. Controllers will be asked to acknowledge the onset of an advisory and specify the point at which the advisory would be issued to the aircraft. The purpose of this test is to evaluate the format and timing of advisories under varying traffic conditions.

In the third stage, real-time controller-in-the-loop simulations will be performed to investigate overall performance of the system. Active advisories will be presented and controllers will issue advisories to pilots controlling aircraft via the PAS interface.

Concluding Remarks

A prototype decision support tool for assisting terminal area air traffic controllers in managing and controlling departure air traffic is under development at NASA Ames Research Center. The Expedite Departure Path (EDP) tool is aimed at providing TRACON Traffic Management Coordinators with pertinent departure traffic loading and scheduling information, and radar controllers with advisories for tactical control of TRACON departure traffic. EDP employs the CTAS trajectory synthesis routine to provide conflict-free altitude, speed and heading advisories. A generic knowledge-based sequencing and deconfliction algorithm, developed and tested for CTAS's Active Final Approach Spacing Tool (aFAST), will be used for departure with minor enhancements. Employing the aFAST concurrent scheduling algorithm will enable EDP to advise tactical maneuvers for: merging departing aircraft into the en route stream, strictly adhering to reduced noise impact trajectories, and performing unrestricted climbs through arrival traffic airspace.

From an analysis of recorded DFW TRACON East gate departure data, the patterns of departure trajectories was characterized. Based on that analysis, roughly half of the East gate departure flights were considered to be eligible for unrestricted climb, demonstrating some of the potential benefits of EDP. Operationally, EDP's scheduling algorithm will explicitly consider the uncertainty in arrival and departure aircraft trajectory predictions in determining when to safely advise unrestricted climbs.

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