IMPROVING TERMINAL OPERATIONS – BENEFITS OF RNAV DEPARTURE PROCEDURES AT DALLAS-FORT WORTH AND HARTSFIELD-JACKSON ATLANTA INTERNATIONAL AIRPORTS

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Abstract

Incremental implementation of terminal Area Navigation (RNAV) procedures has yielded significant operational benefits at major U.S. airports. Key prerequisites of these benefits are the advanced flight automation systems that are available on the majority of today's commercial and corporate aircraft as well as the presently achievable conformance of flight operations to the RNAV route structures. Key implementation sites of RNAV procedures include Dallas-Fort Worth (DFW) and Hartsfield-Jackson Atlanta (ATL) International airports. The RNAV Standard Instrument Departure (SID) procedures implemented at these airports have promised and delivered more efficient utilization of available runways and constrained departure airspace by enabling diverging departure operations. This paper investigates the RNAV route conformance currently observed in RNAV departure operations at DFW and ATL and reviews the mechanism that enables operational benefits. It describes the Monte Carlo modeling approach taken to evaluate operational changes, the methodology used to validate model performance with radar data, and presents estimates of departure capacity and delay reduction benefits. The results of the research suggest that capacity gains of about 10 additional departures per hour and runway are possible resulting in significant benefits to operators when RNAV procedure designs enable airports to conduct diverging departure operations. The paper also compares key performance metrics of the model to performance metrics obtained from extensive pre- and post-implementation operational evaluations. The evaluation results were found to confirm expected operational changes, validate user benefits resulting from diverging RNAV departure operations, and firmly support further terminal procedure implementation at other airports.

Introduction

The FAA Operational Evolution Partnership (OEP) for the U.S. National Airspace System (NAS) addresses the challenge of managing safe and expeditious flight for an increasing quantity of air traffic [1]. Version 8 of the OEP outlines several strategies for improving the efficiency of airport arrival and departure operations and reducing aircraft delays including: (1) terminal airspace design and (2) utilization of new aircraft navigation technologies. Terminal airspace design often involves changing the shapes and volumes of airspaces assigned to air traffic controllers or the number and location of air routes they accommodate. The utilization of advanced navigation capabilities of onboard aircraft Flight Management Systems (FMS) enables automated flight path guidance along pre-defined RNAV arrival and departure routes in the vicinity of the airport. These routes are defined by a sequence of RNAV waypoints which provide greater flexibility in the design of diversified navigation route structures. The implementation of RNAV procedures currently underway at many U.S. airports promises more efficient utilization of limited runway capacity and constrained terminal airspace. The MITRE Corporation's Center for Advanced Aviation System Development (CAASD) was tasked by the Federal Aviation Administration (FAA) to estimate potential benefits of terminal RNAV procedures. To that end, CAASD developed agent-based Monte Carlo modeling capabilities and conducted research to evaluate resulting operational benefits. This paper documents comprehensive implementations of performance-based terminal navigation concepts at major U.S. airports and presents detailed evaluations of associated operational changes and resulting user benefits.

Background

The conventional terminal navigation concepts in use today at most major U.S. airports largely rely on Air Traffic Control (ATC) providing routine navigational guidance. The design and implementation of RNAV arrival and departure procedures enables performance-based operations in the terminal area and aims to fully leverage on-board navigation capabilities of advanced flight automation systems in terminal operations. Terminal RNAV procedures are key building blocks in the FAA's plan to integrate advanced navigation methods into the NAS to achieve greater system capacity and increased operational efficiency. The implementation of RNAV arrival and departure procedures represents a significant milestone toward that goal as outlined in the OEP. The OEP also calls for the development of standards for Required Navigation Performance procedures (RNP) as part of worldwide efforts to develop and implement the next generation of communication, navigation, and surveillance systems in air traffic management (ATM). The accuracy of RNP and its integrity monitoring capability are expected to further enhance the navigational precision of RNAV and define aircraft flight paths within tightly specified airspace corridors.

The FAA Roadmap for Performance-Based Navigation, first published in 2003 and revised in 2006, provides the framework for the integration of advanced navigation methods in the U.S. and outlines key implementation steps [2]. The performance-based navigation (PBN) concept represents a revision of the RNP concept aiming to support regulatory harmonization of the expanding international domain of navigation systems.

In the U.S., the FAA Advisory Circular (AC) 90-100, first published in 2005, provides airworthiness and operational approval guidance material for aircraft conducting terminal and en route RNAV operations [3]. Initial implementations of terminal RNAV procedures at various airports have yielded important lessons and helped streamline the implementation process [4,5,6]. A revision of the AC scheduled for publication in 2007 reflects these lessons learned as well as harmonized international performance-based navigation criteria. On a global level, the International Civil Aviation Organization (ICAO) is currently revising the 2nd edition of Document 9613 - Manual on Required Navigation Performance (RNP) [7]. The new manual, scheduled for publication in 2007 and titled *Performance Based Navigation Manual* is expected to provide navigation specification standards and globally harmonized guidance for PBN operations.

Operational Changes

RNAV Route Conformance

The accuracy and precision with which operations can conform to RNAV route structures is a key enabler for improving (1) the effectiveness of utilizing constrained terminal airspace and (2) the efficiency of conducting terminal operations. Figure 1 illustrates radar tracks associated with the route structure and navigational conformance of RNAV departure operations at DFW. The route structure comprising 16 RNAV departure procedures for both North-flow and South-flow operational configurations was implemented on 6 September 2005. Figure 2 similarly illustrates the observed RNAV route structure and navigational conformance of departure operations at ATL. This RNAV departure route structure was implemented on 13 April 2006 and currently supports East-flow operations. Similar procedures enabling diverging RNAV operations in West flow are expected to become operational in 2007. In most cases, non-vectored RNAV operations were found to remain within 0.4 nautical miles (NM) from the routes defining straight flight segments. With few exceptions, the conformance achieved in turns showed the characteristic dispersions that are largely consistent with differences in turn anticipation distances of FMS navigational solutions derived for varying ground speeds [8].

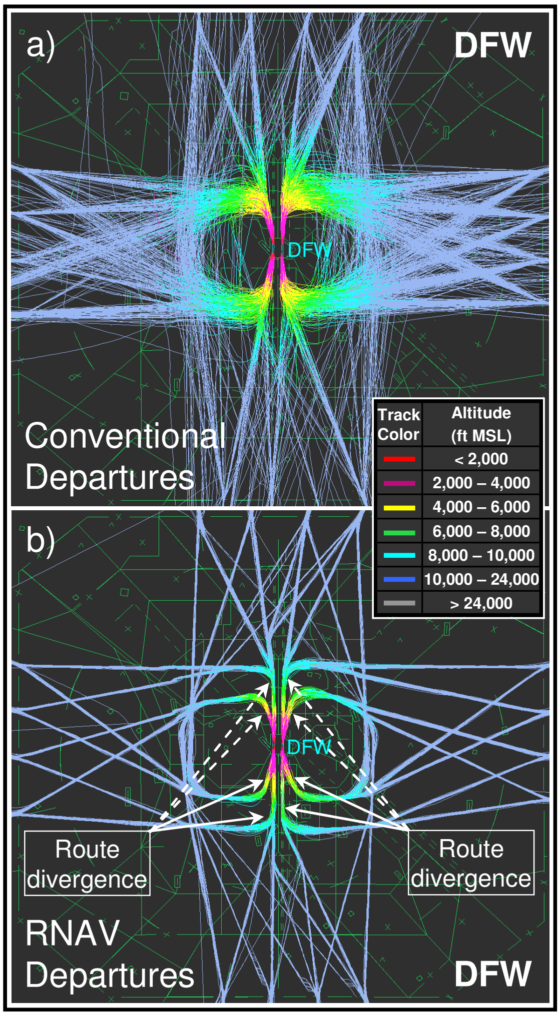

Figure 1. Radar tracks of (a) vectored conventional and (b) non-vectored RNAV departures in both North and South flow configurations illustrating the route conformance of terminal RNAV operations at DFW.

The radar tracks of non-vectored RNAV departures shown in Figures 1 and 2 are contrasted with radar tracks of conventionally vectored operations recorded prior to the implementation of RNAV procedures at DFW and ATL. These radar tracks generally show larger dispersions along both straight and turning flight segments that are characteristic of ATC-vectored operations.

Diverging Departure Operations

Comparing vectored conventional and non-vectored RNAV departure tracks recorded soon after takeoff evinces a key operational change that resulted from the design and implementation of the RNAV procedures at the airports. While the initial flight patterns of conventional operations generally involved single flows of aircraft from each runway complex to points about 5 NM from the runways, the RNAV procedures provide diverging initial route segments for navigation commencing close to the runways. The reduced operational uncertainty and resulting route conformance generally associated with RNAV operations was found to support these designs of dual diverging RNAV route segments that meet existing environmental constraints. The constraints require that terminal traffic patterns conform to noise footprints previously established for the airports.

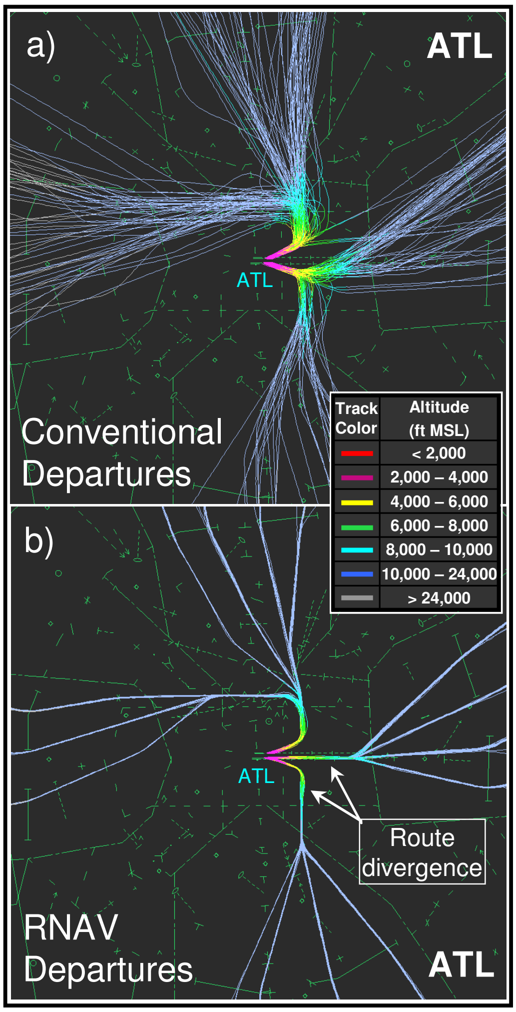

Figure 2. Radar tracks of (a) vectored conventional and (b) non-vectored RNAV departures in East flow configuration illustrating the route conformance of terminal RNAV operations at ATL.

It is important to note that the availability of diverging departure routes enables a key operational change. The routes enable ATC to conduct diverging departure operations, i.e. departure operations that make alternating use of the diverging routes. For a given departure demand scenario, the number of opportunities that exist to conduct diverging departure operations generally increases with increased departure demand and more efficient ATC sequencing of aircraft for diverging departures. While sequencing is often accomplished by ATC during taxi operations, the availability of separate line-up queues (serving initially diverging RNAV routes) generally facilitates ATC sequencing for diverging departures.

Benefit Mechanism

The mechanism that enables operational benefit from conducting diverging departure operations is based on differences in ATC minimum separation standards that currently apply to in-trail and diverging departure operations [9]. The minimum ATC separation standard that applies most frequently to consecutively departing aircraft operating at major U.S. airports, i.e. *Radar Separation*, calls for an initial application of 3-NM spacing between in-trail departures. If the same aircraft can be sequenced for diverging operations and *Same Runway Separation* standards can be applied, a subsequent departure can be authorized to start the takeoff roll if the preceding departure has gained a distance of 6,000 feet and has become airborne. Thus, applicable ATC minimum standards for diverging departure operations generally impose less stringent constraints and enable ATC to effectively reduce inter-operation times between aircraft departing on diverging courses. In-trail and diverging departure operations are illustrated in Figure 3. The gain in departure efficiency associated with implementing diverging departure operations can be expected to result in improved departure performance of the airport. The model analyses of the operational changes and evaluations of delay and capacity benefits are outlined in the following section.

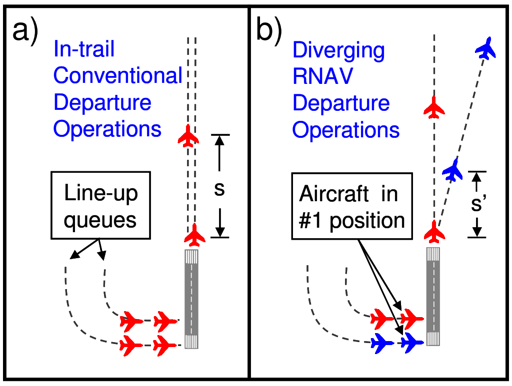

Figure 3. Illustration of (a) in-trail conventional and (b) diverging departure operations.

Pre-Implementation Model Evaluation

Computer simulations of air traffic are a major source of quantified estimates of system benefits that can arise from the implementation of procedural changes. CAASD was tasked to support the FAA in evaluating potential benefits of proposed operational changes and developed fast-time simulation capabilities. Key features of the modeling capabilities include (1) data-driven validation of the simulation model, (2) an agent-based modeling platform, and (3) Monte Carlo modeling techniques [10].

The gains in departure efficiency that can result from conducting diverging departure operations is evidenced by reduced inter-operation times between departing aircraft. Thus, the time effectively applied between departures (subsequently referred to as inter-departure time or departure interval) serves as key metric to quantify operational changes associated with diverging operations and improvements in departure efficiency. This metric was also used to validate the baseline model of conventional departure operations described in the following section.

Model Validation

The model of conventional departure operations employed aircraft flight plan and push-back information derived from Enhanced Traffic Management System (ETMS) data. The departure demand data of one day was selected to represent an average-day demand scenario. In order to extend the validity of the model beyond the single day represented in the demand data, stochastic variations were introduced in the Monte Carlo model designed to reflect the variability of actual aircraft push-back times from their gates. Multiple replicates of Monte Carlo runs were executed and mean values of model metrics were obtained representing the statistics of 50 and 200 days of operations totaling about 50,000 and 200,000 simulated operations per simulated DFW and ATL scenario, respectively [11,12]. Figure 4 compares the inter-departure time distributions associated with operations observed during multiple days of actual operations and the average distribution of inter-departure times obtained from the validated model of conventional departure operations. The comparisons indicate generally good agreement between actual and modeled operations suggesting that significant constraints intrinsic to actual operations were sufficiently accounted for in the model. The performance of the validated model served as a performance baseline for comparing RNAV operational alternatives and estimating potential benefits of diverging departure operations.

Evaluation of RNAV Operations

The distribution of separation times that are effectively applied between departures (inter-departure times) was identified as a key metric quantifying changes in departure efficiency. Figure 5 presents inter-departure time distribution of the validated model of in-trail conventional departure operations (shown in red) and of post-implementation operations (shown in blue) that include diverging RNAV departure operations.

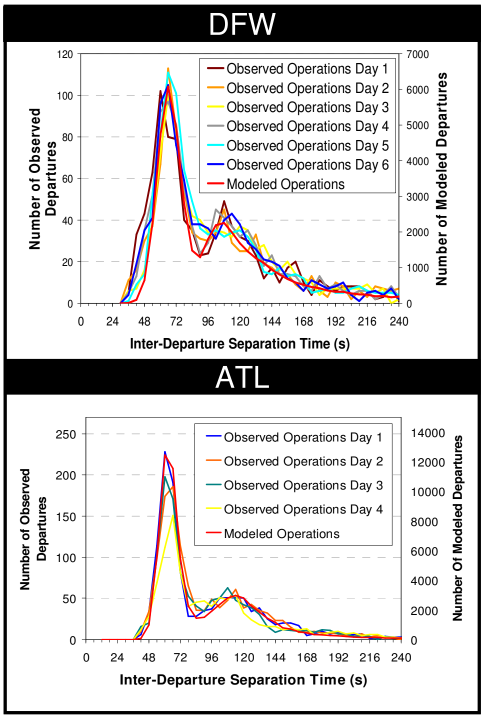

Figure 4. Comparisons of inter-departure time distributions of observed and modeled conventional departure operations at DFW ATL.

These distributions illustrate the impact of operational changes the model suggests to be associated with the implementation of RNAV departure procedures at DFW and ATL. It is important to note that the pronounced mode or peak of the distributions associated with in-trail conventional departures (and separated according to *Radar Separation* standards often resulting in about 60 to 70 seconds of inter-departure time) is essentially split in two smaller components in the case of post-implementation operations. While one component represents a reduced number of radar-separated departures, the second component indicates a sizable number of diverging departures that are more closely spaced according to *Same Runway Separation* standards, typically 40 to 50 seconds apart. It is interesting to note that the distribution associated with post-implementation operations at DFW also features an increased number of departures spaced about 100 to 110 seconds apart. This operational change reflects the impact of mixed-equipage operations that required application of additional spacing in some cases involving consecutive RNAV and non-RNAV departures departing via certain combinations of departure routes. At ATL, the geometry of departure routes was found to require no application of additional spacing in the case of mixed-equipage operations

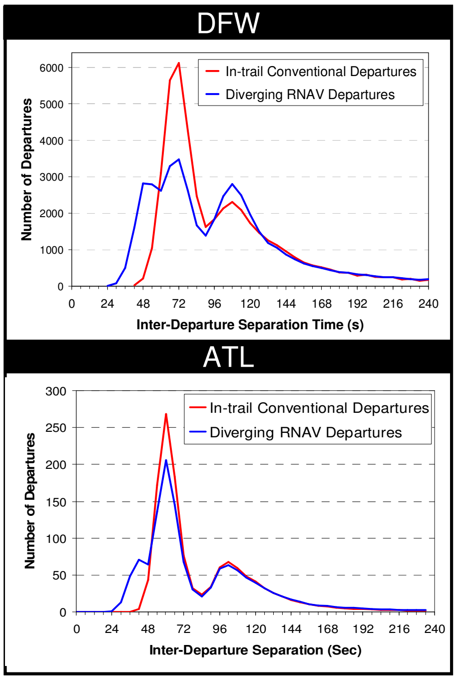

Figure 5. Comparisons of inter-departure time distributions of the validated baseline model of conventional operations (red) and of the model of post-implementation operations (blue) including diverging RNAV departures at DFW and ATL.

and the inter-departure time distribution shows no increase in the number of departures separated in the 100 to 110 second time range (see Figure 5).

Departure Capacity Benefits

Capacity is commonly used as a metric to estimate the average number of operations an airport can conduct in a given time interval that is largely independent of the temporal distribution of demand. Thus, capacity modeling generally evaluates scenarios involving continuous departure demand. It provides an estimate of maximum average throughput, on a long-term basis, given sustained demand [13]. Adopting the modeling capability to provide sustained departure demand, the gain in departure capacity due to conducting diverging departure operations can be used to characterize the capacity impact of operational changes associated with implementation of RNAV departure procedures. The results of the Monte Carlo simulation model analysis suggest a potential for significant departure capacity benefits.

For DFW, a capacity benefit of 11 additional departure operations per hour was found for the fleet mix and RNAV equipage enabling about 84 percent of departures to participate in RNAV operations. The modeling also allowed estimating potential future capacity gains that could result if RNAV equipment levels were to rise and RNAV participation rates were to increase to full participation. Eliminating all mixed-equipage operations at DFW and assuming an RNAV participation rate of 100 percent, the results of the capacity model analysis were found to suggest that capacity gains of up to 20 additional departure operations would be possible for the airport in either North-flow or South-flow operations.

For ATL, the capacity modeling results indicate benefits of 10 additional departure operations when the airport is operated in East flow configuration. Because RNAV equipage currently exceeds 85 percent and no additional spacing was required in the case of mixed-equipage operations at ATL, this capacity estimate was found to be largely independent of the RNAV participation rate at the airport.

Departure Delay Benefits

Gains in departure capacity and associated improvements in departure efficiency enable greater throughput during time periods with sustained departure demand. During these time periods, the ability to conduct more operations entails that aircraft that are lined up for departure at the runway generally need to wait less time to obtain ATC takeoff clearances. This is because of ATC's ability to sequence aircraft for departure to make alternating use of diverging RNAV routes which results in reduced inter-departure times when compared to conventional operations comprising sequential in-trail departures.

The Monte Carlo simulation model was used to estimate potential reductions in departure delay associated with the implementation of RNAV departure procedures. In the model, departure delay was defined as any time an aircraft remained in a line-up queue at a runway (see Fig. 3). In other words, an aircraft accrued departure delay starting the moment it completed taxiing to the runway or when joining the line-up queue that has formed there and until it started to roll for takeoff.

Figure 6 presents average departure delay estimates obtained from the Monte Carlo simulation model of pre- and post-implementation operations at various levels of departure demand. The difference between pre- and post-implementation departure delays represents the benefit potential associated with the implementation of RNAV departure procedures. The modeling results for DFW were found to suggest a difference between average pre- and post-implementation delays of 1.3 minutes per departure at the 2005 level of departure demand. The figure also illustrates model estimates of the impact of increased departure demand on departure delay. A 13-percent increase in departure demand at DFW is seen to result in significant increases in departure delay, especially if the airport

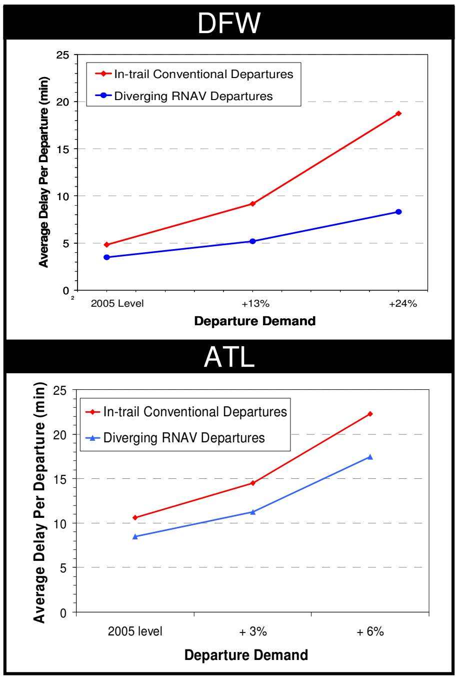

Figure 6. Modeled average departure delay of pre-RNAV implementation (red) and post-RNAV implementation (blue) operations.

continues to conduct conventional departure operations. On the other hand, these results also suggest that delay can be expected to increase more slowly if post-implementation operations involving diverging departures can be employed, indicating an incrementally increasing benefit potential of the RNAV procedures.

The model analysis of delay benefits at ATL was found to indicate an average 2.1-min reduction in departure delay per departure at the 2005 level of departure demand. Because the 2005 level of departure demand more closely compared to the pre-RNAV departure capacity at ATL, the 2.1-min delay reduction as well as the rate of delay growth as a function of departure demand were found to exceed those at DFW.

It is noted that average departure delays per aircraft, particularly at highest demand levels evaluated in this study may have exceeded values that would likely trigger adaptive actions by users and passengers and limit traffic growth rates [14]. It is important to note that the model presented here did not attempt to anticipate possible adaptive actions. Consequently, delay benefits should be considered progressively less reliable as departure delay values increase and adaptive actions become more likely.

Cost Savings to Operators

Estimates of potential cost savings to airline operators that are associated with the implementation of RNAV departure procedures presented here are based on differences between modeled pre- and post-implementation departure delays. As stated above for DFW, modeled post-implementation departure operations were found to accrue – on average – 1.3 minutes less delay per departure at the 2005 level of departure demand. This reduction in departure delay can be expected to result in reduced airline operating costs as aircraft would spend less time during ground operations while awaiting ATC takeoff clearances.

Cost benefits were derived from delay reduction benefits illustrated in Figure 6 and Aircraft Direct Operating Cost (ADOC) values. An ADOC estimate for DFW taxi operations of $22.24 per minute was adopted. This CAASD estimate is based on FAA guidance for estimating aircraft operating costs and 2005 fleet mix data for DFW. Similarly, an ADOC estimate of $26.46 per minute based on 2006 fleet mix data was used to derive cost benefit estimates for ATL.

Annual cost benefits were conservatively estimated by assuming that diverging departure operations can be conducted during 80 percent of the year to account for significant weather events or infrastructure outages that may limit the applicability of diverging departure operations. For DFW, the annual impact of mixed-equipage operations was estimated by evaluating various levels of modeled RNAV participation rates. Figure 7 illustrates the annual cost benefit estimates associated with the implementation of RNAV departure procedures at DFW and ATL. At the 2005 level of departure demand, the results of the benefit model analysis indicate annual cost benefits of $8.5 million for operators at both airports. The cost benefit results are summarized in Table 1.

The results of the model analysis also enable estimations of the cost impact associated with partial RNAV equipage of the aircraft fleet operating at DFW. Assuming an RNAV participation rate of 84 percent, the cost benefit results suggest an annual impact of over $4 million associated with conducting mixed RNAV/non-RNAV operations at DFW at the 2005 level of departure demand. As shown in the table, this cost impact was found to increase significantly to over $10 million annually if departure demand was assumed to increase 13 percent above the 2005 demand level.

At ATL, the geometry of departure routes and equal applicability of in-trail and diverging operations to non-RNAV operations not requiring application of additional spacing in case of mixed-equipage operations was found to result in no cost impact associated with partial RNAV equipage at the airport.

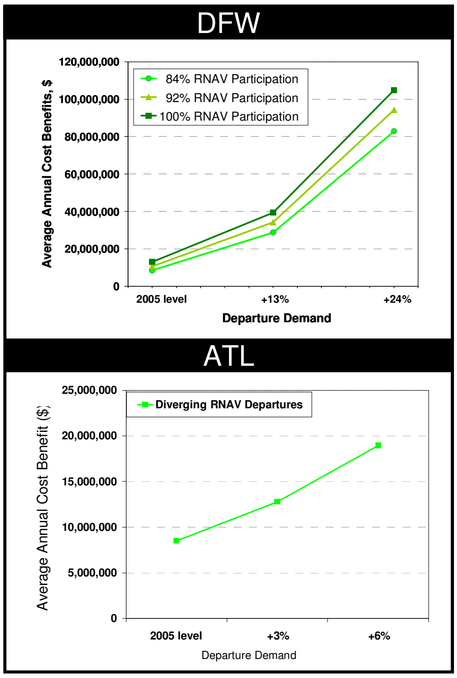

Figure 7. Annual cost benefit estimates of post-RNAV implementation operations at DFW and ATL.

Table 1. Summary of Annual cost benefit estimates of post-RNAV implementation operations at DFW and ATL.

DFW

RNAV Participation Rate (%)	DFW Delay Reduction Benefit (Million $)		
	2005 Level of Departure Demand	2005 Level + 13%	2005 Level +24%
84	8.5	28.7	82.8
92	10.6	34.2	94.3
100	12.9	39.3	104.8

ATL

ATL Delay Reduction Benefit (Million $)		
2005 Level of Departure Demand	2005 Level of Departure Demand + 3%	2005 Level of Departure Demand +6%
8.5	12.8	18.9

Post-Implementation Operational Evaluation

Post-implementation evaluations were carried out in order to validate model estimates of operational changes associated with the implementation of the procedures. As discussed above, a key operational change that resulted from the design and implementation of RNAV departure procedures is associated with diverging initial route segments the procedures provide for navigation soon after takeoff. If aircraft that are lining up for departure at a runway can be queued for diverging departures, applicable ATC minimum separation standards often enable application of effectively reduced inter-operation times between such aircraft. The metric that was introduced to characterize the resulting gain in departure efficiency is the distribution of inter-departure times.

The Monte Carlo model evaluations of the efficiency of DFW departure operations were found to suggest the potential for significant gains in departure efficiency (see Fig. 6). The model predictions of these gains were based on two key assumptions: (1) the departure sequence of two aircraft that have lined up at a runway and have advanced to *#1-Position* in their line-up queues (see Fig. 3) can be optimized at an 80-percent rate and (2) ATC workload considerations have no impact on the expediency of issuing takeoff clearances with an operational variability that is similar to that observed in conventional departure operations. The objective of the post-implementation evaluation was to validate these assumptions and the gains in departure efficiency predicted by the Monte Carlo model of post-implementation operations.

Post-implementation evaluations were carried out approximately two months after implementation of the RNAV procedures [15,16]. In the case of DFW, the two-month time frame was considered sufficient to allow controllers working the Local Control positions in DFW's air traffic control towers to become familiar with the procedures and proficient in implementing the required operational changes. For this evaluation, radar track data recorded during three days of North-flow and an equal number of days of South-flow operations conducted in visual meteorological conditions (VMC) were analyzed and inter-departure times were extracted. In the case of ATL, post-implementation evaluations focused on diverging departure operations from runway 09L (see Figure 2) recorded during two days of VMC operations in East-flow operational configuration.

Figure 8 presents inter-departure time distributions extracted from radar track data of actual operations recorded about 2 months after implementation of RNAV departure procedures. Each observed distribution comprises nearly 6000 separation measurements of actual departure operations at DFW and nearly 3000 measurements at ATL. Figure 8 also shows the validated pre-implementation distribution of modeled conventional departure operations (red) as well as the distribution predicted by the Monte Carlo simulation model of post-RNAV implementation operations (green) previously presented in Figure 5.

The results of the post-implementation evaluations demonstrate the significance of the operational changes associated with the implementation of RNAV departure operations at DFW and ATL. The mode (or peak) of the pre-implementation distribution that mainly characterizes the application of *Radar Separation* standards between consecutive departures is observed to be represented by a wider post-implementation distribution (see section *Evaluation of RNAV Departure Operations*). The increased width of the post-implementation distribution is consistent with a significant number of smaller departure intervals (in the 40 to 60 second time range) characteristic of application of *Same Runway Separation* standards. This part of the distribution is seen to be in generally good agreement with the distribution predicted by the model. As this part of the distribution mainly represents ATC application of *Same Runway Separation* standards to qualifying departures utilizing diverging RNAV route segments, the generally good agreement between the performance predicted by the Monte Carlo model and evidenced in the

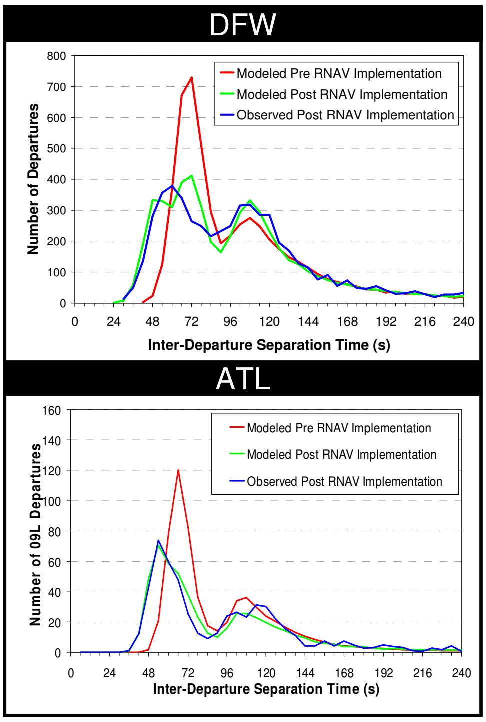

Figure 8. Comparison of inter-departure time distributions. Validated pre-implementation distributions of modeled conventional departure operations (red) are compared to post-implementation distributions of actual operations (blue) at DFW and ATL. Monte Carlo model predictions are shown in green.

data of actual operations suggests that benefit-enabling operational changes were largely realized within the first two months after implementation of the RNAV departure procedures.

For DFW, it is interesting to note that some discrepancies between model performance and observed performance seem to exist at departure intervals ranging from 60 to about 75 seconds of inter-departure time. This observation is consistent with additional operational changes affecting ATC application of *Radar Separation* standards. These additional operational changes, while identified as coinciding with RNAV procedure implementation, occurred independently and were not otherwise associated with the implementation of RNAV departure procedures at DFW.

Conclusions

Incremental implementation of RNAV procedures increasingly leverages on-board navigation capabilities of advanced flight automation systems in terminal operations. The accuracy and precision with which RNAV operations can conform to terminal route structures is generally recognized as a key enabler for improving (1) the effectiveness of utilizing constrained airspace surrounding airports and (2) the efficiency of utilizing available runways. These flight automation systems are currently available on the majority of commercial and corporate aircraft and implementation of the procedures have promised and delivered significant user benefits at major U.S. airports. The research reported in this paper identified key elements of the mechanism that yields operational benefits and results in increased departure efficiency including (1) the design of the RNAV procedures featuring diverging route segments from each primary runway and (2) efficient ATC sequencing of successive departures enabling alternating use of initially diverging routes.

The **capacity analysis** results for DFW suggest potential gains of 11 additional departure operations per hour based on DFW's current RNAV participation rate of about 84 percent. This capacity gain was found to increase to 20 additional departure operations per hour if RNAV participation was assumed to increase to full participation. For ATL, the results suggest that capacity gains of 10 additional departure per hour are possible when the airport is operated in East-flow configuration.

The **delay analysis** results indicate significant delay reduction benefits associated with the increased departure efficiency of post-implementation operations. The results were found to suggest annual delay reduction benefits to users and operators of $8.5 million for both DFW ATL. For DFW, the benefit was found to increase to about $29 million annually if departure demand was assumed to increase about 13 percent above the 2005 level of departure demand. The analysis also supported estimating the cost impact of conducting mixed RNAV/non-RNAV operations at DFW. The results indicate that additional benefit of over $4 million annually could be realized if the RNAV equipment level were to increase enabling 100 percent RNAV participation. These results would support further cost/benefit analyses to increase RNAV equipage of aircraft operating at DFW.

Key performance metrics of the validated Monte Carlo model were compared to performance metrics obtained from extensive post-implementation evaluations. The **post-implementation evaluations** were found to confirm that the required operational changes that enable delay reduction benefits were largely realized within the first two months after implementation of the procedures.

Future Work

The results of the study presented here demonstrate that incremental implementation of RNAV departure procedures can provide significant benefits to users and operators and firmly support further terminal RNAV procedure implementation and design optimization at major airports. The results also illustrate the potential of performance-based navigation concepts to enable fundamental improvements in terminal operations through improved terminal airspace designs and resulting efficiency enhancements of terminal operations. CAASD is currently conducting research into increasing the utilization of 3D navigation capabilities that enable automated lateral and vertical flight path guidance. More extensive use of these capabilities is expected to (1) increase the capacity of terminal airspace through diversification of available terminal route structures, (2) improve the degree of operational independence of arrival and departure operations, and (3) enhance the continuity of departure climbs and approach descents. These improvements can be expected to provide additional benefits to aircraft operators and traffic managers as well as aide in meeting the challenge of managing safe and expeditious flight for an increasing quantity of air traffic.

Key Words

Area Navigation, RNAV, SID, FMS, terminal operations, departure operations, benefit mechanism, divergence, benefits analysis, metrics, capacity, delay.

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