DEVELOPMENT AND OPERATIONAL TRANSITION OF THE FIRST PBN-ENABLED DEPARTURE SEPARATION STANDARD

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Abstract

In 2014, the Federal Aviation Administration (FAA) prioritized Performance-Based Navigation (PBN) capabilities of its Next Generation Air Transportation System (NextGen) and committed to implementing high-priority innovations within the next three years. For 2015, the commitments include the issuance of a national standard for PBN-enabled Equivalent Lateral Spacing Operation (ELSO) departures and ELSO implementations at airports throughout the United States (US) National Airspace System (NAS). Beginning in 2011, flight validations of ELSO-based reduced-divergence procedures at The Hartsfield-Jackson Atlanta International Airport (KATL) demonstrated operational benefits and validated the ELSO concept for the development of the standard. The standard will enable the NAS-wide use of PBN departure procedures with a reduced minimum divergence of 10 degrees instead of the 15 degrees currently required to conduct simultaneous parallel and successive departure operations. This paper describes the process, from inception to integration into the NAS that pioneered the first PBN-enabled reduced separation standard for departures. Further work to identify candidate airports for application and activities supporting the harmonization of PBN-based separation standards in the global air transportation system are also discussed.

Introduction

Performance-Based Navigation (PBN) serves as a cornerstone for transforming the United States (US) National Airspace System (NAS) from a system that primarily relies on ground-based navigation and radar surveillance to a satellite-based system. To further capitalize on PBN-enabled capabilities and enable safe implementation of more closely spaced flight paths, the Federal Aviation Administration (FAA) committed to developing standards for reduced separation and divergence [1]. The commitments include the issuance of a standard for PBN-enabled Equivalent Lateral Spacing Operation (ELSO) departures and ELSO implementations at airports throughout the NAS [2]. The ELSO standard concept provides lateral spacing between reduced-divergence flight paths that is equivalent to the spacing observed in conventional departure operations at minimum divergence requirements of the currently applicable separation standard [3]. Applications of the reduced standard deliver benefits by providing PBN procedure design options to more effectively address terrain, obstacle, or airport noise sensitivity constraints and enable diverging operations to increase departure capacity, reduce departure delay, decrease fuel burn, and lessen aircraft emissions. This paper describes the process applied to successfully operationally transition ELSO as the first PBN-enabled departure separation standard into the NAS and harmonize its adoption in the global air transportation system.

Background

In 2003, the FAA unveiled its strategy for applying PBN capabilities with the publication of the *Roadmap for Performance-Based Navigation.* The roadmap paved the way for NAS-wide implementation of terminal Area Navigation (RNAV) Standard Instrument Departure (SID) and Standard Terminal Arrival (STAR) procedures [4]. Leveraging

the on-board navigation capabilities of advanced flight automation systems that are currently available on the majority of commercial and corporate aircraft, RNAV procedures promised more efficient utilization of available runways and constrained terminal airspaces surrounding major U.S. airports.

Initial implementations of RNAV procedures that provided the most significant benefits included departure procedures at Dallas/Ft. Worth International Airport (KDFW) and The Hartsfield-Jackson Atlanta International Airport (KATL) [5]. At both airports, PBN-based improvements in navigation accuracy and precision enabled the designs of additional departure flight paths.

At KDFW, the designs implemented in 2005 offered two additional diverging departure procedure routes in both North and South airport operational configurations. For each primary departure runway, the designs applied conventional divergence with a minimum of 15 degrees between the initial route segments. A Certificate of Authorization or Waiver (COA or *waiver*) authorized conducting simultaneous PBN operations along initially parallel route segments from runways on both East and West airport complexes [6]. In Figure 1, green and red arrows illustrate the initial course angles that meet the minimum requirement of the conventional divergence standard (15 degrees). Red arrows denote the courses of initial procedure segments of the additional, PBN-enabled departure routes.

At KATL, noise impact considerations and resulting route design constraints limited the number of PBN departure routes to one additional departure route in both East and West operational configurations. Application of conventional divergence requiring course divergence of at least 15 degrees and the need to operate within established noise abatement corridors precluded designs of dual-diverging routes from Runway 08R and Runway 27R. The lack of divergence necessitated that these departures remain in-trail of each other and prevented full realization of the efficiency benefits associated with diverging operations at the airport. Furthermore, the use of the PBN-enabled dual-diverging departure routes from Runways 09L and 26L had to be discontinued during periods when the airport conducted Triple departure operations requiring Air Traffic Control (ATC) personnel to issue initial aircraft headings (radar vectors) to aircraft departing from some of the runways. The initial divergence angles of the departure tracks implemented in 2006 are illustrated in Figure 2. As before, red arrows denote initial courses of PBN-enabled additional departure routes.

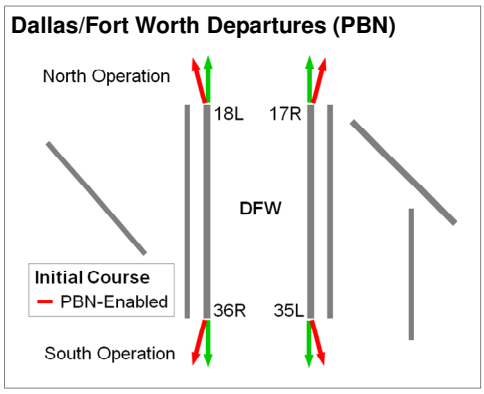

Figure 1. Initial Divergence of KDFW's PBN Procedures Implemented in 2005

The following sections review current requirements of the conventional 15-degree divergence standard and describe key steps in the development and implementation of a PBN-enabled reduced divergence standard.

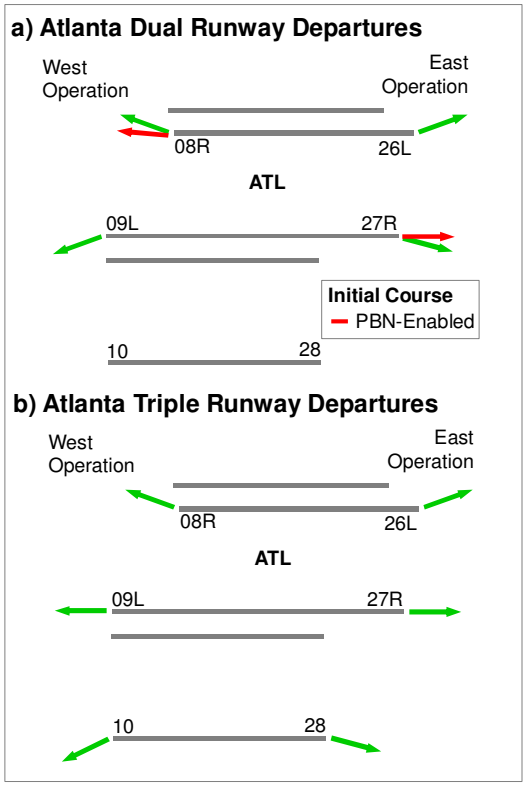

Figure 2. Initial Divergence of KATL's Dual and Triple Departure Tracks Implemented in 2006

Conventional Divergence Standard

A single 15-degree divergence requirement of the radar separation standard applies when conducting departure operations. This rule has been in place for the past 50 years. The standard currently applies equally to conventional departures that follow ATC-assigned aircraft headings (i.e., radar vectors) and PBN departures that proceed along designed procedure routes. FAA Order (FAAO) JO 7110.65 - Air Traffic Control and International Civil Aviation Organization (ICAO) Doc 4444 Procedures for Air Navigation – Air Traffic Management (PANS-ATM) define the requirements for conducting diverging departure operations [7,8].

There are three key rules pertaining to diverging departure operations from the same runway or parallel runways. In each of these cases, radar identification with the aircraft must be established within one mile of the takeoff runway end and courses must diverge by 15 degrees or more immediately after departure. Figure 3 illustrates minimum separation requirements for operations conducted in the radar environment. Figure 3a) refers to aircraft departing from the same runway and Figure 3b) refers to aircraft departing from the same airport or adjacent airports with parallel runways that are separated by less than 2,500 feet. In these cases, wake turbulence requirements must be applied longitudinally between aircraft departing the same or parallel runways. Figure 3c) refers to aircraft departing parallel runways that are spaced 2,500 feet or more apart. In this case, aircraft may depart independently and no wake turbulence requirements apply.

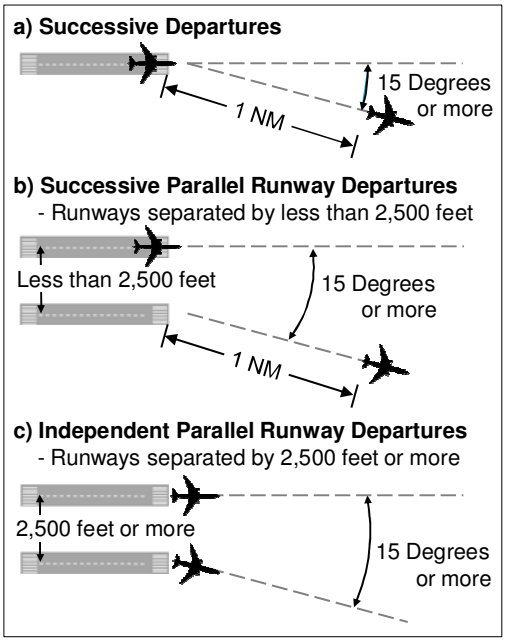

Figure 3. Applications of the Current 15-Degree Divergence Standard

Reduced Divergence Standard

In 2010, FAA Next Generation Air Transportation System (NextGen) strategy and mid-term implementation objectives included the goal of more effectively addressing terrain, obstacle, or airport noise sensitivity constraints and increase operational efficiencies. The strategy called for the development and adoption of a PBN-enabled reduced divergence standard to facilitate the design of multiple departure paths from each runway end [9,10]. With the initial goal of enabling diverging departure operations from all primary departure runways at KATL, the process adopted to reduce the divergence standard represents a multi-year effort across various FAA lines of business, and between the FAA and aviation industry. The various activities can be grouped in the following steps:

- Operational Need
- Concept Development
- Concept Application
- Technical Review
- Operational Transition
- Document Change
- NAS-Wide Application
- Global Harmonization

Key elements of each step are described in the following sections.

Operational Need

In 2008, the Atlanta Terminal Radar Approach Control (TRACON) Airspace and Procedures Office identified the need to overcome the design limitations described previously to fully realize the efficiency benefits of diverging departure operations (see Figure 2). The office proposed a plan to evolve the designs

of KATL's PBN departure procedures to Atlanta's Capacity Enhancement Working Group (CEWG)[1]. Primary objectives of the evolution plan included the goals of increasing departure capacity and thus improving schedule integrity of airline hub operations at the airport [11]. To this end, the plan called for enabling air traffic controllers to conduct successive and/or simultaneous RNAV SID operations from dual/triple parallel runways with reduced divergence. The use of reduced divergence was necessary to provide additional departure paths within KATL's established noise abatement corridors and lessen the environmental impact on areas surrounding the airport. A secondary goal was to enhance operational safety by enabling consistent use of RNAV *off-the-ground* (OTG) operations, i.e., no longer requiring ATC issuance of initial radar vectors to departing aircraft when the airport conducted triple runway departure operations.

Initial Concept Development

In 2009, the FAA Performance Based Navigation Policy and Support Group (AJV-14) tasked The MITRE Corporation's Center for Advanced Aviation System Development (MITRE CAASD) to review the operational changes expected to result from KATL's evolution plan and estimate associated benefits to airline operators. The preliminary findings indicated potential annual benefits in the $10 to $20 million range [12]. The findings validated KATL's business case for reduced-divergence departure operations. Follow-on tasking included investigations of PBN-based options to advance the divergence standard with the initial goal of enabling reduced-divergence departure operations at the airport.

In 2010, the ELSO concept was proposed to enable departure operations along departure paths with reduced divergence and along initially parallel departure paths [3]. The concept provides lateral spacing between departure paths that is equivalent to or greater than the spacing of departure paths associated with conventional diverging departure operations based on minimum requirements of the currently applicable divergence standard. This comparative approach also suggested an equivalent or greater level of safety for ELSO departure operations.

The ELSO standard concept provides an analytic expression that describes the divergence angle as a function of three components that take into consideration observed navigational performance and runway layout characteristics [3]. Depending upon the runway layout geometry, diverging application of the ELSO standard typically supports reduced divergence angles of 5 to 10 degrees for RNAV 1 departure operations. As described in the *Document Change* section below, the standard eventually adopted for NAS-wide application solely capitalizes on PBN-enabled improvements in navigational performance. Figure 4 illustrates the PBN component of the ELSO concept.

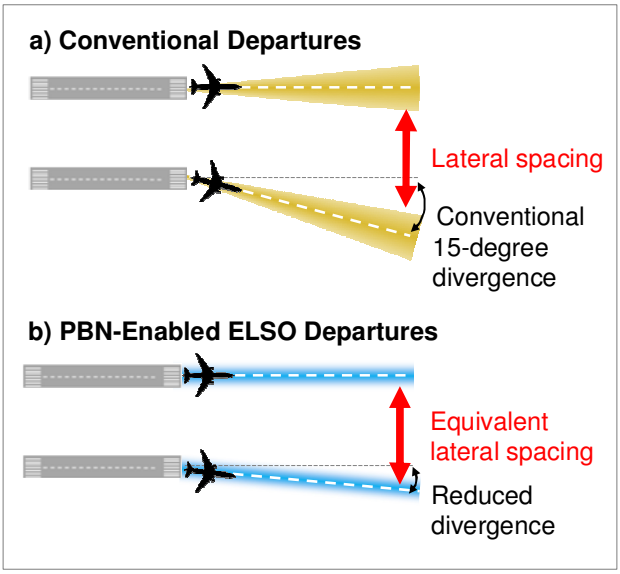

Figure 4. Diverging Application of the PBN Component of the ELSO Concept

Concept Application

To achieve the goals of its RNAV SID evolution plan, KATL sought approval for a waiver to apply reduced course divergence. The plan showed that application of reduced divergence enables dual-diverging operations from KATL's two primary departure runways and independent operations from its three widely-spaced parallel runways. The initial divergence angles of the departure routes are illustrated in Figure 5. Initial review of the route designs showed that the proposed divergence angles meet or exceed ELSO divergence requirements [3].

[1] A local workgroup comprised of representatives from the aviation industry, the local airport authority, and FAA.

In 2010, Atlanta TRACON convened a Safety Risk Management Panel (SRMP) to meet the Safety Management System (SMS) requirements for the proposed operational changes. The panel conducted a safety risk analysis in support of the proposed operations with reduced divergence. It identified and addressed safety risk management issues and mitigation actions pertaining to the proposed operational changes and developed a Safety Risk Management Document (SRMD) for FAA review and approval [13].

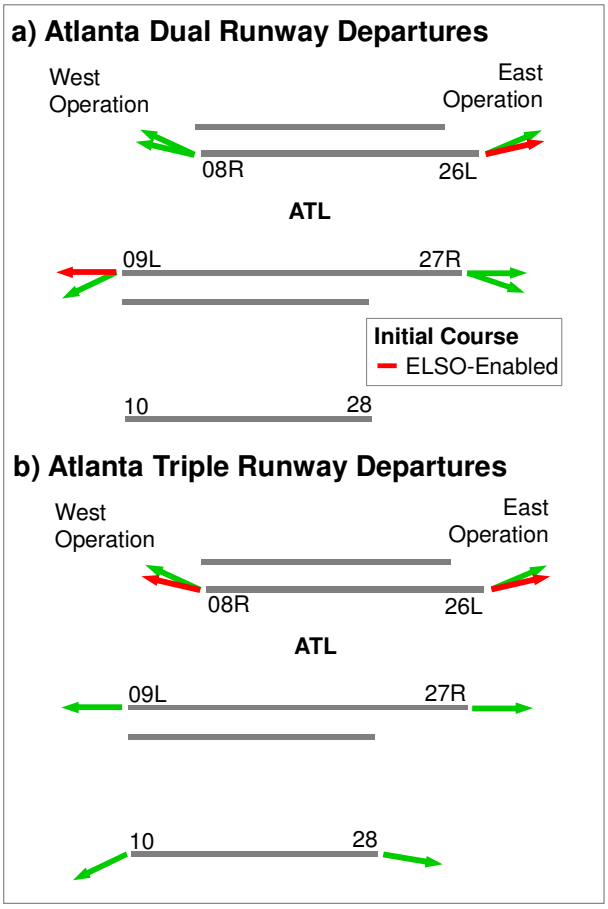

Figure 5. Initial Divergence of KATL's PBN Procedures Implemented in 2011

Technical Review

FAA technical review of the ELSO concept led by Flight Technologies and Procedures Division (AFS-400) commenced in 2011. It included AJV-14 as well as Terminal Safety and Operations Support (AJT-2) and focused on evaluating risks that may result from application of the concept at KATL. The initial review validated the comparative approach of the ELSO concept and the absence of negative impacts on risks associated with operations on reduced-divergence departure routes. Subsequent review by FAA RNAV and Required Navigation Performance (RNP) Group (AJR-37) determined the acceptability of ELSO departure operations from a safety aspect and facilitated the SMS process applicable to FAA's Air Traffic Organization (ATO) [14].

Operational Transition

Approval

On 22 August 2011, FAA Terminal Operations and Safety Support (AJS-22) approved Atlanta's waiver request for reduced course divergence and authorized Atlanta Tower and TRACON to conduct reduced-divergence continuous RNAV off-the-ground operations for successive departures and dual/triple simultaneous parallel departures by implementing NextGen RNAV ELSO procedures [15]. With an effective date of 20 October 2011, the waiver paved the way for operational demonstrations of reduced-divergence departure operations at KATL and served to validate the ELSO concept.

Implementation

On 20 October 2011, Atlanta implemented a set of sixteen NextGen RNAV ELSO departure procedures that provided additional departure paths within KATL's established noise abatement corridors. Various pre-implementation activities were carried out in close collaboration among Atlanta Tower, Atlanta TRACON, Atlanta Air Route Traffic Control Center (Center), airline operators, and surrounding communities. These activities implemented measures preempting possible operational issues for which the SRMP previously identified mitigation actions. Most importantly, they included controller and pilot training to ensure that aircraft navigate along the routes on which they were cleared to depart.

To facilitate the transition to reduced-divergence departure operations, Atlanta Tower temporarily opened an additional Ground control position. On initial call up, the controller staffing this *Meter* position verified that the assigned departure runway and initial navigational fix associated with the departure procedure were correctly loaded in the aircraft Flight Management System (FMS).

The phraseology in use by the Local controller when issuing takeoff clearances also specifies the name of the fix to which the departure is initially cleared. Use of this phraseology promotes final flight-crew verification of the procedure (initial fix) and requires read-back to ensure proper course guidance along the cleared route of flight [16]. Another measure requires the Local controller to monitor the departure either visually or by using a Certified Tower Radar Display (CTRD) to assure timely aircraft turn initiation before instructing the aircraft to contact Departure control.

Further monitoring of the flight's route conformance by Departure control was aided by additional markings on video map overlays developed for use by TRACON Automated Radar Terminal System Color Displays (ACD). These measures proved effective in assuring aircraft divergence and continue to be in use today.

Other measures were taken to accommodate non-participating aircraft, i.e., aircraft that lack the required PBN capability, or contingencies that preclude execution of the RNAV ELSO procedures (e.g., equipment outages, weather events). They included the development of runway-specific conventional procedures and revising the Letter of Agreement (LOA) between Atlanta Tower and TRACON to reflect the changes. The various implementation measures were taken in close consultation with the airlines operating at the airport to ensure flight crew awareness of the operational changes. They also included publications of a Letter to Airmen, Attention All Users Pages (AAUP) to pilots, as well as updates to flight crew check lists [17].

Validation

In 2012, the FAA tasked MITRE CAASD to assess the operational changes that are directly associated with the ELSO-enabled diverging departure operations. The assessment quantified associated annual operator benefits at nearly $20 million [18]. As stated previously, the RNAV ELSO procedure designs increased the number of departure routes from three routes to four routes (see Figure 5). In an East operation, the additional route permits diverging departure operations from Runway 08R. Figure 6 compares East operation radar tracks before and after implementation of the NextGen RNAV ELSO procedures and illustrates the reduced-divergence departure operations at the airport.

The waiver that enabled KATL to conduct RNAV ELSO departure operations initially required biannual review and renewal. In preparation for its first request for renewal in 2013, Atlanta TRACON personnel reviewed the safety data that were collected over a period of nearly two years by its ongoing safety monitoring program. The review established the effectiveness of the measures taken to mitigate possible operational issues. No operational errors were attributed to the reduction of departure divergence and the request for waiver renewal was granted.

The successful flight validations at KATL paved the way for policy changes to facilitate beneficial ELSO application throughout the NAS without the need for airport-specific reviews and authorizations.

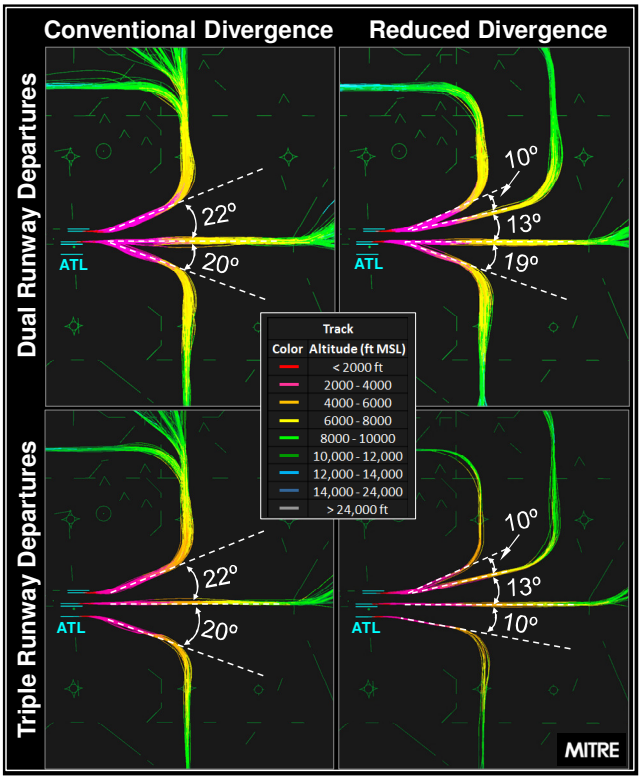

Figure 6. Radar Tracks Illustrating KATL's Reduced Divergence Departure Operations

Document Change

In 2012, FAA commenced a multi-phased initiative to update its Air Traffic Control Handbook, FAAO JO 7110.65. Update recommendations

included changes to Section 5-8-3 (Successive or Simultaneous Departures) to enable NAS-wide application of the ELSO standard [19]. The FAA tasked MITRE CAASD to perform a NAS-wide survey of candidate implementation airports. The survey results suggested the potential for beneficial application of reduced-divergence departure operations at other airports and supported the decision to propose a national policy change [20].

In 2013, the FAA tasked MITRE CAASD to develop a single divergence requirement for uniform application throughout the NAS. The adoption of a single divergence requirement forgoes the complexities of leveraging runway layout characteristics and solely capitalizes on PBN-enabled improvements in navigational performance [21]. FAA technical review by AFS-400 determined a single reduced value of 10 degrees appropriate for all PBN (RNAV 1) departure operations and for achieving a level of safety equal to or better than that experienced by conventional departures using 15 degrees divergence [22]. A SRMP was convened in 2014 to analyze the hazards and unintended consequences of introducing the proposed NAS-wide change. The work of the panel centered on examining KATL's operational experience conducting reduced-divergence departure operations and found no evidence to suggest that the reduction of divergence to 10 degrees has introduced risk into the NAS [23].

In 2014, the FAA Terminal Procedures Office (AJV-822) initiated a Document Change Proposal (DCP) and drafted language to authorize a minimum of 10 degrees of course divergence between successive and simultaneous RNAV SID departures. Following a review and comment period, FAA Air Traffic Procedures (AJV-8) approved the document change for publication in FAAO JO 7110.65 with an effective date of 25 June 2015. Specifically, the change:

- Defines *immediately after departure* turn requirements as any turn that provides at least 15 degrees of divergence that begins no more than 2 miles from the departure end of the runway (DER)
- Defines the requirement that the only type SID that can be used for reduced divergence procedures are RNAV SIDs constructed with a specific lateral path that begins at the DER
- Authorizes 1 mile initial separation for aircraft departing the same runway or parallel runways separated by less than 2,500 feet provided both aircraft are flying an (appropriate) RNAV SID and their courses diverge by 10 degrees or more immediately after departure
- Authorizes simultaneous takeoffs between aircraft departing in the same direction from parallel runways if the centerlines are separated by at least 2,500 feet and courses diverge by 10 degrees or more when both aircraft are flying an (appropriate) RNAV SID.

NAS-Wide Application

The scheduled inclusion of the reduced divergence standard in FAAO JO 7110.65 permits PBN procedure implementations with reduced divergence at eligible locations throughout the NAS. Capitalizing on improved navigational precision of PBN operations, these reduced-divergence departure paths provide benefit by improving the ability of parallel and same runway operations to do the following: address terrain, obstacle, or noise sensitivity constraints; increase departure capacity or throughput during peak demand periods; reduce departure delay associated with taxi-out time; and reduce fuel burn and emissions. The new standard provides additional options for procedure designers as they seek to provide increased efficiency, safety, and environmentally friendly alternatives. The FAA plans to use the Metroplex [2] process along with single-site implementation to deploy the capability. Candidate sites are currently being examined for consideration [2].

Global Harmonization

The FAA's business is driven by four strategic priorities. One priority is advanced by initiatives to improve safety, air traffic efficiency, and environmental sustainability across the globe through an integrated, data driven approach that shapes global standards, enhances collaboration and harmonization, and better targets FAA resources and efforts. The

[2] FAA initiative which focuses on a systems approach to PBN implementation and airspace design in large metropolitan areas.

reduced divergence standard meets all of the requirements of this priority.

Beginning in 2011, the FAA introduced the reduced divergence standard concept to ICAO [24,25]. After initial review recommendation by ICAO's Separation and Airspace Safety Panel (SASP), ICAO's Air Navigation Commission (ANC) approved further work toward adopting a global reduced divergence standard.

In 2012, review of the theoretical assumptions and modeling of the concept by the Mathematician's Subgroup (MSG) of the SASP further supported ELSO-based reduced divergence requirements [26]. In 2013, the panel endorsed a proposal to draft an amendment proposal for PANS-ATM for the introduction of a global standard with a minimum requirement of 10-degree divergence for use by aircraft authorized to conduct terminal PBN (RNAV 1) operations [27,28]. The FAA is currently drafting the Circular and preparing the Impact Statement needed to support final ANC review of the reduced divergence standard and anticipates completion of the review process to enable publication in the next available edition of ICAO PANS-ATM.

Summary and Next Steps

The FAA is committed to capitalizing on PBN-enabled capabilities currently available on commercial and corporate aircraft operating in the NAS and enabling safe implementation of more closely spaced flight paths. In 2010, development of national standards for reduced separation and divergence commenced. The five-year process for the development, validation, NAS-wide integration, and global harmonization of a first PBN-enabled departure separation standard involved numerous lines of business within the FAA, aviation industry, and the international aviation community.

The new standard for reduced divergence enables the design of RNAV procedure paths with a minimum of 10 degrees of divergence instead of the 15 degrees currently required. Publication of the national standard for reduced divergence is scheduled for 25 June 2015 in FAAO JO 7110.65. Publication of the international standard in ICAO PANS-ATM is expected in 2018. The process applied to develop and integrate the reduced-divergence standard comprised eight steps that may serve as a framework for future advances in the development of aircraft separation standards that further leverage NextGen capabilities.

The goals of enhancing the efficiency with which departure operations are conducted at KATL and reducing the noise footprint of the airport provided a sustained local impetus toward the development and operational validation of the reduced divergence standard. The standard is based on the ELSO concept which provides lateral spacing between reduced-divergence flight paths that is equivalent to the spacing observed in conventional departure operations at minimum divergence requirements of the currently applicable separation standard. ELSO's comparative approach facilitated the SMS review and approval processes applicable to FAA ATO and ICAO SASP. The FAA Metroplex process currently serves to apply the standard in redesigns of departure procedures and to beneficially deploy reduced-divergence departure operations at airports throughout the NAS.

Further gains in NAS operational efficiencies of departure and arrival operations are expected to increasingly rely on developing advanced spacing concepts that capitalize on NextGen capabilities to evolve applicable separation standards. In the case of departures, further study currently investigates additional reductions in the required minimum divergence as well as enabling initially parallel departure paths. Capitalizing on Required Navigation Performance (RNP) technology to improve operational efficiencies of arrival operations, the Established-on-RNP (EoR) concept aims to safely guide aircraft to simultaneous parallel final approach paths without the requirement for vertical separation from aircraft on adjacent approaches. Flight trials to validate the EoR concept are currently conducted at Denver International Airport (KDEN).

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