Tenth USA/Europe Air Traffic Management Research and Development Seminar (ATM2013)

Operational Demonstration of a Performance-Based Separation Standard at The Hartsfield-Jackson Atlanta International Airport

Implementation and Benefits of Equivalent Lateral Spacing Operation (ELSO) Departures

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Abstract—**Performance-Based Navigation (PBN) represents a cornerstone of the Federal Aviation Administration (FAA) Next Generation Air Transportation System (NextGen). Improvements in aircraft navigation precision associated with PBN operations enable the development of advanced spacing concepts that evolve currently applicable separation standards. The Equivalent Lateral Spacing Operation (ELSO) concept was developed to advance the current 15-degree divergence requirement for independent parallel as well as successive departures and enables reduced-divergence departure operations. The concept was first presented at the Ninth ATM Seminar in 2011. The Hartsfield-Jackson Atlanta International Airport (KATL) implemented reduced-divergence Area Navigation (RNAV) departure procedures based on this concept on 20 October 2011. This paper outlines the standard concept and reviews KATL's designs of RNAV ELSO procedures. It also describes the implementation approach taken to demonstrate the standard concept and presents the methodologies developed to characterize associated operational changes and estimate resulting benefits. For the 2011 level of departure demand, the results indicate a net average operator benefit of $44.00 per KATL departure and a net annual operator benefit of $19.2 million at the airport. Successful operational demonstration of the ELSO concept at KATL paves the way for regulatory changes that adopt the concept as a separation standard.**

Keywords-Innovative ATM Concepts; Area Navigation (RNAV), parallel departures, divergence standard, reduced divergence, Equivalent Lateral Spacing Operation (ELSO)

I. INTRODUCTION

The current separation standard for independent parallel departure operations requires a fixed minimum of 15 degrees of divergence. It applies equally to conventional departures that proceed along Air Traffic Control (ATC)-assigned aircraft headings (i.e., radar vectors) and Performance-Based Navigation (PBN) departures that follow designed routes. The Equivalent Lateral Spacing Operation (ELSO) concept capitalizes on the increased navigational precision of PBN departure operations and flexibly adapts to advantageous runway layout geometries [1]. The concept re-defines minimum divergence requirements and offers additional departure procedure design options not currently available.

On 20 October 2011, The Hartsfield-Jackson Atlanta International Airport (KATL) implemented reduced-divergence Area Navigation (RNAV) Standard Instrument Departure (SID) procedures. The procedures were designed to meet ELSO divergence requirements, offer additional departure paths within KATL's established noise abatement corridors, increase departure efficiencies, and reduce departure delays at the airport. The KATL implementation of RNAV ELSO procedures currently serves as an operational demonstration of the ELSO standard concept.

The Federal Aviation Administration (FAA) tasked the MITRE Corporation's Center for Advanced Aviation System Development (CAASD) to evaluate the operational changes and benefits to aircraft operators that resulted from implementation of RNAV ELSO departure procedures at KATL. The study focused on evaluating operational changes that are directly associated with the additional, ELSO-enabled diverging departure operations from two of its runways.

The study aimed to support the FAA Next Generation Air Transportation System (NextGen) strategy and mid-term implementation goals to reduce divergence requirements for parallel departures as well as integrate arrival/departure airspace and procedures with multiple departure paths from each runway end through RNAV and Required Navigation Performance (RNP) procedures [2,3].

This paper reviews the ELSO standard concept, describes KATL's RNAV ELSO procedure implementation, and documents the various elements of the study, including evaluations of airport performance data, analyses of surveillance data to characterize changes in operational efficiencies, and the comparative modeling approach taken to quantify and validate operational benefits.

II. ELSO CONCEPT

A key characteristic of the ELSO standard concept is that the lateral spacing between departure paths of ELSO-based reduced-divergence operations is defined to be equivalent to the spacing of departure paths achieved in conventional diverging departure operations based on minimum requirements of the currently applicable divergence standard [4]. It provides an analytic expression that describes the divergence angle as a function of observed navigational performance and runway layout characteristics [5]. Thus, the standard concept offers reduced divergence angles while maintaining conventional minimum lateral spacing between departure paths. Departure efficiency increases are expected when ELSO applications enable diverging operations. Figure 1 illustrates the PBN component of the ELSO concept.

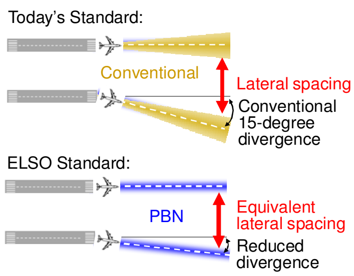

Figure 1. Notional illustration of the PBN component of the Equivalent Lateral Spacing Operation (ELSO) concept

The reduced divergence angles of the standard offer additional procedure design options not currently available to better accommodate airspace and environmental procedure design constraints. Depending upon the runway geometry, diverging application of the ELSO standard typically enables reduced divergence angles of 5 to 10 degrees for RNAV-1 departure operations.

III. ELSO CONCEPT DEMONSTRATION

In 2010, MITRE evaluated KATL's proposal for reduced divergence departure operations. The proposal included new and modified RNAV departure procedures and aimed to reduce departure delay as well as increase schedule reliability at the airport [6]. In the evaluation, MITRE assessed the designs of diverging departure routes to ensure that they meet or exceed ELSO divergence requirements [7]. The results supported KATL's waiver request for reduced departure divergence requirements and the work of a Safety Risk Management (SRM) panel tasked to assess the risk associated with implementation of the procedures.

In 2011, FAA Flight Technologies and Procedures Division (AFS-400) provided technical review and validation of FAA Flight Standards support for the ELSO concept demonstration. The review concluded that ELSO application at KATL has no negative impacts on the aircraft collision risk [8]. Following final review by the FAA Office of Safety (AJS-22), a waiver to FAA Order JO 7110.65 divergence requirements was issued on 22 August 2011 [9]. Effective 20 October 2011, the waiver authorizes KATL Terminal Radar Approach Control (A80) and KATL Airport Traffic Control Tower (ATCT) personnel to conduct RNAV off-the-ground operations for successive departures and dual/triple simultaneous parallel departures by implementing RNAV ELSO procedures [10].

IV. KATL DEPARTURE OPERATIONS

KATL has five parallel east-west runways. Two runways (8L/26R and 9R/27L) are designated as primary arrival runways, two are designated as primary departure runways (8R/26L and 9L/27R), and the fifth runway (10/28) is designated as either a departure or arrival runway depending on demand. At times, the fifth runway is used as both an arrival and departure runway. KATL primarily operates in either a dual departure runway or a triple departure runway configuration. Aircraft will all arrive and depart to the east, which is referred to as an East Operation, or will all arrive and depart to the west, which is known as a West Operation.

A. *Before ELSO*

KATL initially implemented RNAV departure procedures in 2005 [11]. There are a total of 16 procedures in use. All jet aircraft that are capable of flying RNAV departure procedures are assigned an RNAV SID. This currently constitutes 96.4 percent of the operations. The SIDs overlay noise abatement corridors. Before implementation of the RNAV ELSO procedures, these noise abatement corridors, combined with FAA Order JO 7110.65 divergence requirements, enabled dual RNAV routes off only two runway ends, i.e., Runway 09L and 26L. These dual RNAV routes initially diverged by a minimum of 15 degrees, permitting ATL air traffic controllers to apply diverging departure separation minima to these departures [4]. Figure 2 illustrates KATL's RNAV departure procedure routes implemented in 2007. Operations conducted before the implementation of the RNAV ELSO departure procedures in 2011 are subsequently referred to as *Before ELSO* operations.

Before ELSO, an East Operation dual departure runway configuration required all aircraft departing Runway 8R to be established on a single route. In West Operation, aircraft departing Runway 27R were typically required to be established on a single route. During time periods of peak demand for South departures, Runway 27R departures were initially issued radar vectors: 270 degrees (South) and 250 degrees (East). In these cases, Runway 26L operations departing to the West were also issued radar vectors (290 degrees). In either East or West triple departure runway configuration, all departures were initially issued radar vectors.

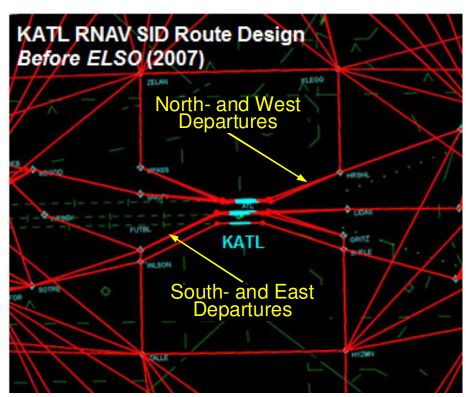

Figure 2. Departure route design based on conventional divergence

Thus, changes in runway configuration and demand characteristics often entailed changes in how course guidance was initially applied (RNAV off-the-ground versus issuance of initial radar vectors) in *Before ELSO* operations.

B. *With ELSO*

Figure 3 presents the RNAV ELSO procedure designs implemented in 2011. It illustrates the ELSO-based reduced-divergence routes including two additional departure routes that enable diverging departure operations on Runway 08R and Runway 27R. Operations conducted after implementation of the RNAV ELSO procedures are subsequently referred to as *With ELSO* operations.

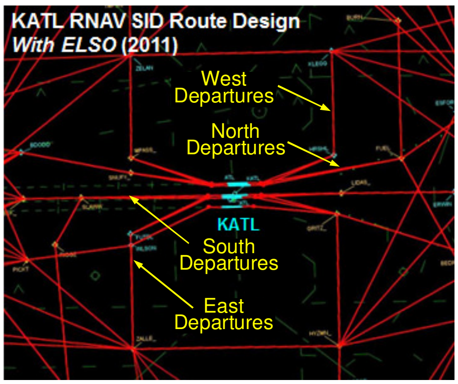

Figure 3. Departure route design based on ELSO-enabled reduced divergence

V. OPERATIONAL CHANGES

In both East and West Operations, the ELSO divergence requirements allowed for the design of a fourth departure route in airspace that previously supported only three routes. The additional ELSO-enabled departure routes of the RNAV ELSO procedures are shown in Figure 4. The figure illustrates the divergence angle values that meet local noise abatement requirements and enable successive departures as well as dual/triple simultaneous parallel departures at the airport.

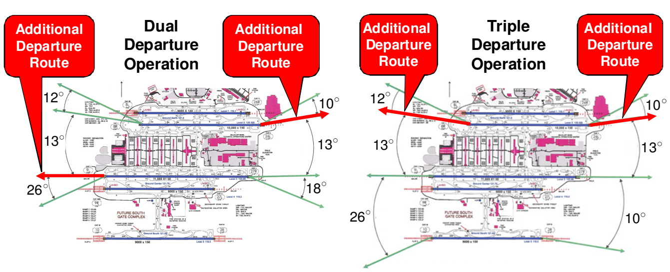

Figure 4. Key RNAV ELSO procedure design elements illustrating reduced divergence angles for successive departures and dual/triple simultaneous parallel departures

Primary objectives for the design and implementation of RNAV ELSO procedures at KATL included:

- Improved airport departure efficiency and schedule/system integrity
- Consistent use of RNAV off-the-ground operations for successive departures and dual/triple simultaneous parallel departures

Key operational changes resulting from the implementation of RNAV ELSO procedures are discussed in the following sections.

A. *Departure Efficiency*

The design and implementation of the RNAV ELSO procedures enabled dual diverging departure operations from Runway 08R and Runway 27R. The primary advantage of conducting departure operations along multiple diverging departure paths from a runway is the delay reduction benefit that results from the associated increase in runway capacity [12].

B. *Departure Track Miles*

Changes to the routing of Runway 08R and Runway 27R operations that depart to the North and South, respectively, generally entail increases in distances (or *track miles*) flown by these departures (see Figures 2 and 3).

C. *Departure Climb Continuity*

Changes to the routing and associated increases in track miles was anticipated to affect the continuity with which these departure climb operations can be conducted. De-confliction of the departure operations from arriving aircraft approaching the airport over the Northeast or Southwest corner posts was expected to occasionally require prolonged level flight segments (at 10,000 feet) until the departures cross underneath the paths of the arrivals and departing aircraft can be cleared to climb.

VI. EVALUATION METHODOLOGY

Methodologies were developed to assess the operational changes. Analyses of surveillance data of actual flight operations recorded before and after implementation of the RNAV ELSO procedures served to characterize and validate the operational changes evaluated in this study. In addition, estimates of departure efficiency benefits were based on analysis that employed a validated simulation model. The operational and model evaluation methodologies are described in the following sections.

A. *Operational Evaluation*

Track data of A80's Automated Radar Terminal System (ARTS) served to characterize the operations before and after implementation of the RNAV ELSO departure procedures. The data were recorded by a single sensor located in close proximity to the runways. Nearly 0.9 million tracks recorded during three evaluation periods were processed for consideration. Departures from KATL's three primary departure runways, i.e., Runway 8R/26L, Runway 9L/27R, and Runway 10/28, were selected.

The selection of tracks by ATL's primary departure runways yielded 337,132 departures. For each primary departure runway, Table I lists the number of radar tracks that resulted from application of the runway-specific track selection criteria.

TABLE I. RADAR TRACK DATA OF KATL DEPARTURES

Runway	Number of Radar Tracks		
	Before ELSO*	With ELSO**	With ELSO***
08R	19,732	21,151	25,365
09L	19,729	19,443	20,607
10	1,030	281	147
26L	40,159	36,169	38,241
27R	30,613	29,567	28,974
28	2,537	1,806	1,581

* July 2011 - September 2011

** November 2011 - January 2012

*** 7 March 2012 - 6 June 2012

1) Evaluation Metrics

Three metrics were developed and applied to the track data to assess changes in departure efficiency, track miles, and climb continuity. The metrics are described in the following sections.

a) Departure Efficiency

Departure efficiency was evaluated using two metrics that evaluate the spacing between pairs of successive departures. The **Departure Spacing Distance** metric evaluates the spacing in terms of distance, i.e., in terms of a length. The **Departure Spacing Time** metric expresses the spacing in terms of time, i.e., in terms of a duration or time interval [13]. By measuring differences in aircraft locations and times, the metrics capture the spacing values between departures that are realized in actual operations and compile summary statistics that illustrate how measured spacing values are distributed over the range of all observed values.

The numbers (or frequencies) of observed spacing distances were determined by grouping measured spacing values in distance ranges (or bins) of 0.1 nautical mile (NM) width to obtain distributions of departure spacing distances. Similarly, frequencies of spacing times were determined by grouping measured time values into 3-second (s) bins.

b) Departure Track Miles

Departure track miles were evaluated using the **Track Length** metric. The track length metric evaluates the distance flown by an aircraft and defines the track length as the along-track length of a track between two specified lines in space. The lines in space are defined for a group of tracks selected for evaluation to ensure equal footings for each group of measurements. By measuring along-track lengths of radar tracks, the metric captures the track miles that are realized in actual operations and compiles summary statistics that illustrate how measured track mile values are distributed over the range of all observed values.

c) Departure Climb Continuity

Departure climb continuity was evaluated using the **Time in Level Flight** metric. The metric evaluates the continuity of departure climbs and quantifies the time the operations were observed to remain in level flight [14].

The radar track data and applications of the Departure Spacing Time metric also served to validate the model evaluation of departure efficiency benefits. The benefit model evaluation methodology is described in the following section.

B. Model Evaluation

MITRE's General Aviation Analysis, Experimentation, and Evaluation Environment *change*Evaluator model served to model departure operations for the purpose of evaluating operational changes that resulted from the implementation of RNAV ELSO departure procedures at KATL. The *change*Evaluator is a general-purpose model that includes European Organization for the Safety of Air Navigation (EUROCONTROL) Base of Aircraft Data (BADA) aircraft performance, trajectory modeling, fuel flow modeling, and operational data analysis, as well as three-dimensional (3D) visualization and animation capabilities for evaluating operational changes and quantifying operational benefits [15,16].

The *change*Evaluator's discrete-event aviation modeling capability comprises object classes (or agents) whose actions are designed to mirror flight operations as well as ATC control activities [17]. This capability serves as the simulation platform designed for model evaluations of proposed flight navigation and ATC decision-making processes that are subject to procedural constraints and operational variability. It comprises a scalable four-dimensional (x,y,z,t) flight trajectory generation capability that supports Monte Carlo modeling techniques involving large numbers of flight operations as well as Ground Controller and Local Controller agents. It is supported by tools for generating stochastic variations of modeling parameters and procedures for metric evaluation of model output.

The model was adapted to estimate changes in runway system delay that result from the implementation of RNAV ELSO departure procedures at KATL. For both East and West Operations, differences in initial departure spacing applied before and after implementation of the procedures were modeled on a flight-by-flight basis. While *Before ELSO* scenarios evaluated in-trail operations of Runway 08R and Runway 27R departures, *With ELSO* scenarios evaluated, when possible, diverging departure operations from these runways. Flight plan data served as a key input to the model. The input data are described in the following section.

1) Input Data

In addition to the inputs required for modeling operations on KATL's runways, flight plan data provided information characterizing the cardinal direction of flight needed for runway assignments and aircraft spacing applications.

a) 2011 Demand

Modeled aircraft trajectories were based on FAA Traffic Flow Management System (TFMS) data [18]. One year of TFMS flight plan data for calendar year 2011 formed the basis for traffic demand. Flight plan information was extracted for aircraft departing KATL. Data processing ensured that each flight plan contains the final flight plan prior to departure and only for flights that actually operated. Routing in the flight plan includes departure and arrival airports, departure and arrival procedures, as well as navigational fixes, navigational aids, and en route procedures.

b) Future Demand

Future demand was based on 2011 demand and FAA Terminal Area Forecast (TAF) demand level forecasts [19]. A ten-year time range was identified for evaluation (2011-2021). For each day and demand level, departure demand was increased by duplicating a fraction of the 2011 flight plans to reflect the traffic growth associated with the demand level. The following demand levels were included:

2011 + 0.0 percent increase (2011)

2011 + 3.7 percent increase (2013)

2011 + 10.5 percent increase (2015)

2011 + 15.7 percent increase (2017)

2011 + 20.6 percent increase (2019)

2011 + 25.6 percent increase (2021)

The flight plans were chosen randomly for duplication leaving RNAV equipage levels represented in the demand data largely unchanged and resulting in demand timing characteristics that are qualitatively similar to the timing characteristics reflected in the 2011 demand. For each of the six levels of departure demand, Table 2 lists the scenarios evaluated in this study and the number of departure operations modeled in each scenario. In total, the modeling results presented in Section VII were based on nearly 12 million simulated departure operations.

TABLE II. NUMBER OF MODELED DEPARTURE OPERATIONS

Demand Scenario	Number of Modeled Departure Operations			
	Before ELSO		With ELSO	
	East Operation	West Operation	East Operation	West Operation
2011	438,994	438,994	438,994	438,994
2011 + 3.7 %	455,011	455,011	455,011	455,011
2011 + 10.5 %	485,015	485,015	485,015	485,015
2011 + 15.7 %	507,825	507,825	507,825	507,825
2011 + 20.6 %	529,250	529,250	529,250	529,250
2011 + 25.6 %	551,199	551,199	551,199	551,199

2) Assumptions

Runway assignments and assignments of departure procedures were carried out by the Ground Controller agent of the model. For each airport operational mode (East and West Operation), the agent's assignment decisions were based on three criteria: The cardinal direction of flight, the aircraft type, and scheduled departure time.

In the dual departure runway configuration, for example, North and West departures were assigned Runway 08R. South and East departures were assigned runway 09L. This 08R/09L assignment scheme or *split* serves as the primary split in East operation. The routing of Runway 08R departures in the *With ELSO* scenario reflected the diverging departure routes that became available with the implementation of the RNAV ELSO departure procedures. Aircraft of weight class Heavy were exclusively assigned to Runway 09L/27R. Because of the NW/SE split, Heavy aircraft that were North- or West-bound required additional routing to accommodate these *cross complex* departures (see Figure 3).

For the vast majority of departure operations, the Ground Controller agent of the model assigned runways in dual departure runway configuration. However, during certain time periods of the day (or *time windows*), the agent made assignments in triple departure runway configuration. Analysis of 2011 FAA Aviation System Performance Metrics (ASPM) data served to identify and characterize the time windows [20]. The time windows were validated to ensure that the number of modeled Runway 10/28 departure operations closely matched the number of actual departure operations recorded during the *Before ELSO* evaluation period. During triple departure time windows, aircraft that otherwise would be assigned Runway 09L/27R and were eligible for triple departure operations (i.e., non-Heavy) were assigned Runway 10/28 instead.

The Local Controller agent of the model sequenced and spaced aircraft in accordance with the separation standards that apply to the *Before ELSO* and *With ELSO* scenarios [4].

3) Evaluation Metrics

Metrics were developed and applied to modeled departure operations to characterize and quantify changes in departure efficiency and runway system delay. The metrics are described in the following sections.

a) Departure Efficiency

In a manner analogous to the Departure Efficiency evaluation described above, modeled departure operations were evaluated using a **Departure Spacing Time** metric. By measuring differences in airborne times, the metric captures the inter-departure times realized in modeled operations and compiles summary statistics that illustrate how measured spacing values are distributed over the range of all observed values.

b) Runway System Delay

The metric used to quantify delay reduction benefits characterized departure delay associated with the KATL runway system. On a departure-by-departure basis, this **Runway System Delay** was defined as the sum of delays aircraft accrue while awaiting take-off clearance at the runways. It represents the time aircraft spend after joining a line-up queue at a runway up to the moment the flights commence takeoff roll [12]. In other words, runway system delay is defined here as the difference between the actual departure time of a flight and the time it completes taxiing and joins a line-up queue at a runway.

VII. EVALUATION RESULTS

The methodologies for assessing operational changes described in Section VI served to analyze surveillance data of actual flight operations recorded before and after implementation of the RNAV ELSO procedures as well as simulation model evaluations of operational benefits. The analysis results are presented in the following sections.

A. *Departure Efficiency*

The track data were evaluated using the Departure Spacing Distance and Departure Spacing Time metrics outlined in Section VI. Figure 5 compares departure spacing distance and time distributions of Runway 08R and Runway 27R departures before and after implementation of the RNAV ELSO procedures. The results indicate that a 3-NM departure spacing distance was realized most frequently in *Before ELSO* scenarios, and that a reduced spacing distance of approximately 2.2 NM was most often observed in *With ELSO* scenarios after implementation of the RNAV ELSO procedures. While the former spacing generally reflects application of the Radar Separation standard to operations that depart in-trail of each other, the latter is consistent with diverging departure operations and application of the Same Runway Separation standard [4]. The results obtained in applications of the Departure Spacing Time metric indicate corresponding departure spacing times of about 63 seconds in in-trail and 48 seconds in diverging departure operations.

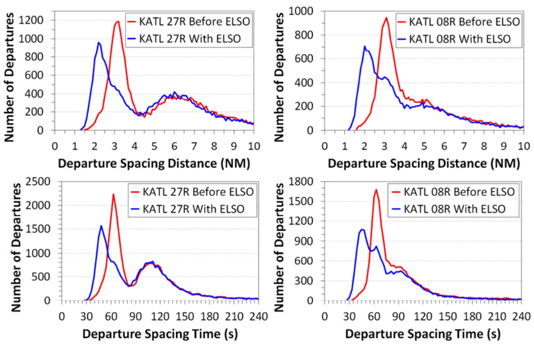

Figure 5. Comparison of departure spacing distance and time distributions measured before and after implementation of RNAV ELSO procedures

B. *Departure Delay*

The delay reduction benefits resulting from application of reduced spacing in diverging departure operations were evaluated using the validated departure efficiency model outlined in Section VI. Departure spacing time distributions measured in actual departure operations conducted before and after implementation of the RNAV ELSO procedures served to validate the model. The model validation results are presented in the following sections.

1) *Model Validation*

For each of the primary departure runways under investigation, the model validation comprised two steps. In a first step that validated the model of *Before ELSO* operations, modeled departure spacing time distributions were compared with the corresponding distributions obtained from the analysis of radar track data of actual operations. A second step similarly compared departure spacing time distributions of modeled *With ELSO* scenarios and actual departures evaluated after implementation of the RNAV ELSO procedures.

a) *Before ELSO*

Figure 6 compares departure spacing time distributions of departure operations measured and modeled before implementation of the RNAV ELSO departure procedures. The measured distributions are identical to those shown in Figure 5. The agreement between the departure spacing applied in the distributions reflecting actual and modeled operations suggests that the validated departure efficiency model closely matches the departure efficiency observed in actual operations.

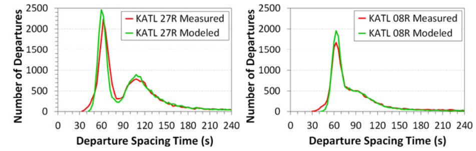

Figure 6. Comparison of departure spacing time distributions of operations measured and modeled before implementation of RNAV ELSO procedures

Figure 7 compares the average ASPM-derived daily runway system delay and corresponding modeled runway system delay. The modeled delay resulted from application of the Runway System Delay metric described in Section VI to output from the modeling of departure operations during the entire 2011 evaluation period (see Table II). The comparison illustrates the similarities as well as key differences between the two delay metrics. While the ASPM-derived metric reflects the effects of local events (e.g., runway closures) and non-local events (e.g., ground delay programs) on departure delay at the airport, the model-based metric quantifies delay in a manner that is largely independent of these effects. This approach ensured selective and conservative evaluations of delay reduction benefits that directly result from the operational changes associated with the implementation of the RNAV ELSO departure procedures and application of reduced spacing in diverging departure operations.

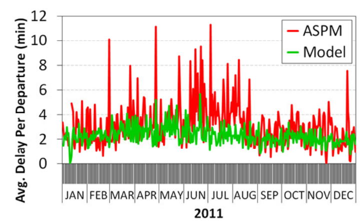

Figure 7. Comparison of ASPM-derived and modeled average daily runway system delay

b) *With ELSO*

Figure 8 compares departure spacing time distributions of departure operations measured and modeled after implementation of the RNAV ELSO departure procedures. The measured departure spacing time distributions shown are identical to those shown in Figure 5. The agreement between the departure spacing applied in actual (measured) and modeled operations suggests that the validated departure efficiency model closely matches the departure efficiency observed in actual operations after implementation of the procedures.

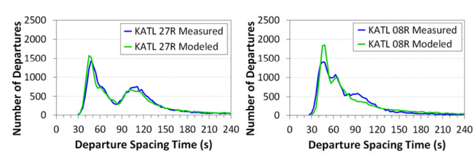

Figure 8. Comparison of departure spacing time distributions of operations measured and modeled after implementation of RNAV ELSO procedures

2) *Runway Departure Delay*

In order to investigate changes in runway-specific departure delays associated with the use of dual and triple departure operations, the Runway System Delay metric was applied to output from the validated model of *Before ELSO* and *With ELSO* departure operations on a per-runway basis.

Figure 9 compares the runway departure delays modeled before and after implementation of the RNAV ELSO departure procedures. For *Before ELSO* East Operation departures, the results indicate an average Runway 08R delay of nearly 4 minutes per departure in either dual or triple departure runway configuration. Due to ELSO-enabled diverging departure operations, this average delay is reduced by 3.4 minutes to about 0.6 minutes in the corresponding *With ELSO* scenario.

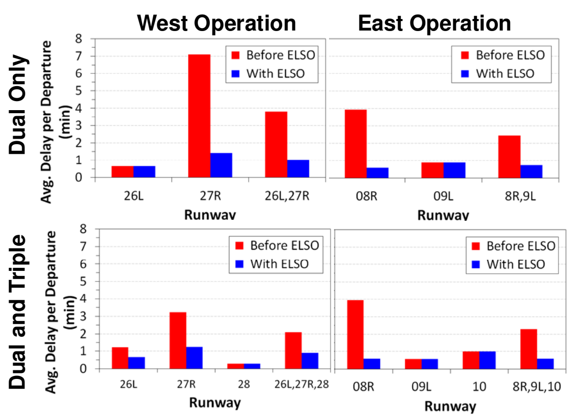

Figure 9. Comparison of average delays per departure modeled before and after implementation of RNAV ELSO procedures

In *Before ELSO* West Operation dual departure runway configuration, an average Runway 27R delay of over 7 minutes demonstrates an increased need for application of triple departure operations. While occasional use of triple departure operations was found to reduce this delay to about 3.2 minutes per Runway 27R departure (dual and triple), the delay associated with the runway system (26L, 27R, 28) remained at an average value of 2.1 minutes per ATL departure. With ELSO-enabled diverging departure operations on Runway 27R, the results suggest further delay reductions by 1.2 minutes resulting in an average delay associated with the runway system of approximately 0.9 minutes per ATL departure in West Operation.

3) *Airport Departure Delay*

The Runway System Delay metric described in Section VI was applied to the 24 *Before ELSO* and *With ELSO* modeling scenarios listed in Table II. For the time period comprising all 365 days of 2011 evaluated in this study, the following section presents average delay and average delay reduction benefit estimates on a per-departure basis.

a) Average Delay per Departure

Figure 10 presents average departure delays and delay benefits per ATL departure before and after implementation of the RNAV ELSO departure procedures obtained for the six levels of departure demand described in Section VI. The delay results obtained for the *Before ELSO* scenario and the 2011 level of departure demand suggest average departure delays of 2.3 and 2.4 minutes for East and West Operation departures, respectively. For *With ELSO* scenarios, the figure indicates reduced average delays of 0.6 (East Operation) and 0.9 minutes (West Operation) of departure delay. Also shown are the results obtained for the cases that evaluated the five additional traffic growth scenarios indicated in the figure.

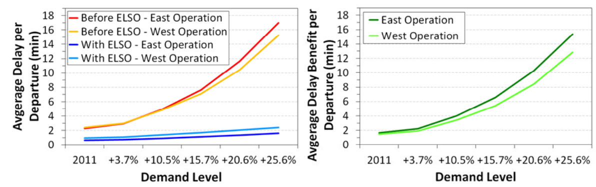

Figure 10. Comparisons of modeled average delays per departure before and after implementation of RNAV ELSO departure procedures

It is noted that average departure delays per aircraft, particularly at the highest demand levels evaluated in this study, may have exceeded thresholds that would likely trigger adaptive actions by users and passengers and limit traffic growth rates [21]. It is important to note that the model presented here did not attempt to anticipate possible future adaptive actions. Consequently, delay estimates should be considered progressively less reliable as departure delay values increase and future adaptive actions become more likely.

In order to estimate the benefits that result from the implementation of the RNAV ELSO departure procedures, differences between the average delays accrued in the *With ELSO* and *Before ELSO* evaluation scenarios served to define the resulting delay reduction benefits. Separately for East and West Operation departures, Figure 10 also presents the resulting delay reduction benefit estimates. For the 2011 level of departure demand, the results suggest an average delay reduction benefit of nearly 1.7 minutes per East Operation departure and approximately 1.5 minutes per West Operation departure.

Taking into consideration KATL's East Operation-West Operation split of 34.4-65.6 percent, Figure 11 presents the resulting estimates of average delay reduction benefits per ATL departure that are associated with the implementation of the RNAV ELSO departure procedures at the airport. For the 2011 level of departure demand, the results suggest an average departure delay reduction benefit of 1.5 minutes per departure.

In order to estimate monetary benefits that result from the delay reduction benefits presented in Figure 11, the delay reduction benefits were multiplied by an Aircraft Direct Operating Cost (ADOC) value that characterizes the average cost of operating aircraft at KATL. A CAASD estimate for ground operations of $32.47 per minute was adopted. This ADOC estimate comprised a fuel component of $8.06 and a crew/maintenance component of $24.40 per minute of delay. It was based on 2011 data of operations conducted at KATL and FAA Office of Aviation Policy and Plans (APO) guidance for estimating aircraft operating costs [22]. Figure 11 also presents the resulting estimates of monetary operator benefits per ATL departure indicating an average operator benefit of $49.74 per departure at the 2011 level of departure demand.

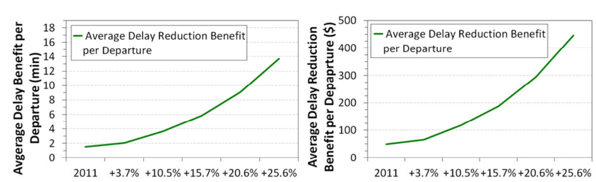

Figure 11. Average delay reduction benefits per departure associated with the implementation of RNAV ELSO departure procedures

b) Total Annual Delay

In a manner similar to Figure 11, Figure 12 presents total departure delay benefits accrued by all KATL departures evaluated for all 365 days of KATL departure operations evaluated in this study. The results suggest a total annual departure delay reduction benefit of 0.67 million minutes resulting in a monetary annual delay benefit to operators of $21.8 million for the 2011 level of departure demand.

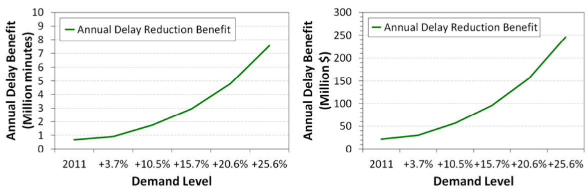

Figure 12. Total annual delay reduction benefits associated with the implementation of RNAV ELSO departure procedures

C. Departure Track Miles

In order to quantify the operational impact and estimate costs associated with the increases in track miles outlined in Section V, radar track data of *Before ELSO* and *With ELSO* departures were evaluated using the *Track Length* metric described in Section VI. Figure 13 illustrates sample radar track data recorded before and after implementation of the RNAV ELSO departure procedures at KATL. The figure illustrates *With ELSO* departure operations along the ELSO-enabled, additional RNAV routes described in Section IV.

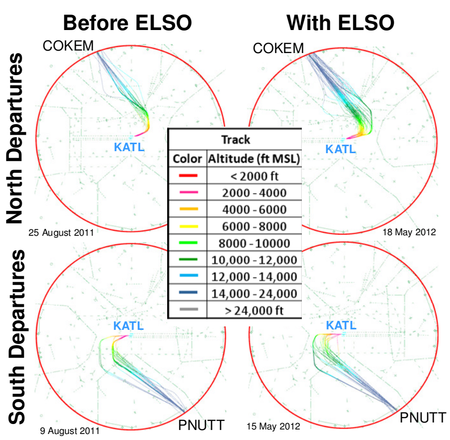

Figure 13. Sample radar track data illustrating Runway 08R North departures and Runway 27R South departures before and after implementation of RNAV ELSO departure procedures

Application of the Track Length metric to the track data quantified the track miles that were flown in actual operations. Figure 14 presents track mile averages measured before and after implementation of the RNAV ELSO departure procedures for all 16 departure procedures and associated navigational fixes indicated in the figure. For East Operation departures, the results indicate appreciable increases in track miles flown by North departures via the COKEM, CADIT, NUGGT, and SUMMT waypoints. Similar increases were measured in West Operation for South-bound departures via the PNUTT, BRAVS, THRSR, and NOVSS waypoints. Little or no changes were observed for departures via all other waypoints.

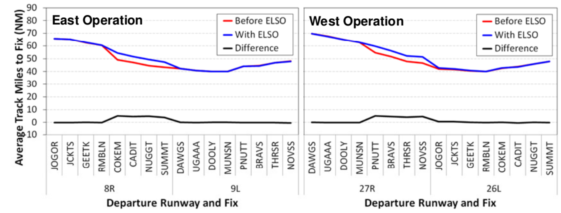

Figure 14. Comparisons of average track miles measured before and after implementation of RNAV ELSO departure procedures

In order to estimate the cost impact associated with the changes in track miles flown after implementation of the RNAV ELSO departure procedures, the measured track-mile differences shown in Figure 14 were multiplied by the annual number of operations departing via the various departure fixes to obtain the annual distance impact. The annual distance impact served to estimate the associated monetary impact [16].

For the 2011 level of departure demand, the analysis was found to suggest an average track mile cost impact of $4.36 per ATL departure. For the same level of departure demand (2011), the total annual cost impact was estimated at $2.00 million. Figure 15 presents track mile cost increase estimation results obtained for the 2011 level of departure demand as well as for the five additional demand levels evaluated in this study.

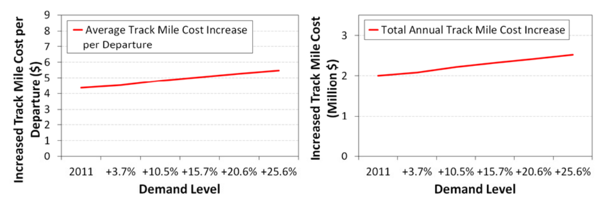

Figure 15. Track mile cost increase estimates associated with the implementation of RNAV ELSO departure procedures

D. Departure Climb Continuity

The changes in routing of North departures (East Operation) and South departures (West Operation) outlined in Section V also affected the continuity with which these departure climb operations could be conducted. Figure 16 shows three-dimensional illustrations of radar tracks of Runway 08R operations that departed to the North via the COKEM waypoint and Runway 27R operations that departed

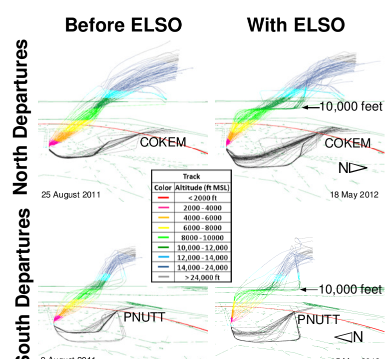

Figure 16. Sample radar track data illustrating climb profiles of Runway 08R North departures and Runway 27R South departures before and after implementation of RNAV ELSO departure procedures

the airport to the South via PNUTT. The figures also show vertical projections of the tracks, or *track shadows*, in black. Primarily for operations of *With ELSO* scenarios that closely follow a departure procedure, the radar tracks indicate occasional level-offs at an altitude of 10,000 feet.

The radar track data were evaluated using the Time In Level Flight metric described in Section VI. Application of the Time in Level Flight metric quantified the time actual departures operated in level flight. Figure 17 presents average times in level flight measured before and after implementation of the RNAV ELSO departure procedures. For East Operation departures, the results indicate appreciable increases in level flight at 10,000 feet by North departures via the COKEM, CADIT, NUGGT, and SUMMT waypoints. Similar increases were measured in West Operation for South-bound departures via the PNUTT, BRAVS, THRSR, and NOVSS waypoints. Little or no changes were observed for departures via all other waypoints.

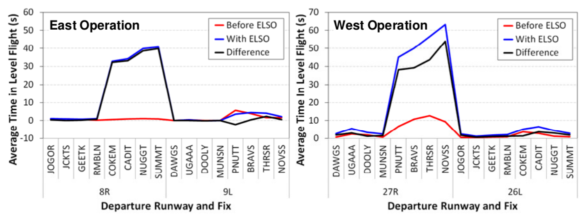

Figure 17. Comparisons of average times in level flight measured before and after implementation of RNAV ELSO departure procedures

In order to quantify the cost impact associated with more frequent level-offs at 10,000 feet after implementation of the RNAV ELSO departure procedures, the associated fuel burn cost impact was estimated [16]. Based largely on the average times in level flight presented in Figure 17, the resulting cost impact estimates are presented in Figure 18.

For the 2011 level of departure demand, the analysis suggests an average time-in-level-flight cost impact of \$1.38 per ATL departure. For the same level of departure demand, the total annual cost impact was estimated at \$0.63 million. Corresponding time-in-level-flight cost impact estimates for the five additional demand levels evaluated in this study are also shown in the figure.

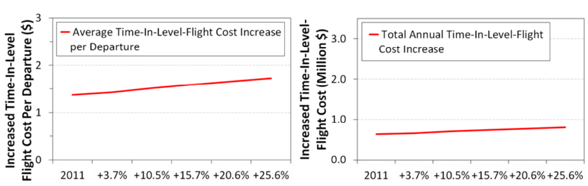

Figure 18. Time-in-Level-Flight cost increase estimates associated with the implementation of RNAV ELSO departure procedures

E. Benefit Summary

Taking into consideration the delay reduction benefits, the cost impact estimates for increased track miles and time in level flight at 10,000 feet, Figure 19 presents the resulting balance of operational benefits associated with the implementation of RNAV ELSO departure procedures. For the 2011 level of departure demand, the results indicate a net average operator benefit of \$44.00 per ATL departure and a total annual benefit of \$19.2 million at the 2011 level of departure demand. The fuel burn component of the benefit translates to a total annual carbon dioxide (CO_2) emission reduction benefit of approximately thirteen thousand metric tons at the 2011 level of departure demand.

For the case that assumes no growth in traffic demand at the airport, a lower-bound discounted (current year) cumulative benefit of about \$210 million was estimated for the 2011-2021 time period. For the case that assumes the departure demand growth projections also shown in Figure 19 and no other changes at the airport, an upper-bound cumulative operator benefit was estimated at approximately \$1 billion for the 2011-2021 time period. Additional benefits include operational simplifications associated with consistent use of PBN operations and runway use changes that reduce reliance on triple departure configurations and associated runway crossings at the airport.

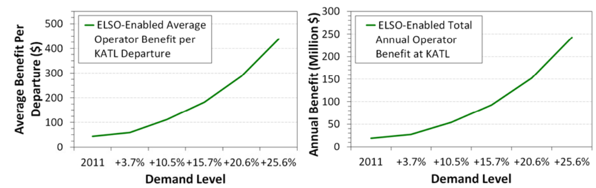

Figure 19. Average operator benefits per departure and total annual operator benefits associated with the implementation of RNAV ELSO procedures

VIII. Conclusions

On 20 October 2011, the FAA commenced an operational demonstration of the RNAV ELSO standard concept at KATL. The ELSO standard concept re-defines minimum divergence requirements and offers additional PBN procedure design options not previously available. In each airport operational configuration, a revised set of RNAV SID procedure designs added a fourth departure route within KATL airspace that previously supported only three routes and permit conducting diverging departure operations from two additional runways. The primary operational changes that are directly associated with the additional, ELSO-enabled diverging departure operation were evaluated and resulting benefits were estimated.

The results firmly established the operational benefits of the ELSO-based separation standard concept that enabled additional, efficiency-enhancing diverging departure operations at KATL. At the 2011 level of departure demand, delay reduction benefits were estimated at an average of 1.5 minutes per departure. Taking into consideration the delay reduction benefits and the cost impacts associated with increased track miles and changes in climb continuity, the net benefit to aircraft operators was estimated at an average of \$44.00 per KATL departure and a net annual operator benefit of \$19.2 million. For this level of departure demand (2011), associated reductions in annual CO_2 engine exhaust emissions were estimated at thirteen thousand metric tons.

The results obtained for future demand scenarios indicate potential cumulative benefits ranging from \$0.2 to \$1.0 billion and associated CO_2 reductions of approximately 143 to 860 thousand metric tons for the 2011-2021 evaluation time period.

The delay reduction results suggest that associated improvements in schedule integrity position the airport for future growth in the coming decade.

IX. NEXT STEPS

As part of the suite of NextGen activities, the FAA has begun work to propose amendments to FAA Order JO 7110.65, paragraph 5-8-3 that reduce the currently required 15-degree of divergence on a NAS-wide level. The FAA is also planning to provide ELSO-enabled improvements at major airports in the U.S. airspace system over the next few years, and to working with a wide range of domestic and international partners to ensure that the needed changes are harmonized. In its 21st Separation and Airspace Safety Panel (SASP) meeting of the Working Group of the Whole, the International Civil Aviation Organization (ICAO) reviewed the ELSO concept and KATL demonstration results. The Working Group endorsed the work undertaken to date and outlined a path forward to amend ICAO Doc 4444 including further analysis of observed navigational performance, as well as the development of procedure design and charting requirements.

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NOTICE

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