NextGen for Airports, Volume 1: Understanding the Airport's Role in Performance-Based Navigation: Resource Guide

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ACRP REPORT 150

NextGEN for Airports

AIRPORT COOPERATIVE RESEARCH PROGRAM

Volume 1

Understanding the Airport's Role in Performance-Based Navigation Resource Guide

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Understanding the Airport's Role in Performance-Based Navigation Resource Guide

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AIRPORT COOPERATIVE RESEARCH PROGRAM

Airports are vital national resources. They serve a key role in transportation of people and goods and in regional, national, and international commerce. They are where the nation's aviation system connects with other modes of transportation and where federal responsibility for managing and regulating air traffic operations intersects with the role of state and local governments that own and operate most airports. Research is necessary to solve common operating problems, to adapt appropriate new technologies from other industries, and to introduce innovations into the airport industry. The Airport Cooperative Research Program (ACRP) serves as one of the principal means by which the airport industry can develop innovative near-term solutions to meet demands placed on it.

The need for ACRP was identified in TRB Special Report 272: Airport Research Needs: Cooperative Solutions in 2003, based on a study sponsored by the Federal Aviation Administration (FAA). ACRP carries out applied research on problems that are shared by airport operating agencies and not being adequately addressed by existing federal research programs. ACRP is modeled after the successful National Cooperative Highway Research Program (NCHRP) and Transit Cooperative Research Program (TCRP). ACRP undertakes research and other technical activities in various airport subject areas, including design, construction, legal, maintenance, operations, safety, policy, planning, human resources, and administration. ACRP provides a forum where airport operators can cooperatively address common operational problems.

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Foreword

By **Lawrence D. Goldstein**
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The Next Generation Air Transportation System (NextGen) refers to the federal programs (predominately airspace, air traffic, or avionics related) that are designed to modernize the National Airspace System (NAS). ACRP's NextGen initiative aims to inform airport operators about some of these programs and how the enabling practices, data, and technologies resulting from them will affect airports and change how they operate.

ACRP Report 150: NextGen for Airports, Volume I: Understanding the Airport's Role in Performance-Based Navigation: Resource Guide, the first report in this series, provides comprehensive information to practitioners concerning all aspects of Performance-Based Navigation (PBN) and how implementation affects overall airport operations. This *Resource Guide* encompasses background information, description of effects on short- and long-term airport development, impacts on safety and performance measures, and other critical factors affecting future airport operations. In addition to providing guidance to users on available resources for additional assistance, this volume also includes lessons learned and best practices based on findings from case studies that examined the airport operator's role in PBN implementation.

"NextGen" is an umbrella term for the ongoing transformation of the National Airspace System (NAS) and is the focus of this ACRP NextGen initiative. The comprehensive ACRP initiative encompasses five distinct projects which have been conducted simultaneously. *ACRP Report 150, Volume I* concentrates on performance-based improvements of the overall program. The other supporting and coordinated initiatives in the ACRP series include the following:

- ACRP Project 01-27, NextGen—A Primer;
- ACRP Project 01-28, NextGen—Guidance for Engaging Airport Stakeholders;
- ACRP Project 03-33, NextGen—Airport Planning and Development; and
- ACRP Project 09-12, NextGen—Leveraging NextGen Spatial Data to Benefit Airports.

Some of the known or anticipated airport-relevant effects that are expected from implementation of NextGen procedures include the following:

- Safety—situational/proximity awareness, incident recovery;
- Efficiency—aircraft fuel savings, airspace utilization, landside operations and performance, airside operations and maintenance;

- Environment—emissions reductions, noise distribution;
- Reliability—consistency in practice, international aircraft procedure/avionics standardization, improved access to airports; and
- Planning/design—customer service, facility use, demands for infrastructure.

PBN, the subject of *ACRP Report 150, Volume I,* is a critical near-term component of the NextGen program. In the broader context, design and implementation of PBN will have significance for airports of all sizes. Development of PBN procedures is currently underway, or will be underway shortly, in a number of communities. Involvement by airport operators is essential for successful implementation; and potential opportunities exist for realizing operational and environmental benefits as well as improvements to safety, reliability, and efficiencies of air services to the community. To maximize their productivity, airport operators need to have an understanding of the FAA design and implementation process and have the means to identify and monitor metrics of expected benefits and impacts of these procedures so they can report back to their communities. To help implement that program, the aviation community needs comprehensive and understandable information concerning PBN, presented in a usable and accessible format—describing implementation requirements, related benefits, and potential costs.

In support of this comprehensive initiative to create an understandable description of NextGen PBN and its various components, Architecture Technology Corporation (under the direction of Sebastian Timar) in concert with Ricondo Associates, BT Aeronautical Consulting, and Air Traffic Management Consulting, has created this *Resource Guide* for airport practitioners based on information obtained through literature review, stakeholder outreach, and case studies. The literature review compiled fundamental information regarding PBN procedures: their technical foundations; previous, ongoing, and planned implementations; processes, personnel, tools, and environmental requirements for implementation; and their impacts on the airport, local communities and other stakeholders. As part of the study, stakeholder outreach clarified the roles and potential contributions of the airport authorities, communities, aircraft operators, and others in, and challenges to, PBN implementation. Case studies evaluated PBN implementations at Atlanta, Seattle, Denver, Minneapolis, Henderson, and Houston Metroplex airports to identify lessons learned and best practices for airport authorities in PBN implementation. An additional component of the research and as background for Report 150, the contractor's Final Report for ACRP Project 03-34 is available online at http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=3709. *ACRP Report 150, Volume I* is a usable and accessible guide for airport authorities to facilitate effective implementation of NextGen procedures in a complex environment.

Contents

1 Introduction

Purpose

Performance-based navigation (PBN) is a critical component of the Federal Aviation Administration (FAA) Next Generation Air Transportation System (NextGen) program to modernize the United States (U.S.) air transportation system. The design and implementation of PBN procedures can provide airports operational and environmental benefits as well as improvements to safety, reliability, and efficiencies of air services. Involvement by airport operators is essential for successful implementation of PBN. However, a failure to bring together key airport stakeholders and identify their needs could result in a stalled or even ceased implementation. Airport operators need to understand PBN technologies, the FAA's goals for NextGen, the role of PBN within the FAA's NextGen program, the FAA's design and implementation process for PBN procedures, and they need to be willing to engage in the process to ensure compatibility with the local airport environment. Airport operators can promote the benefits and communicate the impacts of the PBN initiative to local stakeholders and identify and monitor the metrics of expected benefits and impacts of PBN procedures.

The purpose of this Airport PBN Resource Guide is to provide comprehensive information concerning PBN presented in an understandable, usable, and accessible format for airport operators, planners, managers, and other appropriate stakeholders. The content of this Airport PBN Resource Guide includes the following:

- PBN background information, federal policy, trade-offs, and impacts to stakeholders;
- PBN short- and long-term development affecting airport infrastructure, throughput, safety, and runway and taxiway usage;
- PBN issues related to safety enhancements, efficiency of operations at airport and surrounding airspace, environmental outcomes, and performance measures;
- Environmental requirements and considerations for PBN, including the National Environmental Policy Act (NEPA) of 1969 and other applicable requirements;
- Guidance materials, practices, methods, and techniques airport operators can use to work with their surrounding communities, the FAA, and other stakeholders in all phases of PBN development and implementation;
- Lessons learned and best practices based on the findings of case studies examining the airport operator's role in PBN implementation;
- Quantitative and qualitative methods and metrics to evaluate PBN applications and implementation; and
- Resources airports can draw on for assistance.

Background

PBN technology is one of the most mature NextGen technologies. Development programs to enable area navigation (RNAV) and required navigation performance (RNP) capability have been ongoing since the late 1990s, including research and development efforts from the National Aeronautics and Space Administration (NASA), the FAA, The MITRE Corporation, the International Civil Aviation Organization (ICAO), and government industry groups such as the Radio Technical Commission for Aeronautics (RTCA), the Terminal Area Operations Aviation Rulemaking Committee (TAOARC), and the Performance-Based Aircraft Aviation Rulemaking Committee (PARC). As a result of these efforts, the FAA moved to define, regulate, and invest in National Airspace System (NAS) infrastructure and air traffic programs supporting PBN technology while relying on the aircraft operators and airports to invest in the enabling technology to allow the operations. Figure 1-1 illustrates the relationship between the FAA, aircraft operators, and airports to achieve the benefits of PBN.

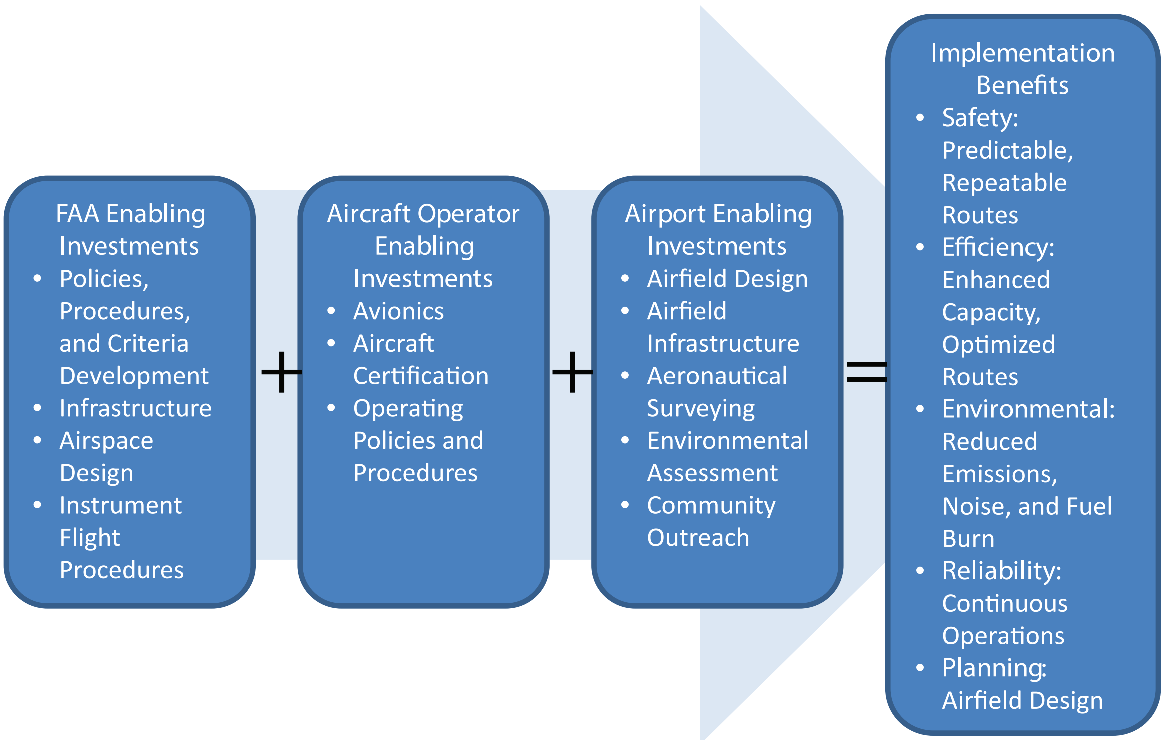


Figure 1-1. *FAA PBN investments.*

PBN defines the performance requirements for routes and procedures that enable aircraft to navigate with greater precision and accuracy (Federal Aviation Administration 2013b). Performance requirements include the navigation accuracy, integrity, continuity and functionality requirements for an aircraft to use PBN procedures in the NAS. PBN may define required aircraft- and ground-based sensors and equipment. The aircraft's flight management system (FMS) is typically the primary tool for conducting PBN operations. Two key components of PBN are RNAV and RNP. RNAV permits flight paths within the limits of space-, ground- or aircraft-based navigational aids. RNAV is split into two categories: (1) lateral navigation (LNAV), and (2) lateral and vertical navigation (LNAV/VNAV) which uses barometric pressure sensing for vertical guidance. RNAV enables the aircraft to follow the route of flight with a certain degree of lateral and/or vertical precision. RNP extends the LNAV/VNAV capability of aircraft with onboard monitoring of its navigation performance and alerting to the flight crew if the required navigation precision cannot be met. RNP authorization required (AR) is an application of RNP that requires special aircraft and air crew authorization to conduct high-precision instrument flight operations, and leverages radius-to-fix (RF) curved path navigation capability of a properly equipped aircraft.

PBN is leveraged in the design of flight procedures for the departure, en route, arrival, and approach phases of flight. These are called instrument flight procedures (IFPs). Procedures may include lateral routes, altitude restrictions, speed restrictions, and other specifications for aircraft guidance. Procedures most relevant to the airport include departure procedures from the airport, terminal arrival procedures to the airport, and approach procedures to the landing runway of an airport. The procedures are referred to as, respectively:

- Standard instrument departures (SIDs),
- Standard terminal arrivals routes (STARs), and
- Standard instrument approach procedures (SIAPs).

PBN procedures provide a foundation for flight paths, airspace design, route separation, and obstacle clearance. RNAV procedures provide routing flexibility; efficient flight paths that can reduce fuel burn, noise, and emissions; airport access in congested airspace or instrument meteorological conditions (IMC) (conditions where low cloud ceiling and restricted visibility require the use of instruments); and reduced pilot-controller communications. RNP procedures can increase airport access in certain situations and help to procedurally separate multi-airport traffic, particularly through the use of curved paths. PBN arrival procedures enable the use of optimized profile descents (OPDs) that can further reduce fuel burn, noise, and emissions.

The FAA's plans call for implementing PBN procedures at airports throughout the U.S. Initial plans focus on airports in major metropolitan areas that have the highest volume of traffic and complex, high-density operations (Federal Aviation Administration 2012f, 2012g, 2013f, 2014h). These airports have been determined to have the greatest impact on the performance of nationwide air traffic. As of May 29, 2014, most major airports in the U.S. had an inventory of PBN departure and arrival procedures, and many had PBN approach procedures. The FAA has undertaken implementing PBN procedures through its Metroplex initiative, its third party vendor process, as well as its legacy PBN process. The FAA's Metroplex program calls for the design and implementation of PBN procedures at major airports in the following areas, including Washington D.C., North Texas, Houston, Charlotte, Atlanta, Northern California, Southern California, Florida, Phoenix, Chicago, Memphis, Cleveland/Detroit, and Boston. To date, the Metroplex program has completed its implementation of PBN procedures in Houston, Washington D.C., North Texas, and Northern California.

Document Structure

This Airport PBN Resource Guide is structured as follows:

1. ***Chapter 1, Introduction:*** Provides background information on PBN, the purpose of the Resource Guide, and an outline of the structure of the document.
2. ***Chapter 2, PBN Components:*** Describes the navigation aids and aircraft navigation capabilities comprising PBN, and the types of PBN flight procedures that leverage these capabilities.

3. ***Chapter 3, PBN Implementation:*** Presents the near-, mid- and long-term plans for implementing PBN procedures and related operations as well as projected equipage levels enabling these implementations.
4. ***Chapter 4, Impact of PBN on Airports:*** Addresses the breadth of capacity, flight efficiency, and noise impacts that different types of PBN procedures may have on airports and discusses specific examples.
5. ***Chapter 5, Procedure Design Processes, Personnel, and Tools:*** Summarizes the FAA 5-phase, Metroplex program and third-party vendor program procedure design processes, identifies the personnel involved in procedure design and their roles, and describes the various tools used in procedure design.
6. ***Chapter 6, Environmental Requirements for Procedures:*** Summarizes the environmental review requirements for PBN procedures.
7. ***Chapter 7, Stakeholders and Challenges in PBN Implementation:*** Provides an overview of the concerns and contributions of the primary stakeholders—other than the FAA—in PBN procedure design and implementation, including airport operators, community members, and aircraft operators. This chapter also presents some of the challenges of PBN procedure development and implementation.
8. ***Chapter 8, Potential Contributions of the Airport to the Procedural Development:*** Suggests potential contributions of the airport at each phase, as synthesized from stakeholder surveys.
9. ***Chapter 9, Lessons Learned and Best Practices:*** Compares and contrasts the PBN implementation initiatives of six different sites and summarizes the lessons learned and best practices from these initiatives for numerous aspects of PBN procedure implementation, including initiation, personnel, process, environmental, outreach, post-implementation assessment, and outcomes.
10. ***Chapter 10, Metrics for Assessing the Impact of Procedures:*** Presents established and alternative metrics for evaluating the impact of PBN procedures, including noise and emissions.
11. ***Chapter 11, Procedure Design and Execution:*** Discusses the flight procedure and aircraft performance characteristics that have an impact on PBN design, implementation, and utilization. This chapter also provides an example of a PBN flight procedure and discusses the design aspects and trade-offs for meeting flight efficiency, community noise, and other design objectives and constraints.
12. ***Chapter 12, Summary:*** Provides concluding remarks concerning suggestions and potential pitfalls for airport operators in PBN implementations.
13. ***Appendix A, Acronyms & Initialisms:*** Defines the acronyms and initialisms occurring within PBN.
14. ***Appendix B, Glossary of Terms:*** Provides a glossary of industry terms pertaining to PBN.
15. ***Appendix C, Case Studies:*** Documents detailed case studies of PBN implementations at six different airports and metroplexes.
16. ***Appendix D, Annotated Bibliography:*** Provides an annotated bibliography of literature spanning the breadth of relevant subject areas. These areas include reviews and suggestions on PBN implementations, background of PBN, design and implementation of PBN procedures, metrics for evaluating PBN procedures, airport planning and environmental processes, airport community outreach, FAA orders governing PBN flight procedures, FAA advisory circulars concerning PBN flight procedures, and federal regulations concerning PBN flight procedures.

2 PBN Components

The key components of PBN are enabling technologies that include navigation aids for aircraft, aircraft navigation capabilities based on equipage, and the PBN procedures themselves. The ground-based and airborne navigation technologies are leveraged in the implementation of different types of PBN procedures used for specific applications.

Aircraft Navigation Aids

Navigation aids provide estimates of aircraft position and are fundamental to enabling the use of PBN procedures. Examples of different types of navigation aids that enable PBN procedures are listed in Table 2-1. Navigation aids vary by their data source and level of accuracy.

Table 2-1. Navigation aids for PBN procedures.

SYSTEM	DESCRIPTION
Global Positioning System (GPS)	GPS uses a constellation of 32 satellites to estimate the three-dimensional position of an aircraft anywhere in the world. The position measurements of GPS have an accuracy of 100 meters (328 feet).
Wide Area Augmentation System (WAAS)	WAAS is a system implemented by the FAA to improve the accuracy, integrity, and availability of GPS measurements. The position measurements of WAAS have an accuracy of 7 meters (23 feet).
Ground-Based Augmentation System (GBAS)	GBAS is a system implemented and maintained by the airport (not the FAA) to improve the accuracy, integrity, and availability of GPS measurements around the host airport. The position measurements of GBAS have an accuracy that is equal to or more precise than 1 meter (3 feet). Currently GBAS may be used to conduct precision approaches with visibility minimums and decision altitudes equivalent to instrument landing system (ILS) Category (CAT) I operations. GBAS is under development to be used to conduct precision approaches with visibility minimums and decision altitudes equivalent to ILS CAT II and III operations.
Distance Measuring Equipment (DME)	DME is a system on board the aircraft to estimate the position of the aircraft relative to a ground-based very high frequency (VHF) omnidirectional radio range (VOR) transponder. The position measurements of DME have an accuracy of 185 meters (606 feet).

Table 2-1. Continued

SYSTEM	DESCRIPTION
Inertial Reference Unit (IRU)	IRU is a system on board the aircraft to estimate the position of the aircraft via cumulative measurements of aircraft motion from a given initial position. The position measurements of an IRU may have an accuracy of 400 meters (1,312 feet). However, the accuracy depends on the accuracy of the estimated initial position of the aircraft, the "drift rate" of the IRU, and the ability of the IRU to update the cumulative position estimates.
Flight Management System (FMS)	An FMS is a specialized computer system that automates a wide variety of in-flight tasks, reducing the workload on the flight crew to the point that modern aircraft no longer carry flight engineers or navigators. A primary function is in-flight management of the flight plan. Using navigation aids to determine the aircraft's position, the FMS can guide the aircraft along the flight plan. The FMS is normally controlled through an interface in the cockpit of the aircraft that incorporates a small screen and keyboard or touchscreen. The FMS sends the flight plan for presentation to the flight crew on the instrument display system in the cockpit of the aircraft.
Flight Management Computer (FMC)	The FMC manages and processes the components of the FMS including navigation radio receivers; inertial reference systems; air data systems; navigation, flight, and instrument displays; flight control systems; the engine and fuel system; and the data link. The FMC provides the primary navigation, flight planning, and optimized terminal routes and en route guidance for the aircraft and is typically composed of interrelated functions such as navigation, flight planning, trajectory prediction, performance computations, and guidance. A fundamental component to the FMC is the navigation database (NDB). The NDB contains all the information required to create a flight plan and to process that plan when airborne. The NDB contains all the fixes, waypoints, navigation aids, jet routes, arrival and departure routes, airport information, and other data necessary for navigation.

WAAS and GBAS improve the precision of GPS position measurements within a certain radius of coverage. They enhance the ability of the aircraft to conduct RNAV within that area of coverage. GBAS is installed at an airport, with the airport and the FAA sharing the costs of installing this system. WAAS and GBAS support precision instrument approach procedures to improve access to the airport in reduced visibility conditions.

Aircraft Navigation Capabilities

The particular PBN procedures an aircraft may fly are first and foremost determined by the navigation capabilities of the aircraft. Key aircraft navigation capabilities required for PBN are listed in Table 2-2. RNAV and RNP capabilities are the cornerstones of the FAA PBN program.

Table 2-2. Navigation capabilities for PBN procedures.

CAPABILITY	DESCRIPTION
Area Navigation (RNAV)	RNAV is a method of navigation that permits aircraft operations on a desired flight path within the coverage of ground- or space-based navigational aids, within the limits of aircraft-contained navigational systems, or within a combination of these systems. RNAV is enabled through the use of a flight management system (FMS), flight management computer (FMC), or global positioning system (GPS) receiver on the aircraft. An RNAV 1 flight procedure requires the aircraft to sustain a lateral accuracy of +/- 1 nautical mile within the centerline of the route of flight for 95% of the flight time along the route.
RNAV Lateral Navigation (LNAV)	LNAV is the aircraft navigation capability that performs lateral guidance of the aircraft along the flight procedure. LNAV is achievable with an FMS, FMC, or GPS receiver on the aircraft.
RNAV Vertical Navigation (VNAV)	VNAV is the aircraft navigation capability that performs vertical guidance of the aircraft along the flight procedure. VNAV provides guidance to the aircraft according to the detailed flight path computed by the FMS, FMC or GPS receiver on board the aircraft. VNAV may conduct vertical guidance of the aircraft during the takeoff, climb, cruise, descent, approach, and missed approach phases of flight. The vertical profile of the planned flight path satisfies the altitude and speed restrictions of the flight procedure, and attempts to maximize flight efficiency according to the performance and weight of the aircraft, and the winds and weather that the aircraft is estimated to encounter. VNAV which uses barometric pressure of the atmosphere for altitude measurement and vertical guidance is referred to as Baro-VNAV.
RNAV Localizer Performance (LP)	RNAV LP approach procedures use position measurements from the wide area augmentation system (WAAS) to perform lateral guidance. They are similar to approach procedures that rely on the localizer of an instrument landing system (ILS).
RNAV Localizer Performance with Vertical Guidance (LPV)	RNAV LPV approach procedures use position measurements from WAAS to perform lateral and vertical guidance. They are similar to approach procedures that rely on the localizer and glide slope of an ILS.
Required Navigation Performance (RNP)	RNP uses the RNAV capability of the aircraft and uses a system on board the aircraft that monitors the actual navigation performance (ANP) of the aircraft. The RNP system alerts the flight crew if the ANP does not meet the RNP during operation. RNP uses position measurements from GPS for lateral navigation and Baro-VNAV for vertical navigation. An RNP 1 flight procedure requires the aircraft to sustain lateral navigation accuracy of 1 nautical mile for 95% of the flight time along the route.

Table 2-2. Continued

CAPABILITY	DESCRIPTION
RNP Authorization Required (AR)	An RNP AR flight procedure requires advanced aircraft navigation capabilities and crew procedures to conduct the flight procedure. Advanced capabilities may include radius-to-fix (RF) navigation capability to fly a constant-radius, semi-circular turn about a center fix, and more precise RNP values that are lower than the standard RNP values in various segments of the procedure.
Advanced RNP	Advanced RNP is an aircraft certification specific to a bundle of FMS features including terminal RF legs, scalable/selectable RNP, parallel offset routes in the en route environment, RF transitions in the en route environment, time of arrival control, and RNP holding. Advanced RNP aims to streamline aircraft certification and operator approval to use the advanced FMS functions. Advanced RNP has not yet been implemented by FAA but is likely to emerge within the 10-year planning horizon to enable more efficient en route transition, arrival and departure routes, and trajectory-based operations.

Types of Procedures

The types of flight procedures utilizing PBN vary based on specific applications. Types of PBN procedures in the en route and terminal domains that serve airport arrivals and departures or traffic flows proximate to the airport are listed in Table 2-3.

Table 2-3. PBN en route, departure and arrival flight procedures.

TYPE	DESCRIPTION	AIRCRAFT CAPABILITIES
Area Navigation (RNAV) 2 Q-routes	RNAV 2 Q-routes are routes for high altitudes in the en route airspace 5,486 meters to **13,716 meters** (18,000 feet to 45,000 feet above ground jevel AGL). Aircraft fly these procedures using GPS or DME and IRU navigation aids (GPS or DME/DME/IRU navigation).	GPS- or DME/DME/IRU-based RNAV[1]
RNAV 2 T-routes	RNAV 2 T-routes are for general aviation traffic in lower altitudes in busy terminal areas. Aircraft fly these procedures using GPS or DME/DME/IRU navigation.	GPS- or DME/DME/IRU-based RNAV

Table 2-3. Continued

TYPE	DESCRIPTION	AIRCRAFT CAPABILITIES
RNAV 1 Standard Terminal Arrival Routes (STARs)	RNAV 1 STARs are procedures for aircraft arriving to an airport. Aircraft fly these procedures using GPS or DME/DME/IRU navigation. Aircraft use lateral navigation (LNAV) to remain within 1 nautical mile for 95% of the flight time along the procedure. The RNAV 1 STARs may include altitude restrictions at waypoints to provide windows for aircraft to conduct optimized profile descents (OPDs) or altitude restrictions at waypoints to procedurally separate the arrivals from terrain or other traffic in the airspace, and aircraft may use barometric pressure-based vertical navigation (Baro-VNAV) to satisfy these restrictions. RNAV 1 STARs may be designed to connect approach procedures to individual runways of an airport, or may end at a point from which air traffic controllers vector aircraft to the runway or its approach procedure. RNAV 1 STARs are being implemented at most major hub airports in the United States.	GPS- or DME/DME/IRU-based RNAV and LNAV, Baro-VNAV
RNAV 1 Standard Instrument Departures (SIDs)	RNAV 1 SIDs are departure procedures requiring RNAV 1 navigation capability of the aircraft. Aircraft fly these procedures using GPS or DME/DME/IRU navigation. Aircraft use LNAV to remain within 1 nautical mile for 95% of the flight time along the procedure. RNAV 1 SIDs may include altitude restrictions at waypoints to procedurally separate the departures from other traffic in the airspace or terrain, and aircraft may use Baro-VNAV to satisfy these restrictions. RNAV 1 SIDs may be designed with initial departure paths that begin at individual runways of an airport (RNAV off the ground) and that concentrate aircraft away from noise sensitive areas around the airport. An RNAV 1 SID may be designed to begin at a point away from the airport, thereby requiring air traffic controllers to vector aircraft to the initial waypoint of the procedure. The vectoring may be conducted to disperse aircraft to minimize the concentration of aircraft over particular areas around the airport. Aircraft performance measures such as climb rates are important to consider in the design of RNAV SIDs.	GPS- or DME/DME/IRU-based RNAV and LNAV, Baro-VNAV

Table 2-3 Continued

TYPE	DESCRIPTION	AIRCRAFT CAPABILITIES
Required Navigation Performance (RNP) 1 STARs and SIDs	RNP 1 STARs and SIDs may be implemented to meet local needs for procedural separation of airport arrivals or departures from other traffic or obstacles in the airspace. However, there are no existing public criteria for designing such procedures according to monitoring and alerting requirements. RNP STARs and SIDs are not likely to be implemented, particularly in the near-term time frame.	GPS- or DME/DME/IRU-based RNAV and LNAV, Baro-VNAV, RNP monitoring and alerting

[1]Aircraft conducting RNAV with DME/DME/IRU use DME measurements from at least two VORs, along with the IRU, to estimate aircraft position (Federal Aviation Administration 2011).

The various types of PBN SIAPs that might be implemented at an airport to serve one or more runways are presented in Table 2-4.

Table 2-4 PBN SIAPs.

TYPE	DESCRIPTION	AIRCRAFT CAPABILITIES
Area Navigation (RNAV) Lateral Navigation (LNAV)	RNAV LNAV standard instrument approach procedures (SIAPs) are non-precision approach procedures. The aircraft uses the global positioning system (GPS) or the Wide area augmentation system (WAAS) navigation aids and LNAV for lateral guidance along the flight procedure. RNAV LNAV SIAPs can be designed to minimum descent altitudes (MDAs) as low as 76 meters (250 feet) above ground level (AGL).	GPS- or WAAS-based RNAV and LNAV
RNAV Localizer Performance (LP)	LP SIAPs are non-precision approach procedures. The aircraft uses the WAAS navigation aid and LNAV for lateral guidance along the flight procedure. LP SIAPs can be designed to MDAs as low as 76 meters (250 feet) AGL. LP SIAPs are used to replace localizer-only approach procedures for use by general aviation (GA) aircraft. LP SIAPs are typically used where terrain or obstructions do not allow LPV approach procedures.	WAAS-based RNAV and LNAV

Table 2-4 Continued

TYPE	DESCRIPTION	AIRCRAFT CAPABILITIES
RNAV Required Navigation Performance (RNP) 0.3	RNAV RNP 0.3 SIAPs are non-precision approach procedures with vertical guidance. Aircraft use GPS navigation, LNAV for lateral guidance, and RNP monitoring and alerting to remain within 0.3 nautical miles of the lateral path of the procedure. Aircraft use Baro-VNAV for vertical guidance. RNAV RNP 0.3 SIAPs can be designed to decision altitudes (DAs) as low as 76 meters (250 feet) AGL. RNAV RNP 0.3 SIAPs may enable approaches to the parallel runways of an airport in reduced visibility conditions. They are typically used by commercial air carriers. They were originally developed as public approaches, with no authorization required.	GPS-based RNAV and LNAV, Baro-VNAV, RNP monitoring and alerting
RNAV LNAV/ Vertical Navigation (VNAV)	RNAV LNAV/VNAV SIAPs are non-precision approach procedures with vertical guidance. Aircraft use GPS navigation, LNAV for lateral guidance, and Baro-VNAV for vertical guidance. RNAV LNAV/VNAV SIAPs enable approaches to the parallel runways of an airport in reduced visibility conditions and can be designed to DAs as low as 76 meters (250 feet) AGL.	GPS-based RNAV and LNAV, Baro-VNAV
RNAV Localizer Performance with Vertical Guidance (LPV)	RNAV LPV SIAPs support approaches in visibility conditions of 805 meters (one-half mile or 2,400 feet) and DAs of 61 meters (200 feet) similar to instrument landing system (ILS) Category (CAT) I operations. Aircraft use WAAS navigation and LNAV with VNAV for lateral and vertical guidance. RNAV LPV SIAPs are primarily for GA aircraft; commercial carriers are generally not equipping their aircraft for these procedures.	WAAS-based RNAV, LNAV and VNAV

Table 2-4 Continued

TYPE	DESCRIPTION	AIRCRAFT CAPABILITIES
RNP Approval Required (AR)	RNP AR approaches include unique capabilities that require special aircraft and aircrew authorization similar to ILS CAT II/III operations. RNP AR SIAPs support LNAV precisions down to 0.11 nautical miles. Aircraft use GPS navigation aid, LNAV, and RNP monitoring and alerting for lateral guidance, and may also use radius-to-fix (RF) navigation capability of the aircraft for lateral guidance. The aircraft use baro-VNAV for vertical guidance. RF legs may be included anywhere in the procedure, including the final approach segment. Air crew training, aircraft database validation, and operating procedures are required to conduct AR procedures. RNP AR SIAPs may enable approaches to closely spaced parallel runways in reduced visibility with DAs of 76 meters (250 feet) AGL.	GPS-based RNAV, Baro-VNAV, RNP monitoring and alerting, possibly RF navigation
Ground Based Augmentation System (GBAS)	GBAS SIAPs are intended to provide precision approaches with minimum visibilities and decision altitudes similar to ILS CAT I, II, and III operations. However, GBAS SIAPs are currently only certified for ILS CAT I minimum visibility and DAs. The final approach path is uploaded to the aircraft. The aircraft uses the GBAS navigation aid with LNAV for lateral guidance and VNAV for vertical guidance, and deviations from the flight path are transmitted to the multi-mode receiver. GBAS SIAPs require RNAV or RNP transition procedures or vectors to the final approach segment of the SIAP. GBAS SIAPs also require a conventional or RNAV missed approach procedure.	GBAS Multi-Mode Receiver for GBAS-based RNAV, LNAV, and VNAV for final approach; RNP monitoring and alerting; GPS RNAV, LNAV and VNAV for transition to final approach and missed approach

3 PBN Implementation

Among the key factors impacting the utilization of PBN procedures are (1) the FAA's NextGen Implementation Plan for implementing or leveraging PBN and other relevant NextGen capabilities and 2) the ability of aircraft to utilize the PBN procedures.

FAA Implementation Plans

The FAA's plans for implementing PBN procedures and other relevant NextGen capabilities are included in the FAA's NextGen Implementation Plan. These plans and other relevant NextGen capabilities are presented in Table 3-1 according to their estimated time frame for implementation (near-, mid- and long-term), similar to the time frames for airport master planning.

The FAA's near-term focus for PBN is the design and implementation of PBN procedures at airports across the U.S. Other capabilities relevant to PBN include utilization of data communications (Data Comm) to issue pre-departure clearances to aircraft, and deploying ground-based augmentation system (GBAS) at airports in order to support CAT I precision approaches. The FAA near-term PBN procedures and their associated NextGen capabilities are presented in Table 3-1.

Table 3-1. The FAA near-term PBN and NextGen implementation plans.

TIME FRAME	FAA PBN	FAA NEXTGEN
Near Term (0–5 Years)	In the en route/terminal airspace: Area navigation (RNAV) 2 Q-routes RNAV 2 T-routes	Data Comm: Air traffic control (ATC) to issue pre-departure clearances and revised clearances to flights Automatic dependent surveillance-broadcast (ADS-B) out of aircraft position is mandatory for aircraft on January 1, 2020

Table 3-1. Continued

TIME FRAME	FAA PBN	FAA NEXTGEN
	In the terminal airspace: RNAV 1 standard terminal arrival routes (STARs) with or without optimized profile descents (OPDs) RNAV 1 standard instrument departures (SIDs) with or without unrestricted climbs Required navigation performance (RNP) 1 STARs and SIDs with or without radius-to-fix (RF) legs RNAV standard instrument approach procedures (SIAPs) including lateral navigation (LNAV), LNAV with vertical navigation (LNAV/VNAV), localizer performance (LP), LP with vertical guidance (LPV), RNP 0.3 and RNP approval required (AR)	FAA optimization of airspace & procedures in the metroplex (OAPM), currently metroplex controller-pilot data link communications (CPDLC) Ground-based augmentation system (GBAS) precision approaches equivalent to instrument landing system (ILS) category (CAT) I precision approaches[1]

[1]Note: FAA is participating in, but does not fund, GBAS installations providing CAT I precision approach services (Federal Aviation Administration 2016a).

The FAA's mid- and long-term plans for PBN are presented in Table 3-2. The FAA's mid- and long-term plans for PBN are not clearly specified by FAA, and therefore are somewhat speculative. The FAA's mid- and long-term plans for other NextGen capabilities, however, are a bit more clearly specified.

Table 3-2. FAA mid- and far-term PBN and NextGen implementation plans.

TIME FRAME	FAA PBN	FAA NEXTGEN
Mid Term (5–10 years)	Concept of operations, requirements, criteria, rules and regulations to address mixed aircraft navigation equipage and capabilities	Data Comm for air traffic control (ATC) to issue airborne clearances for in-flight route negotiation between ATC and the flight crew Ground based augmentation system (GBAS) to support precision approaches equivalent to instrument landing system (ILS) Cat II/III approaches[1] Automatic dependent surveillance-broadcast (ADS-B) Out for ATC separation and advisory services

Table 3-2. Continued

TIME FRAME	FAA PBN	FAA NEXTGEN
Long Term (10–20 years)	Implementation of policies and operations to address mixed aircraft navigation equipage and capabilities Advanced required navigation performance (RNP) standard terminal arrival routes (STARs), standard instrument departures (SIDs) and standard instrument approach procedures (SIAPs) combining NextGen technologies to enable integrated operations Scalable RNP RNP Holding Required time of arrival (RTA) navigation capability of aircraft to meet a scheduled time at a waypoint Air traffic control ability to assign and aircraft ability to fly dynamic RNP routes PBN for unmanned aerial vehicle (UAV) operations	Data Comm and ADS-B In for flight information services-broadcast (FIS-B), traffic information services broadcast (TIS-B), cockpit display of traffic information (CDTI) and alerting, interval management (IM), advanced flight-deck IM (FIM), closely spaced parallel runway operations (CSPRO), and in-trail procedures (ITP)

[1]Note: The FAA NextGen Implementation Plan includes standards validation and federal approval development for GBAS installations providing CAT II/III precision approach services (Federal Aviation Administration 2016a).

PBN implementation in the midterm may focus on developing a concept of operations for planning and managing aircraft of different capabilities including aircraft type, levels of navigation capability, and flight performance. One example is the FAA's best-equipped best-served concept of operations proposed to address mixed equipage (Federal Aviation Administration 2012b). Procedures for managing mixed equipage traffic are not explicitly included in the FAA's NextGen Implementation Plan; instead, they fall under the FAA's NextGen Portfolio of Separation Management. The aim of Separation Management is to develop air traffic control tools and procedures to separate aircraft that have different kinds of navigation equipment and wake performance capabilities.

PBN implementation in the long term includes: leveraging the required time of arrival (RTAr) capability of aircraft to meet scheduled times to navigation waypoints; the integration of PBN procedures with other NextGen technologies and capabilities to enhance their collective benefits; the utilization of dynamic PBN routes to support the strategic and tactical management of air traffic; and PBN for UAV operations.

NextGen capabilities relevant to PBN in the mid term include a number of enabling technologies. Data link communications will allow air traffic control (ATC) to negotiate reroutes with the flight deck and to issue clearances to aircraft while airborne. Development of GBAS will enable Cat II and III precision approaches at airports. Automatic dependent surveillance-broadcast (ADS-B) Out from aircraft will increase position accuracy, expand surveillance coverage, and enable ATC to provide enhanced separation and advisory services in remote areas not covered today. Other NextGen capabilities in the mid-term time frame relevant to PBN include the use of ADS-B In to aircraft to support a broad range of capabilities (Informal Pacific Air Traffic Control Coordinating Group 2013). These include:

- Traffic information services-broadcast (TIS-B) to broadcast the positions of air traffic in areas where not all aircraft have ADS-B for presentation on aircraft cockpit displays and alerting to pilots;
- Flight information services–broadcast (FIS-B) to provide meteorological and aeronautical information such as weather images, weather forecasts, airspace restrictions, and notices to airmen;
- Cockpit display of traffic information (CDTI) to present on aircraft cockpit displays the positions of air traffic in the area, possibly with on-board alerting of conflicting traffic for non-traffic collision avoidance system (TCAS) aircraft;
- Interval management (IM) to manage in-trail spacing of aircraft in all flight phases, including ground-based interval management—spacing (GIM-S) and flight deck based interval management—spacing (FIM-S) applications;
- Applications to closely spaced parallel runway operations (CSPRO) at airports, for instance, enhanced visual approaches using CDTI; and
- In trail procedures (ITP) in oceanic airspace.

Equipage Levels of Aircraft at Airports

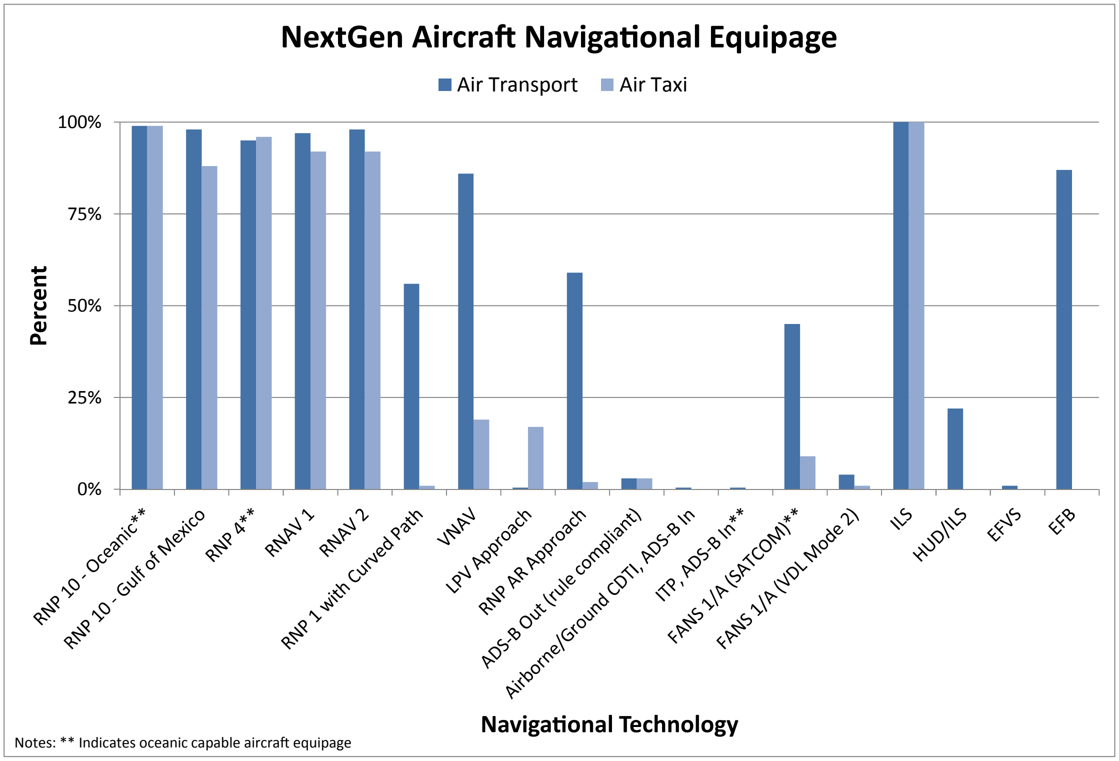
The implementation of particular PBN procedures at an airport, and the utilization of those PBN procedures, depends on the navigation capabilities of aircraft among the fleet the airport serves and on aircraft operator policy regarding the use of PBN procedures. Figure 3-1 depicts the current equipage levels among air transport operators [14 Code of Federal Regulations (CFR) Part 121 operators] and air taxi operators (14 CFR Part 91K and 135 operators) as determined by the FAA (Federal Aviation Administration 2016b).

Figure 3-1 indicates that almost 100 percent of commercial air carrier operators are equipped to perform RNAV 1, RNAV 2, RNP 1, and RNP 2 PBN procedures and approximately 50 percent of air transport aircraft and almost no air taxi aircraft are equipped to perform RNP 1 with curved paths or RNP AR Approaches.

Figure 3-2 depicts the historical and forecast PBN capabilities of the aircraft operating under instrument flight rules (IFRs) at the top 50 airports in the U.S. (The MITRE Corporation 2011). The results are based on analysis of the fleets of aircraft filed to fly to and from the top 50 airports in the U.S.

Figure 3-2 indicates that only 60 percent of commercial air carriers will be equipped and approved to conduct RNP AR procedures by 2024. This data indicate a potential high level of future participation on oceanic, en route, SID, and STAR procedures, but a lower participation on SIAPs.

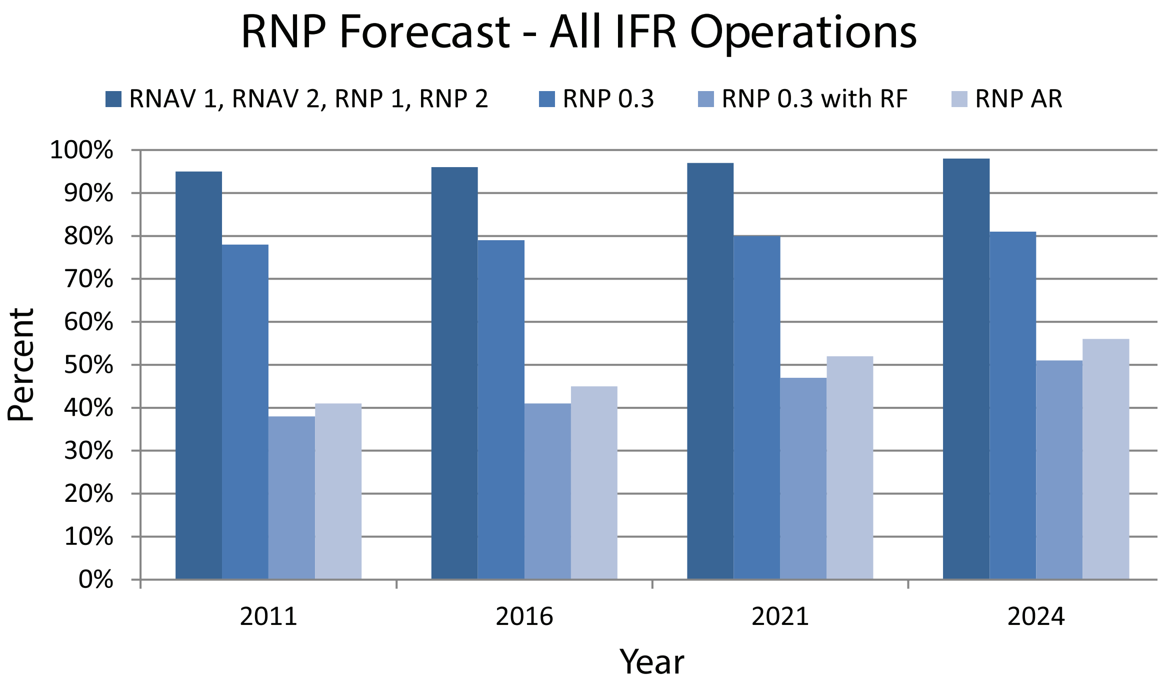
In addition, stakeholder outreach was conducted to gain insight into the intentions of aircraft operators to equip their aircraft for PBN procedures and to implement policies encouraging the use of PBN procedures. Regarding levels of PBN capability among aircraft operators, survey respondents indicated their fleets were 100 percent equipped for GPS navigation and RNAV procedures in the en route and terminal airspace domains, and many were certified for RNP procedures. Few were equipped for LPV approaches, although equipage for and utilization of LPV approaches was expected in the future. RNP



Source: Federal Aviation Administration 2016b.

Figure 3-1. *Current navigation capabilities among air transport and air taxi operators.*

AR procedures were a significant differentiator among aircraft operators due to their aircraft equipage and crew training requirements. While some carriers have fleets entirely equipped for and regularly use RNP AR procedures, others were not equipped for them and had no plans to equip for them in the near future. Regarding wide area augmentation system (WAAS), some operators reported WAAS capabilities of their fleet or were planning future installation and use of WAAS, while other carriers had no intention of WAAS utilization. Regarding GBAS, there was support indicated from the major carriers, with some exploring GBAS, while others stated there was not a business case for it. Regarding ADS-B, all operators surveyed planned to be equipped for it to meet the 2020 mandate. Some were already using ADS-B Out to communicate aircraft state information, and some had plans to use ADS-B In for weather data from a third-party vendor. Many aircraft operators have policies that encourage the use of PBN procedures, some have standard operating procedures to use PBN procedures, and one even requires using PBN procedures. However, in many cases, the use of PBN procedures was subject to pilot discretion and usage among them varied from 85 to 100 percent. Most operators surveyed are flying RNAV SIDs, RNAV STARs with OPDs and RNAV approaches as often as possible.



Source: The MITRE Corporation 2011.

Figure 3-2. *Forecast navigation capabilities among aircraft at top 50 U.S. airports.*

Mixed Equipage of Aircraft at Airports

As indicated in Figure 3-1 and Figure 3-2, equipage levels among aircraft vary and will continue to vary for the foreseeable future. The varying capabilities of aircraft operating in the NAS are referred to as "mixed equipage." Mixed equipage presents a barrier for the realization of full NextGen capability and benefits throughout the NAS. A mixed equipage environment will have an increased level of traffic complexity and higher controller workload and may preclude advanced operations during peak traffic conditions.

Today, air traffic services are provided on a first come, first served basis. The aviation industry is promoting policies for PBN-equipped aircraft to be given priority over non-equipped aircraft. Such policies would benefit aircraft operators who have invested in PBN avionics and would promote increasing equipage levels by encouraging the other operators to invest.

FAA has held industry meetings to discuss such policies and, despite the issues with mixed equipage, has stated that they are working toward infrastructure and operational changes that will gradually accommodate such policies. The desire is to allow PBN operations while also accommodating legacy operations. Among the areas being looked into are:

- Traffic management based on predicted and actual four-dimensional trajectories of aircraft (latitude, longitude, altitude, and time);
- Simultaneous dependent approaches to closely spaced parallel runways;

- Using CDTI enabled by ADS-B to allow visual separation in IFR conditions;
- Using collision risk management criteria to determine separation standards;
- Using digital air/ground communications to achieve more efficient traffic flow; and,
- Achieving efficiencies through development and application of systemwide information management.

In addition to strategies for managing mixed equipage, utilization of PBN procedures also depends on the tactical management of mixed equipage traffic. This requires improved controller tools and operations to manage traffic using PBN procedures without vectoring aircraft. To manage traffic without vectoring, controllers need traffic planning and control tools as well as associated operating procedures for metering, sequencing, spacing, and separation assurance. Research efforts including the NASA terminal sequencing and spacing (TSS) (Swenson et al. 2011) and the MITRE relative position indicator (RPI) (The MITRE Corporation 2012) are steps towards this. However these efforts and previous ones have not borne the necessary operational changes (Poole 2013).

Mixed equipage will have ground-side impacts on the airport. As the efficiencies of air-side operations increase, resultant throughput increases may require changes to how ground-side processes, from ramp and gate management to passenger accommodations, are implemented. This is a long-term process; nevertheless, airport management should be aware of the possible impacts of FAA NextGen PBN changes and how they can influence those impacts.

4 Impact of PBN on Airports

This chapter summarizes the impacts that PBN procedures may have on airports and the local airspace. In general, there are many potential benefits to implementing PBN procedures, depending on the particular application and the design.

Impacts of PBN Arrival, Departure, and Approach Procedures

PBN procedures currently deployed at a number of airports have been credited with providing measurable benefits to the airport stakeholders. The benefits include increases in airport and local airspace capacity, increased trajectory efficiency of aircraft the airport serves, reduced emissions from aircraft, reduced noise exposure, improved safety, and reduced controller workload (RTCA 2014, Federal Aviation Administration 2014e). The benefits of PBN arrival, departure and approach procedures serving various U.S. airports are listed in Table 4-1.

Table 4-1. Characteristics of PBN arrival, departure, and approach procedures and their impacts on airports.

PBN PROCEDURE CHARACTERISTIC	IMPACT ON AIRPORT
More direct lateral paths	May increase flight efficiency by reducing and improving the predictability of flight time in the airspace local to the airport. May reduce the fuel burn and emissions of aircraft. May shift the airport arrival and departure traffic, thereby exposing different segments of the surrounding community to the noise and presence of aircraft. While the noise exposure may change, the associated noise contours may not; this is fairly common and can be a major issue for airports and the communities.
More efficient aircraft descent and climb profiles	May reduce fuel burn and emissions of aircraft. May result in quieter climb and descent procedures for airport arrivals and departures.
More precise lateral containment of aircraft	May reduce the impact of aircraft noise on the local community by increasing adherence to designated noise corridors and reducing the dispersion of aircraft noise. However, can increase the concentration of flight tracks over a particular segment of the surrounding community, thereby increasing the number of noise events.

Table 4-1. Continued

PBN PROCEDURE CHARACTERISTIC	IMPACT ON AIRPORT
Procedurally separated traffic flows	May increase airport throughput by eliminating this constraint on traffic flow. However, the shifted routes and altitude profiles may change the characteristics of noise exposure on the surrounding community, and the throughput increase may increase occurrence of noise events.
Additional departure routes	May increase departure throughput of the airport. The additional route may change the characteristics of noise exposure on the surrounding community by increasing the dispersion of operations to reduce noise concentration on a segment of the community. However, this may also introduce noise to other segments of the community previously not exposed to noise. The throughput increase may increase the occurrence of noise events.
Reduced in-trail separations	May increase the arrival and departure throughput of the airport; however, may increase the occurrence of noise events over affected areas of the community.
Reduced separation from 5 nmi to 3 nmi in metroplex airspace	May increase airport throughput by reducing the degree to which separation constrains the traffic flow. However, may increase the occurrence of noise events over affected areas of the community.

The key benefits of PBN approach procedures serving various U.S. airports are listed in Table 4-2.

Table 4-2. Characteristics of PBN approach procedures and their impacts on airports.

PBN APPROACH PROCEDURE CHARACTERISTIC	IMPACT ON AIRPORT	APPLICABLE PROCEDURES
Instrument Landing System (ILS)-like final approach with CAT I minimums	May increase airport capacity with lower ceiling and visual range minimums. This is most beneficial for general aviation (GA) aircraft landing to runways without an ILS. This may increase runway accessibility and use. There is no equipment cost. However, most airlines do not plan to equip their aircraft for LPV approaches.	Localizer Performance (LP), with Vertical Guidance (LPV)

Table 4-2. Continued

PBN APPROACH PROCEDURE CHARACTERISTIC	IMPACT ON AIRPORT	APPLICABLE PROCEDURES
Radius-to-fix (RF) transition to final approach permits reduced staggered separation between arrivals to parallel runways with centerlines spaced 2,500 feet or greater	May increase arrival throughput to parallel runways through reduced in-trail separation. There is no equipment cost.	Required Navigation Performance (RNP) Approval Required (AR)
Approach paths which avoid terrain or proximate traffic flows	May increase airport arrival throughput by enabling approaches to terrain-constrained airports or procedural separation of multi-airport metroplex traffic flows. May reduce flight distance and time to final approach, and reduce aircraft fuel burn and emissions during final approach. There is no equipment cost.	RNP AR
Approaches for dependent parallel arrival runways with centerlines separated by 2,500 feet or greater.	May increase airport throughput with lower ceiling and visual range minimums for dependent parallel runways. There is no equipment cost.	PBN Approach Procedures

In addition to the benefits listed above, PBN procedures may also reduce controller and pilot workload and increase safety by reducing the number of required radio transmissions, and by providing repeatable and predictable flight paths (RTCA 2014).

Specific Examples

This section provides specific examples of the different ways in which PBN procedures, in combination with emerging ATC procedures, can increase the arrival and departure capacity of the airport, improve the flight efficiency of aircraft flying to and from the airport, and reduce the noise impact of airport traffic on the surrounding community. Table 4-3 presents several successful implementations, ongoing efforts, and future intentions of the FAA in leveraging PBN to provide a breadth of benefits to airport stakeholders. For each of these programs, PBN is the primary enabler of the application, along with new ATC procedures, new flight procedure design criteria, and various levels of the FAA Safety Management System (SMS).

Table 4-3. Examples of PBN Implementations.

APPLICATION	DESCRIPTION	EXAMPLE
Equivalent Lateral Spacing Operations (ELSO)	Leverages lateral containment of area navigation (RNAV) to permit additional departure routes from parallel runways to increase departure throughput and disperse aircraft noise at an airport	ELSO are currently implemented at Atlanta Hartsfield-Jackson Airport (ATL) to enable an additional standard instrument departures (SID) from one or two runways. In turn, ELSO provides ATL with additional capacity of 8–12 departures per hour (Mayer, R., et al., 2013)
Established on Required Navigation Performance (EoR)	Involves a required navigation performance (RNP) approval required (AR) with a radius-to-fix (RF) leg approach and a parallel instrument landing system (ILS) approach to parallel runways. The RNP AR approach comprises an RNP downwind leg, an RNP AR with RF turn onto final leg, and an RNP final approach RNP lateral containment throughout the approach supplants current-day separation requirements of 3 nmi laterally or 1,000 feet vertically until established on final approach. This increases arrival throughput by reducing the required minimum inter-flight spacing	The FAA has ongoing efforts at Seattle-Tacoma Airport (SEA) and Denver Airport (DEN) to implement EoR procedures. Technical complications currently being addressed include managing mixed equipage (i.e., RNP AR-incapable aircraft to the non-ILS runway) and achieving precise timing to satisfy minimum separation standards while maintaining the RNP AR procedure
RNP Parallel Approach with Transition (RPAT)	Involves a RNP AR with RF leg approach and a parallel ILS approach to closely spaced parallel runways. RNP AR leverages the path keeping and vertical guidance capabilities of the aircraft to the runway threshold. The RNP aircraft visually separates from the ILS aircraft Permits near-simultaneous arrivals to the parallel runways in reduced ceiling and visibility conditions. This can increase the airport arrival rate in marginal weather	At San Francisco International Airport (SFO), the airport arrival rate is typically reduced from 60 to 30–35 aircraft per hour in low visibility conditions. The RPAT may permit airport arrival rates of 36 to 43 aircraft per hour (Nakamura, 2007)

Table 4-3. Continued

APPLICATION	DESCRIPTION	EXAMPLE
Dual STARs and Runway Transitions	Dual standard terminal arrival routes (STARs) promote optimized profile descents (OPDs) by dispersing traffic between the two routes and permitting greater utilization of the parallel runways of an airport with runway transitions to both runways	FAA Metroplex study team final report of Charlotte Metroplex
Procedural Separation	When two or more airports are in close physical proximity, the ILS approach to the airport's runway can interfere with the traffic flow to or from the runway of another airport An RNP AR approach procedure with a curved, RF leg can provide the approach guidance and navigation to the airport runway while mitigating the interference	An RNP AR approach procedure to Chicago Midway International Airport (MDW) runway 13C with a RF leg procedurally separates the arrivals from Chicago O'Hare International Airport (ORD) departures via runway 22L. This obviates the need for a ground delay program (GDP) and permits ORD to maintain a 92 arrival rate (Belle, A., 2013).
Noise Abatement Procedures	RNAV enables more routing alternatives to avoid noise-sensitive areas, proximate traffic flows; terrain or special use airspace (SUA) RNAV and RNP enable greater conformance to noise corridors	The RNAV SID departure flight procedure STREL fornoise abatement d at John Wayne, Orange County Airport (SNA). Departures fly 1 nmi beyond the shore of Newport Bay to gain altitude and mitigate noise after turning east. The approach procedure to runway 19 of the Ronald Reagan Washington National Airport (DCA) follows the Potomac River to minimize the noise impact of arrivals on the surrounding community while avoiding SUA.
RNAV STARs with OPDs	RNAV enables lateral paths to meet the requirements for conducting OPDs, more direct lateral paths to the airport, which reduces the time and geographic extent of noise event exposure and can reduce the fuel burned during transit OPDs enable reduced descent speeds, which reduce the noise generated during descent and reduce fuel burn via fuel efficient vertical flight paths	The RNAV STAR arrival flight procedure EAGUL at Phoenix Sky Harbor Airport (PHX) evolved from multiple step-downs and level-offs at lower altitudes to dramatically reduced level segments, finally to "stair rail" (constant) descent profiles at higher altitudes.

5 Procedure Design Processes, Personnel, and Tools

This section summarizes the processes for implementing PBN procedures and the personnel who may be involved in developing and implementing these procedures. In this section, *programs* are specific efforts undertaken by the FAA or other entities to promote implementation of PBN flight procedures. *Procedures* are the PBN flight procedures that are the focus of the program.

Processes

The FAA has three processes it is using to develop and implement PBN procedures at airports: the 5-phase process, the metroplex process, and the third-party vendor process. The use of a particular process depends upon the particular initiative that is driving the implementation of PBN procedures at an airport. Procedure development processes typically consist of five steps, loosely summarized as:

1. Definition of the procedure design problem,
2. Design and evaluation of the procedures,
3. Documentation of the designed procedures,
4. Implementation of the procedures, and
5. Post-implementation assessment of the procedures.

The FAA's 5-phase process is the most explicitly documented, while the others are less well documented in their details. The metroplex process has been utilized and developed at numerous sites and is the most explicit in addressing environmental assessment of the proposed procedures. Application of the third-party vendor process is limited to required navigation performance (RNP) authorization required (AR) approach procedures.

5-Phase Process

The FAA 5-Phase Process for implementing public and special PBN procedures originated from a process developed by The MITRE Corporation in the early 2000s, known as the 18-step process. The 5-phase process streamlined the 18-step process into phases and was formally documented in the FAA Order 7100.41, *Performance Based Navigation Implementation Process*. The order describes the process framework, the participants, and the roles and responsibilities of the participants in the process, albeit at a high level. The order explicitly identifies the airport authority as a principal participant in the core working group for developing the PBN procedures. The airport authority contributes information concerning potential operational or environmental impacts on the airport or communities, planned airport development projects, and airport obstacle data. The process is focused on the technical aspects of flight procedure design and therefore does not incorporate community and stakeholder outreach or engagement. A summary of the 5-phase process, as documented in the FAA Order, is summarized in Table 5-1.

Table 5-1. Summary of FAA 5-phase instrument flight procedure (IFP) design process.

STEP	DESCRIPTION
Preliminary Activities	Identify issues with the legacy flight procedure. Specify design objectives for the proposed procedure and metrics to assess them. Analyze baseline operations under the legacy flight procedure to inform the design and support assessing the benefits of the proposed procedure. Propose a PBN procedure to meet the design objectives, including developing conceptual designs, identifying potential environmental issues, and assessing the benefits, costs, and risks of the proposed procedure. Submit the proposed procedures to the Regional Airspace Planning Team (RAPT) for review.
Development Work	Evaluate the proposed procedure against the specified design objectives and any constraints on the design. Assess the viability of the proposed procedure based on its communications, navigation, surveillance and other requirements. Assess the design of the proposed procedure against procedure design criteria and within the subject airspace using the terminal area route generation, evaluation, and traffic simulation (TARGETS) procedure design tool and the aviation environmental design tool (AEDT) noise screening tool. Perform environmental analysis to determine if a categorical exclusion (CatEx) is sufficient or if an environmental assessment (EA) or environmental impact statement (EIS) is required for the procedure to satisfy requirements of the National Environmental Policy Act (NEPA).
Operational Preparations	Address the operational needs for implementation of the proposed procedure, including planning and implementing controller training and air traffic control (ATC) automation updates, pilot training, and flight management system (FMS) database verification.
Implementation	Publish the charted procedures. An implementation team supports deployment of the charted procedure.
Post-Implementation Monitoring and Evaluation	Monitor the procedure after implementation, evaluate against the original design objectives for the procedure, and modify the procedure as needed to meet the original design objectives. Document the analysis of the baseline operations under the legacy procedure, the design of the implemented flight procedure, FAA forms and waivers, environmental reviews, actions, and decisions, the RAPT consensus form, and post-implementation analysis findings.

The Radio Technical Commision for Aeronautics (RTCA) NextGen Advisory Committee (NAC) recently published the *Blueprint for Success to Implementing PBN* procedures (RTCA 2014). This document specifies categories of stakeholders in PBN development and provides descriptions of procedure development and recommendations to the FAA for conducting the 5-phase procedure development process. For each phase, recommendations account for capturing the needs of stakeholders, defining objectives and metrics for the flight procedures, involving technical and non-technical stakeholders in the development process, planning and coordinating community outreach with flight procedure development, managing data, and capturing lessons learned. While these recommendations are pending review and approval of the FAA, and may not be accepted and applied wholesale, they can help to gain further understanding of each design phase and the potential contributions of the airport operator.

Metroplex Process

The FAA uses a similar process for designing flight procedures in its Metroplex program. The process takes approximately three years to complete but has widely been considered beneficial. It has been extensively applied and refined in numerous PBN flight procedure design projects across the U.S. It directly incorporates the EA process as part of NEPA in the development of the flight procedures. It includes characterization of current day operations to establish a sound baseline for flight procedure design and to assess the benefits of the procedures. It also includes a formal process for deploying the procedures. The steps are summarized in Table 5-2.

Table 5-2. Summary of FAA Metroplex program IFP design process.

STEP	DESCRIPTION
Study and Scoping (3 months)	The study team meets with facility and industry representatives to identify issues with the legacy procedures and airspace and to propose solutions. The study team produces conceptual designs of proposed procedures and a high-level assessment of the benefits, costs, and risks of the procedures.
Design (6–9 months)	The design & implementation team (D&I) conducts integrated airspace and procedure design based on the findings of the study team. The D&I team includes representatives of the lead aircraft operator. Additional analyses, including human-in-the-loop simulations, may be conducted to support this work.
Evaluation (12–18 months)	The D&I Team conducts operational modeling, safety management system (SMS) analyses, and environmental reviews with representatives of the lead carrier. The evaluation phase may also continue design analyses. Evaluation includes a project kickoff, completing the design of the procedures, and validating the final operations. The evaluation phase includes SMS processes of facilitating the safety risk management (SRM) panel, completing the SMS process, and creating and completing the final SMS documentation. Evaluation includes drafting the complete EA as required by NEPA, including the Purpose and Need section, the Alternatives section, the Affected Environment section, and the Environmental Consequences section with a goal of achieving the final EA finding of no significant impact (FONSI).
Implementation (9–15 months)	The D&I Team works with the representatives of the lead aircraft operator to conduct all steps for implementation, including flight inspections, publishing procedures and planning, and executing training. Implementation includes developing a procedure implementation plan, a training plan, flight checks, stakeholder coordination, training, and procedure implementation.
Post-Implementation Monitoring and Evaluation (2–3 months)	The D&I team reviews the benefits and impacts of the implemented airspace and procedures and modifies the procedures as needed.

The metroplex process includes extensive analysis to characterize baseline operations and to support the design and benefits analysis of the PBN procedures. Analyses may include the following:

- Characterizing standard terminal arrival route (STAR) traffic flow conflicts with other flows;
- Characterizing the level segments of arrival or departure flights;
- Quantifying the number of aircraft in each arrival traffic flow to the airport as well as major and satellite airport arrivals;
- Analyzing the traffic loading of airspace sectors;
- Comparing the tracks and published routes;
- Conducting conceptual airspace and procedure design and simulation;
- Analyzing traffic management initiatives and playbook route usage;
- Analyzing annual traffic counts and aircraft type;
- Developing traffic density charts; and
- Evaluating the fleet mix from PBN capability report.

The metroplex process may also include outreach to impacted stakeholders with regularly scheduled briefings for each milestone in the design and development phase.

Third-Party Vendor Process

In 2007, the FAA developed a pilot program to certify third-party commercial vendors for the development of RNP AR procedures. This program was mandated by Congress and was intended to accelerate the availability of PBN procedures throughout the NAS. The program is limited to RNP AR procedures and requires the third-party vendor to own, maintain, and assume the liability of the procedures it develops. This is in contrast to procedures developed under public and special programs.

Table 5-3 highlights the difference between the third-party vendor, special, and FAA programs for developing flight procedures. In this table, *public* refers to procedures developed by the FAA. *Special* refers to procedures developed by aircraft operators or vendors. *Third Party* refers to procedures developed by third-party vendors. For public programs, the FAA certifies, owns and maintains the flight procedures, and assumes the liability for them. The FAA Metroplex program is developing public flight procedures as a distinct public development program. For special programs, flight procedures are developed by any vendor or airline and are certified and maintained by the FAA.

Table 5-3. IFP Development Program Comparison.

Program	Owner	Developer	Certifier	Maintenance	Liability
Public	FAA	FAA	FAA	FAA	FAA
Special	FAA[1]/ Operator	FAA or Any Service Provider	FAA	FAA	FAA
Third Party	Third-Party Vendor	Third-Party Vendor	FAA	Third-Party Vendor	Third-Party Vendor

[1]FAA owns and maintains some special approach procedures in cases where there is benefit to the NAS.

FAA Advisory Circular 90-110A *Instrument Flight Procedure Service Provider Authorization Guidance for Required Navigation Performance Authorization Required Procedures* details the certification requirements and guidance on the procedure development process for third-party vendors. To date, there are three vendors who are certified as part of this program. Very few procedures have been developed under this program due to the liability requirements associated with the program. The procedure development process specified by the Federal Aviation Administration (2015a) is summarized in Table 5-4. With respect to airport environmental concerns, it was stated that the vendor's responsibility included preparing environmental paperwork for EAs, although this was not explicitly accounted for in documentation of their processes.

Table 5-4. Summary of FAA third-party vendor IFP design process.

STEP	DESCRIPTION
Preliminary Activities	Preliminary activities include initial coordination among the working group members including air traffic facilities, the airport, aircraft operators and the IFP service provider; approval by the RAPT; and a project kickoff meeting to confirm the objectives, finalize the conceptual design, and establish the project timeline among the working group members.
Procedure Design	Procedure design includes developing the concept for the procedure, including defining the lateral and vertical path of the procedure; conducting environmental review as per FAA Order 1050.1 (FAA 1986); validating the concept for the procedure; and developing the procedure design.
Instrument Flight Procedure Validation (IFPV)	IFPV includes ground obstacle assessment, simulator evaluations, airborne obstacle assessment, and flight validation of the detailed procedure design as per FAA Advisory Circular 90-113 (FAA 2011a) and FAA Order 8900.1 Volume 11, Chapter 12 (FAA 2010).
Pre-Implementation	In pre-implementation, the IFP service provider coordinates the final design with all stakeholders. The readiness of aircraft operators and air traffic control for the new procedure is addressed. The final procedure is reviewed.
Publish Procedure	The final procedure is prepared for publication, published, and deployed operationally.
Post-implementation Review	The IFP service provider conducts implementation review of the implemented procedure consistent with principles of the FAA SMS.

Source: Federal Aviation Administration 2015a.

Design Iteration to Address Noise

The U.S. Government Accountability Office's analysis of the New York/New Jersey/Philadelphia airspace design provides an example for evaluating and addressing noise issues in the development of flight procedures. The following sequence of steps was used to address noise issues identified during the design. This process could be applied within the frameworks of the FAA 5-phase, FAA metroplex or FAA third-party vendor procedure development processes:

1. *Develop alternative procedure designs,*
2. *Analyze the alternatives for operational impacts,*
3. *Analyze the alternatives for noise impacts,*
4. *Select the preferred alternative,*
5. *Identify potential noise mitigation measures,*
6. *Analyze mitigation measures for operational impacts,*
7. *Analyze mitigation measures for noise impacts, and*
8. *Develop mitigated preferred alternative.*

After selecting the preferred alternative, the designers began identifying measures to mitigate the noise impacts associated with the preferred alternative, and initiating an iterative process of identifying potential noise mitigation strategies and using operational and noise modeling tools to measure impacts. In this process, noise mitigation served as a design constraint, not as a design objective.

Personnel

The FAA 5-phase, metroplex, and third-party vendor processes, as well as other sources, indicate the design and implementation of PBN procedures may include the personnel listed in Table 5-5. An airport authority or operator is called out explicitly in the FAA 5-phase process. Other personnel that may represent the interests of the airport include the FAA Airports Office and FAA Air Traffic Organization (ATO) Service Center Operations Support Group, and the aircraft operator. Others, such as the PBN Policy and Support Group and the TARGETS operator, are conducting analyses that may use airport data and determine the impact on the airport and its communities.

Table 5-5. Personnel involved in PBN IFP development.

ENTITY	ROLE
Instrument Flight Procedure (IFP) Proponent	Contracts with the FAA or an approved service provider to design the IFP. The IFP Proponent may be an airport sponsor, an aircraft operator, a facility, or an entity of the FAA requesting an IFP for specific airspace.
FAA Airports Office	Supports identifying standards for airport design, construction, and operation.
FAA Flight Procedures Office	Supports identifying the design and obstacle clearance standards, criteria, and policies governing departure, en route, arrival, and approach IFPs.
Facilitator	Manages and oversees the IFP development project.

Table 5-5. Continued

ENTITY	ROLE
Aircraft Operator	Fulfills the technical role of lead operator and coordinates with industry stakeholders throughout the IFP development. Assesses the proposed IFPs according to the needs of the air crew, the aircraft, and the FMS of the aircraft.
Airport Authority or Operator	Provides information on the local operational or environmental considerations for the proposed IFP, including potential impacts on the surrounding communities. Provides knowledge of airport construction and obstacles that may impact the design of the IFP. Provides input or support in the local stakeholder engagement efforts.
Air Traffic Facilities	Provides detailed operational insight that supports the design of the IFP and develops and implements training programs and updates automation in order to implement the IFP.
FAA ATO Service Center Operations Support Group (OSG)	Provides expertise in the areas of environmental, local air traffic, airspace, operational rules, and flight procedures. Personnel will include an environmental specialist to identify issues and ensure compliance with governing standards, criteria, and policy; and a flight procedures specialist to develop the IFP and ensure compliance with governing standards, criteria, and policy.
Regional NextGen Branch	Represents the FAA Flight Standards division and provides policies and procedures concerning PBN capabilities leveraged in the procedure design.
PBN Policy and Support Group	Determines if categorical exclusion (CatEx) criteria apply or if an environmental assessment (EA) or environmental impact statement (EIS) is required to satisfy the National Environmental Policy Act (NEPA). This includes conducting noise screening analysis, assessing the navigation requirements, and assessing the feasibility of the proposed IFP in preparation for submission to the regional airspace and procedures team (RAPT).
Analyst	Models the proposed IFP and evaluates the flyability, operational viability, and other technical aspects of the proposed procedure.
FAA Aeronautical Information Services	Validates the new procedures against design criteria and publishes the new procedures on charts.

The personnel listed in Table 5-5, as well as others, may be involved in development of the PBN flight procedures. All flight procedure requests are submitted to the RAPT for review and ultimate approval.

Regional Airspace and Procedures Team (RAPT)

The RAPT meets monthly to review flight procedure requests in the local context, and approves or denies the requests based on a number of criteria. The RAPT evaluates and approves or denies all local requests for flight procedures.

RAPT personnel include numerous Operations Service Center (Western, Central, or Eastern) managers including the Regional Airports Division, ATO Support, Flight Standards, and the NextGen Branch. Personnel may also include airport operators and users and ATC Facilities. The Regional Airports Division Manager ensures that airport projects do not interfere with the proposed procedures and that the proposed procedures meet the standards in the FAA Advisory Circular 150/5300-13A, *Airport Design*. The Regional Airports Division Manager and airport operators and users can work to ensure that the proposed PBN procedures meet local airport and community criteria and concerns. Ultimately, procedure design is decided upon by the FAA and in coordination with the lead carrier(s).

The criteria for assessing procedure requests include national initiatives, congressional mandates, industry activities, airport operator and users' needs, conceptual design, traffic flow, and airport layout. The team looks for possible conflicts with waivers, naming, equipage, infrastructure, and non-standard methods, and considers timing of implementation of the proposed procedure with activities of the airport, FAA, and others.

The National Airspace Planning Team (NAPT) provides national-level oversight to ensure standard methods are applied across the regions.

Tools

Standard tools are used in the design of flight procedures. The design tools are used to verify that aircraft can fly the designed procedure and to estimate the resulting noise, fuel burn, and exhaust emissions of aircraft flying the designed procedure. These tools are also useful in assessing the impacts of the flight procedure on the airport, local community, and the environment. The primary tools for designing procedures are listed in Table 5-6.

Table 5-6. Standard tools for designing flight procedures.

TOOL	DESCRIPTION
Terminal Area Route Generation, Evaluation, and Traffic Simulation (TARGETS)	TARGETS is a flight procedure design tool with navigation data presentation, procedure design tools, flyability assessment and traffic simulation capabilities. It supports noise screening and operational assessment of proposed procedures according to the mix of aircraft types and percentage of area navigation (RNAV) equipped aircraft.
RNAV Pro™	RNAV-Pro™ is the FAA's flight standards-approved tool for screening of RNAV and required navigation performance (RNP) route elements. Screenings include terminal instrument procedures (TERPS) criteria, flyability, distance measuring equipment (DME), radar coverage, and communication coverage.

Table 5-6. Continued

TOOL	DESCRIPTION
Aviation Environmental Design Tool (AEDT)	AEDT is a software system that models aircraft performance in space and time to estimate fuel consumption, emissions, noise, and air quality consequences. AEDT replaced the Integrated Noise Model (INM) and the Noise Integrated Routing System (NIRS) in 2015 and is a comprehensive tool that provides information to FAA stakeholders on each of these specific environmental impacts. AEDT facilitates environmental review activities required under NEPA by consolidating the modeling of these environmental impacts in a single tool. AEDT is designed to model individual studies ranging in scope from a single flight at an airport to scenarios at the regional, national, and global levels. AEDT leverages geographic information system (GIS) and relational database technology to achieve this scalability and offers rich opportunities for exploring and presenting results. The use of AEDT is required for all new environmental projects. However, projects initiated in previous years may still be using INM or NIRS.

Additional tools have been used on particular projects on a case-by-case basis. The Total Airspace and Airport Modeler (TAAM) is a simulation tool that models airports and airspace and is used to assess the traffic flow impacts of flight procedures. The Monte-Carlo FMS Aircraft Simulation Tool (MFAST) models aircraft FMS characteristics and is used to assess the operational variation in the trajectories of aircraft flying the procedure. The Base of Aircraft Data (BADA) is an energy-based kinetic aircraft performance model used for trajectory simulations and predictions, in particular for estimating the fuel burn of aircraft flying a procedure. The Graphical Airspace Design Environment (GRADE) is used for displaying, analyzing, designing, and evaluating air traffic operations; it has been used to assess level-offs of arrivals to support designing and analyzing the benefits of PBN arrival procedures.

6 Environmental Requirements for Procedures

Implementation of PBN procedures must comply with government rules and regulations. This section provides a brief summary of the NEPA and environmental processing requirements governing airport operations and PBN procedures. These are the typical environmental requirements for the implementation of flight procedures.

National Environmental Policy Act

As per FAA Order 1050.1F, *Environmental Impacts: Policies and Procedures*, the potential environmental effects of the proposed flight procedures must be assessed to comply with NEPA. The FAA official responsible for overseeing the proposed procedures (e.g., the proposed action) ensures that the appropriate level of environmental review is completed for the implementation of the proposed airspace action. The level of environmental review is determined by the nature of the proposed change and the potential for adverse effects or a high level of public controversy. The three levels of environmental review are:

- Categorical exclusion (CatEx);
- Environmental assessment (EA); and,
- Environmental impact statement (EIS).

CatExs for Flight Procedures

CatExs are categories of actions that normally do not individually or cumulatively have significant adverse effects on the human environment. However, actions that are normally categorically excluded may have *extraordinary circumstances*, that is, significant environmental effect in certain circumstances that would prevent the issuance of a CatEx. CatExs include administrative/general; certification; equipment and instrumentation; facility siting, construction and maintenance; procedural; and regulatory.

Standard categorically excluded actions concerning flight procedures are specified in FAA Order 1050.1F, paragraph 5-6.5.i:

> i. Establishment of new or revised air traffic control procedures conducted at 3,000 feet or more Above Ground Level (AGL); procedures below 3,000 feet AGL that do not cause traffic to be routinely routed over noise sensitive areas; modifications to currently approved procedures conducted below 3,000 feet AGL that do not significantly increase noise over noise sensitive areas; and increases in minimum altitudes and landing minima. For modifications to procedures at or above 3,000 feet AGL, the Air Traffic Noise Screening (ATNS) procedure should be applied.

Congressional legislation under the *FAA Modernization and Reform Act of 2012* has categorically excluded PBN procedures from the environmental review process if they meet certain criteria, as per the evaluation and judgment of the FAA Administrator. Categorical exclusions identified as a result of the *FAA Modernization and Reform Act of 2012* are provided in FAA Order 1050.1F, paragraphs 5-6.5.q and 5-6.5.r:

> q. The following procedures taken in accordance with section 213 of the *FAA Modernization and Reform Act of 2012*, conducted at, above, or below 3,000 feet AGL, unless there is a determination that extraordinary circumstances exist:
>
> (1) Area Navigation/Required Navigation Performance (RNAV/RNP) procedures proposed for core airports and any medium or small hub airports located within the same metroplex area considered appropriate by the Administrator; and
>
> (2) RNP procedures proposed at 35 non-core airports selected by the Administrator.
>
> r. Any navigation performance or other performance based navigation procedure that, in the determination of the Administrator, would result in measurable reductions in fuel consumption, carbon dioxide emissions, and noise, on a per flight basis, as compared to aircraft operations that follow existing instrument flight rules procedures in the same airspace. This CatEx may be used irrespective of the altitude of such procedures.

Additional specific guidance is provided in FAA Order 1050.1F.

The legislative categorical exclusions listed in paragraphs 5-6.5.q and 5-6.5.r of FAA Order 1050.1F have resulted in the implementation of PBN procedures that, in some cases, do not meet the needs of airport operators and the local communities, and have generated significant public controversy. The FAA is addressing some of these issues by incorporating environmental reviews into the PBN procedure design process for its Metroplex program and its standard 5-phase process and preparing EAs for the implementation of metroplex airspace redesigns.

Extraordinary Circumstances to CatExs

Extraordinary circumstances or factors may arise such that normally categorically excluded actions may have a significant environmental effect under certain circumstances. FAA Order 1050.1F section 5-2 lists the extraordinary circumstances that may exist. Those most commonly affecting the implementation of flight procedures include, but are not limited to:

- An adverse effect on cultural resources protected under the National Historic Preservation act of 1966, as amended.
- An impact on properties protected under United States Department of Transportation (U.S.DOT) Section 4(f).
- A significant noise impact on noise sensitive areas.
- An impact on air quality or violation of federal, state, tribal, or local air quality standards under the Clean Air Act (CAA).
- Impacts on the quality of the human environment that are likely to be highly controversial on environmental or other grounds.

Significance thresholds are specified for different criteria to determine if extraordinary circumstances exist. For noise as a criterion, an increase of 1.5 decibels (dB) in the day-night average sound level (DNL) at or above 65 dB (for example, an increase from 63.5 to 65.0 dB) is considered significant. For air quality as a criterion, exceeding one or more national ambient air quality standards (NAAQS) established by the EPA is considered significant. The NAAQs establish primary and secondary air quality standards for 6 *criteria pollutants* comprising carbon monoxide (CO), lead (Pb), nitrogen dioxide (NO_2), ozone (O_3), particulate matter (PM10 and PM2.5), and sulfur dioxide (SO_2). For each pollutant, the NAAQs specify each as primary or secondary to public health and specify the averaging time, level, and form of exposure standards.

Regarding documentation of the assessment of extraordinary circumstances, the FAA may formally or informally document CatEx determination for record-keeping purposes or in anticipation of litigation. Paragraph 5-3.b.(4) of FAA Order 1050.1F identifies that known controversy and public opposition to a project may warrant the preparation of additional CatEx documentation or an EA. Given the level of public controversy related to the implementation of PBN procedures and the perception that regulations have not been followed, it is anticipated that additional FAA disclosure, as well as a closer working relationship with airport sponsors in the development of the procedures, may be required in the future.

EAs and EISs

As per FAA Order 1050.1F paragraph 3-1.2.b.(12), actions regarding flight procedures normally requiring an EA include:

> b. New air traffic control procedures (e.g., instrument approach procedures, departure procedures, en route procedures) and modifications to currently approved procedures that routinely route aircraft over noise sensitive areas at less than 3,000 feet AGL (unless otherwise categorically excluded under Paragraphs (procedures category) 5-6.5.q and 5-6.5.r).

The EA scoping process includes a 30-day period for resource agencies, industry groups, and affected communities to review the scoping package describing the proposed action and to address the issues of greatest concern to them. The comments and concerns raised during the scoping process are considered in the preparation of the EA. The EA includes:

- The purpose and need for the proposed action;
- An identification and evaluation of alternatives to the proposed action;
- The environment potentially affected by the proposed action;
- The potential environmental consequences (including cumulative impacts) of implementing the proposed action, prudent and feasible alternatives to the proposed action, and the no action alternative;
- The identification of measures to mitigate any adverse effects to below significance criteria, as appropriate; and
- Agency and public coordination.

After a draft EA is prepared, it is circulated for a minimum 30-day public and agency review period. The FAA then prepares a final EA, which includes responses to comments received during the public and agency review process. The responsible FAA official determines whether a finding of no significant impact (FONSI) can be issued, or that an EIS is needed. In some cases, a FONSI record of decision (ROD) is prepared by FAA to document FAA's compliance with NEPA, present the FAA's decision on the proposed action, and to identify mitigation and monitoring measures for the proposed action.

An EIS is required when the proposed FAA actions and their reasonable alternatives would cause potential significant individual or cumulative environmental impacts such that a FONSI cannot be issued. The EIS has similar content to the EA, however additional agency and public coordination is required.

Summary of Requirements

The United States Government Accountability Office provides a succinct, comprehensive summary of the environmental review requirements for new and revised flight procedures in its report titled *Next-Gen Air Transportation System: FAA Has Made Some Progress in Midterm Implementation, but Ongoing Challenges Limit Expected Benefits*. These are listed in Table 6-1.

Table 6-1. FAA Environmental review process for new and revised procedures.

ALTITUDE REGIME	REQUIREMENT
18,000 feet Above Ground Level (AGL) and above	Changes to flight procedures can be implemented using a categorical exclusion (CatEx), with no screening or analysis required.
10,000–18,000 feet AGL	Changes to flight procedures can be implemented using a CatEx. Fuel burn and CO_2 emissions analyses are required. Noise screening is required for special circumstances.
3,000–10,000 feet AGL	Changes to flight procedures can be implemented using a CatEx. However, while eligible for a CatEx, significant controversy has been associated with PBN implementations including operations above 3,000 feet. In proposing to use a CatEx to implement a change, care should be taken to understand the potential impacts on and/or reaction of the community. Fuel burn and emissions analyses are required. Noise screening is required, and certain noise increases may require an environmental assessment (EA). Noise and emissions analyses are required for changes to arrival procedures within 3,000–7,000 feet AGL, and for changes to departure procedures within 3,000–10,000 feet AGL.
3,000 feet AGL and below	Changes to flight procedures typically require an EA. Fuel burn and emissions analyses are required, and air quality analysis under the CAA is required. Changes may be made using a CatEx if they occur over a non-noise sensitive area or if they are part of a legislative CatEx. Any potential adverse significant impact on noise sensitive areas requires an Environmental Impact Statement (EIS) and noise screening.

Source: Government Accountability Office.

7 Stakeholders and Challenges in PBN Implementation

A broad range of stakeholders in PBN were surveyed in order to understand their levels of knowledge, perspectives, and attitudes regarding PBN and airport operations. Stakeholders surveyed included airport operators, aircraft operators, aviation regulators, procedure designers and implementers, system operators, researchers and developers, avionics and aircraft manufacturers, airline technical pilots, and environmental and noise groups. The findings from the survey provided insight into the nature and extent of airport involvement in the flight procedure design and implementation process. The findings describe the knowledge and understanding of key stakeholders in flight procedure design and implementation, including airport operators, aircraft operators, and communities as well as challenges regarding PBN procedure implementation. The findings are summarized in the sections below.

Stakeholders

Immediate stakeholders in the design and implementation of flight procedures include airport operators, aircraft operators, and the community. This section documents the concerns of each of these stakeholders and the high-level contributions that each may make to the development and implementation of procedures.

Airport Operators

The involvement of airport operators benefits procedure design by potentially enabling the maximum achievable environmental benefits given local constraints, allowing for community buy in, and aiding in the seamless implementation of FAA's NextGen Program. Typical concerns of airport operators and high-level guidelines for their engagement in developing procedures are detailed below.

Concerns

The concerns of airport operators related to the design of flight procedures serving their airport include efficient access of passengers and aircraft to the NAS, meeting environmental requirements for the airport, satisfying the needs of the communities proximate to the airport, maximizing airport revenue, and minimizing operational costs of the airport.

Contributions

Airport personnel can address these concerns by engaging in the procedure development process. The airport operator is recognized as a primary stakeholder in PBN development through the FAA's 5-phase PBN Implementation Process (FAA Order 7100.4) and the Standard Operating Procedure for Safety

Risk Management Under the FAA Office of Airports (ARP) Safety Management System (ARP SOP 4.00). To engage meaningfully and proactively in the procedure design process, airport representatives must be sufficiently knowledgeable of PBN. While the involvement of airports is particularly important in the initial specification and preliminary design of the PBN procedures, airport representatives should be engaged from inception of the procedure development project all the way through to post-implementation assessment of the procedures. Airport representatives may best participate in procedure development through a targeted FAA stakeholder engagement process, perhaps as part of the FAA's 5-phase process. The PBN development process will be sponsored and managed by FAA's procedure design team. In procedure development projects undertaken by institutions such as FAA or an aircraft operator, the airport will typically assume an advisory role in development process. However, the airport could assume a lead role in a procedure development projects it initiates. In an advisory role, the airport will advise the design team of important considerations for the airport and local airspace, such as noise-sensitive areas. The involvement of airports in the procedure development process should not extend the time for design and implementation of the procedures or delay the benefits of implementing the procedures. When advising regarding the procedure design, airports and all other stakeholders should consider the interests of all stakeholders: industry and community, local and national. This includes considering the larger benefits of PBN procedures beyond the local domain of the airport. Airport authorities should understand the design trade-offs that are required to ensure that the greater NAS benefits of capacity, access, and flight efficiency potentially afforded by PBN procedures are not excessively compromised in meeting the local needs of the airport. Depending on the project and the community and other stakeholders involved, the greater needs of the NAS may or may not justify varied levels of impact on the ground.

Airport operators can contribute to flight procedure design and implementation through local knowledge, environmental analysis, and infrastructure planning and investment. Regarding local knowledge, the airport can contribute knowledge of local operational considerations and constraints concerning the airfield and local airspace to support baseline operations characterization. The airport operator can support specifying design objectives, constraints, and performance metrics. The airport operator can also assist in identifying operational and environmental impacts of proposed procedures to the airport and community. Local knowledge useful to the development project may include preferred runway configurations and routes, obstructions, noise-sensitive areas, aircraft operator characteristics, concerns of the community, and current and forecasted equipage types and traffic levels at the airport. Airport operators can also review proposed procedure designs to be sure they are compatible with noise abatement procedures, land uses, and the concerns of surrounding communities; that the procedures are useful to aircraft operators; and that the lowest minimums have been achieved in the design of approach procedures. Regarding environmental analysis, airport personnel may conduct local studies, such as noise or traffic flow analyses, to support the design, implementation, and cost-benefits analysis of the procedures and to monitor the environmental impact of the implemented procedures. Airport operators may also fund the EA of the proposed procedures to contribute to their implementation. Regarding infrastructure, airports may conduct airport planning and infrastructure investment to support realizing or maximizing the benefits of the procedures.

Airport operators can also contribute to flight procedure design through outreach to local FAA personnel and nearby communities. Regarding outreach to local FAA personnel, the airport operator can establish and maintain relationships with the local FAA Service Center (eastern, central or western), the terminal radar approach control (TRACON) facility manager and air traffic control tower (ATCT) representatives to understand the local airspace, collaborate in procedure design, and conduct outreach with the community. Regarding outreach to communities, airport personnel can identify local persons or groups representing the community and conduct outreach to those individuals or organizations. This is often better than outreach to the general public. The airport staff can educate the community regarding the capabilities and benefits of PBN. Community outreach and education should include basic information that explains varying levels of aircraft equipage and the aircraft capabilities and limitations for the intended operations. Airport personnel may also brief the community on designed procedures, obtain the understanding and approval of the community at different stages throughout the design process, and hold follow-up meetings with the community as part of the post-implementation assessment of the procedures.

Communities

Input from community representatives is valuable in helping to ensure that the needs of the community are understood and considered in the procedure design. Typical concerns of the community and high-level guidelines for their engagement in procedure development are detailed below.

Concerns

The concerns of communities proximate to airports regarding flight procedure design include the concentration of aircraft noise, increases in air traffic, local air quality, and the presence of air traffic.

Contributions

Communities can address these concerns by being aware of and understanding the procedure development project and having opportunities to voice their concerns. It is important that the flight procedure implementation process is transparent to the community to allow them to feel that they have a stake in the implementation of procedures. It is better to have the community participate through representative bodies, such as noise forums, city councils, planning divisions, or other organizations rather than in an ad-hoc manner. Such representative bodies are informed about land use and noise sensitive areas within communities that will potentially be affected by the procedures and therefore can contribute constructively. Representative bodies also offer the opportunity for education regarding PBN, airport operations, and other matters, which is more difficult with ad-hoc or general public audiences. Input from community representatives is valuable to ensure the needs of the community are met in the procedure design. Input from the community is typically more valuable in the initial stages of the procedure design. Input may also be valuable in post-implementation assessment of procedures to validate the planned results. While NEPA provides a framework for community engagement as part of the EA process, outreach efforts beyond those satisfying NEPA requirements is advisable.

Aircraft Operators

Aircraft operators are typically a project sponsor and may design their own procedures for an airport. Typical concerns of aircraft operators and high-level guidelines for their engagement in procedure development are detailed below.

Concerns

Aircraft operators want to ensure the usability of the published procedures. They typically want designs that they can use and that are approved by ATC. Additional concerns of aircraft operators include design for fuel and time savings as well as providing reliable access to airspace and airports. Aircraft operators are also concerned with the aircraft equipage required and the costs of training crew members to fly the procedures. Most aircraft operators have equipped their aircraft to fly PBN procedures in en route and terminal airspaces, and many operators have policies encouraging the use of PBN procedures. However, the particular equipage for different types of approach procedures varies among operators, and usage policies among operators and pilots vary as well.

Contributions

Aircraft operators can contribute site-specific information fundamental to the procedure design including defining their normal operations, understanding of their flight planning process, the capacities of their aircraft, the typical weights and climb profiles of their aircraft, and the current and planned PBN capability levels of their fleet. In addition, aircraft operators can conduct flyability assessment of proposed procedures to determine their operational viability. Aircraft operators can participate with airport operators to provide accurate operational information as part of a community outreach program during public meetings.

Other Stakeholders

The RTCA NAC recently published the *Blueprint for Success to Implementing PBN Procedures* (RTCA 2014). This document provides useful descriptions of technical and non-technical stakeholders and recommendations for outreach to those groups. Non-technical stakeholders include the public, community groups and non-governmental organizations, airport authorities, airport advisory boards, and local, state and federal government officials. Technical stakeholders include industry representatives, including the lead operator, Airlines For America (A4A), the National Business Aviation Association (NBAA), the Regional Airlines Association, airport authorities, air traffic facilities, pilot unions, the Department of Defense, third-party procedure developers, and others.

The document provides three recommendations for working with or considering non-technical stakeholders, eight recommendations for working with or considering technical stakeholders, eight recommendations for PBN implementation outcomes and assessment metrics, six recommendations for capturing lessons learned from individual implementation efforts and applying them to future efforts, and three additional recommendations for checklists to support the procedure implementation process, including accommodating flight procedures implemented under special programs for different circumstances.

The FAA has recently responded to the NAC with full concurrence on all of the non-technical stakeholder recommendations, full concurrence of seven and partial concurrence on one of the technical stakeholder recommendations, full concurrence of one and partial concurrence of seven of the outcome and metrics recommendations, full concurrence of three and partial concurrence of three of the lessons learned and future effort recommendations, partial concurrence of one and full concurrence of one checklist recommendations, and full concurrence on the special procedures recommendation.

Challenges

Numerous challenges to implementing PBN procedures were identified in the stakeholder survey. Airport operators should be aware of these challenges when proposing or engaging in the development of PBN procedures. The categories of these challenges include planning, outreach, technical design, utilization, and process.

Planning

Understanding the FAA's planned and actual time frames for implementing PBN procedures and other NextGen capabilities helps for airport master planning and Federal Aviation Regulation (FAR) Part 150 studies, and land use planning by local jurisdictions.

An airport master plan should consider the timing and effects of PBN implementation on airport capacity and traffic demand, facility requirements, alternatives, noise, and implementation schedules for major capital improvements. This will ensure that airport infrastructure will meet the needs of the potential increase in operations enabled by PBN.

A FAR Part 150 Noise Compatibility Study should consider PBN airspace alternatives designed to avoid noise-sensitive land use areas and thereby reducing the overall impact of noise on a community. Planning PBN noise abatement alternatives prior to the implementation of a metroplex or other PBN implementation project is prudent. The alternatives may be considered as part of the design phase, taking advantage of the resources available through the process.

A good example demonstrating this concept is the case of the Louisville International Airport FAR Part 150 program, completed in the early 2000s. Shortly after the completion of the Part 150 project, the FAA began an unrelated initiative to implement RNAV SIDs and STARs at the airport. The Louisville Regional Airport Authority was able to work with the local FAA representatives and the design team to influence the development of the SIDs to include some of the recommendations and noise initiatives contained in the FAR Part 150 study while capturing the air traffic efficiencies intended. These procedures were developed and implemented in the late 2000s and have been effective in mitigating noise and increasing throughput.

All PBN planning efforts should consider tradeoffs associated with implementation. As previously discussed, negative effects of PBN implementation may include a concentration of noise over a small area where there was previous dispersion of noise. It is imperative that these issues be addressed and understood, and mitigation methods analyzed for these situations.

Outreach

Challenges in outreach include community opposition and resources. Community opposition to PBN procedures may be due to limited knowledge and understanding and can hamper the implementation of procedures. Outreach to communities prior to and throughout the procedure development process can help to obtain their understanding and approval. However, this may require significant resources depending on the nature of the project and level of interest and concern of the community. Educating the community on the benefits associated with PBN is paramount; airports typically have outreach programs and procedures in place, which can be leveraged to support PBN outreach efforts.

Technical Design

Challenges in technical design may include PBN procedure requirements, aircraft performance differences, and stakeholder needs. Regarding procedure requirements, when coupled with local terrain and airspace constraints, it is possible that the procedures may be operationally challenging or infeasible to implement, or may have high ceiling and visibility requirements. Regarding aircraft performance, different aircraft and their FMS's can exhibit performance differences while flying the same procedure. Accounting for the breadth of performance differences in the design and evaluation of the procedures can be challenging. Regarding stakeholder needs, achieving the benefits of the proposed procedures, while adjusting their design to meet the needs of all the stakeholders without compromising the design objectives, can be challenging.

Utilization

Challenges in utilization are aircraft equipage and ATC. Regarding equipage, being able ultimately to use PBN procedures that were implemented depends on the levels of equipage among the aircraft fleet at the airport. The decision to implement a particular PBN procedure is often dependent on the accuracy of predicted aircraft equipage levels. Regarding ATC, utilization depends upon the ability of ATC to manage aircraft flying PBN procedures with high traffic volumes and mixed equipage. Specialized tools and operations may be required to enable controllers to manage traffic.

Process

Challenges in the procedure development process are numerous and include the following key examples. First, it can be challenging to adequately define the design objectives, characterize the baseline operations and use of the legacy procedures, and assess the benefits. Second, given the breadth and potentially differing perspectives of the procedure design team members, conflicts and challenges may occur in coordination and execution during design and implementation of the procedures. Third, the design and EA processes can be lengthy and involved. Fourth, often there are insufficient budgets and timelines allocated for implementation and training of pilots and controllers in use of the new procedures, which can pose a significant impediment to utilization of the procedures. Lastly, developing methods and criteria for post-implementation assessment of the procedures can be challenging.

8 Potential Contributions of the Airport to the Procedural Development

This chapter describes where and how aircraft operators can contribute to the process of designing flight procedures. These suggestions are based on the responses of the broad range of stakeholders surveyed. The potential contributions of airport personnel are presented within the framework of FAA's 5-phase process, although are applicable to any procedure development process.

Phase 1: Preliminary Activities

- Establish and maintain relationships with FAA and airline personnel involved in the design of PBN procedures.
- Share known limitations of the current flight procedures and their impacts on the airport, aircraft operators, and local community.
- Support specification of objectives and constraints for design of the procedures to address the limitations of the legacy procedures and airspace as well as other issues, including noise.
- Support the characterization of the baseline operations of the airport and local airspace with analysis and information.
- Identify noise-sensitive areas around the airport, specify allowable noise thresholds for those areas, and propose design features to satisfy the constraints.
- Communicate the limitations of the legacy flight procedures, the design objectives, and the potential impacts of the proposed procedures to the community and other stakeholders.
- Understand the concerns of the stakeholders regarding the proposed design.
- Translate concerns of the community and other stakeholders into design objectives and constraints for the procedures.
- Communicate the concerns of the community and other stakeholders to the design team.
- Translate their concerns into procedure design considerations.
- Propose refinements to the objectives and constraints of procedure design to address the concerns of the community and other stakeholders.

Phase 2: Development Work

- Share airport data, information, and operating characteristics to support the design and simulation-based evaluation of the PBN procedures. This could include data such as preferred runway configurations, preferred routes, airport survey data, current and predicted equipage types and levels of aircraft, and noise-sensitive areas.

- Support specifying and verifying modeling assumptions and input data for evaluation of the procedures. This could be as involved as working with an analyst to configure parameters for TARGETS, AEDT, and/or other software tools.
- Evaluate noise and emissions analysis results generated by the procedure design team analysts to assess compatibility of the proposed procedures with the airport's environmental requirements. For example, comparing generated noise contours against known noise-sensitive areas and thresholds, or conducting independent analysis of data to assess noise impacts.
- Brief the community on the evolving design in scoping sessions or other outreach forms and obtain their feedback.
- Propose design changes to satisfy the environmental requirements where potential issues have been identified.
- Brief the community on the resulting design in scoping sessions or other outreach forums to educate them regarding the design objectives and constraints, design approach and tradeoffs, anticipated impacts on the airport, airline(s), FAA and other stakeholder(s), the community, and the environment.

Phase 3: Operational Preparations

- Conduct or support completing any final environmental review, community outreach or other activities in preparation for implementation.

Phase 4: Implementation

- Review published procedures to ensure they comply with the requirements of the airport operator, community, and other stakeholders.
- Communicate identified or potential issues to the design team.

Phase 5: Post-Implementation Monitoring and Evaluation

- Conduct independent analysis of the impacts of the procedures, such as noise, throughput, or flight efficiency.
- Evaluate noise and emissions analysis results to assess the compatibility of the implemented procedures with the airport's environmental requirements and to assess their agreement with the impacts estimated in Phase 2: Development Work and the design objectives specified in Phase 1: Preliminary Activities.

- Obtain feedback from the community regarding their perceptions of the impact of the procedures.
- Communicate identified issues to the design team and propose design changes to the procedures to address the issues.

9 Lessons Learned and Best Practices

Case studies of PBN implementation projects for six selected airports and metroplexes were conducted in order to identify lessons learned and best practices for airport operators to work with the FAA, their surrounding communities, and other stakeholders in all phases of flight procedure design and implementation. The case study airports were selected based on a number of factors including airport size, unique applications of PBN, and specific challenges related to implementation. The airports and the PBN implementations projects are listed below.

- Hartsfield-Jackson Atlanta International Airport (ATL)—PBN departure implementation.
- Denver International Airport (DEN)—PBN arrival, approach, and departure implementation.
- Henderson Executive Airport (HND)—PBN Arrival, approach, and departure implementation.
- Houston Metroplex—PBN arrival, approach, and departure implementation.
- Minneapolis-St. Paul International Airport (MSP)—PBN arrival, approach, and departure implementation.
- Seattle-Tacoma International Airport (SEA)—Greener Skies PBN arrival and approach implementation.

This chapter is divided into two sections. The first section summarizes the common factors and unique characteristics of the case study airports and implementations. The second section summarizes the lessons learned and best practices identified from the case studies.

Summary of Case Studies

The projects selected for case study analysis spanned a range of characteristics relevant to the development and implementation of PBN procedures. The characteristics included:

- Land use surrounding the airport,
- Project initiators,
- Levels of airport involvement,
- Types of PBN development processes used,
- Development of new flight procedure design criteria,
- Environmental impact assessments and assessment preparers,
- Levels of community input and public outreach, and
- Challenges encountered.

A successful outcome is defined as a project in which the designed flight procedures were implemented and consistently utilized, without significant and consistent opposition from the community. Table 9-1 provides a summary of the common characteristics associated with each case study.

Table 9-1. Summary of case study factors.

	HARTSFIELD-JACKSON ATLANTA INTERNATIONAL AIRPORT (ATL)	DENVER INTERNATIONAL AIRPORT (DEN)	HENDERSON EXECUTIVE AIRPORT (HND)	HOUSTON METROPLEX	MINNEAPOLIS/ST. PAUL INTERNATIONAL AIRPORT (MSP)	SEATTLE-TACOMA INTERNATIONAL AIRPORT (SEA)
Airport Size Land Use Surrounding Airport	Large Hub Industrial, and low- and middle-income residential	Large Hub Rural and middle-income residential	Small Reliever Master planned middle- to upper-income residential, undeveloped land parcels	Multiple Hubs Industrial and lower-income residential	Large Hub Upper- and middle-income residential	Large Hub Industrial and middle-income residential
Project Initiator	Atlanta ATC	Denver ATC and industry	Local aircraft operators	FAA Metroplex	Metropolitan Airport Commission with Minneapolis ATC and industry	Seattle ATC and industry
Airport Involvement	Design yes, outreach yes	Design yes, outreach somewhat	Design somewhat, outreach no	No	Design somewhat, outreach somewhat	Design yes, outreach somewhat
Processes Used	Local feasibility/ FAA 18-step process	Local feasibility/FAA 18-step process	FAA 18-step process	Metroplex process	Local feasibility of 2 departures/FAA 18-step process	Local Feasibility/ FAA 18-step process
Flight Procedures Implemented	Equivalent lateral spacing operation (ELSO) RNAV SIDs	RNAV STARs, RNAV SIDs, RNP AR SIAPs, Established on RNP (EoR) SIAPs	RNAV SIDs, RNAV STARs, RNAV SIAPs	RNAV SIDs, RNAV STARs, RNP AR SIAPs	RNAV SIDs, RNAV STARs, RNP AR SIAPs	RNAV SIDs, RNAV STARs, RNP AR SIAPs, EoR SIAPs
New Criteria	ELSO	EoR	RNAV Category C Missed Approach	No	No	RNAV/RNP Parallel Simultaneous Operations, EoR

Environmental Preparer	City of Atlanta Department of Aviation	FAA	FAA	FAA	Metropolitan Airports Commission	FAA
Community Input	Yes	Yes	No	No	Late in development process	Late in development process
Public Outreach	Project team meetings with community throughout process	FAA environmental contractor meetings with local government throughout process	No	Limited briefings to community by FAA	Time-limited airport campaign to community, FAA briefing to community on final design	FAA briefing to community on final design, airport supporting
Challenges	Criteria for ELSO reduced lateral spacing, noise sensitivities of communities	Satisfying inter-governmental agreement for noise	Missed approach criteria, proximity to Las Vegas McCarran airport	Minimal flight path changes below 10,000 feet	Public opposition to developed procedures	Criteria for EoR, public opposition to developed procedures
Outcome	Developed and applied new ELSO criteria; increased departure throughput; satisfied community noise sensitivities	Applied EoR criteria; reduced flight distance, fuel burn and emissions; enhanced airport arrival throughput; met stringent noise exposure requirements	Overcame terrain and proximate airport traffic challenges; improved access to airport	Reduced flight distance, fuel burn and emissions; adequately informed community	Inadequate public outreach, community halted implementation of procedures	Developed and applied EoR criteria; overcame initial community opposition; reduced flight distance, fuel burn and emissions

For the six case study airports, the research team found that the PBN implementations had positive outcomes and some challenges for the airport, aircraft operators, and communities. The reasons why a project had positive or a negative outcome varies for each airport. For example, the ATL and DEN projects were successful due to the level of coordination and participation of the airport and community. HND and Houston were successful with airport participation but had little community input. At MSP, success was hindered due to the community becoming involved late in the process. SEA was successful with airport involvement, but lacked significant community involvement. The case studies confirm that successful implementation is dependent on both the characteristics and the involvement of the airport and its surrounding community.

Lessons Learned and Best Practices

A number of lessons learned and best practices synthesized from the case studies can enhance the likelihood of a successful implementation of flight procedures. While the circumstances, operational environment, and local issues associated with each case study are very different, it is possible to develop guidance for future PBN implementation projects. The findings are summarized below according to elements common to all PBN projects, including initiation, personnel, process, environmental, outreach, post-implementation assessment, and outcomes. Best practices or lesson learned, along with specific examples from each case study, are listed for each common element.

Initiation

This section provides guidelines concerning the initiation of flight procedure development projects. The lessons learned and best practices concerning initiation of procedures include:

- Procedure development projects are undertaken for a range of reasons and objectives, such as reducing fuel burn and emissions, improving airspace design, reducing community noise exposure, and/or increasing airport throughput.
- Procedure development projects may be initiated by local or federal FAA, aircraft operators, members of industry, or the airport authorities.
- Procedure development projects originating locally may be taken over as federal initiatives.

The remainder of this section describes each of these in greater detail and references specific examples from individual case studies.

Procedure Development Projects Are Undertaken for a Range of Reasons and Objectives

PBN initiatives may be undertaken for a variety of objectives, including reducing fuel burn and emissions of aircraft arriving to or departing from the airport, reducing time exposure in the airspace, increasing airport throughput, reducing community noise exposure, or reducing controller workload. For example:

- The project at SEA was undertaken to reduce fuel burn and emissions and to demonstrate the navigation capabilities of current-day aircraft.
- Projects at MSP were initiated to reduce community noise exposure and reduce fuel burn and emissions of arrival aircraft.

- The project at ATL was undertaken to increase departure throughput of the airport.
- The project at DEN sought to reduce controller workload, improve predictability of flight paths, and reduce fuel burn and emissions, based on the specific objectives of each of the participants. The airport's primary desire was to increase its ability to efficiently handle arriving traffic and to minimize the environmental impacts of traffic growth. The FAA wanted to improve safety and efficiency and lessen controller and pilot workload. The airlines wanted to reduce the miles flown in the terminal area.
- The project at HND was undertaken to improve access to and increase utilization of the airport.
- The project at the Houston Metroplex was initiated to improve the flight efficiency of arrivals and departures and to increase arrival throughput.

Procedure Development Projects May Be Initiated by Local or Federal FAA, Aircraft Operators, Members of Industry, or the Airport Authorities.

PBN initiatives may originate from different organizations on the local and federal level. Projects originating locally have been initiated by the local FAA ATO, such as TRACON managers; by airport authorities; and by aircraft operators, air carriers, and other members of industry. FAA headquarters has initiated other projects, typically through the metroplex and other initiatives. For example:

- Projects at SEA and MSP were initiated by local airport authorities.
- Projects ATL and DEN were initiated by managers at local FAA facilities.
- One project at HND was led by the airport authority and by managers at local FAA facilities, while another was led by NetJets, a user of the airport and international fractional ownership operator.
- At DEN, Jeppesen led the development of PBN approach procedures.
- The project at the Houston Metroplex was undertaken by the FAA through its program.

Procedure Development Projects Originating Locally May Be Taken Over as Federal Initiatives.

Some projects that originated locally have remained as local initiatives. Others have transitioned to the FAA headquarters level, while still involving the airport to varying degrees. For example:

- Projects at MSP and SEA transitioned to the federal FAA ATO; however, the airports remained aware of and involved in the development process.
- Projects at ATL, DEN and HND remained as local efforts supported by FAA headquarters.

Personnel

This section concerns the personnel who may be involved in flight procedure development projects and provides guidance for airport operators to successfully engage. The lessons learned and best practices concerning personnel include the following:

- Airport personnel may be deeply involved in procedure development projects.
- Projects include local and federal FAA personnel, local aircraft operators and other industry representatives, and may include local departments of transportation.
- Airport representatives should be knowledgeable of PBN and the local airspace and have relationships with local community and government.

- Locally led initiatives require knowledgeable leadership and a cohesive team.
- Airports can be involved in FAA-led initiatives.

The remainder of this section describes each of these in greater detail and references specific examples from individual case studies.

Airport Personnel May Be Deeply Involved in Procedure Development Projects

In the majority of successful PBN implementation projects, the airport operator was involved in the design, advising the design team on noise sensitive areas of the community and other local concerns. Airport representatives may be from airport noise and environmental offices, particularly if noise abatement factors heavily in the design of the flight procedures. For example:

- At SEA and ATL, airport authorities supported designing the routes, including specifying the locations of routes and waypoints. Airport authorities also supported community outreach to explain the design and impacts on the community.
- At DEN, a representative from the noise abatement office collaborated on the design of the procedures to ensure their compatibility with stringent noise requirements.

Projects Include Local and Federal FAA Personnel, Local Aircraft Operators and Other Industry Representatives, and Local Departments of Transportation

Projects typically include FAA personnel from the local TRACON, ATCT, adjoining Air Route Traffic Control Centers (ARTCCs), the appropriate FAA operations support group (OSG), and FAA headquarters. Personnel will also include a lead aircraft operator at the airport and other industry representatives, and may include as well representatives from the local department of transportation. For example:

- At ATL and DEN, personnel from the local ATCT, TRACON and ARTCC facilities were deeply involved in the procedure design, and the City of Atlanta Department of Aviation (ADOA) was a key stakeholder and led the EA.
- At HND, procedure development involved the collaboration of the local TRACON, ARTCC, and the National Air Traffic Controllers Association (NATCA), and the Clark County Department of Aviation (CCDOA), which led the development of approach procedures.
- At MSP, Delta Air Lines supported procedure design and community outreach.
- At DEN, United Airlines and Southwest Airlines supported procedure design.
- At SEA, Boeing supported procedure design and criteria development, and Alaska Airlines and Horizon Air supported flight simulation evaluation.

Airport Representatives Should Be Knowledgeable of the PBN and the Local Airspace and Have Relationships with Local Community and Government

Airport and local representatives involved in the PBN process should possess a comprehensive understanding of the local airspace structure and flight procedures. They should have thorough knowledge of the community, particularly as it relates to the local environment and noise considerations, and have established relationships with the local community and its political leadership. Throughout the process, these personnel can provide important local and environmental information which may supplement the procedure design, identify procedure design considerations, conduct community outreach, and coordinate between the airport, FAA, aircraft operators, community and action groups. Such knowledge and relationships ensure the airport and local representatives can meaningfully engage with the FAA throughout the design process and ensure the PBN procedures meet the objectives and constraints of FAA air traffic operations, aircraft operators, and surrounding communities. For example:

- At MSP, the Noise Oversight Committee (NOC) is the ultimate authority on flight procedures and airport noise, and is the primary interface for community concerns regarding aircraft noise and traffic. The NOC comprises six community and six industry representatives, including representation from the airlines.
- At SEA, airport personnel who were knowledgeable of PBN and involved in the design of the procedures worked with the FAA to recommend the placement of procedure waypoints to avoid noise-sensitive areas of the surrounding communities. The airport representatives also communicated with members of surrounding communities in discussion forums regarding the proposed procedures and their impact.
- At DEN, the Noise Abatement Office representatives were intimately familiar with defined contours and grid points defining noise-sensitive areas. They also understood the design of the current arrival procedures and air traffic considerations associated with them.
- At ATL, project personnel met with city officials and representatives of surrounding communities to describe the project history, the nature of the project, the justification for the design, and design considerations and trade-offs.

Locally Led Initiatives Require Knowledgeable Leadership and a Cohesive Team

Locally initiated PBN implementation projects may have a greater chance of success when directed by someone who is technically knowledgeable regarding PBN, flight procedures criteria and flight standards, and is familiar with the FAA lines of business relevant to implementation of PBN flight procedures. There is a greater chance of success when all members of the PBN Team remain engaged throughout the development process rather than individuals working independently throughout different project phases. For example:

- At DEN, FAA and airline personnel on the design team helped move the project forward when serious roadblocks were encountered throughout the development and implementation process. Flight procedure development was conducted with considerable collaboration between the DEN Noise Abatement Office and other project team members.
- At ATL, procedure development was guided by an Atlanta TRACON manager with extensive knowledge of PBN and criteria. He was instrumental in securing support and coordination from the appropriate FAA divisions for the certification and implementation of the procedures. In this case, the project leader was able to partition the development among individual team members.

Airports Can Be Involved in FAA-Led Initiatives

In initiatives initiated or overtaken by the FAA, airports may remain deeply involved in the design, or can expect to be briefed by the FAA. In the latter case, the briefings may be at the beginning of the project and concern the intended scope and goals of the project; briefings may be at the end of the design phase and concern the proposed design of the PBN procedures; or briefings may be at multiple points throughout the process. Airports may want to reach out to the FAA project representative to request briefings and track project progress. For example:

- At SEA, the FAA met with the airport representatives, controllers, and airlines to decide on the placement waypoints for each procedure.

- At MSP, the FAA engaged with airlines, NATCA, and others in the development of the procedures, and MSP staff were invited to attend all meetings and engaged in and monitored the design process.
- At the Houston Metroplex, the FAA's design team briefed representatives of the Houston Airport System (HAS) and the community regarding the objectives of the project at the outset and on the final design of the procedures at the end.

Process

This section covers processes and considerations for developing PBN flight procedures. The lessons learned and best practices concerning the process include:

- Primary procedure design guidance includes the FAA 5-phase PBN Implementation Process (FAA Order 7100.41) and the FAA metroplex study and design process.
- Procedure design is unique to each airport and surrounding airspace, which requires balancing multiple, sometimes competing objectives of the FAA ATO, aircraft operators, airport operators, and surrounding community.
- Air traffic management methods may be a component of the procedure to meet design objectives.
- New criteria for flight procedures have been developed in previous PBN initiatives.

The remainder of this section describes each of these in greater detail and references specific examples from individual case studies.

Primary Procedure Design Guidance Includes the FAA 5-Phase PBN Implementation Process (FAA Order 7100.41) and the FAA Metroplex Study and Design Process

The FAA 5-phase (previously 18-step) process was used across the majority of the airspace projects surveyed. The current FAA metroplex process includes a study team and design and implementation (D&I) team. The study team is composed of trained metroplex representatives, airspace subject matter experts, ATC area representatives, and the lead operator. The team examines the current airspace structure, traffic flows, and other operational considerations. The three to six month process results in airspace and procedure design recommendations that are submitted to the design and implementation team. The D&I team, also trained for the project, analyzes the study results and develops the specific procedures and airspace changes to accommodate them. The environmental process is also included throughout, along with regular outreach to industry. Extensive human-in-the-loop (HITL) simulations are conducted that permit controllers to manage traffic with the proposed procedures. The process takes up to two years to complete. Metroplex does not have a formal process for community outreach. For example:

- Projects at SEA, HND, DEN and ATL all cited the FAA 18-step process as the basis for their PBN projects.
- At the Houston metroplex, the FAA metroplex process was used but with some modifications to the environmental and outreach components that were deemed acceptable prior to initiating the project.

Design Is Unique to Each Airport and Requires Balancing Multiple, Sometimes Competing Objectives of the FAA ATO, Aircraft Operators, Airport Operators, and Surrounding Community

Procedure design requirements are specific to each airport and the surrounding airspace. PBN procedures may be developed to meet community noise constraints, airspace confines, and obstacles. However, meeting the community needs may result in a less efficient flight procedure, such as adding miles to avoid noise-sensitive areas, thereby increasing fuel usage and emissions. A reasonable balance between meeting the needs of the community, the airport, aircraft operators, air traffic control, and other stakeholders must be achieved. PBN does have limitations and may not always be a method to avoid sensitive areas surrounding an airport. In addition, the requirements of air traffic control and aircraft automation tools, such as ground support tools used by controllers to manage air traffic and the FMS of aircraft should be considered early in the design and evaluation of flight procedures. Compatibility issues of the designed procedures with various automation systems may be resolved through successive design iterations and/or criteria changes. For example:

- At ATL, the initial leg of one departure procedure was extended to avoid exposing a school in the local community to noise. Another departure procedure was rerouted slightly north to avoid another segment of the community. These changes were made while still retaining additional routes enabled by RNAV.
- At DEN, procedures were designed to raise the vertical profile for improved efficiency and decreased exposure to low-level turbulence and to provide a less restrictive lateral route to the airport. They also met stringent noise contour requirements and grid point noise limits. However, the complexities of the procedures created operational issues for pilots and controllers.
- At MSP, the majority of the land use is residential, and the surrounding communities pay close attention to the operations of the airport, so design to minimize noise exposure can be challenging.
- At the Houston Metroplex, the majority of the land use surrounding the airport is industrial; therefore, design challenges to avoid noise-sensitive areas are not necessarily significant.

Air Traffic Management Methods May Be a Component of the Procedure to Meet Design Objectives

Air traffic controllers may develop traffic management methods to enable or enhance implementation and utilization of PBN flight procedures. For instance, vector to RNAV procedures are useful for dispersing noise where land use otherwise precludes tight corridors (i.e., communities). Otherwise, RNAV permits routing flights over areas compatible with air traffic noise, such as industrial and other less sensitive areas. For example:

- At MSP, vector to RNAV departure procedures require controllers to direct aircraft along different departure headings, thereby fanning departures to avoid concentrating noise to a particular segment of the community.
- At DEN, TRACON controllers may assign equipped and non-equipped aircraft to different runways and approach procedures, thereby enabling PBN flight procedure use and improving runway utilization.
- At the Houston Metroplex, ATCT, and TRACON controllers are segregating traffic by equipage.

New Criteria for Flight Procedures Have Been Developed in Previous PBN Initiatives

New flight procedure design criteria can be developed and implemented to support operations as part of a PBN initiative. For locally sponsored design initiatives, the design team may seek outside consultation to conduct a credible safety case for the new criteria. This supports FAA Flight Standards in evaluating the procedures and criteria, and may increase the chance of FAA approval. Two instances are established on required navigation performance (RNP) (EoR) approach procedures and equivalent lateral separation operations (ELSO) departure procedures. EoR approach procedures permit reduced approach path length and separation between aircraft on independent and dependent approaches to parallel runways. ELSO departure procedures permit reduced lateral separation of a ten degree divergence between departures from parallel runways with centerlines separated by 2,500 feet and successive departures from the same runway. For example:

- At SEA, the acquisition management system engineering and safety risk management processes are used for developing new flight procedure design criteria. Boeing successfully supported the FAA in evaluations to reduce the separation standards for EoR approach procedures. These procedures have been implemented and are in use at SEA and DEN.
- At ATL, the design team solicited the support of the MITRE Corporation to investigate the safety case for new criteria for ELSO departure procedures. These procedures have been implemented to include an additional departure route while maintaining the same overall airspace used by departure traffic.

EA

This section concerns the EA as part of the development and implementation of flight procedures. The lessons learned and best practices concerning environmental include:

- EA can depend on the altitude regime where changes are being made.
- EA depends on the particular PBN implementation initiative.
- Airports can conduct their own EAs.

The remainder of this section describes each of these in greater detail and references specific examples from individual case studies.

EA can Depend on the Altitude Regime Where Changes Are Being Made

The depth of the assessment may vary according to how the flight procedures are altered, the design of the Class B airspace, and the resulting impact on the airport and community. Regarding procedure changes and their impact on the airport and community, changes 18,000 feet AGL have the least impact; changes between 18,000 and 10,000 feet AGL can have more impact; changes 10,000 feet AGL and below can have the greatest impact. Airspace actions below 3,000 feet require more complex EAs. Operations below 3,000 feet can result in significant public opposition, so consideration of community concerns should be a part of the process, as with any PBN project. For example:

- At the Houston Metropelx, the majority of the procedure design changes were above 10,000 feet, and thus warranted less complex EA regarding the impact on the airport and its local airspace.

EA Depends on the Particular PBN Implementation Initiative

The FAA leads the EA effort for its own initiatives. However, the airport authority or the local department of transportation has led the EA in local initiatives. The FAA Modernization and Reform Act of 2012 allows for a categorical exclusion (CatEx) for new PBN procedures that routinely route aircraft over noise sensitive areas below 3,000 feet. As per FAA Order 1051.1F, this is provided that an appropriate noise screening and extraordinary circumstances analysis has been performed. In most cases, the FAA conducted an EA including noise analysis and public outreach as part of the NEPA process. In other cases, it conducted an environmental worksheet and obtained a CatEx for the procedures. In some cases, previous EAs led by federal or local authorities for previous projects were sufficiently broad to cover changes resulting from new procedures. For example:

- At SEA, DEN, and the Houston Metroplex, the FAA conducted its own EA, including analysis of noise, with the assistance of private consulting firms.
- At ATL, the ADOA led the environmental effort.
- At MSP, the FAA prepared an environmental worksheet and issued a non-published CatEx for the proposed procedures, and did not conduct an EA or EIS.
- At HND, the EA conducted for a previous project was sufficient to obtain a CatEx for the new SIDs and STARs.

Airports Can Conduct Their Own EAs

Airports can support developing PBN flight procedures, interpreting noise contours, and providing insight into the noise impacts of proposed procedures. The FAA may conduct noise analysis as part of the NEPA process, however the airport may conduct its own noise analysis to supplement that of the FAA in order to assess adherence of the proposed procedures to local noise constraints. Noise analysis should compare the noise contours and other metrics of the PBN procedures against the legacy procedures. Noise metrics which have been used in assessments include day-night average noise level (DNL) and equivalent continuous level (LEQ). For example:

- At MSP, the Minneapolis-St. Paul Metropolitan Airport Commission (MAC) conducted its own noise analysis comparing the legacy procedures to the proposed procedures to determine that the changes would have no significant impact with community noise exposure.
- At DEN, the airport's noise abatement office conducted extensive analysis of the proposed flight procedures to ensure adherence to stringent noise contour and grid point limits.

Outreach

This section concerns outreach to the community to garner understanding of flight procedures. The lessons learned and best practices concerning outreach include:

- Early outreach to the community and other stakeholders is critical to the success of PBN initiatives.
- Sufficient resources need to be allocated to outreach.
- The impacts of the proposed procedures must be described in terms understandable to the community.
- The FAA may undertake its own outreach in procedure development initiatives it leads.

The remainder of this section describes each of these in greater detail and references specific examples from individual case studies.

Early Outreach to The Community and Other Stakeholders Is Critical to the Success of PBN Initiatives

Prior to the development of PBN, outreach and coordination with communities and other stakeholders is crucial to understanding noise and environmental concerns, in addition to garnering community support. Waiting until procedures are complete, or nearly complete, before briefing interested stakeholders may be met with resistance and could lead to the need to redesign procedures and delay projects. Community outreach, with full explanation and disclosure, engenders community understanding. The FAA 5-phase process does not have explicit provisions for community outreach during the design process. Local action groups have been able to place pressure on the FAA, leading to the cancellation of certain procedures. For example:

- At MSP, the public was not briefed about the procedures during the project. Instead, the public was briefed only after the design was complete and was not given sufficient time to consider and respond to the proposed designs. Public opposition to proposed procedures halted their implementation.
- At SEA, the public was not briefed until after the EA of the designed procedures, and the outreach finally conducted was inadequate. This resulted in resistance from segments of the surrounding communities.
- At MSP, DEN and SEA, the airports are bordered on all sides by residential areas. The local governments are very knowledgeable of the impact of airport operations on the community and conduct extensive community outreach.
- At DEN, the design team met with state and national park representatives early in the process to ensure compliance with noise restrictions.

Sufficient Resources Need to be Allocated to Outreach

Sufficient time must be allocated to outreach for a particular initiative. The community must have sufficient time to review and understand the proposed changes, provide feedback, and engage in a discussion with the airport authority. The duration required will vary with location and procedures. An adequate public outreach campaign may include a web site, briefings to city council and other local government representatives, open houses, news channel presentations, newspaper articles, periodic (e.g., quarterly) meetings with the public, and distribution packets with all relevant project information. For example:

- At DEN, a level of outreach similar to that described above was proposed, and was successful in educating local government officials and the community and garnering their support.
- At MSP, a level of outreach similar to that described above was proposed, however, the time frame was limited to 60 days. This proved to be insufficient time to brief the communities and allow them to understand the proposed airspace redesign, and to earn their approval.
- At the Houston metroplex, the FAA Metroplex team met with the HAS three times during the design process and attended noise round table public meetings held by the HAS. Other meetings were held by HAS to brief the public and respond to their questions.

The Impacts of The Proposed Procedures Must Be Described in Terms Understandable to the Community

The impacts of PBN that are of interest to the community include reduced exposure to aircraft noise, reduced local greenhouse gas emissions, increased air transportation system efficiency, increased safety, locations where flight paths are changing, locations where noise levels would change, the basis for noise estimates, and how and why the noise changes would or would not impact the community. The impacts of the procedure changes need to be explained in terms understandable to the community. For example:

- At MSP and SEA, the impacts mentioned above were the particular impacts that were identified to be of greatest interest to community members.
- At SEA, detailed technical descriptions of the impacts of the proposed procedures, such as incremental changes in the decibel level of the DNL, were confusing to the community members.

The FAA Will Undertake Its Own Outreach in Procedure Development Initiatives It Leads

The FAA will typically undertake its own outreach initiative to satisfy the NEPA process. The FAA may delegate outreach to a contractor it hires to conduct the EA or EIS. However, local FAA airport representation, working with airport authorities, can be a more effective approach to outreach than representatives of FAA headquarters working alone; the FAA can incorporate the support of the local airport and that airport's local knowledge, relationships, and tools. The extent of the FAA's outreach efforts can vary. It can be as extensive as initial scoping or meetings, meetings for mid-term review of the semi-final design with community and local government groups, or in some cases, after all work has been completed and submitted. For example:

- At SEA and MSP, the FAA conducted its own community outreach in open forums toward the end of the development process.
- At DEN, a contractor to the FAA conducted three stages of public and agency meetings including initial scoping, mid-term review, and draft EA meetings.
- At MSP, airport representatives have collaborated with local FAA representatives to conduct public outreach campaigns.

Post-Implementation Assessment

This section addresses post-implementation analysis conducted by airports. The lessons learned and best practices related to post-implementation assessment includes thatrequirements for post-implementation assessment vary according to local needs.

The type and rigor of post-implementation assessment of procedures conducted by the airport varies according to the local needs. Post-implementation assessment has included monitoring aircraft noise and assessing operational benefits. Noise assessment has included aggregate analysis of air traffic to estimate noise contours, as well as observation of individual flight tracks to investigate reported violations. Operational benefits assessments have included airport throughput and frequency of arrival flight execution of optimized profile descents (OPDs). Larger airports have worked with vendors and the FAA to develop specialized analysis capabilities. For example:

- MSP is developing tools to estimate if an arrival aircraft conducted an OPD and to conduct aggregate analysis of OPD flights.
- DEN is evaluating conformance to stringent noise constraints, monitoring operational throughput and aircraft flight distance, including fuel burn.
- ATL is primarily concerned with departure throughput, and only evaluates noise compliance in response to complaints.

- SEA is monitoring fuel burn and emissions of aircraft.
- Houston is monitoring flight distance, fuel burn and emissions of aircraft, and controller workload.
- The FAA is monitoring usage levels of the PBN procedures at individual airports in each metroplex.

Outcomes

This section concerns potential outcomes of flight procedures after they have been deployed and utilized. The lessons learned and best practices concerning outcomes include that PBN flight procedures can yield positive impacts for airports, aircraft operators, and the surrounding community.The outcomes of implementing PBN flight procedures can vary depending upon numerous factors, including the implementation objectives, the procedure design, the local airspace, as well as airport characteristics, equipage types and levels among aircraft. The following outcomes have been identified in the case studies:

- Improving access to airports. For example, at HND, the procedures have deconflicted HND traffic flows from those of Las Vegas airport, and the procedures have also improved access to HND as a reliever airport, making it attractive to GA and business aircraft operators.
- Maximizing the use of existing airspace by effectively containing aircraft within a more confined space. For example, at ATL, additional equivalent lateral spacing operation (ELSO) departure routes enabled additional throughput. At SEA, established on required navigation performance (EoR) approach procedures enabled greater utilization of parallel arrival runways.
- Reducing aircraft emissions with more direct routes and more fuel efficient flight procedures. This has been demonstrated at multiple sites, including SEA, The Houston Metroplex, DEN and MSP.
- Improving the airport's adherence to noise abatement programs. For example, at DEN, PBN procedures improved adherence to stringent noise contour requirements and noise level thresholds. At MSP, PBN procedures were designed to route aircraft over less noise-sensitive areas.
- Promoting more efficient use of the runways of an airport, with potential increases in airport throughput and surface traffic efficiency. For example, at DEN, PBN procedures have augmented runway balancing and utilization, thereby increasing throughput.
- Increasing safety by reducing controller workload for managing traffic and improving flight track repeatability and predictability. At the Houston Metroplex, controllers are issuing few vectors to arrivals, improving safety and repeatability.

10 Metrics for Assessing the Impact of Procedures

There are numerous metrics to assess the impacts of PBN procedures on the airport, the local community, aircraft operators, and other stakeholders. Selection of metrics depends upon the primary stakeholders and their objectives for the PBN initiative. Metrics may be used in the design phase of procedure implementation to assess the proposed design against the objectives, and in the post-implementation phase to assess the final implementation against the objectives.

When conducting post-implementation assessment, all stakeholders, including airports, aircraft operators, and the FAA should ensure the accuracy of any operational information they provide and that is used by the community, and that the information is understood by the intended audiences. Information and data that the public accesses related to aircraft flight paths and their impacts, such lateral paths, vertical profiles, timing, noise, emissions, or other characteristics and effects of aircraft arriving to or departing from the airport must be accurate and valid. Inaccuracies may occur, for instance, due to the differences in the accuracy and precision of aircraft position, navigation and timing measurements obtained from different surveillance systems. Inaccurate data can generate unnecessary community concern and ineffective responses of the FAA, aircraft operators, and other stakeholders to the concerns of the community.

Table 10-1 lists metrics documented in various sources that have been used, or have been proposed to be used, to assess the capacity, flight efficiency, fuel burn, emissions, and noise impacts of PBN procedures on airport operations, as compared to current-day or legacy procedures. In addition, the RTCA *Blueprint for Success to Implementing PBN* (RTCA 2014) describes an extensive set of metrics to measure the local and global impacts of PBN procedures. While the FAA has twelve metrics which have been congressionally mandated for assessing the impact of the FAA's NextGen Program (Federal Aviation Administration 2013g), many are too broad in scope to assess the local impact of PBN procedures on the airport and its community.

Table 10-1. Candidate metrics for airports to assess the impacts of PBN procedures.

METRIC	DESCRIPTION
Capacity	• Average hourly operations are the number of aircraft arriving to and departing from an airport in an hour (Federal Aviation Administration 2013g).

Table 10-1. Continued

METRIC	DESCRIPTION
Flight Efficiency	• Average gate-to-gate times or distances are the average of the elapsed times of flights between departing from origin airport gate and arriving to destination airport gate (Federal Aviation Administration 2013g).
	• Average flight distance or time in the terminal airspace is the average of the actual flown distances or times of flights in the airspace, which is under the jurisdiction of the terminal radar approach control (TRACON) local to the airport.
	• Level-off flight distance or time evaluates the cumulative distance or time of level-off segments in the vertical profile of an arrival flight between top of descent (TOD) and runway or within an altitude regime [for example, 30,000 to 10,000 feet above ground level (AGL)] (Robinson and Kamgarpour 2010). Similar analysis may be applied to departure flights.
Fuel Burn and Emissions	• Cumulative gallons of fuel burned and tons of carbon dioxide emitted by all flights within airspace or between pairs of cities (Federal Aviation Administration 2013g).
Noise	• Day-night average sound level (DNL) evaluates the 24-hour period noise exposure. One event occurring in the evening from 10 p.m. to 7 a.m. is equivalent to ten events occurring in the day outside of those times (Federal Aviation Administration 2015e). NEPA defines thresholds for acceptable noise levels and changes in noise level.
	• Sound exposure level (SEL) evaluates, for a single flyover, the equivalent sound level if the cumulative exposure is compressed into a 1-second time period (U.S. Government Accountability Office 2008). There are no established thresholds for acceptable noise levels and changes in noise level to assess the impact of noise with this metric.
	• Time-above evaluates the fraction of a total time period that the noise exposure level exceeds a specified decibel level (U.S. Government Accountability Office 2008). There is no established threshold for acceptable noise levels and changes in noise level associated with this metric to assess the impact of noise.
	• Number-of-events-above (NA) evaluates the number of noise events above a specified threshold decibel level. This metric may be used to quantify the effect of concentrating flight operations over a particular segment of the community near an airport. There is no established threshold for acceptable noise levels and changes in noise level for this metric to assess the impact of noise.

The details and considerations regarding these metrics to assess the impacts of PBN procedures at an airport are described as follows:

- Regarding capacity, the average hourly operations can be computed to track airport capacity and any changes due to PBN procedures.
- Regarding flight efficiency, PBN procedures can help to reduce the flight time and distance in the terminal airspace. Reductions in flight time and distance may also improve other aspects of flight efficiency, such as fuel burn, emissions and noise exposure. Variability in flight time corresponds to flight predictability for aircraft operators. The flight distance or time of level-off segments in the trajectory of an aircraft indicates the degree to which optimized profile decsents (OPDs) are being realized among arrivals as well as the climb efficiency of departures.
- Regarding fuel burn and emissions, flight efficiency improvements enabled by PBN procedures can reduce the fuel burn and emissions from aircraft. Capacity increases enabled by PBN procedures may also reduce fuel burn and emissions, for instance, by reducing departure queuing and taxi time at the airport.

The FAA's *FAR Part 150: Airport Noise Compatibility Planning Program, An Overview* (FAA 2014j) cites DNL as the primary noise metric for airport noise compatibility planning. The RTCA NAC recommended to the FAA use the DNL metric in conjunction with its proposed net noise reduction method. The New York/New Jersey/Philadelphia airspace redesign identified that supplemental noise metrics would have provided information that may have been more readily understood by decision makers and the public than the DNL metric. The SEL and time-above were cited as alternatives. However, while alternatives such as SEL capture noise level and duration, there are no accepted criteria or thresholds for evaluating impact, and, in addition, the selection of points on ground and noise threshold complicate application. The FAA Aviation Environmental Design Tool (AEDT) is the tool for evaluating noise, fuel burn, and emissions of instrument flights procedures (IFPs). Estimates may be obtained from analysis of simulated or actual flight tracking data.

FAA Order 1050.1F, *Environmental Impacts: Policies and Procedures* (FAA 2015e) describes comprehensively the FAA policies and procedures for complying with NEPA and regulations issued by the Council on Environmental Quality (CEQ). It describes the regulations, affected environment, environmental consequences, supplemental noise analysis, additional noise guidance, and noise mitigation.

Evaluating the Noise of PBN Procedures

In accordance with FAA Order 1050.1F, noise screening tools and methodologies may be used to determine if a proposed action may be categorically excluded with respect to noise. Detailed noise analysis is employed if the action cannot be categorically excluded, or for post-implementation. Standard noise analysis is done using the FAA AEDT tool, and DNL is the noise metric recognized by the FAA.

Regarding the evaluation of noise of aircraft flying PBN procedures that may be categorically excluded as per the FAA Modernization and Reform Act of 2012, the net noise reduction method for noise screening is the RTCA NextGen Advisory Committee's (NAC's) recommendation for comparing an existing procedure to a proposed PBN procedure (RTCA 2013a). The purpose is to identify (1) the number of people who experience a reduction in noise compared to the number of people who experience an increase in noise, at noise levels greater than DNL 45 dB and (2) any increase in the number of people experiencing DNL 65 dB or greater. The process may be summarized as identifying the areas around the airport where people might be impacted and the points representing the centers of the populations (otherwise known as census block centroids) of those areas, computing the DNL at the census block centroids, and determining the overall (not centroid-by-centroid) change in the number of people exposed to noise in individual DNL bands with the PBN procedures versus the conventional procedures.

Regarding the detailed evaluation of noise of aircraft flying PBN procedures, which may not be categorically excluded or have already been implemented, detailed noise assessment may be performed using computer models approved by the FAA. The FAA AEDT is the foremost tool for airports to use in their analyses. Data input to the model should accurately reflect the previous and current conditions; that is, flight tracks from the legacy procedures, and flight tracks from the current PBN procedures. The computer models generate noise contours corresponding to 65, 70, 75, and other user-specified decibel levels, as well as grid point and/or change of exposure noise data.

Evaluating the Emissions of PBN Procedures

The FAA is required to prepare an environmental document for federal actions that have the potential to affect air quality, as defined in two applicable laws: NEPA and the Clean Air Act (CAA). FAA guidance for evaluating the effects of air traffic actions on air quality, including greenhouse gas emissions and climate, are prescribed in FAA Order 1050.1F. The FAA AEDT tool is the approved model for air quality analysis.

Analysis of emissions first and foremost focuses on pounds of carbon dioxide (CO_2). For purposes of greenhouse gas emissions disclosure, carbon dioxide equivalent (CO_{2e}) emissions are estimated from fuel burn as a proxy for actual CO_2 emissions estimates. The CO_{2e} emissions are computed directly from fuel burn analysis as 9.7438 kilograms of CO_2e per gallon of fuel.

In addition, the EPA states that emissions of PBN procedures are to be assessed for areas that have been designated as non-attainment (not meeting) or maintenance (having previously not met, but now meeting) with respect to the National Ambient Air Quality Standards (NAAQS) for one or more criteria pollutants. The 6 "criteria pollutants" are carbon monoxide (CO), lead (Pb), nitrogen dioxide (NO_2), ozone (O_3), particulate matter (PM_{10} and $PM_{2.5}$), and sulfur dioxide (SO_2). All air traffic between the ground and "mixing height" of 3,000 feet AGL or mixing height specified in a state implementation plan (SIP) must be evaluated against the air quality standards.

11 Procedure Design and Execution

The trajectories of aircraft flying PBN procedures determine the noise profile, fuel burn and emissions, flight time, track mileage, capacity, efficiency, and safety. All of these performance factors and impacts, representing the range of interests among the stakeholders in PBN, must be balanced in the design of PBN procedures. These trajectories are influenced by the design parameters of the procedure, including the phase of flight or segments of a procedure, waypoints, leg types, and altitude restrictions. The trajectories of aircraft flying PBN procedures are also influenced by the accuracy of navigational systems, including the path planning and following characteristics of the aircraft's flight management system (FMS).

Flight Procedure Design

The trajectories of aircraft flying IFPs determine the noise profile, fuel burn and emissions, and other impacts on the airport and its surrounding community. These trajectories are influenced by the design parameters of the procedure, including the phase of flight or segments of a procedure, waypoints, leg types, and altitude restrictions of the procedure.

Phase of Flight and Segments of an IFP

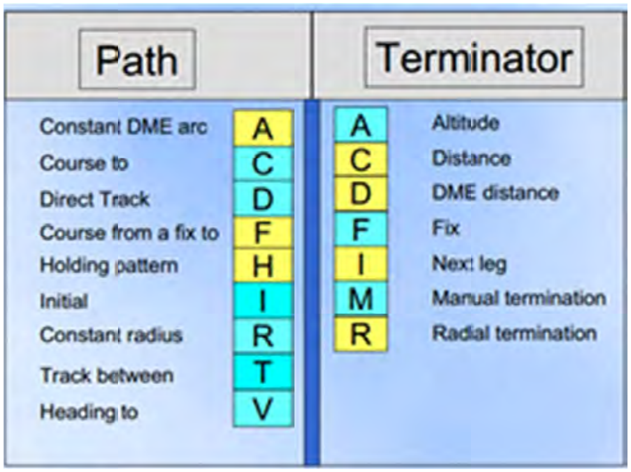
An IFP is composed of several segments as the aircraft transitions to or from the runway, terminal, and en route phase of the flight environment. The purpose of a standard terminal arrival route (STAR) is to descend and transition aircraft from the en route environment to the terminal approach environment. The segments of a STAR include an en route transition, a common waypoint or route, and a runway transition. The purpose of a standard instrument departure (SID) is to transition aircraft from the runway environment to the en route structure. The segments of a SID include a runway transition, a common waypoint or route, and an en route transition. The names of STARs and SIDs are based on the common waypoint in the route of flight.

The purpose of a standard instrument approach procedure (SIAP) is to provide navigation from the terminal environment to the runway environment. A SIAP is composed of multiple segments including a feeder route, initial approach, intermediate approach, final approach, missed approach, and holding segments. SIAPs are named based on the type of navigation used [e.g., area naviation (RNAV), required navigation performance (RNP), instrument landing system (ILS)] and the runway they serve.

Waypoints and Leg Types

Waypoints are sets of coordinates that identify a point in physical space and are named based on a five letter system in a manner that is phonetically pronounceable. Waypoints are combined together in an IFP to establish a route of flight. There are two types of waypoints: Fly-by and fly-over. With fly-by waypoints, aircraft initiate the turn to the next leg prior to the waypoint where the leg begins. With fly-over waypoints, aircraft fly directly over the waypoint and initiate the turn to the next leg after the waypoint where the leg begins.

The combination of two waypoints in a route constitutes a flight leg of a procedure. There are different types of flight legs, which are named according to a two-letter convention. The first letter corresponds to the path type of the flight leg, and the second letter corresponds to the type of terminator for the flight leg. Figure 11-1 presents the types of paths and terminators that are the foundations of different leg types.



DME = distance measuring equipment

Source: Rawlings/Eurocontrol 2007.

Figure 11-1. *Path and terminator elements for all possible leg types.*

Among the breadth of possible leg types, there are 23 leg types specified in the ARINC 424 Specification (ARINC 2015) and in the FAA's Instrument Procedures Handbook FAA-H-8083-16A (Federal Aviation Administration 2015c), which enable RNAV SIDs, STARs, approach transitions, and missed approaches listed in Table 11-1.

Table 11-1. RNAV Leg Types.

LEG TYPE	DESCRIPTION
IF	The initial fix (IF) leg defines a database fix as a point in space. It is only required to define the beginning of a route or procedure.
TF	The track to a fix (TF) leg defines a great circle track over ground between two known databases fixes. This is the preferred method for specifying straight legs. While course or heading can be mentioned on charts, the designer should ensure a TF leg is used for coding.
RF	The radius-to-fix (RF) constant radius arc leg defines a constant radius turn between two fixes in the navigation database (NDB), lines tangent to the arc and a center fix.
CF	The course to a fix (CF) leg defines a specified course to a specific fix in the NDB. TF legs should be used instead of CF whenever possible.

Table 11-1. Continued

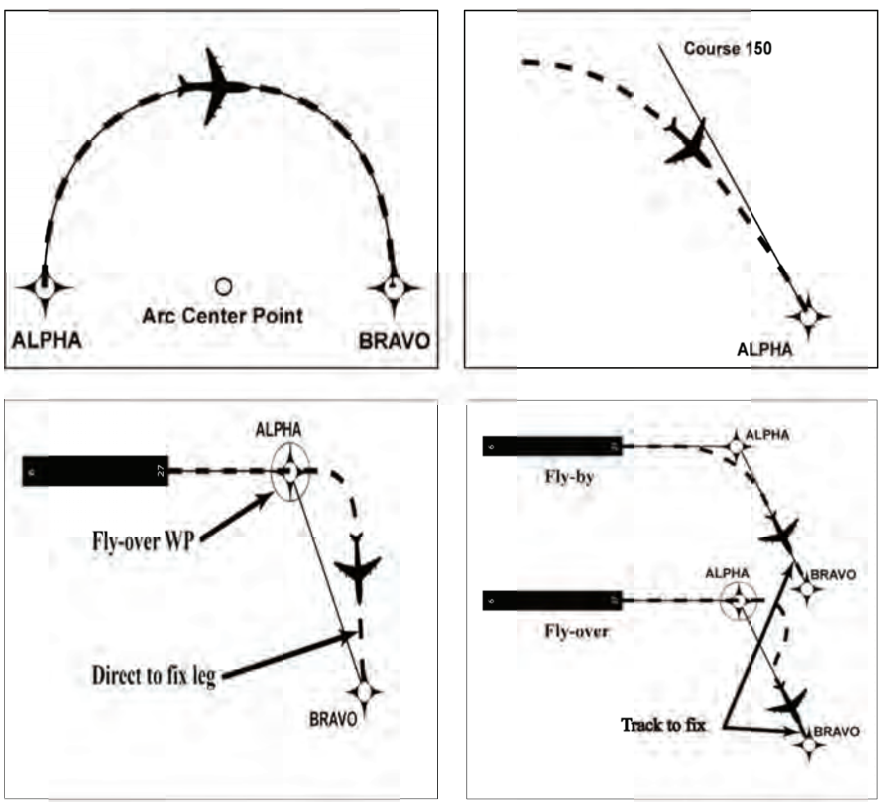
LEG TYPE	DESCRIPTION
DF	The direct to a fix (DF) leg defines an unspecified track starting from an undefined position to a specified fix. Procedure designers should take into account that the flight management system (FMS) flight path depends on initial aircraft heading.
FA	The fix to an altitude (FA) leg defines a specified track over ground from a fix in the NDB to a specified altitude at an unspecified position.
FC	The track from a fix from a distance (FC) leg defines a track over ground for a specific distance from a fix in the NDB.
FD	The track from a fix to a distance measuring equipment (DME) distance (FD) leg specifies a track over ground from a fix to a particular DME distance from a DME navigational aid. The fix and DME navigational aid are in the NDB.
FM	The track from a fix to a manual termination (FM) leg defines a specified track over ground from a NDB fix until manual termination of the leg.
CA	The course to an altitude (CA) leg defines a specified course to a specific altitude at an unspecified position.
CD	The course to a DME distance (CD) leg defines a specified course to a specific DME distance which is from a specific DME navigational aid in the NDB.
CI	The course to an interceptor (CI) leg defines a specified course to intercept a subsequent leg.
CR	The course to a radial termination (CR) leg defines a course to a specified radial from a specific very high frequency (VHF) omnidirectional radio range (VOR) navigational aid in the NDB.
AF	The arc to a fix (AF) leg defines a track over ground at specified constant distance from a DME navigational aid in the NDB.
VA	The heading to an altitude termination (VA) leg defines a specific heading to a specific altitude at which the leg terminates. The specific position at which the leg terminates is unspecified, and is an outcome of achieving the termination altitude.
VD	The heading to a DME distance termination (VD) leg defines a specified heading terminating at a specified DME distance from a specific DME navigational aid in the NDB.
VI	The heading to an interceptor (VI) leg defines a specified heading to intercept the subsequent leg at an unspecified position.
VM	The heading to a manual termination (VM) leg defines a specified heading until a manual termination.
VR	The heading to a radial termination (VR) leg defines a specified heading to a specified radial from a specific VOR navigational aid in the NDB.

Table 11-1. Continued

LEG TYPE	DESCRIPTION
PI	The procedure turn (PI) leg defines a course reversal starting at a specific database fix, including an outbound leg followed by a left or right turn and 180 degree course reversal to intercept the next leg.
HA, HF, HM	The racetrack course reversal (HA, HF and HM) leg types define racetrack pattern or course reversals at a specified fix in the NDB.

Source: ARINC 2015.

Among the 23 leg types, the RTCA DO-9236C (RTCA 2013c) specifies the permissible leg types for SIDs, STARs, approaches, and missed approaches in the navigation database to be IF, TF, RF, CF, DF, FA, HM, HA, and HF legs because these leg types are fixed and not subject to interpretation. Examples of RF, CF, DF, and TF leg types and the hypothetical flight paths of aircraft flying those legs are depicted in Figure 11-2.



Source: Federal Aviation Administration 2015b.

Figure 11-2. *Leg types for RNAV procedures include RF (top left), CF (top right), DF (bottom left) and TF (bottom right).*

The notional flight tracks depicted for the leg types in Figure 11-2 indicate that the selection of a particular leg type for the design of a procedure determines the resulting flight paths of aircraft conducting the procedure, and that the resulting flight path may not follow the path implied by the sequence or structure of the waypoints bounding the flight leg and may not be immediately clear from the depiction of the procedure as published on the charts. The particular flight legs and the characteristic flight paths of aircraft along those legs determine the areas surrounding the airport that are exposed to overflights of aircraft to and from the airport, and the noise contours associated with arrival and departure traffic of the airport. Therefore, understanding and specification of leg types is important in meeting procedure design objectives and in interpreting a published procedure and estimating its local impact.

Lateral Precision

The required LNAV precision for aircraft flying an IFP also determine the flight tracks of aircraft executing the IFP; the more precise the RNP, the less lateral dispersion in the flight paths of the aircraft conducting the procedure. Table 11-2 lists the standard lateral precisions for IFP approach procedures, and for IFPs in the terminal, en route, and oceanic airspace domains.

Table 11-2. RNAV Leg Types.

REQUIRED NAVIGATION PERFORMANCE (RNP) LEVEL (NAUTICAL MILES)	TYPICAL APPLICATION	PRIMARY ROUTE WIDTH (NAUTICAL MILES)
0.1 to 0.3	RNP Approval Required (AR) Approach Segments	0.2 to 0.6
0.3 to 1.0	RNP Approach Segments	0.6 to 2.0
1.0	Terminal Airspace, En Route Airspace	2.0
2.0	En Route Airspace	4.0
4.0	Oceanic Airspace	Not applicable
10.0	Oceanic Airspace	Not applicable

Source: RTCA 2013c.

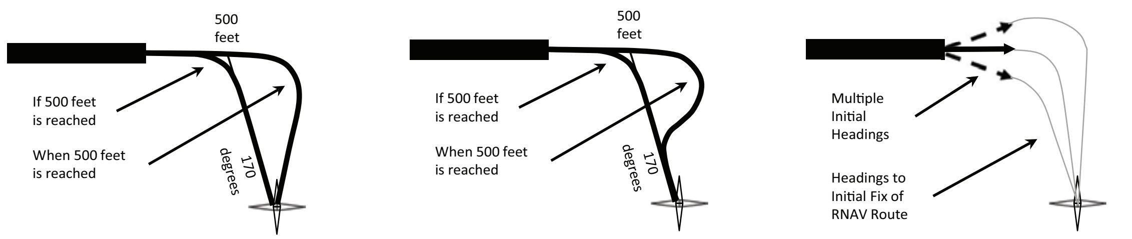
The values indicate that the highest level of precision is required for approach procedures to an airport, and that the precision required decreases as the traffic density of the airspace decreases.

Lateral Path and Vertical Profile

There are limitations to what can be accomplished in the procedure design due to performance limitations of aircraft. For example, the distance of turn anticipation (DTA) is addressed in multiple FAA 8260 series orders and is defined as the earliest distance at which the next waypoint can be achieved, thereby constraining the minimum length of the leg. DTA requirements are based on performance characteristics of FMS and autopilot systems operating in the NAS today. If these requirements are not met, the aircraft will not be able to maintain an intended track. These requirements may also constrain the design of flight procedures that are desired to meet the requirements of the airport, aircraft operator, community and other stakeholders, such as conforming to noise corridors.

For the design of OPD arrival procedures, the lateral path must be designed to balance the interests of multiple stakeholders, and specification requires the collaboration and consideration of the needs of the individual project stakeholders. For example, aircraft operators prefer the most efficient routing possible with the fewest track miles. However, because optimal profiles may vary between different aircraft types, some efficiency may have to be sacrificed for operational, noise, or community interests. The runway transitions should connect to instrument approach procedures, when possible. The airspace must be modified to accommodate the optimal vertical profile generated by the aircraft's FMS. The designer should seek to minimize the altitude constraints, while meeting traffic separation and airspace needs. In general, at-or-above altitude constraints at a waypoint are preferred, followed by a range of acceptable altitudes, otherwise known as "altitude windowing," achieved with simultaneous at-or-above and at-or-below altitude constraints at a waypoint.

For the design of SIDs, there are several techniques available to manage departure ground tracks. Three common design (leg coding) techniques include a heading to an altitude followed by a DF, a VA followed by a CF leg, or a vector to join an RNAV route. Common techniques are show in Figure 11-3.



Heading to Altitude (VA) Leg Followed by a Direct to Fix (DF) Leg

Heading to Altitude (VA) Leg Followed by a Course to Fix (CF) Leg

Heading to Initial Fix (IF) Leg of an RNAV Route

Source: Federal Aviation Administration 2015b and 2016c.

Figure 11-3. *Effects of waypoint and leg type sequences.*

The ground track in the VA to DF design example will vary based on when the aircraft reaches the initial coded altitude. Each aircraft will reach the desired altitude at a different point due to variable performance characteristics and takeoff profiles (weight, flaps, etc.) Once the altitude is reached, the aircraft will proceed directly to the next fix.

The ground track in the VA to CF design example will vary based on when the aircraft reaches the initial coded altitude and the established course designed in the procedure. If the altitude is reached prior to the course (170° used in the example), the aircraft will attempt to reach the course and execute the turn considering DTA similar to a fly-by waypoint. If the aircraft reaches altitude beyond the established course, it will execute a turn considering DTA and fly back to the course and proceed to the next fix.

The ground track in the vector to join an RNAV design example will vary directly off the runway end based on the initial heading given by the ATCT. Once the pilots establish communication with the TRACON, they will be vectored to the IF of the RNAV route, which will bring the aircraft through to the en route environment. This technique results in a "fanning" of aircraft off the end of the runway and may be useful to airports with noise abatement procedures where the noise is distributed over a community equitably.

In addition to these design techniques, *ACRP Report 86: Environmental Optimization of Aircraft Departures: Fuel Burn, Emissions, and Noise* (Kim et al. 2013) provides detailed guidance and analysis methods for the design of departure procedures to optimally balance fuel burn, emissions and noise. The reference includes a working spreadsheet model to use to design procedures.

Aircraft Performance Variables

The trajectories of aircraft flying PBN procedures determine the noise profile, fuel burn and emissions, and other impacts on the airport and its surrounding community. The trajectories of aircraft flying PBN procedures are influenced by the accuracy of navigational aids and the path planning and following characteristics of the aircraft's FMS.

Navigation System Accuracy

The accuracy of different navigation systems can influence the spatial dispersion in trajectories. As indicated in Table 2-1, GPS, wide area augmentation system (WAAS), ground-based augmentation system (GBAS), DME, and inertial reference unit (IRU) provide different levels of accuracy in their estimates of aircraft lateral position. IRU has bias error due to the initial position programmed by the pilot. GPS, WAAS, and barometric pressure-based vertical navigation (baro-VNAV) provide different levels of accuracy in aircraft vertical position estimation. Navigation aid accuracy impacts the planning of flight trajectories and the ability of the aircraft to adhere to the desired flight path.

Flight Path Planning

The path planning characteristics of the pilot or FMS can impact the lateral and vertical profiles of the aircraft's trajectory in flying PBN procedures. In particular, the vertical component can vary greatly based on the characteristics of the FMS flight path planning algorithms and associated modeling errors. The impact of different economical or geometrical FMS descent planning methods, ambient conditions, and flight path modeling errors such as headwind or tailwind on the flight paths of aircraft are succinctly presented in a report on *Flight Management Computer Systems (FMCS): Vertical Navigation (VNAV)* (The MITRE Corporation 2010).

The economical and geometrical vertical flight path planning methods vary in the vertical profiles they plan for the aircraft. The economical method provides a vertical flight path that minimizes fuel burn for given conditions, such as winds and aircraft weight. This flight path, and its resulting noise contour and fuel burn, will change under different conditions. The geometrical method provides a fixed flight path that will not change for the given conditions. However, the resulting fuel burn and noise of the aircraft transiting the fixed path will change as aircraft and ambient conditions change, as required to maintain the fixed flight path. Nevertheless, although noise exposure may vary based on meteorological conditions, an arrival using an OPD will typically be less noisy than a conventional, step-down descent.

Flight Path Following

The flight path following characteristics of the pilot or FMS can impact the lateral and vertical profiles of the aircraft's trajectory in flying PBN procedures. In particular, the aircraft guidance and control algorithms, the aircraft configuration, and the ambient conditions can impact the vertical profile.

Headwinds and tailwinds unaccounted for in the flight path planning introduce variation in the actual flight paths of aircraft as they fly the procedure. Headwinds may require more throttle for the aircraft to maintain its planned flight path, thereby increasing fuel burn, emissions, and noise. Tailwinds may result in changes to the actual flight path of the aircraft to avoid over-speed, thereby impacting the noise profile, and likely the fuel burn and emissions, as well.

The dispersion of the altitude profiles of aircraft flying the same arrival procedure can be extensive, as demonstrated in flight trials of a prototype OPD arrival procedure, the RNAV STAR arrival procedure called VIKNN at Hartsfield-Jackson Atlanta International airport (ATL) (Nagle et al. 2009). The procedure was designed with altitude windows to enable aircraft to conduct OPDs. The evaluations were conducted for different types of aircraft: Boeing B757-200, B767-300 and B767-400ER, and Airbus A300F and A310F. The results indicate the vertical profiles of flight tracks are dispersed by thousands of feet, even for the same type of aircraft, due to FMS differences, aircraft characteristics, wind variation, and radar accuracy.

Flyability

Flyability is a common term used in air traffic procedures design and validation. The flyability of a flight procedure is a check or system of checks to ensure the procedure can be safely flown by aircraft as designed. This is a coupled evaluation of the flight procedure design in conjunction with the characteristics of the aircraft that are to use the procedure. These checks may include, but are not limited to, the acceptability of any deviations from standards, bank angles, airspeeds, climb/descent gradients, roll rates, track lengths, pilot workload issues, procedure complexity, runway alignment, and other considerations. Also, if a ground-based or space-based navigational aid is used solely as a waypoint (latitude/longitude coordinates only), a flight validation is necessary for the flyability of the fix in the procedure design.

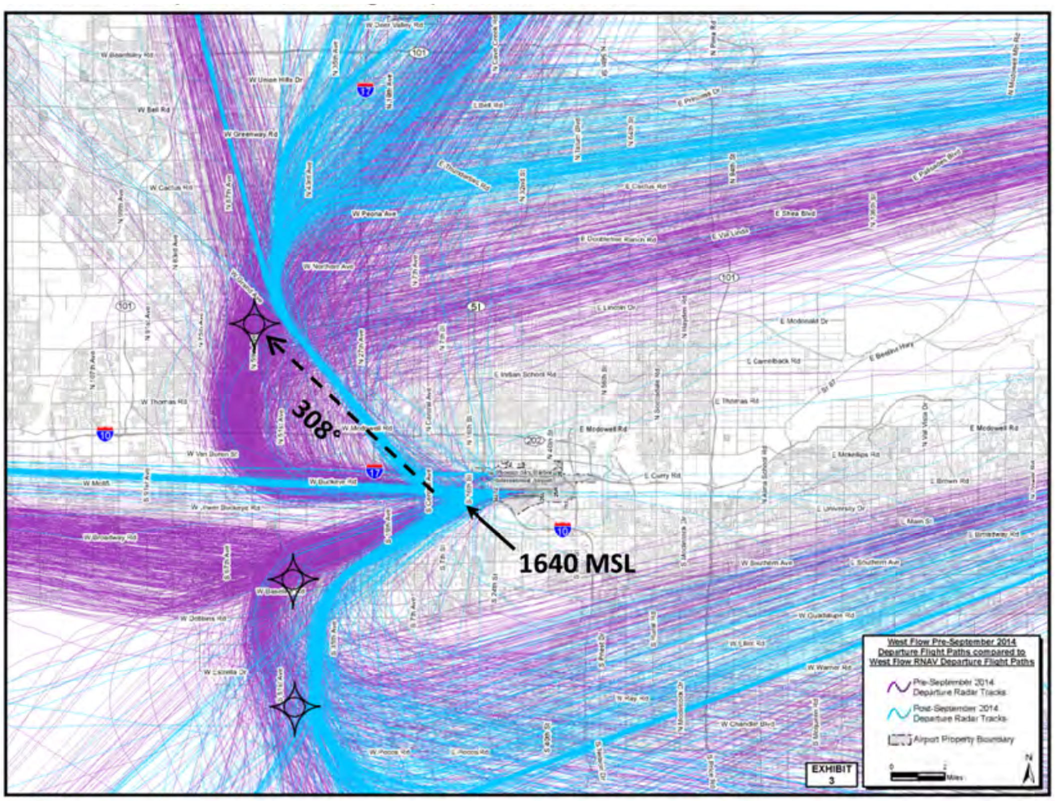
FAA criteria drive the construct of a given procedure, which is integrated in the terminal area route generation, evaluation, and traffic simulation (TARGETS) software. This aids the procedure designers in assuring that the appropriate leg types, path terminators, turn anticipation, as well as the desired speed and altitude constraints meet the capabilities of a wide cross section of aircraft types and FMSs. TARGETS will generate a flyability check that will indicate if the proposed procedure meets the criteria standards. It should be noted this does not always guarantee the desired or expected results of the actual published procedure. Tools are under development to augment the current process.

As proposed procedures mature through the design process, flyability is also accounted for in various flight simulator tests and trials. Flight simulators are specific to flight management computers (FMCs) and aircraft manufacturers, and range from desktop to full motion simulators, with a variation of fidelity. Full-motion simulators provide the highest level of fidelity for flyability checks for the obvious reasons of providing realistic atmospheric and operational conditions that aircraft would encounter with the actual procedure. Desktop simulators may not possess the needed fidelity, so consideration should be given for true flyability checks.

In some cases, it is not always possible to know exactly how well a procedure will perform until the procedure is actually in use. An effective tool used for flyability checks is the actual aircraft. The FAA and aircraft operators have worked together on numerous initiatives involving pre-coordinated flights of approved procedures prior to their actual implementation. This affords a controlled environment to identify any adjustments that may be needed and validates that the procedure is delivering as expected for ATC and operators.

Procedure Design Example

The resulting ground tracks from the implementation of an RNAV procedure can provide dramatic improvement in efficiency, noise, and emissions. The results may also concentrate flight tracks and create more noise over a tight corridor. In many cases this result is acceptable, especially if the land use below the flight track is compatible with airport noise. Figure 11-4 depicts a comparison of west departure flight tracks before and after RNAV implementation at Phoenix International airport (PHX).



Source: City of Phoenix Aviation Department

Figure 11-4. *Ground tracks at PHX—before and after RNAV implementation.*

The dark purple lines represent departure flight tracks to the west before RNAV implementation and the blue lines represent departure flight tracks to the west after RNAV implementation. The RNAV design for north- and eastbound departures turning right requires aircraft climb on an initial runway heading and intercept a 308 degree course to the initial flyby fix where aircraft make a turn toward the en route transition. The RNAV design technique for south- and east-bound departures turning left require an aircraft to climb to 500 feet above the airport [1640 mean sea level (MSL)] and make a turn, to the first flyby waypoint where aircraft make a turn toward the en route transition.

12 Summary

Airport operators can play an important role in developing PBN procedures for their airport. Airport operators can be valuable to each step of the PBN implementation process, from the initial request through the design and evaluation, implementation, documentation, deployment, and post-implementation assessment. Airport operators have knowledge of the local airspace, aircraft operators and airport characteristics, and relationships with the local community. Their support of the PBN design process can ensure some level of compatibility with these local needs, balanced with the objectives of the air transportation system they operate within.

Areas for potential airport contribution to the PBN implementation process include:

- Understanding the limitations of the current flight procedures and their impacts on the airport, aircraft operators, and local community and specifying objectives for design of PBN procedures based on those limitations.
- Providing airport data, information and operating characteristics, such as preferred runway configurations, preferred routes, airport survey data, and airport fleet mix characteristics to support the design of the PBN procedures.
- Supporting the characterization of the baseline operations of the airport and local airspace, for the design and benefits assessment of the PBN procedures.
- Supporting evaluation of PBN procedures in the design and post-implementation phases by identifying noise-sensitive areas around the airport, specifying allowable noise thresholds for those areas, assessing the impact of the procedures on those areas, and proposing design changes to satisfy the constraints.
- Reviewing published procedures to ensure they comply with airport and community requirements and constraints.
- Maintaining relationships with relevant FAA personnel involved in the design of PBN procedures, such as the Traffic Management Unit of the local TRACON, ATCT, and the representative of the governing service center.
- Communicating with groups representing the local community and other stakeholders in order to explain the plans for and potential impacts of proposed PBN procedures, understand the concerns of the stakeholders, support translating these concerns into design objectives and constraints for the PBN procedures, and obtain feedback from the community in the post-implementation phase regarding the impact on PBN procedures.

In addition to areas of potential contribution, areas of process vulnerability include:

- Not sufficiently accounting for the needs and considerations of the airport, community, aircraft operators, and other local stakeholders when establishing the objectives and constraints for the procedure design process. For example, noise-sensitive areas proximate to the airport that might limit the available routing alternatives.

- Changes to the proposed procedures that might occur through successive design iterations implemented in order to better accommodate the needs of other stakeholders or satisfy other design criteria. Such changes might introduce conflicts with local needs and considerations, even if they were initially accounted for in the problem definition process.
- Not being able to satisfy the needs of all community members or other local stakeholders in the final design of the flight procedures, due to other severe design constraints or compromises that must be made to satisfy other design criteria.
- Inadequate outreach to community, government, and other local stakeholders as part of the procedure design process to communicate design objectives, considerations, trade-offs, and propositions in order to obtain understanding. This includes CatExs to proposed procedures, which obviate the EA or EIS processes and their associated public outreach requirements.
- Not communicating the purpose and impacts of the procedure design initiative in terms understandable or relevant to the community in order to obtain their understanding.
- Differences between the performances of the PBN procedures anticipated during the design phase and realized in post-implementation, such as unintended noise impacts. This may be due to differences in the modeling of aircraft for the design phase and the actual flight performance of aircraft in implementation, or the natural variability in the flight performances of aircraft due to, for example, atmospheric conditions, aircraft weight, and other parameters.

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A Acronyms & Initialisms

ACRONYM	DEFINITION
A4A	Airlines For America
AAR	Airport Arrival Rate
AC	Advisory Circular
ACI-NA	Airports Council International-North America
ACRP	Airport Cooperative Research Program
ADOA	City of Atlanta Department of Aviation
ADS-B	Automatic Dependent Surveillance Broadcast
AEDT	Aviation Environmental Design Tool
AGL	Above Ground Level
AIM	Aeronautical Information Manual
ANSP	Air Navigation Service Provider
AR	Approval Required
ARP	Administrator for Airports
ARTCC	Air Route Traffic Control Center
ATC	Air Traffic Control
ATCT	Air Traffic Control Tower
ATL	Hartsfield-Jackson Atlanta International Airport
ATNS	Air Traffic Noise Screening
ATO	Air Traffic Organization
CAA	Clean Air Act
CatEx	Categorical Exclusion
CCDOA	Clark County Department of Aviation
CDTI	Cockpit Display of Traffic Information
CEQ	Council on Environmental Quality
CFR	Code of Federal Regulations
CPDLC	Controller-Pilot Data Link Communications
CSPRO	Closely Spaced Parallel Runway Operations
CWG	Core Working Group
DA	Decision Altitude
dB	Decibels
DEN	Denver International Airport
DME	Distance Measuring Equipment
DNL	Day-Night Average Sound Level
DOT	Department of Transportation
DTA	Distance of Turn Anticipation
EA	Environmental Assessment
EIS	Environmental Impact Statement
ELSO	Equivalent Lateral Spacing Operations
EMS	Environmental Management System

ACRONYM	DEFINITION
EoR	Established on RNP
ERAM	En Route Automation Modernization
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FIM-S	Flight Deck-based Interval Management-Spacing
FIS-B	Flight Information Services-Broadcast
FMC	Flight Management Computer
FMS	Flight Management System
FONSI	Finding of No Significant Impact
FPT	Flight Procedures Team
GA	General Aviation
GAO	Government Accountability Office
GBAS	Ground-Based Augmentation System
GHG	Greenhouse Gas
GIM-S	Ground-based Interval Management-Spacing
GIS	Geographic Information System
GPS	Global Positioning System
HAS	Houston Airport System
HITL	Human-in-the-Loop
HND	Henderson Executive Airport
IAP	Instrument Approach Procedure
ICAO	International Civil Aviation Organization
IDP	Instrument Departure Procedure
IFP	Instrument Flight Procedure
IFR	Instrument Flight Rules
IGA	Inter-Governmental Agreement
ILS	Instrument Landing System
IM	Interval Management
IMC	Instrument Meteorological Conditions
INM	Integrated Noise Model
IRU	Inertial Reference Unit
ITP	In-Trail Procedures
KPA	Key Performance Area
LEQ	Equivalent Continuous Level
LNAV	Lateral Navigation
LP	Localizer Performance
LPV	Localizer Performance with Vertical Guidance
MAC	Minneapolis-St. Paul Metropolitan Airports Commission
MDA	Minimum Decision Altitude
MSP	Minneapolis-St. Paul International Airport
NA	Number of Events Above
NAAQS	National Ambient Air Quality Standards
NAC	NextGen Advisory Committee
NAPT	National Airspace Planning Team

ACRONYM	DEFINITION
NAS	National Airspace System
NATCA	National Air Traffic Controllers Association
NAVAIDs	Navigational Aids
NBAA	National Business Aviation Association
NDB	Navigation Database
NEPA	National Environmental Policy Act of 1969
NIRS	Noise Integrated Routing System
NOC	Noise Oversight Committee
NOTAM	Notice To Airmen
OAPM	Optimization of Airspace and Procedures in the Metroplex
ODP	Obstacle Departure Procedures
OEP	Operational Evolution Plan
OPD	Optimized Profile Descent
OSG	Operations Support Group
PARC	Performance-Based Aircraft Aviation Rulemaking Committee
PBN	Performance-Based Navigation
RAPT	Regional Airspace Planning Team
RF	Radius-to-Fix
RNAV	Area Navigation
RNP	Required Navigation Performance
ROD	Record of Decision
RPAT	RNP Parallel Approach with Transition
RTA	Required Time of Arrival
SAAAR	Special Aircraft and Aircrew Authorization Required
SEA	Seattle-Tacoma International Airport
SEL	Sound Exposure Level
SIAP	Standard Instrument Approach Procedures
SID	Standard Instrument Departure
SIP	State Implementation Plan
SMS	Safety Management System
SRM	Safety Risk Management
STAR	Standard Terminal Arrival Route
SUA	Special Use Airspace
TARGETS	Terminal Area Route Generation, Evaluation, and Simulation
TBFM	Time-Based Flow Management
TCAS	Traffic Collision Avoidance System
TERPS	Terminal Instrument Procedures
TIS-B	Traffic Information Services-Broadcast
TOD	Top of Descent
TRACON	Terminal Radar Approach Control
UAV	Unmanned Aerial Vehicle
VFR	Visual Flight Rules
VNAV	Vertical Navigation
VOR	Very High Frequency (VHF) Omnidirectional Radio Range
WAAS	Wide Area Augmentation System

B Glossary of Terms

TERM	DEFINITION
Above Ground Level (AGL)	The altitude expressed in the actual number of feet measured with respect to the underlying ground surface. The distance of the aircraft above the ground.
Administrator for Airports	The Federal Aviation Administration's office responsible for reviewing and deciding on projects involving airports, overseeing their construction and operations, and ensuring compliance with federal regulations.
Air Traffic Control (ATC)	A service provided by ground-based controllers who direct aircraft on the ground and through controlled airspace, and can provide advisory services to aircraft in non-controlled airspace. The primary purpose of ATC is to promote the safe, orderly, and expeditious flow of air traffic.
Air Traffic Noise Screening (ATNS)	A computer program that evaluates the potential noise impacts resulting from changes in airport arrivals and departures by screening proposed changes to determine whether new or increased noise is likely to exceed permissible levels over communities beneath the aircraft route. ATNS is a computerized version of the former FAA Notice N 7210.360, "Noise Screening Procedure for Certain Air Traffic Actions Above 3,000 Feet AGL."
Airport Arrival Rate (AAR)	A parameter specifying the number of arrival aircraft that an airport, in conjunction with terminal airspace, can accept under specific conditions throughout any consecutive 60-minute period.
Airport Cooperative Research Program (ACRP)	An applied research program that develops practical solutions to problems faced by airport operators. ACRP is managed by the Transportation Research Board (TRB) of the National Academies of Sciences, Engineering, and Medicine and sponsored by the FAA.
Area Navigation (RNAV)	A method of navigation that allows an aircraft to choose any course within a network of navigation beacons, rather than navigating directly to and from the beacons. This can conserve flight distance, reduce congestion, and allow flights into airports without beacons.
Authorization Required (AR)	Refers to Required Navigation Performance (RNP) Instrument Approach Procedures (IAP) with Authorization Required (AR). Authorization is typically associated with aircraft avionics equipment, operator requirements, and pilot training. These were previously known as RNP Special Aircraft and Aircrew Authorization Required (SAAAR) operations.
Automatic Dependent Surveillance Broadcast (ADS-B)	An element of the U.S. Next Generation Air Transportation System (NextGen), ADS-B is an air traffic surveillance technology that enables aircraft to be accurately tracked by air traffic controllers and other pilots without the need for conventional radar.
Aviation Environmental Design Tool (AEDT)	A comprehensive software system that dynamically models aircraft performance in space and time to produce estimates of noise, fuel burn and emissions at global, regional, and local levels. AEDT is currently used by the U.S. government to consider the interdependencies between aviation-related noise, hazardous air pollutants (HAPs) and greenhouse gas (GHG) emissions, and fuel consumption.

TERM	DEFINITION
Clean Air Act (CAA)	A United States federal law, first enacted in 1955, with major revisions in 1970 and 1977, designed to protect human health and the environment from the effects of air pollution. Under the CAA, the Environmental Protection Agency (EPA) is required to establish national ambient air quality standards (NAAQS) to protect public health and welfare and to regulate emissions of hazardous air pollutants. State and local governments monitor and enforce CAA regulations, with oversight by the EPA.
Closely Spaced Parallel Runway Operations (CSPO)	A procedure used by air traffic controllers to space aircraft closer together on takeoff and landing at major U.S. airports for the purpose of increasing airspace capacity. Under CSPO, aircraft pairs arriving at an airport with parallel runways that are separated by 2,500 feet or less are staggered to observe 1.5 nm diagonal separations between leading and trailing aircraft on the separate runways.
Cockpit Display of Traffic Information (CDTI)	A CDTI is a generic display that provides the flight crew with surveillance information about other aircraft, including their position. Traffic information for a CDTI may be obtained from one or multiple sources, including ADS-B, traffic collision avoidance system (TCAS), and traffic information services-broadcast (TIS-B). Direct air-to-air transmission of ADS-B messages supports display of proximate aircraft on a CDTI.
Code of Federal Regulations (CFR)	The codification of the general and permanent rules and regulations published in the Federal Register by the executive departments and agencies of the federal government of the United States.
Core Working Group (CWG)	A group established in Phase One of the *Performance-Based Navigation Implementation Process*—FAA Order 7100.14 to perform the baseline analysis and to finalize the project's mission statement.
Day-Night Average Sound Level (DNL)	Expressed in decibels (dB), DNL is a 24-hour average noise level used to define the level of noise exposure on a community. The DNL represents the average sound exposure during a 24-hour period and does not represent the sound level for a specific noise event. A 10 dB correction is applied to nighttime (10:00 p.m. to 7:00 a.m.) sound levels to account for increased annoyance due to noise during the night hours.
Decibels (dB)	The logarithmic unit used to measure the intensity of a sound measuring from the threshold of human hearing, 0 dB, upward towards the threshold of pain, about 120 to 140 dB. An increase of 10 dB is perceived by human ears as a doubling of noise.
Distance Measuring Equipment (DME)	Equipment (ground and airborne) used to measure and report to the pilot the slant range distance, in nautical miles, of an aircraft from the DME navigational aid.
Distance of Turn Anticipation (DTA)	The distance from a waypoint that an aircraft is expected to start a turn in order to intercept the course/track of the next segment.
Environmental Assessment (EA)	Assessment performed under the National Enviromental Policy Act (NEPA) used to predict the environmental consequences of a plan, policy, program, or project prior to the decision to move forward with the proposed action. The EA will determine either the need to prepare an environmental impact statement (EIS) or justify a finding of no significant impact (FONSI).
Environmental Impact Statement (EIS)	A document required by NEPA for certain actions that may significantly affect the quality of the human environment. The purpose of an EIS is to analyze and disclose the significant effects resulting from a federal action and also list alternative actions that may be chosen instead of the action described in the EIS.

TERM	DEFINITION
Equivalent Lateral Spacing Operations (ELSO)	A procedure used by air traffic controllers to space aircraft closer together on takeoff and landing at major U.S. airports for the purpose of increasing airspace capacity. ELSO reduce the divergence angle between the departure routes of aircraft on takeoff, therefore allowing controllers to space routes more closely together and clear aircraft for takeoff more efficiently.
Established on RNP (EoR)	A RNP AR with a radius-to-fix (RF) leg approach and parallel Instrument landing system (ILS) approach to parallel runways. The RNP AR approach comprises an RNP downwind leg, an RNP AR with RF turn on to final leg, and an RNP final approach. RNP lateral containment throughout the approach supplants current-day separation requirements of 3 nmi laterally or 1,000 foot vertically until established. This increases arrival throughput by reducing the required minimum inter-flight spacing.
Finding of No Significant Impact (FONSI)	A document required by the NEPA explaining why the proposed action will have no significant effects on the human environment. It is based on the EA and comments of agencies and the public. The FONSI is separate from the EA, and it is detailed enough in drawing from sections in the EA to stand alone.
Flight Information Services–Broadcast (FIS-B)	A component of ADS-B technology that provides free graphical National Weather Service products, temporary flight restrictions (TFRs), and special-use airspace information.
Flight Management System (FMS)	A suite of avionics programs on board an aircraft used to calculate the most economical flying speeds and altitudes during a flight and to identify possible choices in emergencies.
General Aviation (GA)	All civil aviation operations other than scheduled air services and non-scheduled air transport operations for remuneration or hire. The majority of the world's air traffic falls into this category, and most of the world's airports serve GA exclusively.
Global Positioning System (GPS)	A system of satellites, computers, and receivers that is able to determine the latitude and longitude of a receiver on Earth by calculating the time difference for signals from different satellites to reach the receiver. In aviation, GPS data allows pilots to obtain precise three-dimensional or four-dimensional location data.
Government Accountability Office (GAO)	An independent, nonpartisan agency established by the Budget and Accounting Act of 1921 that investigates how the federal government spends taxpayer dollars.
Ground-Based Augmentation System (GBAS)	A system that provides differential corrections and integrity monitoring of global navigation satellite systems. GBAS provides navigation and precision approach service in the vicinity of the host airport, broadcasting its differential correction message via a very-high-frequency radio data link from a ground-based transmitter. GBAS yields the extremely high accuracy, availability, and integrity necessary for Category I, and eventually Category II and III precision approaches.
Interval Management (IM)	IM is a set of applications that enable more precise and consistent spacing between aircraft to increase throughput and efficiency. IM is composed of ground-based IM (GIM) and a flight-deck-based IM (FIM). GIM provides air traffic controllers with speed advisories to achieve and/or maintain a desired spacing interval with a target aircraft and also helps controllers initiate the flight-deck operation (FIM). FIM uses avionics to provide guidance to the flight crew to achieve and/or maintain a desired spacing interval with a target aircraft.
Instrument Flight Procedure (IFP)	A description of a series of predetermined flight maneuvers by reference to flight instruments, published by electronic and/or printed means.

TERM	DEFINITION
Instrument Landing System (ILS)	A radar-based instrument approach system that provides precision lateral and vertical guidance to ILS-equipped aircraft approaching and landing on a runway, enabling a safe landing during instrument meteorological conditions (IMC), such as low ceilings or reduced visibility.
Integrated Noise Model (INM)	INM is a computer model that evaluates aircraft noise impacts in the vicinity of airports. The INM can output either noise contours for an area or noise level at pre-selected locations. In the U.S., INM is the preferred model used for Federal Aviation Regulation (FAR) Part 150 noise compatibility planning and for FAA Order 1050 EAs and EISs.
Inertial Reference Unit (IRU)	A type of inertial sensor that uses only gyroscopes to determine a moving aircrafts change in angular direction over a period of time.
In-trail Procedures (ITP)	An ADS-B application developed by the FAA. The use of flight level change procedures, enabled by ADS-B ITP, enables flight level changes for aircraft operating in oceanic airspace and being held at non-optimal flight levels due to conflicting traffic.
Lateral Navigation (LNAV)	GPS-based non-precision instrument approach procedure that provides horizontal approach navigation without approved vertical guidance. The approach minimums for LNAV approaches are higher than that of ILS approaches, and RNAV approaches that incorporate vertical guidance.
Localizer Performance (LP)	An RNAV function using a final approach segment data block that computes, displays, and provides horizontal approach navigation using the horizontal accuracy and integrity of localizer performance with vertical guidance (LPV) without approved vertical guidance. The LP line of minima is provided at locations where issues prevent the use of vertical guidance and provides a higher probability of achieving the lowest minimum at these locations.
Localizer Performance with Vertical Guidance (LPV)	An RNAV function using a final approach segment data block, which computes, displays and provides both horizontal and approved vertical approach navigation to minimums as low as 200 foot ceiling and ½-mile visibility.
Minneapolis-St. Paul Metropolitan Airport Commission (MAC)	The MAC is a Minnesota State government agency that owns and operates the Minneapolis-St. Paul International Airport and six other reliever airports in the region.
National Airspace Procedures Team (NAPT)	A team established at Washington headquarters to provide direction and guidance for regional airspace procedures team (RAPT)-related matters.
National Airspace System (NAS)	The FAA created the NAS to protect persons and property on the ground, and to establish a safe and efficient airspace environment for civil, commercial, and military aviation. The NAS is made up of a network of air navigation facilities, ATC facilities, airports, technology, and appropriate rules and regulations that are needed to operate the system.
National Ambient Air Quality Standards (NAAQS)	Standards established by the EPA under authority of the CAA that apply for outdoor air throughout the country. Primary standards are designed to protect human health. Secondary standards are designed to protect public welfare from any known or anticipated adverse effects of a pollutant.
National Environmental Policy Act (NEPA) of 1969	A congressional act which established the national policy for disclosing the potential impacts of Federal actions. Compliance with NEPA requires the completion of an environmental document that outlines impacts that may significantly affect the quality of the human environment.

TERM	DEFINITION
Noise Compatibility Programs (NCP)	A program that promulgates recommendations on the abatement and/or mitigation of existing impacts of aviation noise, and the prevention of future incompatibilities in areas identified as being significantly impacted by aircraft noise. An NCP is created or updated as part of the FAR Part 150 process, following the completion of existing and future noise exposure maps (NEMs).
Noise Exposure Map (NEM)	Noise exposure contours overlaid on a background map which identifies existing or future noise exposure conditions at an airport. An NEM is typically developed as part of the FAR Part 150 process.
Noise Oversight Committee (NOC)	Committee established by MAC in August 2002 to bring industry and community representatives together to address aircraft noise issues and to bring policy recommendations to the MAC.
Operational Evolution Plan (OEP)	FAA-sponsored blueprint, first introduced in 2001 to enhance capacity of the NAS, formalizes a wide range of efforts such as automated controller tools, new weather systems, data link communications for pilots and controllers, airspace changes, new runways, and air traffic procedures. The OEP also establishes solution sets for problem areas, which include increasing airport arrival rates, minimizing congestion at high altitudes, and reducing the impact of bad weather at airports.
Optimized Profile Descent (OPD)	An aircraft approach method designed to reduce fuel consumption and noise compared to other conventional descents. Instead of approaching an airport in a stair-step fashion, OPD allows for a smooth, constant-angle descent to landing.
Performance-Based Navigation (PBN)	A term used to describe the broad range of technologies that move aviation away from a ground-based navigation system toward a system that relies more on the performance and capabilities of equipment on board the aircraft. PBN specifies that aircraft RNP and RNAV systems performance requirements be defined in terms of accuracy, integrity, availability, continuity and functionality required for the proposed operations.
Radius-to-Fix (RF)	A turn between two waypoints in the terminal/approach phase of flight using a constant turn radius commensurate with the maximum ground speed and the maximum allowable bank angle. The inbound and outbound legs are tangential to the arc.
Regional Airspace Procedures Team (RAPT)	A team established at each FAA region for the purpose of coordinating and processing requests for new or modified flight procedures and related airspace matters.
Required Navigation Performance (RNP)	A type of PBN that allows an aircraft to fly a specific path between two 3D-defined points in space. RNP equipment provides onboard navigation capability that allows crews to accurately fly aircraft along a precise flight path. RNP also refers to the level of performance required for a specific procedure or a specific block of airspace. An RNP of ten means that a navigation system must be able to calculate its position to within a circle with a radius of ten nautical miles.
RNP Parallel Approach with Transition (RPAT)	An RNP AR operation designed to improve arrival capacity of parallel runways with centerline separations less than 4,300 feet in marginal visual meteorological conditions when the airport acceptance rate is reduced due to discontinued use of simultaneous independent parallel approaches.
Safety Risk Management (SRM)	A component of the FAA's Safety Management System, FAA Order 8000.369. The objective of SRM is to provide supporting information for decision makers by convening a panel of experts to identify hazards, analyze and assess safety risk, and develop controls and document processes.

TERM	DEFINITION
Sound Exposure Level (SEL)	The most common metric for measuring cumulative noise exposure for a single aircraft flyover, computed from measured dB sound levels. The SEL metric measures the entire event, and, therefore, does not directly represent the sound level heard at any given time.
Standard Instrument Approach Procedure (SIAP)	A predetermined maneuver for the orderly transfer of an aircraft under instrument flight conditions from the beginning of the initial approach to a landing or to a point from which a landing may be made visually or the missed approach procedure is initiated. It is prescribed and approved for a specific airport by a competent authority.
Standard Instrument Departure (SID)	A preplanned instrument flight rule (IFR) departure procedure published for pilot use, in graphical or textual format, that provides obstruction clearance from the terminal area to the appropriate en route structure.
Standard Terminal Arrival Route (STAR)	A published IFR arrival procedure describing specific criteria for descent, routing, and communications for a specific runway at an airport.
State Implementation Plan (SIP)	An enforceable plan developed at the state level that explains how the state will comply with air quality standards according to the CAA. The CAA requires each state to produce and regularly update an SIP and requires that SIPs include a description of control strategies, or measures, to deal with pollution for areas that fail to achieve the NAAQS.
Terminal Area Route Generation, Evaluation, and Simulation (TARGETS)	A software application that offers a combination of capabilities for RNAV procedure design, flyability assessment, and air traffic service provider and operator evaluation.
Terminal Radar Approach Control (TRACON)	An FAA ATC facility that uses radar and two-way radio communication to provide separation of air traffic within a specified geographic area in the vicinity of one or more large airports.
Traffic Collision Avoidance System (TCAS)	An aircraft collision avoidance system designed to reduce the incidence of mid-air collisions between aircraft. TCAS is based on secondary surveillance radar transponder signals and operates independently of ground-based equipment to provide advice to the pilot on potential conflicting aircraft. The International Civil Aviation Organization (ICAO) mandates that the system be fitted to all aircraft with a maximum take-off mass of over 5,700 kilograms (12,600 pounds) or authorized to carry more than 19 passengers.
Traffic Information Services-Broadcast (TIS-B)	TIS-B is the broadcast of ATC-derived traffic information to ADS-B-equipped (1090ES or UAT) aircraft from ground radio stations. The source of this traffic information is derived from ground-based air traffic surveillance radar sensors. TIS-B service will be available throughout the NAS where there are both adequate surveillance coverage (radar) from ground sensors and adequate broadcast coverage from ADS-B ground radio stations.
Vertical Navigation (VNAV)	A form of precise vertical (altitude) guidance using the aircraft FMS. VNAV is the vertical navigation flight profile that is the predicted flight trajectory of the airplane in the vertical plane as a function of distance along the horizontal flight path defined by the LNAV flight plan.
Wide Area Augmentation System (WAAS)	An air navigation aid developed by the FAA to augment the GPS, with the goal of improving its accuracy, integrity, and availability. WAAS is intended to enable aircraft to rely on GPS for all phases of flight, including precision approaches.

C Case Studies

This section documents the following case studies conducted for the ACRP 03-34 project:

- Hartsfield-Jackson Atlanta International Airport—PBN Departure Implementation.
- Denver International Airport—PBN Departure, Arrival, and Approach Implementation.
- Henderson Executive Airport—PBN Departure, Arrival, and Approach Implementation.
- Houston Metroplex—PBN Departure, Arrival, and Approach Implementation.
- Minneapolis/St. Paul International Airport—PBN Departure and Arrival Implementation.
- Seattle-Tacoma International Airport—PBN Departure, Arrival, and Approach Implementation.

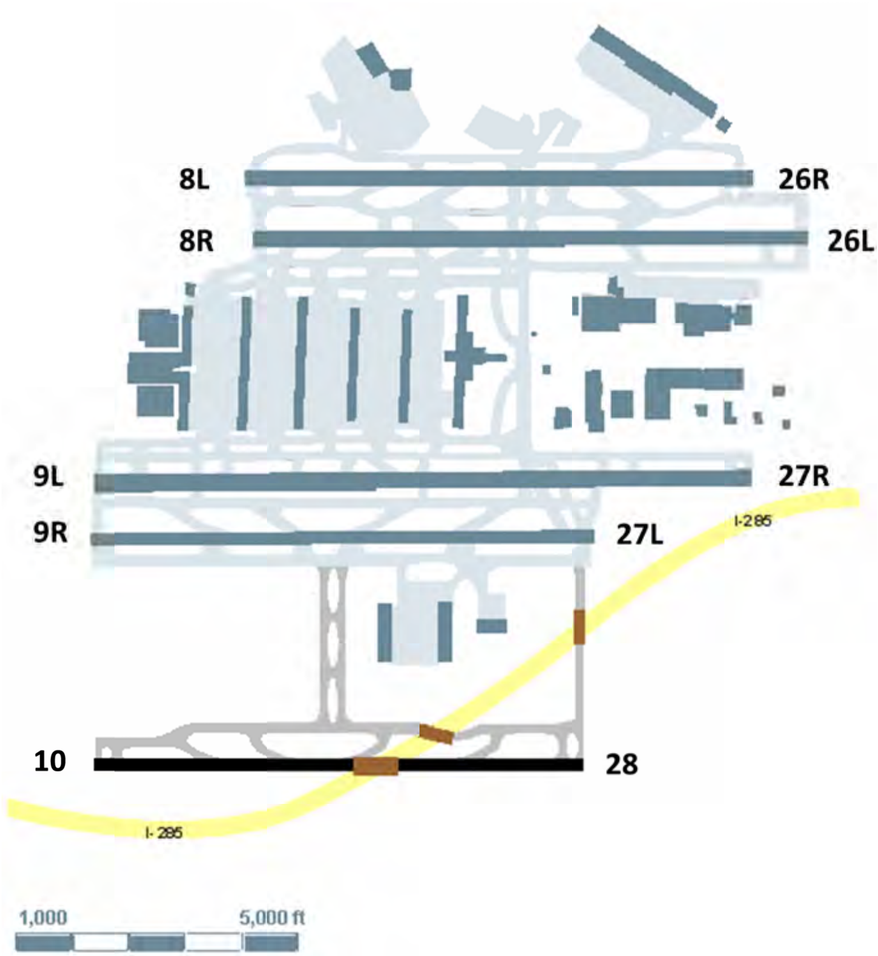
Hartsfield-Jackson Atlanta International Airport—PBN Departure Implementation

PBN departure implementation was initiated by ATCT personnel to increase capacity. The project team engaged the primary stakeholders in the project including Atlanta TRACON (A80), Delta Airlines, and the ADOA. The team developed new procedure design criteria that supported implementing dual eastbound and westbound departure routes from individual runways into the existing airspace. Community outreach served to educate the community regarding the proposed procedures and address their concerns regarding noise in the design.

Introduction

According to FAA data, the Hartsfield-Jackson Atlanta International Airport (ATL) has been one of the busiest airports in the world for many years, both in passenger traffic as well as the number of landings and take-offs (operations). Several NextGen capabilities and enabling improvements have been implemented, including Airport Surface Detection Equipment — Model X (ASDE-X), OPD, Automated Terminal Proximity Alert (ATPA), PBN procedures and airspace redesign, basic rerouting, and Adjacent Center Metering, Expanded Low-Visibility Operations Using Lower Runway Visual Range Minima, Wake Recategorization, Phase 1, and Dual Independent Parallel Operations. These improvements are described in ACRP Project 01-27, "NextGen—A Primer."

The airport operates five runways. The runways are depicted in Figure C-1. Two of the runways are designated as primary arrival runways (Runways 8L-26R and 9R-27L) and two runways are designated as primary departure runways (Runways 8R-26L and 9L-27R). The fifth runway (Runway 10-28) is used for arrivals or departures depending upon the flow and demand. ATL has two terminals with seven concourses, and is a focus city for Southwest Airlines and primary hub of Delta Air Lines and Express-



Source: Federal Aviation Administration

Figure C-1. *Plan view of Hartsfield-Jackson Atlanta International Airport.*

Jet; at nearly 1,000 flights a day, the Delta hub is the world's largest airline hub. In 2013, ATL had 45,308,407 enplanements and 868,359 operations.

The FAA's NextGen Metroplex initiative is currently redesigning airspace and addressing airspace inefficiencies, introducing new PBN procedures, and making use of time based flow management (TBFM) to make the Atlanta Metroplex airspace more efficient and improving access to its airports. The effort focuses on four airports, including Hartsfield-Jackson Atlanta International (ATL), Fulton County Airport-Brown Field (FTY), DeKalb-Peachtree (PDK), and Cobb County Airport-McCollum Field (RYY).

The three other airports within the Atlanta Metroplex are general aviation reliever airports. FTY is located approximately seven miles west of Atlanta's central business district. It is categorized as a local Class D general aviation reliever airport for Hartsfield-Jackson International Airport. FTY has three runways and in 2013 had 397 enplanements and 97,370 operations. FTY has an FAA-operated control tower. PDK is located in Chamblee, Georgia, just northeast of Atlanta. It is categorized as a general aviation reliever airport for the region and has one airline service with Southern Airways Express. The airport is the second-busiest airport in Georgia in the number of flight operations per year and is the seventh-busiest general aviation airport in the U.S. In 2013, PDK had 2,119 enplanements and 284,308 operations. RYY is located 21 miles northwest of central Atlanta. The airport has one runway and is categorized as a general aviation reliever airport for Hartsfield-Jackson International Airport and is home to two charter companies. In 2013, RYY had 265 enplanements and 133,144 operations.

The FAA's PBN Dashboard provides analysis of the equipage levels among general aviation, Part 121 major, regional, and cargo aircraft, as well as IFR operations at ATL as of January 2015 (Federal Aviation Administration 2015). The results indicate that almost all Part 121 aircraft and IFR operations, and 70% of general aviation aircraft, are capable of RNAV with lateral navigation precision of 1 nautical mile (RNAV 1). One hundred percent of the Part 121 regional aircraft, but only 70% of the other categories, are capable of RNP with lateral precision within 0.3 to 1 nautical mile (RNP 0.3-1). Only 30% of general aviation and IFR operations, and essentially none of the Part 121 aircraft, are capable of RNP AR. The FAA's PBN Dashboard indicates ATL has an inventory of 16 RNAV SIDs, seven RNAV STARs, and four RNP approach procedures.

The focus of this case study is the ATL PBN departure implementation project that was initiated in 2007 by ATCT personnel as a way to increase capacity. The project team engaged the primary stakeholders in the project including Atlanta TRACON (A80), Delta Airlines, and the ADOA. The project team also coordinated with a noise advocacy group representing College Park, East Point, and Lake City. FAA personnel provided RNAV and RNP procedure design with input from Delta Airlines, ADOA, and a governmental liaison from the surrounding community. DAL served as the lead carrier in the project, performing flyability assessment from an aircraft performance and pilot's perspective, and ADOA prepared the EA as part of the project.

Demographics

The land use in the areas immediately surrounding ATL is mostly industrial and commercial with some medium-income residential development to the west and northwest. Figure C-2 depicts ATL and the surrounding community.

Source: Google Maps

Figure C-2. *Hartsfield-Jackson Atlanta International Airport and the surrounding area.*

Project Description

The PBN departure implementation project was a follow-on to work previously conducted in 2004 that resulted in the implementation of RNAV STARs and SIAPs. RNAV SIDs were originally proposed for the east and west airport configurations as part of this project. However, automation issues were encountered due to the number of en route transitions, rendering the design infeasible. Project efforts were continued by the National Airspace Redesign group and were ultimately taken over and "championed" locally through efforts by ATCT and A80 personnel. The project focused on the implementation of 16 SIDs, each of which is acceptable to any of the five runways at ATL and compatible with automation. Delta Airlines saw potential for increased capacity at the airport and participated in the effort as the lead carrier. The local personnel recommended several key changes in procedures and technologies to enable the PBN departure implementation:

- Updates to the video map for controllers in order to better define the flight tracks for easier blunder identification.
- Requirements for the tower controller to validate the first fix that the aircraft has in its FMS in order to verify pilots have the correct SID loaded in their FMS, thereby eliminating blunders and ensuring separation.
- Changes to the airport ATCT's procedures so that the tower controller maintains control of the departure until the aircraft initiates the first turn, then hands control of the departure off to the A80 Departure Controller. This procedure serves to verify aircraft are travelling in the correct direction, ensures proper separation, and avoids blunder occurrences when aircraft are transitioning between the radio frequencies of the ATCT Local and A80 Departure Controller.
- The concept and preliminary design of the procedures were developed locally and then handed off to the FAA PBN Office and Flight Standards in Washington, D.C.

Processes Used

The processes used for the development were based on the National Airspace Redesign program and local initiatives for the development of the preliminary procedures. The local FAA served as leaders and "champions" of the project, working with the airport, community, and FAA headquarters to find solutions to challenges as they arose. When the official request for the development of the procedures was made, the existing work was folded into the FAA 18-step process and the guidelines identified in FAA Order 7400.2 Procedures for Handling Airspace Matters.

Criteria Development

The RNAV design was based on the use of two new departure routes that provided less than 15 degrees of separation (current minima) from parallel or concurrent runway operations. New ELSO separation criteria were developed and implemented to allow air traffic control personnel to use any combination of RNAV (GPS or RNP) departures for parallel dependent and simultaneous independent operations from dual/triple parallel runways separated by at least 2,500 feet. The ELSO criteria development began with an initial PowerPoint presentation explaining the design concept. The A80 manager and the project leader met with FAA PBN Office and Flight Standards representatives in Washington, D.C. to brief the concept. FAA Flight Standards indicated the need for a SMS review and approval in order to approve the concept.

Following the meeting, The MITRE Corporation was engaged to develop the safety case for ELSO and assist in the safety case analysis. MITRE assembled a team to analyze runway spacing, stagger, airport geometry, and other parameters to compute the divergence required to provide the level of safety equivalent to vectoring. The key technical component was crediting the lateral containment afforded by the RNAV capability of the aircraft with meeting the separations implied in established minimum requirements. The findings were forwarded to the FAA Safety Risk Management panel for review, validation, and approval. The ELSO criteria were approved in 2008 as a waiver to criteria. The criteria are applicable at other airports in the NAS and are in the process of being incorporated into upcoming revisions to the FAA Joint Order 7100.65 Air Traffic Control.

These new criteria allow a reduced angle between the departure routes from the minimum 15 degrees to as little as ten degrees on parallel runways spaced 2,500 feet or more apart. This permits simultaneous independent operations, not staggered dependent operations in Instrument or Visual Flight Rules (IFR or VFR), with aircraft side-by-side, with ten degrees divergence during the departure. ELSO applies to successive same-runway and non-closely spaced parallel runway departures from three or four runways. That is, successive departures diverge by ten degrees, including aircraft from parallel runways. There are no weather restrictions on ELSO other than SID takeoff minimums, which vary by runway based on their local obstructions. However, during certain wind conditions the ELSO operations are discontinued due to the potential for wind drift of aircraft reducing separation. The discontinuance of ELSO is based on the judgment of the A80 or ATCT controllers. A crosswind component in excess of 25 knots or when an aircraft is observed drifting too far north or south are general rules of thumb for shutting down ELSO. When ELSO is discontinued, departure throughput decreases because operations revert back to radar vectors procedures with aircraft separated by 15 degrees. ELSO may also be discontinued due to errors in the GPS signal, bad navigation databases, and other causes.

Project Communication and Public Outreach

The ATL PBN departure implementation project was a collaborative effort between FAA ATCT, A80, Delta Airlines, and residential communities of College Park, Lake City, and East Point. FAA ATCT met multiple times with Delta Airlines and ADOA personnel to discuss the design of the procedures, flyability, flight tracks, and potential environmental impacts. Delta Airlines flight technical representatives worked with the FAA on the flyability and equipage issues. The ADOA agreed to prepare and fund an EA associated with the new procedures.

Local FAA project representatives met multiple times with city officials and an advocate representing the communities of College Park, East Point, and Lake City. At these meetings FAA shared the entire project history, what they were doing, why the flight procedures were designed as they were, and communicated that they were trying to find the best possible design of the procedures to satisfy the noise sensitivities of the community. These outreach efforts were able to alleviate community concerns about the project.

A number of design choices were made to mitigate the impact of noise on the surrounding communities. Woodward Academy High school is located northwest of the airport in College Park. The community asked FAA to extend the initial departure leg out to 1.2 miles for aircraft prior to a turn. Aircraft would proceed straight out further before their initial turn, avoiding the school. Residents of East Point were concerned about the northwest departure routes. Of the three departure routes, referred to as the 290, 280 and 270 routes, the 290 route from Runway 26L went over a bridge. The community requested the routes to be farther north of the bridge. The FAA was able to fit in the 4th departure route while avoiding moving the northwest 290 departure route farther north beyond the bridge. The southwest route from Runway 10 went over Lake City. Lake City residents wanted the route farther south or north. The FAA was able to use the same waypoint for Runway 9L departures and employed reduced divergence criteria with the departure route from Runway 10 to obtain this goal. The design of the SIDs still gained all the desired efficiencies but minimized their impact on the surrounding community.

Environmental Analysis

The ADOA agreed to lead the environmental effort for the project and was able to combine the analysis into the EA for the extension of Runway 9L-27R. The EA was conducted following NEPA standards and guidelines. A FONSI ROD was issued by FAA in August of 2009.

Project Outcomes

Outcomes from the Atlanta PBN departure implementation project include:

- Development and implementation of 16 PBN departure procedures.
- Establishment of ELSO criteria.
- Implementation of two new departure routes enabling simultaneous and concurrent departures along five diverging headings to the east and five diverging headings to the west.

Post-Implementation Metrics

The airport's primary metric in assessing the impact of the new departure procedures is airport departure throughput. The new design results in an increase of eight to 12 additional departures per hour. The increases can be attributed to the addition of two new departure paths that can be used in simultaneous parallel operations, concurrent operations, reduced departure spacing distances, reduced departure spacing time, and improvements in continuous climb performance. The airport also investigates noise complaints on a case-by-case basis by analyzing flight tracks in response to individual noise complaints. The airport does not continuously monitor or evaluate noise. The FAA's PBN Dashboard provides analysis of the average daily number of IFR operations and the average daily usage levels of individual RNAV SIDs and for a specified calendar year at ATL (Federal Aviation Administration 2015). It indicates an average of 2,395 daily IFR operations, and the average daily usage counts of the RNAV SIDs sum to 1,985 departures.

Lessons Learned and Best Practices

The lessons learned from the Atlanta case study include:

- PBN initiatives undertaken at a local level can be successful when including all stakeholders.
- Successful implementation requires a champion to spearhead the project.
- The champion must be technically savvy regarding PBN, flight procedures criteria, and flight standards; politically sensitive; and knowledgeable of inner workings of the FAA.
- Procedures requiring the development of new criteria take additional time and effort to implement.
- Outside consultation in the development of a credible safety case for new criteria and procedures bolsters likelihood of FAA approval.
- Design of PBN procedures can address community noise constraints, airspace confines and obstacles while providing significant benefits. Inclusion of community input can enhance the outcomes of PBN projects.
- Community outreach with full explanation and disclosure engenders community understanding and approval.
- Local air traffic control operations support is critical to successful implementation and utilization of PBN procedures.

- Lessons learned are often not communicated to a broader audience. For example, ELSO can be developed and applied at other airports. To assist in communicating the accomplishments and lessons learned, the FAA is developing a lessons learned tool and a project tracking tool to support developing PBN procedures.

Denver International Airport—PBN Departure, Arrival, and Approach Implementation

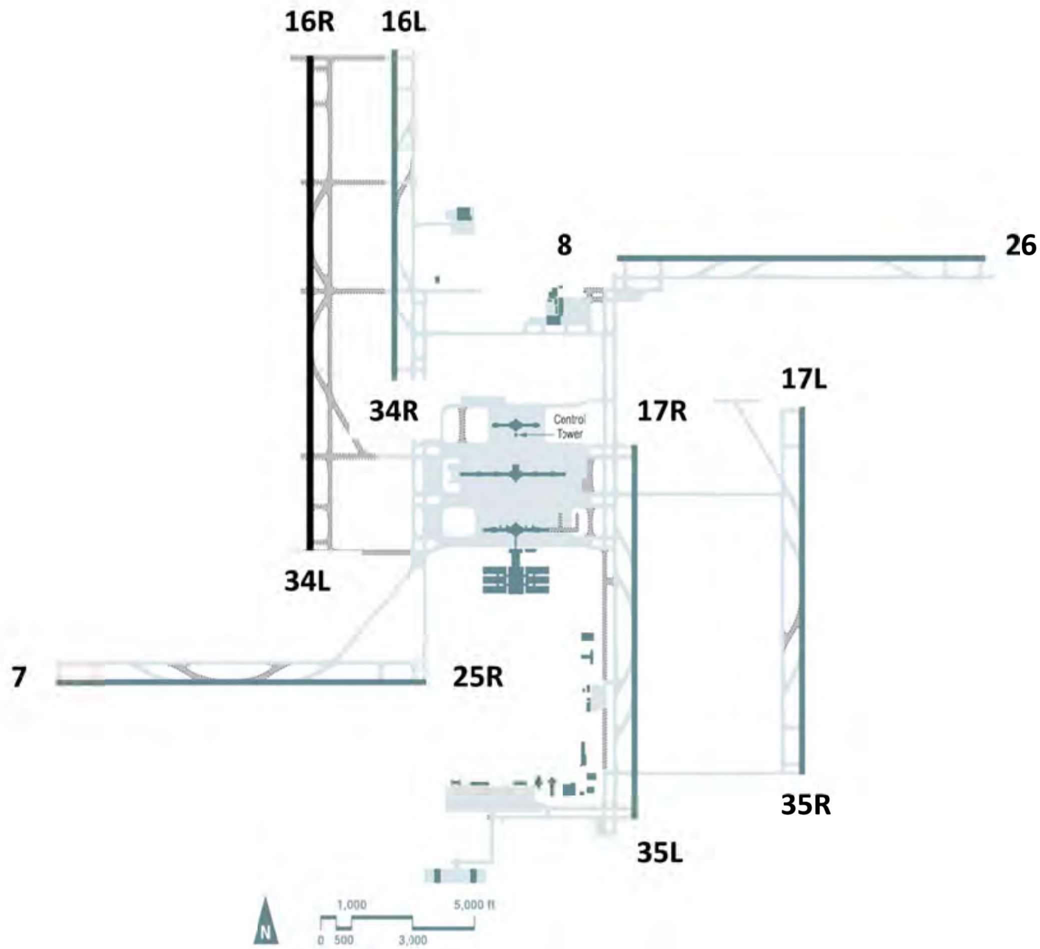
PBN departure implementation was initiated by TRACON personnel to facilitate managing arrival traffic to DEN and to improve flight efficiency. The project team included the TRACON, ATCT, federal FAA, aircraft operator, and other industry and airport personnel. Personnel from DEN's noise abatement office were deeply involved in the design to ensure it complied with stringent noise limits, with periodic compliance assessments and hefty fines, stipulated in an inter-governmental agreement. The team leveraged new procedure design criteria for approach procedures to increase use of the parallel runways. The environmental contractor to the FAA conducted extensive community outreach throughout the design. The final design has resulted in significant fuel burn and emissions reductions while meeting the stringent noise limits.

Introduction

The Denver Metroplex serves the metropolitan area of Denver, Colorado, and includes Denver International Airport (DEN), Centennial Airport (APA), and Rocky Mountain Metropolitan Airport (BJC). DEN is a large hub airport located 25 miles from central Denver and is the largest airport in the U.S. by total area and the fifth busiest airport in North America in terms of passenger traffic. The airport has six runways. The runways are depicted in Figure C-3. Four of them are orientated on a north-south parallel heading (Runway 16L-34R and 16R-34L, and Runway 17L-35R and 17R-35L) and two runways are oriented on an east west alignment (Runway 7-25 and Runway 8-26). The runway configuration supports triple simultaneous arrivals and departures in multiple wind conditions. The airport has one terminal, three concourses, and is the main hub for Frontier and Great Lake Airlines. In 2013, DEN had 25,496,885 enplanements and 1,162,021 operations.

APA is located in Dove Valley, 17 miles southeast of central Denver. The reliever airport has three runways and an FAA-operated control tower. Centennial Airport does not offer scheduled airline passenger service. In 2013, APA had 1,679 enplanements and 601,841 operations. BJC is located 16 miles northwest of central Denver, between Denver and Boulder. The reliever airport has three runways and an FAA operated control tower. BJC does not offer scheduled airline passenger service. In 2013, the airport had 717 enplanements and 230,109 operations.

The FAA's PBN Dashboard provides analysis of the equipage levels among general aviation, Part 121 major, regional, and cargo aircraft, and IFR operations at DEN as of January 2015 (Federal Aviation Administration 2015). The results indicate that over 90% of Part 121 aircraft and IFR operations, and 50% of general aviation aircraft, are capable of RNAV 1. Over 90% of the Part 121 aircraft and IFR operations, and 50% of the other categories, are capable of RNP 0.3-1. Over 50% of the Part 121 major aircraft and IFR operations are capable of RNP AR, while essentially none of the general aviation and Part 121 regional and cargo aircraft are capable of RNP AR. The FAA's PBN Dashboard indicates DEN has an inventory of 16 RNAV SIDs, 16 RNAV STARs, and 12 RNP approach procedures.



Source: Federal Aviation Administration

Figure C-3. *Plan view of Denver International Airport.*

The focus of this case study is the Denver PBN project that was initiated in 2009 by Denver TRACON (D01) and The Denver International Airport and included the Denver ARTCC (ZDV), Jeppesen, United Airlines, Southwest Airlines, and Frontier Airlines as project stakeholders.

Demographics

DEN is located within Denver County but is surrounded by Adams County. The land use in the immediate area surrounding the airport is primarily industrial and agricultural. There are multiple low density residential areas located to the north and east of the airport. Figure C-4 depicts the areas surrounding DEN.

Source: Google Maps

Figure C-4. *Denver International Airport and the surrounding area.*

Project Description

The Denver PBN project involved the development and implementation of RNAV SIDs, STARs, and RNP SIAPs at DEN. The project also included RNAV SID procedures for APA and BJC. The PBN implementation initiative at DEN was distinct from the FAA Metroplex program. It began as a "home grown" effort initiated by the Denver TRACON (D01). The impetus for PBN implementation was increasing levels of traffic, which created significant inefficiencies with vectoring-based approaches for managing and sequencing traffic in the terminal area. In order to manage inflows of arrivals at each corner post from ZDV, D01 controllers were vectoring aircraft well out of the way of their intended routes. The vector operations created compliance issues with noise agreements established with multiple communities surrounding DEN. As an example, if an aircraft arriving via the south was flying the downwind portion of the arrival route to DEN runway 16L, the aircraft would continue to fly the downwind beyond the base leg, far northeast of the airport, then join the northeast arrival traffic flow, finally landing on a different runway.

When the airport was built in 1995, an inter-governmental agreement (IGA) was established permitting Denver to build the new airport in Adams County. The agreement limits the amount of noise the airport can generate at specific locations in the surrounding areas. Failure to comply with the noise limits results in substantial financial penalties. As part of the noise compliance monitoring efforts, airport staff members routinely worked closely with FAA to monitor flight tracks and procedures in an effort to stay within the noise limits imposed by the agreement. DEN reports annually to the county regarding its performance, identified violations, and mitigations to violations. Penalties of up to $51 million per year are possible. In particular, the agreement stipulates an LEQ of 30-40 dB as the cumulative annual limit for points along an arc along the west side of the airport and that the 65 DNL contour for the baseline procedures is not exceeded in its geographic limits. The arc along the west side of the airport comprises 101 grid points spaced a mile apart along the arc to the west. At the end of every year, the annual report documents DEN's compliance with the 65 dB noise contour and the LEQ levels at the points along the western arc. Contour violations can result in a $500,000 fine. Grid point violations also can result in a $500,000 fine per event per point. Thus, moving flight tracks even slightly has huge impact on non-compliance and the cost to DEN.

The D01 controllers felt that PBN could mitigate this traffic issue, particularly with improving the predictability of traffic and provide noise compliance. At that time, Denver was not a part of the FAA Metroplex program. Therefore, they decided to pursue the initiative locally by partnering with the DEN ATCT; the Denver Air Route Traffic Control Center, ZDV; the Denver International Airport; United Airlines; Southwest Airlines, and Jeppesen. The project initially focused on the implementation of RNAV arrival and departure procedures but expanded to include the development of RNP approach procedures to each runway. Jeppesen, located in Englewood, CO, had a close relationship with the airport and volunteered to chart RNP approach procedures to showcase the next generation of PBN capabilities and procedures. Southwest Airlines supported the effort as they were particularly interested since they were somewhat equipped to use the RNP procedures. Jeppesen ultimately designed all of the 12 RNP AR approach procedures.

Processes Used

As previously indicated, the initial design and collaboration efforts were conducted locally through the design team. The procedure development process followed the FAA 18-step process. Development and implementation of the procedures was a three year process beginning in January 2010. The RNAV SIDs and RNAV STARs were implemented in two phases. The RNAV STARs were published in December 2012 and the RNAV SIDs and RNP AR SIAPs were published in March 2013.

The initial design violated the IGA with the communities around DEN, and required re-work to comply with the IGA. This demonstrates the value of collaboration with the airport and communities and an awareness of noise conditions and constraints before designing procedures.

Criteria Development

DEN obtained a waiver to conduct dual simultaneous RNP AR approaches to its widely spaced parallel runways (centerlines separated by more than 9,000 feet) with visual approach to the middle runway (Runways 16L, 16R and 17R). During months where VFR can be used, DEN may have up to 2,000 RNP AR arrivals. DEN is a second demonstration site for the FAA's Established on RNP procedures, behind Seattle-Tacoma Airport. This technique of air traffic management considers an aircraft on an RNP approach established or stabilized, therefore eliminating the requirement to maintain standard radar separation (3 nm lateral or 1,000 feet vertical) between other aircraft on a simultaneous independent and/or dependent parallel approach path to an adjacent parallel runway. DEN is currently pursuing a waiver in order to conduct RNP AR approaches to the three parallel runways (Runways 34R, 35L, 35R) in IMC.

Project Communication and Public Outreach

The FAA worked side-by-side with DEN and the environmental contractor. DEN staff was involved throughout the entire process. One component to the successful collaboration was that the TRACON, ATCT, airport, airline staff, and other people on the design team worked well together and trusted one another. Also, several of the FAA and airline staff members on the design team served as project champions who helped move the project forward when serious roadblocks were encountered throughout the development and implementation process. There was a high level of public interest in Denver due to existing referendums with stringent noise requirements and the IGA's financial penalties of potentially millions of dollars of fines for noise violations.

The IGA governing DEN's operations, which is unique to the airport, drives collaboration, particularly with the city and county surrounding the airport. Such collaboration and openness always has the potential of generating a problem, but it is necessary to be open with such large-scale projects. The design team met with state and national park representatives early in the process to ensure compliance with noise restrictions they impose. The project team included an airspace representative for DEN, but the Airport Noise Abatement Manager oversaw the airspace design aspects because noise abatement became the driving force for design requirements and changes due to the highly sensitive noise restrictions for DEN. The project team met regularly throughout the project and maintained a record of meeting minutes. During the design process, the airport would identify noise sensitive areas and work with FAA representatives to make adjustments to procedures as needed to comply with the stringent noise requirements.

During the environmental analysis phases of the project, the FAA conducted three stages of public and agency meetings: 1) initial scoping meetings, 2) mid-term review meetings of the draft final designs, and 3) draft EA review meetings. Each of these stages included at least one agency meeting for local planning officials and three public meetings at various sites in Denver. The environmental team worked to broadly publish as much information as possible and conducted two levels of outreach: 1) advertisement to the community and 2) distribution packets to elected officials and planning members. Public advertisements to the community included standard legal notices (Federal Register, Denver Business Journal), a published half-page advertisement in the Denver Post during the scoping stage of the project, and a web site. At each stage, the distribution packets with all relevant documentation in hard copy and electronic forms were sent to federal, state, and local elected officials throughout the nine-county Denver metropolitan area.

Environmental Analysis

The FAA ATO led the development of an EA with the assistance of a private contracting firm. The EA followed the NEPA standard process. They conducted three stages of public and agency meetings. The three stages of meetings were initial scoping meetings, meetings for mid-term review of the semi-final design, and then final meetings once the draft EA was available to review. At each stage, the contractor held three public meetings and one agency meeting. The three public meetings included one meeting close to each of the three airports (Denver, Centennial, and Rocky Mountain). The agency meetings were for local planning officials, and included representatives from Centennial and Rocky Mountain Metropolitan Airports. DEN also conducted its own environmental analysis to ensure compliance with these local constraints prescribed in the IGA, since such analysis did not fit with the FAA's noise analysis methodology. This was an iterative process of conducting its own evaluations of the proposed designs, and then proposing adjustments to the design to eliminate identified noise issues.

Project Outcomes

Outcomes from the Denver PBN departure, arrival, and approach implementation project include:

- The implementation of SIDs, STARs, and RNP AR flight procedures.
- Shorter routes resulting in fuel and emissions savings:
  - DEN is saving 4.5 nm in flight distance per RNP arrival compared to the similar conventional approach, although this benefit varies by runway configuration. This provides a significant reduction in fuel consumption and noise exposure.

    - Using RNP AR approach procedures in IMC, flights could possibly save 20-30 nm in flight distance; this is due to the arrival queue lengths which typically arise in IMC, and how far the aircraft have to fly to conduct the final approach procedure.
- Noise reductions and an associated $1.5M reduction in noise violation fines.
- Collaborative working relationships; and public outreach.
- Unique use of RNP AR approach procedures to connect the RNAV STARs with the final approach procedures without having to widen downwind legs of the RNAV STARs.
- RNP approaches benefiting non-participating aircraft. This occurs on Runways 34L/R, which are staggered to the north and Runways 35L/R, which are staggered to the south. The flight efficiency benefits of the RNP AR procedures incentivize equipped aircraft to land on runways with longer taxi distances to the terminal, thus freeing the remaining runways for the non-equipped aircraft. This promotes a mixed equipage management policy, supported by D01 controllers, of segregating equipped and non-equipped aircraft by runway: RNP AR aircraft to one runway, non-equipped to other runways.
- To date, DEN has paid $41M in fines for noise violations. Due to the PBN procedures, DEN is operating well within the boundaries of the 65 dB contours, and three fines totaling $1.5M due to non-compliance with prior noise levels at specific grid points were eliminated.
- To date, there has been no major negative reaction to the designed procedures since they've been implemented in their final form. The airport has received approximately twelve complaints concerning PBN procedures. Initially there was some skepticism from controllers, but they have come to adopt and appreciate the new PBN procedures.
- The north-south directional STARs implemented to permit large altitude windows for arrivals to conduct OPDs were initially too complex for some controllers and flight crews. Simpler approaches to designing procedures have since been implemented.

Post-Implementation Metrics

The primary metric for post-implementation assessment of the PBN procedures from the airport's perspective is noise. The LEQ of noise is assessed at points along an arc along the west side of the airport. The DNL of noise is compared to an established 65 decibel noise contour. On an annual basis, DEN conducts flight track analysis to ensure compliance with the local constraints prescribed in the IGA. In addition, a formal assessment of compliance with the contour and grid point noise thresholds stipulated in the IGA is performed annually. DEN is assessed a significant fine of $500,000 for each exceedance. Analyses indicate a decrease in noise, and increased compliance with IGA noise agreements established through the development of the new airport in 1995.

Additional assessment metrics include airport arrival throughput, flight distance and frequency of RNP AR approach usage. Regarding arrival throughput, DEN monitors its peak arrival throughput, particularly when conducting simultaneous arrivals to its three parallel runways. Regarding flight distance, arrivals to DEN via RNP approach procedures have demonstrated reductions in average flight distance, and greater reductions are expected in IMC. Regarding RNP AR approach usage, DEN is actively tracking how many arrival aircraft are using the RNP AR approach procedures.

The FAA's PBN Dashboard provides analysis of the average daily number of IFR operations, the average daily usage levels of individual RNAV SIDs and RNAV STARs, and the usage levels of RNP AR approaches with RF legs for a specified calendar year for DEN (9). It indicates an average of 1,591 daily IFR operations. The average daily usage counts for the RNAV SIDs sum to 951 departures, and for the RNAV STARs sum to 985 arrivals. RNP AR approaches were executed by 10,939 arrivals among 66,125 candidate aircraft. However, rates of execution were over 50% for the approach procedures to runway 17L and runway 17R.

Lessons Learned and Best Practices

The lessons learned from the Denver case study include:

- Local participation and coordination was a primary reason for success.
- Collaboration with airport, airline, and industry groups was key to the development of the procedure designs.
- Early coordination with entities impacted by aviation noise, before developing preliminary designs, was critical.
- Outreach was broad across the public and elected officials. It included numerous meetings and was deeply informative.
- PBN improved the airport's compliance with rigorous noise abatement programs, increased the airport's throughput, reduced emissions from aircraft, reduced aircraft fuel consumption, reduced public exposure to aircraft noise, and improved the safety of air traffic.
- All members on the design team have to be involved all the time in the development process from start to finish.
- The design process should not be partitioned or worked independently by individuals during different phases of the process.
- Involvement of airports and local personnel in implementing PBN procedures is successful when those who are included are closest to the problems, know the airspace, and have relationships with and knowledge of the local community. DEN was so heavily integrated in the PBN development process, that it wasn't an issue or a requirement to obtain official airport approval. It was important, though, to make sure the airport involved the public.
- Do not wait too long to involve appropriate people who may be impacted by noise resulting from the new PBN flight procedures. Presenting designs that are largely complete to interested parties results in design issues and conflicts.

Henderson Executive Airport—PBN Departure, Arrival, and Approach Implementation

The Clark County Department of Aviation (CCDOA) first developed PBN approach procedures as part of its effort to enhance HND as a reliever airport. This motivated a subsequent effort by the FAA's PBN Program Office to develop preliminary designs for PBN arrival and departure procedures for the airport. The National Business Aviation Association (NBAA) lobbied for final implementation of the PBN arrival and departure procedures to enable using HND for its annual Business Aviation Convention & Exhibition (BACE). Terrain and traffic to Las Vegas McCarran airport presented challenges in the design. A Categorical Exclusion for the procedures was ordered on December 2010, so the community was not involved and outreach did not take place.

Introduction

HND is a general aviation reliever airport for the Las Vegas McCarran International Airport (LAS) serving the Las Vegas/Clark County region of Nevada. HND is located in Clark County, 11 miles south of central Las Vegas. The reliever airport has one terminal, two runways, and an FAA operated control tower. In 2013, HND had 154,051 enplanements and 182,200 operations.

The FAA's PBN Dashboard provides analysis of the equipage levels among general aviation, Part 121 major and regional aircraft, and IFR operations at HND as of January 2015 (Federal Aviation Administration 2015). HND does not support cargo operations. The results indicate that over 100% of Part 121 regional aircraft, and 50% of the other categories, are capable of RNAV 1 and RNP 0.3-1. No aircraft are capable of RNP AR. The FAA's PBN Dashboard indicates that HND has an inventory of three RNAV SIDs, eight RNAV STARs, and no RNP approach procedures.

In 1996, the CCDOA purchased the airport (named Sky Harbor at the time) as part of an ongoing effort to meet the future aviation needs of southern Nevada. This included servicing the rapidly growing local population, and increasing the capacity for commercial operations at LAS by accommodating additional operations at HND. At that time, the airport had one 5,000-foot runway, a single terminal building with a control tower, several large hangars, ten T-hangars, and a handful of trailers. The name was changed to the Henderson Executive Airport, and the airport was reclassified to reliever status within the National Plan of Integrated Airports. The CCDOA invested more than $30 million in Henderson Executive Airport to create a premier corporate aviation facility and an attractive, convenient and economical alternative to LAS. Enhancements included two new parallel runways, a new terminal building, hangars, and transient ramp improvements.

As traffic grew in the Las Vegas area commercial capacity became more of a concern at LAS and peaked during the annual NBAA BACE in the early 2000s. The NBAA BACE is the largest non-military aviation trade show in the world and one of largest trade shows—of any kind—in the world. When held in Las Vegas, LAS becomes saturated with business jet and other general aviation activity creating major delays for the scheduled commercial carriers. During the convention, the impact on operations at LAS reached the point of shutting down Runway 01R-19L due to the lack of space for parking in the general aviation ramp area creating runway/taxiway egress constraints. Scheduled commercial service was disrupted causing significant delay, affecting to both local businesses and the NAS. At that time HND did not have any published instrument flight procedures of its own. Instead, HND traffic would follow the published SIDs and STARs for LAS and expect to be vectored to or from the airport in visual conditions.

The CCDOA worked with NBAA to move the home airport from LAS to HND for the annual convention and exhibition. The new improvements made it an attractive airport and eventually resulted in the NBAA Convention moving operations to HND. In 2006, the CCDOA worked to implement VOR/DME and GPS RNAV SIAPs as well as Obstacle Departure Procedures (ODP) to enable IFR operations. However, the procedures were not efficient because they conflicted with LAS traffic and were limited to use by aircraft in approach categories A and B (the lowest approach-related speed ranges typical of small single- and multi-engine aircraft). In addition, HND arrivals and departures still had to share the SIDs and STARs published for LAS resulting in impacts to the traffic flow at LAS and a limited utilization of the runway capacity at HND.

In 2007 the FAA and MITRE began the Las Vegas optimization of the air traffic routes serving McCarran International Airport, Henderson Executive Airport, and North Las Vegas Airport (LAS Optimization). This was motivated by CCDOA planning initiatives for a new commercial airport, and capacity enhancement changes desired by the Las Vegas TRACON (L30) and the Los Angeles ARTCC (ZLA). The initiative was ordered by the vice president of the FAA's Mission Support Services. The FAA's PBN Program Office led and coordinated the 18-step Process to develop the procedures. The result of this program was a complete preliminary design of SIDs and STARs for all airports in the Las Vegas area.

Although the LAS Optimization program resulted in the preliminary design of SIDs and STARs for HND, at its completion there was no plan for integration. Further work was also required to address the deficiencies in the SIAPs including arrival and departure conflicts with LAS traffic, missed approach conflicts with LAS, and the lack of procedures for category C and D aircraft (those with approach-related speed ranges typical of airline and large/military jets).

In 2009, a local initiative, separate from the LAS Optimization program, was established to improve the GPS RNAV SIAP for HND. The request went through the operations support group (OSG) of the FAA's Western Service Center and was reviewed by the FAA's RAPT for approval and development. In 2010, the NBAA lobbied to have the HND STARs and SIDs processed and implemented separately from the LAS Optimization project. A Categorical Exclusion for the procedures was ordered in December 2010, so the community was not involved and outreach did not take place. The HND procedures were implemented in 2011, in time for the NBAA convention.

Demographics

HND is surrounded by middle-income residential developments to the north and east of and undeveloped Bureau of Land Management park land to the south and southwest of the airport. Figure C-5 depicts the areas surrounding HND.

Source: Google Maps

Figure C-5. *Henderson Executive Airport and the surrounding area.*

Project Description

A collaborative effort to design new PBN procedures was initiated to develop SIDs and STARs and improve the SIAPs at HND. The stakeholders included L30, ZLA, the NATCA, and NetJets (the designated "Lead Operator" at HND). Representatives from each of these groups made up the design team for the new PBN procedures. Several goals were established including:

- Publication of the procedures one cycle before the NBAA Convention date of October 2011.
- Integration and de-confliction of Las Vegas satellite airports.
- Development independent DME/DME/IRU or GPS RNAV 1 SIDs and STARs to serve HND.

At the time, L30 was participating in the third iteration LAS Optimization project, and had already designed multiple SIDs and STARs based on RNAV 1 procedures when the implementation phase of the project came to an end for unknown reasons. Although the LAS Optimization program was stopped, local interest in implementing SIDs and STARs procedures, and improving the SIAPs at HND, was high. Efforts from the local groups continued to move forward. Four RNAV STARs, three RNAV SIDs, and one RNAV GPS SIAP were included in the final designs. The SIDs and STARs were based on the preliminary designs in the LAS Optimization project. The RNAV GPS SIAP was modified to connect with the STARs, avoid conflicts with LAS traffic, and include approach category C aircraft. Upon the completion of the preliminary design, the FAA took over the formal development of these procedures supported by a contracting firm who served as the project coordinator. Under a separate effort, NetJets developed a number of special use procedures composed of RNAV tracks that could be used in visual meteorological conditions (VMCs). This provided improved and safer operations in and out of HND. A GPS approach was also developed with higher landing minima, but allowed for a missed approach procedure that would de-conflict from LAS and accommodate approach category C aircraft.

The FAA's Metroplex initiative announced the kickoff meeting for the LAS Metroplex effort for August 4, 2015. It will be an opportunity for HND to engage directly in developing improved PBN procedures and perhaps coordinate more with the community as part of the process. The NBAA will serve as a co-lead operator in the project, which will be a first for an FAA Metroplex initiative.

Processes Used

The development of the procedures originated from the LAS Optimization project and was conducted by a local procedure design team following the 18-step Process. The design team included airlines and other interested operators, local and regional FAA ATC personnel, FAA Flight Standards, MITRE, and other appropriate contract support. An EA was conducted following the NEPA guidelines and standards.

Criteria Development

A safety case and waiver to criteria was required to include CAT C aircraft on the GPS RNAV SIAP serving HND. The area required for protection in the missed approach expands based on the category of aircraft. The area required for approach category C aircraft encompasses LAS arrival and departures in many configurations. The operations support group (OSG) of the FAA's Western Service Center facilitated the changes to the procedure within the lines of business at the FAA. The FAA RAPT gave the final review and approval of the procedure.

Project Communication and Public Outreach

The LAS Optimization project and the HND PBN implementation effort required communication and coordination between all of the stakeholders. The CCDOA was involved in the development of HND to accommodate business jet traffic, implementation of preliminary SIAPs, and with the initiation of the LAS Optimization (which evolved out of a planning effort for a new commercial airport in LAS). CCDOA supported the FAA's efforts to increase efficiency in the LAS Metroplex and specifically at HND. Multiple public hearings were held associated with the EA completed for the LAS Optimization project. However, relationships with the city of Henderson have been challenging. A community outreach program was not initiated as part of this specific effort. The FAA's Metroplex initiative will be an opportunity for HND to better coordinate and communicate with the community, and to engage with the FAA in procedure development.

Environmental Analysis

An EA was conducted and completed as part of the LAS Optimization project. In September 2012 a FONSI was issued for the proposed design of the air traffic routes in the LAS area. This EA was sufficient to obtain a Categorical Exclusion for the new SIDs and STARs for HND. The modification of the SIAP was evaluated through the completion of an Environmental Worksheet. The worksheet referenced EA efforts associated with the LAS Optimization project and the EA for the airport expansion as justification for a FONSI.

Project Outcomes

Outcomes from the Henderson PBN departure, arrival, and approach implementation projects include:

- The CCOA has successfully developed HND as a reliever airport, increasing capacity at LAS.
- The NBAA's BACE has and will return every odd-numbered year, bringing with it the economic benefits that the community wanted.
- Henderson-based flight departments, as well as transient operators, have published, terminal instrument procedures, increasing the safety and utility of this mountainous location.
- HND and LAS have separate STARs and SIDs serving their airports, improving access to both airports.
- Success of the project can be attributed to collaboration of local FAA and industry to achieve common goals through the implementation of PBN.
- The design team's concepts, while sound, were not universally embraced by all controllers in all sectors. ZLA has changed one of the altitude and speed constraints on the Northwest arrival (ADDEL1 STAR) via a Notice To Airmen (NOTAM) to provide a more comfortable fit with an RNAV STAR for LAS that it shadows. Revised designs have been prepared for when the FAA undertakes its Metroplex initiative in Las Vegas.
- The lack of public outreach in development of PBN procedures may be negatively impacting relationship of HND with the community of Henderson. There may be an opportunity for further outreach as part of the LAS Metroplex initiative in 2015.

Post-Implementation Metrics

No specific post-implementation assessment criteria or metrics were identified in the case study interviews. Representatives from NetJets have indicated that RNAV SIDs, STARs and GPS RNAV approach integrate fairly well into the existing Las Vegas airspace scheme. The NBAA convention continues to be held in Las Vegas to this day and has had less impact on commercial operations at LAS.

The FAA's PBN Dashboard provides analysis of the average daily number of IFR operations, the average daily usage levels of individual RNAV SIDs and RNAV STARS, and the usage levels of RNP AR approaches with RF legs for a specified calendar year for HND (Federal Aviation Administration 2015). It indicates an average of 71 daily IFR operations. The average daily usage counts for the RNAV SIDs sum to 4 departures, and for the RNAV STARs sum to 5 arrivals. Usage of RNP AR approaches is not reported.

Lessons Learned and Best Practices

The lessons learned from the Henderson case study include:

- PBN procedure development projects undertaken at the local level can be highly successful.
- Successful teaming includes local FAA facilities, transportation departments, airports, aircraft operators.
- PBN can be used to overcome significant flight procedure design constraints imposed by terrain and proximate airports.
- Improved access to reliever airports afforded by PBN procedures can make them attractive to additional aircraft operators, with potentially significant local economic impacts.
- Improved access to reliever airports afforded by PBN may increase capacity and/or efficiency at the hub airport in the areas.
- Previous environmental assessments may be sufficiently broad to support new PBN procedure development projects.
- Lack of public outreach in development of PBN procedures can negatively impact the airport's relationship with the surrounding community.

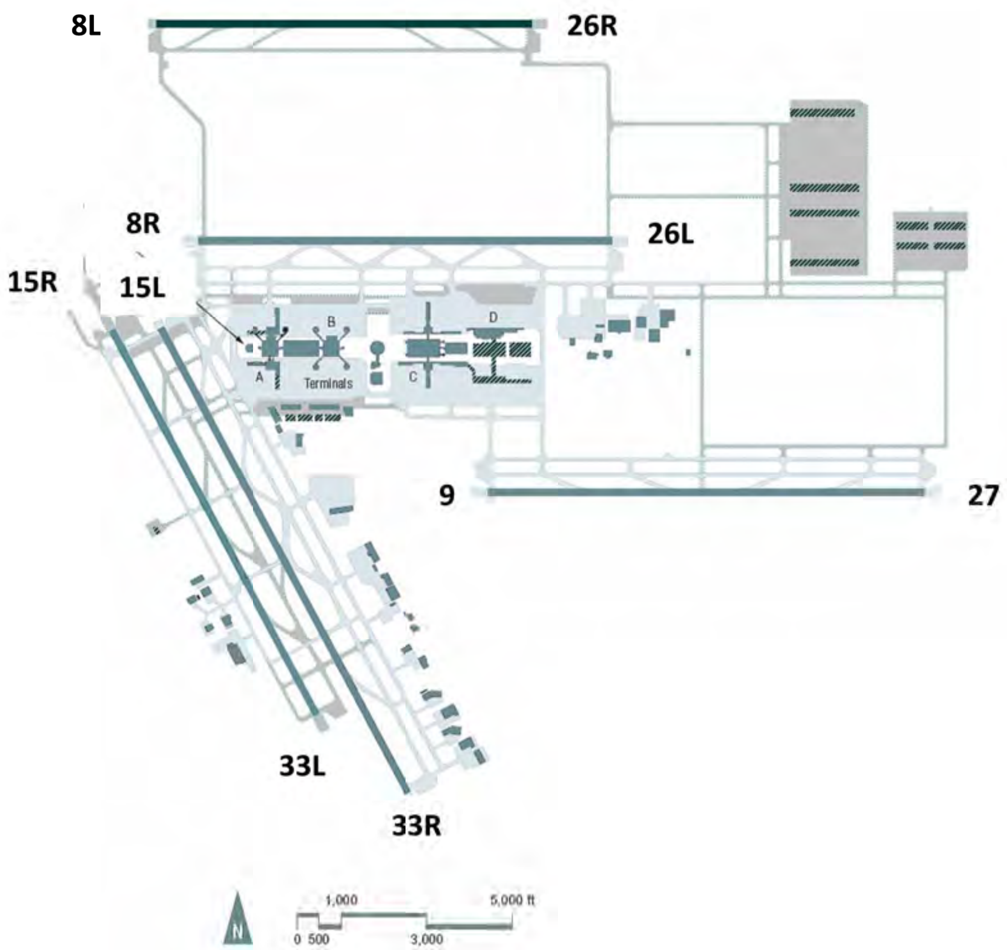
Houston Metroplex—PBN Departure, Arrival, and Approach Implementation

PBN procedures were developed for the Houston Metroplex, in particular for George Bush Intercontinental Airport, by the FAA's Metroplex program. The study team consisted of FAA, NATCA, MITRE, and United and Southwest Airlines representatives. The Metroplex design process resulted in the development of 20 new RNAV STARs, 20 new RNAV SIDS, five new non-RNAV STARs, and four new RNP AR approaches, which have reduced fuel burn, emissions, and noise. The design team conducted limited outreach to the Houston Airports System and local government representatives, and the Houston Airport System (HAS) conducted its own public meetings.

Introduction

The FAA is redesigning airspace and addressing airspace inefficiencies, introducing new PBN procedures and making use of time-based flow management (TBFM) to make the Houston Metroplex airspace more efficient and improving access to its airports. The Houston Metroplex includes George Bush Intercontinental Airport (IAH), David Wayne Hooks Memorial Airport (DWH), William P. Hobby Airport (HOU), and Sugar Land Regional Airport (SGR). HAS is a department of the City of Houston that manages city airports. Its administrative offices are on the property of George Bush Intercontinental Airport, and it manages Bush, William P. Hobby Airport, and Ellington Airport.

IAH is a large hub airport located 23 miles north of central Houston and currently ranks third in the United States among U.S. airports with scheduled non-stop domestic and international service and is the 12th busiest airport in North America in terms of passenger traffic. The airport has five runways and five terminals, as shown in Figure C-6. IAH is the main hub for United Airlines. In 2014, IAH served more than 41 million passengers and accommodated 508,935 landings and takeoffs.



Source: Federal Aviation Administration.

Figure C-6. *Plan view of Houston George Bush Intercontinental (IAH).*

HOU is located seven miles from central Houston, and is the region's secondary aviation facility, handling the area's domestic flights and is an international point of entry for general aviation activity between Texas and Mexico. The airport has four runways, one terminal, and is categorized as a medium hub airport. In 2013, HOU had 5,377,050 enplanements and 410,372 operations. DWH is a general aviation airport located near the city of Tomball, 23 miles northwest of central Houston. It is the busiest general aviation airport in Texas and one of few privately owned airports with an FAA operated control tower. DWI has one terminal and three runways, including a seaplane landing area and is also home to numerous flight schools. In 2013, the airport had 358 enplanements and 345,137 operations. SGR is located in Sugar Land, Texas, approximately 17 miles southwest of central Houston. The airport is categorized as a general aviation airport and is the fourth largest airport in Greater Houston. SGR has one runway, one terminal building, and is served by a non-federal control tower. In 2013, SGR had 979 enplanements and 144,036 operations.

The FAA's PBN Dashboard provides analysis of the equipage levels among general aviation, Part 121 major, regional and cargo aircraft, and IFR operations at airports in the Houston Metroplex as of January 2015 (Federal Aviation Administration 2015). The results for IAH indicate that approximately 100% of Part 121 aircraft and IFR operations, and 80% of general aviation aircraft, are capable of RNAV 1. The same levels among the categories except only 70% of Part 121 cargo carriers are capable of RNP 0.3-1. Fewer than 30% of the Part 121 major aircraft and IFR operations, and none of the other categories, are capable of RNP AR. The results for HOU indicate that over 90% of all categories of aircraft are capable of RNAV 1 and RNP 0.3-1, over 50% of general aviation and IFR operations, and over 10% of the Part 121 regional aircraft are capable of RNP AR.

The FAA's PBN Dashboard indicates IAH has an inventory of 13 RNAV SIDs, 13 RNAV STARs, and six RNP approach procedures, and HOU has an inventory of 11 RNAV SIDs, seven RNAV STARs, and no RNP approach procedures (Federal Aviation Administration 2015). The Houston Metroplex program was initiated by FAA in May 2011 and was the fifth airspace design effort under the FAA Optimization of Airspace and Procedures in the Metroplex program (Metroplex). The study team consisted of FAA, NATCA, MITRE, and United and Southwest Airlines representatives. The Metroplex design process resulted in the development of 20 new RNAV STARs, 20 new RNAV SIDS, five new non-RNAV STARs, and four new RNP AR approaches. A number of existing procedures were redesigned as part of this effort incorporating the design components of the new procedures.

Demographics

The immediate areas surrounding IAH, depicted in Figure C-7, are primarily industrial with the exception of some middle-income residential areas located to the northeast. The immediate areas surrounding HOU, shown in Figure C-8, include industrial areas to the northeast, east, southwest, and west and middle- to low-income residential areas located to the north, southeast, south, and northwest. There are no formal community action groups established who work with the HAS on noise and environmental issues. HAS does receive noise complaints for air traffic to IAH and HOU, but there is no significant opposition from a particular group.

Project Description

The Houston Metroplex initiative focused on leveraging PBN and TBFM capabilities to create more efficient arrival and departure routes, arrival routes enabling OPDs, and departure procedures with fewer climb restrictions. The project area covered the entire airspace of the Houston TRACON (I90). The project included airspace and procedures at DWH, HOU, IAH and SGR. The FAA study teams, working with United Airlines and Southwest Airlines, selected the procedures to be changed.

Processes Used

The Houston Metroplex initiative was a three year process that started in summer 2011 and ended in May 2014. The Metroplex initiative is composed of five phases: Study Team and Scoping; Design and Procedure Development; Operational, Environmental; Safety Review, Implementation and Training; and Post-Implementation Review and Modification. The Study and Scoping phase was completed by a study team while the Design and Procedure Development, Operational, Environment, and Safety

Source: Google Maps

Figure C-7. *George Bush Intercontinental Airport and the surrounding area.*

Review, and Implementation and Training phases were conducted through the efforts of a Design and implementation team. Implementation of the new procedures followed the FAA 5-step process.

The study team collaborated with local air traffic control personnel and industry to understand the local airspace and traffic characteristics, such as flight paths, traffic levels and aircraft equipage, and to identify what improvements may be made. This process took approximately 90 days. The Study Team forwarded its recommendations to the design and implementation team. The design and implementation team leveraged its PBN expertise and collaborated with an environmental consultant to design the procedures to meet the design recommendations. This took approximately 2.5 years.

The design and implementation team first designed the lateral paths of the flight procedures using Performance Data Analysis and Reporting System (PDARS) data and TARGETS. Then cockpit simulations of the different aircraft and equipment characteristic of the airport's traffic were conducted to determine the altitude profiles of the flight procedures. Finally, human-in-the-loop (HITL) simulations with controllers and pilots were conducted to evaluate the compatibility of the procedures with traffic management automation, in particular the FAA's TBFM tool.

Design principles included avoiding moving the ground tracks closer to those noise-sensitive areas; balancing runway usage while avoiding significant changes to traffic loadings of individual airport runways (which would otherwise shift the noise exposure to other areas surrounding the airport); and, near state and national parks, avoiding changes to ground tracks below 18,000 feet AGL.

Source: Google Maps

Figure C-8. *William P. Hobby Airport and the surrounding area.*

Criteria Development

No new criteria were required to be developed as part of the Houston Metroplex project.

Project Communication and Public Outreach

The FAA managed project communications with the study team and the design and implementation team.

As part of the procedure development process used in procedure development projects undertaken by the FAA Metroplex program, the environmental and noise experts of the FAA Metroplex design team typically meet with local airports and noise roundtable groups to understand environmental sensitivities in the preliminary design phases. This includes identifying sensitive land use areas. However, if the surrounding cities and communities don't agree with the procedures design, this can cause conflict. The Houston Metroplex team met with the HAS three times during the process and attended noise round table public meetings held by HAS near William Hobby Airport (HOU). There were specific meetings early on in the project between the FAA Metroplex team and HAS to discuss noise and environment; these meetings are listed in the EA. Other meetings were held by HAS to brief the public and respond to their questions. Airlines, general aviation groups, anyone in industry were also invited to meetings. The design team met the noise requirements imposed by the HAS and the community to the extent possible.

The FAA prepared a project webpage for the study. Project briefing packages were sent out as part of the EA efforts to over 44 Houston area elected officials, multiple state and federal agencies, all counties in the study area, and the Alabama Coushatta Tribe. Each package contained a cover letter, study area information, and the identification of all entities on the mailing list. The FAA also placed public notices in the 19 area newspapers.

The Houston Metroplex project did not conduct a formal public outreach program as part of the EA of the formal design. Other metroplex projects do have public outreach meetings; this varies site by site, and is decided by the FAA Program Office. The Houston Metroplex project was on the White House Infrastructure Dashboard as a project that could be completed quickly, the environmental process could reasonably be accelerated by making minimal changes to the procedures near the ground, and the outcome would have significant economic impact.

Environmental Analysis

The FAA Metroplex projects are constrained to three years or less, which limits the environmental process that can be undertaken. Procedure designs avoid changing the ground tracks of aircraft at or below 10,000 feet and are limited in what changes can be implemented between 18,000 feet and 10,000 feet AGL. The greatest design freedom is above 18,000 feet. Within these constraints, the FAA's approach is to take the legacy procedures and to modify them to the newest standards for RNAV procedures, including shortening routes, reducing level-offs, designing routes to yield more predictable flight paths, and deconflicting departures and arrivals to permit climb via and descend via clearances. When developing procedures, the design team identifies noise-sensitive areas, and tries to be conscious of them in the design. The design team avoids moving the ground tracks closer to those noise-sensitive areas.

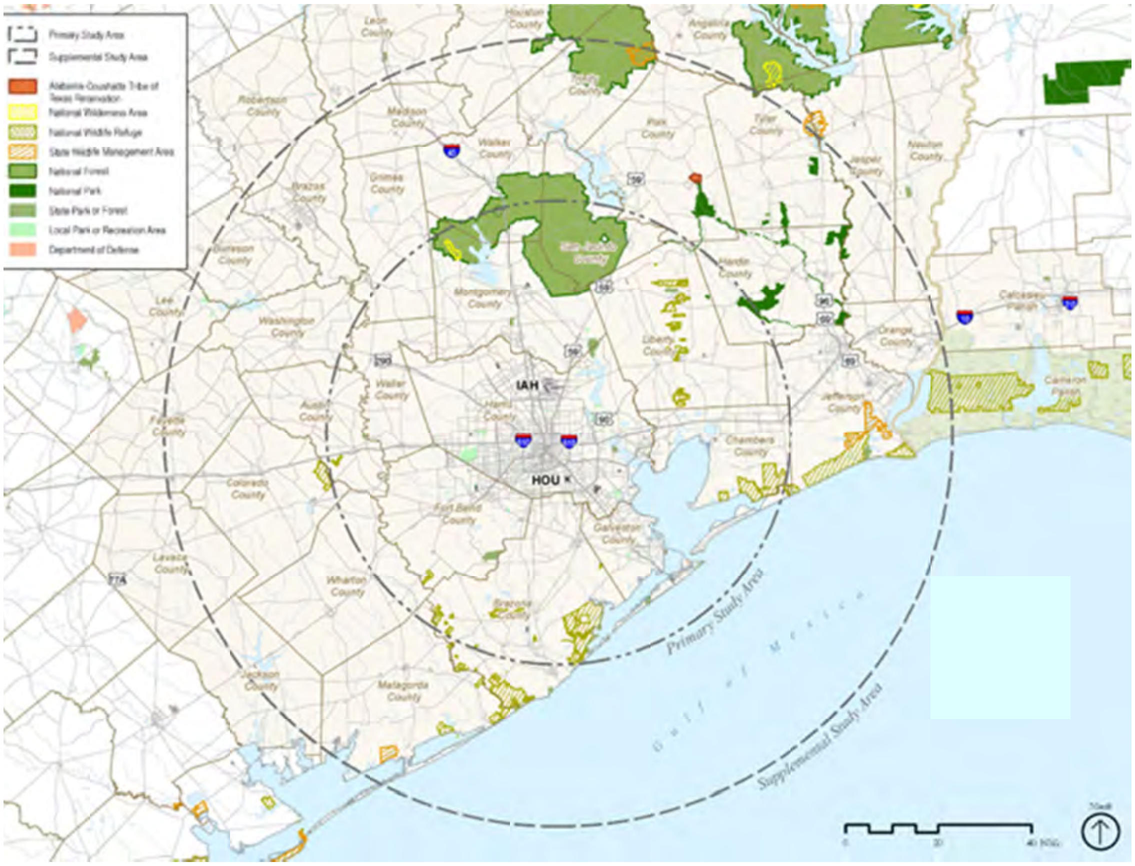
An EA was conducted by the FAA as part of this project following NEPA standards. The study evaluated environmental impacts in primary and supplemental study areas. The primary study area was a 50 nautical mile radius of a point midway between IAH and HOU, below 10,000 feet AGL. The supplemental study area was an 85 nautical mile radius of a point midway between IAH and HOU, between 10,000 and 18,000 feet AGL. Figure C-9 highlights the study area.

The EA was completed in January, 2013 and a FONSI ROD was issued on June 13, 2013 (Federal Aviation Administration 2013). Noise analysis was conducted as part of the EA and included comparing no action versus proposed action alternatives. Noise data were presented on a scale of low, medium, and high. Results of new departure flight procedures show a reduction in geographic range of noise in medium-high noise ranges. The EA did include a public commenting period. However, not many comments were received.

Project Outcomes

Outcomes from the Houston Metroplex PBN departure, arrival, and approach implementation project include:

- Development of 20 new RNAV STARs, 20 new RNAV SIDS, five new non-RNAV STARs, and four new RNP AR approaches. A number of existing procedures were re-designed as part of this effort incorporating the design components of the new procedures.
- Expansion of the four corner post configuration of arrival fixes at the TRACON boundary with dual approaches at each corner to increase airspace capacity.
- Improved unrestricted climbs for departing aircraft.
- Shorter arrival and departure paths.
- Improved efficiency of arrival and departing aircraft within the Houston airspace system.



Source: Federal Aviation Administration

Figure C-9. *The primary study area for the Houston Metroplex environmental assessment.*

- Fuel savings and noise reduction.
- Reports from industry of significant fuel reduction, increased miles saved, and increased ease-of-use by aircraft flight crews by enabling greater use of flight deck automation.
- Controllers are issuing fewer speed, altitude, and heading clearances, which reduces workload and provides extra time to observe traffic.
- The project has had mostly a positive response from the community based on reduced noise from departures as a result of enabling unrestricted climbs.
- The HAS has received questions from the community about how the routes were changed, why the community wasn't notified. The HAS refers all questions to the FAA.

Post-Implementation Metrics

Post-implementation assessment has focused on impacts to industry and air traffic control. Primary metrics of interest to industry have been fuel consumption, flight distance, and flight crew workload. There have been significant reports about fuel reduction, miles saved, and reduced flight crew work-load through greater use of flight deck automation. Primary metrics of interest to the ARTCC control-lers are number of vectors, deviation from defined routes, and number of clearances issued. Vectoring of aircraft within 200 miles of the airport has been mostly eliminated, and there is minimal deviation from the defined routes. Controllers now typically issue a clearance to descend; speed, altitude and heading clearances have been significantly reduced. There are no post-implementation noise data for the procedures at this time.

The FAA discusses the Houston Metroplex project in its NextGen Performance Success Stories (Federal Aviation Administration 2015), however no particular metrics or data are provided. The FAA's PBN Dashboard provides analysis of the average daily number of IFR operations, the average daily usage levels of individual RNAV SIDs and RNAV STARs, and the usage levels of RNP AR approaches with RF legs for a specified calendar year for airports in the Houston Metroplex (Federal Aviation Administration 2015). For IAH, it indicates an average of 1,407 daily IFR operations. The average daily usage counts for the RNAV SIDs sum to 700 departures, and the RNAV STARs sum to 1,700 arrivals. RNP AR approaches were executed by four arrivals among 9,928 candidate aircraft. For HOU, it indicates an average of 528 daily IFR operations. The average daily usage counts for the RNAV SIDs sum to 230 departures, and the RNAV STARs sum to 475 arrivals. Usage of RNP AR approaches is not applicable.

Lessons Learned and Best Practices

The lessons learned from the Houston case study include:

- RNAV can be leveraged to increase airspace capacity with additional routes, and to reduce emissions and noise from aircraft with more efficient departure procedures.
- The FAA is willing to undertake the development of PBN procedures without the involvement of the airports served by the PBN flight procedures, in particular if the procedures are changes in altitude regimes sufficiently high to not immediately impact the airport.
- The FAA conducts an EA including noise analysis and public outreach in its process.
- The airport may not be responsible for noise issues or other environmental impacts of arrival and departure traffic above 3,000 feet AGL.
- If the land use surrounding the airport is otherwise not dense residential, the level of outreach required to gain community approval may not be as high as what is required for airports with dense populations surrounding them.

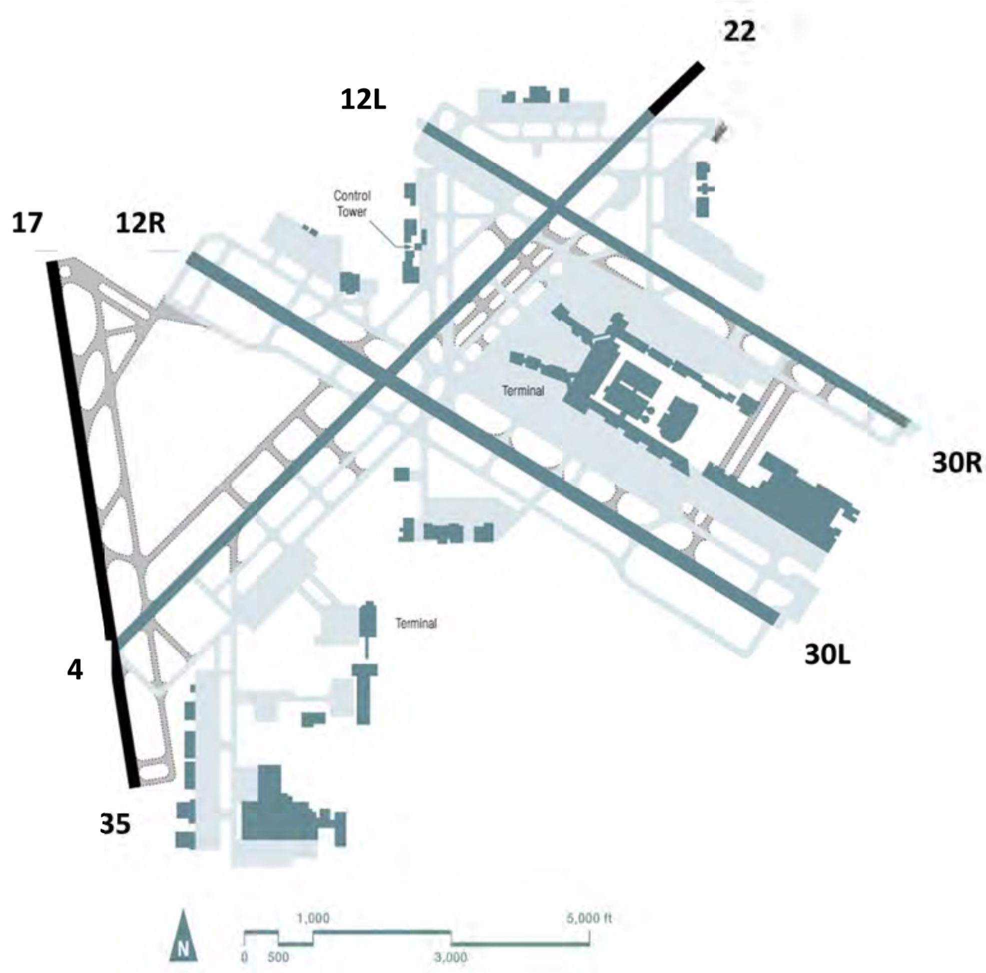
Minneapolis-St. Paul International Airport—PBN Departure and Arrival Implementation

PBN routes were first developed by MSP's Noise Oversight Committee to reduce fuel burn and emissions of aircraft and to reduce noise impact on the surrounding community. In turn, local FAA ATCT personnel, with support from the FAA PBN Program Office, expanded upon these procedures with an airspace-wide design of PBN procedures. The design was a collaboration among FAA, airlines and NATCA, and the airport monitored the process. Insufficient time was allocated for the public outreach campaign to educate the community regarding the designed procedures. Community opposed the RNAV departure procedures to the north due to concentration of operations that increased noise to discrete segments of the population.

Introduction

The Minneapolis-St. Paul Metroplex serves the Twin Cities metropolitan area of Minnesota and includes MSP, Airlake Airport (LVN), Anoka County-Blaine Airport (ANE), Crystal Airport (MIC), Flying

Cloud Airport (FCM), Lake Elmo Airport (21D), and St. Paul Downtown Holman Field (STP). MSP is a large hub and joint civil-military public-use international airport. Located within ten miles of both downtown Minneapolis and downtown St. Paul, it is the largest and busiest airport in the six-state upper Midwest region of Minnesota, Iowa, Nebraska, North Dakota, South Dakota, and Wisconsin. MSP is owned and operated by the MAC. The airport has four runways and two terminals, as depicted in Figure C-10. MSP serves as a major hub for Delta Airlines and is home to the Minneapolis–St. Paul Joint Air Reserve Station. In 2014, MSP served over 35 million passengers and had 412,695 operations.



Source: Federal Aviation Administration

Figure C-10. *Plan view of Minneapolis-St. Paul International Airport.*

The other larger airports within the Metroplex are general aviation airports. ANE is located approximately 11 miles from downtown Minneapolis and 12 miles from downtown St. Paul. It is categorized as a minor-use general aviation reliever airport. ANE has two runways and a non-federal aircraft control tower. In 2014, the airport had 73,951 operations. FCM is located approximately 11 miles southwest of the central business district of Minneapolis. It is categorized as a minor-use general aviation reliever airport for the region and popular as a home base for corporate business jets and turbo-props. It has three runways, an FAA-operated control tower, and an instrument landing system. In 2014, FCM had 75,759 operations. STP is located just across the Mississippi River from downtown St. Paul. It is categorized as an intermediate general aviation reliever airport and is considered to be the metro area's primary facility for private business aviation. The airport has a FAA-operated aircraft control tower, three runways, and is the only reliever airport in the region with a runway longer than 5,000 feet. In 2014, STP had 69,185 operations.

The FAA's PBN Dashboard provides analysis of the equipage levels among general aviation, Part 121 major, regional and cargo aircraft, and IFR operations at MSP as of January 2015 (Federal Aviation Administration 2015). The results indicate that almost 100% of aircraft across all categories are capable of RNAV 1. Almost 100% of general aviation and Part 121 regional aircraft, and over 70% of Part 21 major and cargo aircraft and IFR operations, are capable of RNP 0.3-1. Fewer than 30% of the Part 121 major aircraft and IFR operations, and none of the other categories, are capable of RNP AR. The FAA's PBN Dashboard indicates MSP currently has an inventory of four RNAV SIDs, six RNAV STARs, and five RNP approach procedures.

MSP has an established history of formally acknowledging and addressing air traffic noise. Coordinated noise abatement efforts first began through the establishment of the Metropolitan Airport Sound Abatement Council (MASAC) in 1969.

Over time, the airlines became dissatisfied with the processes followed by the MASAC, resulting in the abandonment of the group in 2000 and the establishment of the Noise Oversight Committee (NOC) in 2002. The NOC is the primary advisory body to MAC on topics related to aircraft noise at MSP. NOC members are officially selected to represent their respective community group and airport user group constituencies and vote accordingly. The NOC is composed of six community and six airport user representatives. The NOC functions as a policy advisory board to the MAC on airport noise issues. The NOC, and its accomplishments, are viewed as a model in the industry.

In July 2007, the NOC began investigating aircraft navigation technology to reduce noise at MSP. In general, RNAV and OPDs were viewed as a critical element to reducing aviation noise exposure to the community as were RNAV SIDs that enhanced compliance with existing vectored noise abatement departure procedures at the airport. In July 2009, the Crossing-in-Corridor and Runway 17 River RNAV departures to route aircraft over noise-compatible land-use areas were submitted to the FAA. Subsequently in 2010, the FAA became interested and proposed a comprehensive airspace-wide PBN project in Minneapolis. The FAA undertook this ambitious airspace design and incorporated the Crossing-in-Corridor and OPD flight procedures into this airspace-wide initiative.

Demographics

The demographics of the areas surrounding MSP are such that commercial and industrial land uses exist to the south and southeast with homogeneous residential development to the north and west of the airport. The communities, particularly those northwest, and west of the airport are primarily white-collar, and middle to high socioeconomic status. These communities are engaged on the airport noise issues and may have connections with local community and business leaders. Figure C-11 shows the areas surrounding MSP.

Source: Google Maps

Figure C-11. *Minneapolis-St. Paul International Airport and the surrounding area.*

Project Description

With support from the FAA PBN Program Office, local FAA ATCT personnel moved forward with the airspace-wide RNAV and RNP implementation at MSP. With the exception of one procedure that proceeded independently, all of the noise-specific RNAV work conducted by the NOC was incorporated into the airspace-wide FAA initiative. In 2011, the NOC began the process of establishing procedure design noise criteria to be forwarded to the FAA for consideration in the procedure development/implementation process at MSP. Given that the FAA was expanding the procedure design and implementation process beyond just a noise reduction effort, the Committee unanimously adopted noise abatement goals and criteria for the FAA to consider in its procedure design and implementation process.

The NOC sent a letter outlining the five key guidelines for the FAA to consider in its procedure design: 1) noise analysis comparing the noise contours and other metrics of the PBN procedures against the legacy procedures, 2) a public information program to inform public, 3) design of the procedures to reduce overflights over sensitive land use areas, 4) design to reduce arrival aircraft noise, and 5) maximize use of RNAV noise tracks as part of the runway use system.

Minneapolis and Edina residents opposed the RNAV departure procedures to the north. The new procedures deviated from the established policy of controllers fanning departures using vectoring in order to disperse the noise of aircraft. Prior to the redesign, local FAA controllers were very good at implementing and adhering to this policy. The "pencil lines" representing a concentration of RNAV operations and increased noise to discrete segments of the surrounding community became the typical "not in my back yard" situation, with no one wanting to bear the brunt of the concentrated aviation traffic if others were more isolated from it. Although the RNAV design was predicated on overlays of legacy flight tracks, they presented a source of real concern and prompted a community member to start the Fair Skies Coalition. The Fair Skies Coalition leveraged social media to speak out against the design.

On November 14, 2012 the NOC determined the FAA adequately considered the NOC criteria in its process. This effort resulted in the establishment of local support for RNAV/RNP OPD STARs to all of the major runways (six different approaches) at the airport and RNAV SIDs for departure operations off of three of the five major runway ends at the airport. Opposition to RNAV SIDs to the northwest of the airport remained significant. After hearing the concerns of the community, the MAC Commission was not able to fully support the PBN design. A compromise was reached involving a partial implementation of RNAV procedures and on November 19, 2012, the MAC Full Commission took action in support of a partial implementation of the RNAV procedures, excluding the RNAV departure procedures for Runways 30L and 30R to the northwest of MSP. In response, the FAA initiated a safety study to evaluate the partial implementation of the procedures.

On February 1, 2013, the MAC sent a letter to the FAA recommending 5 outreach requirements. The requirements included the following: 1) Timing, requesting partial implementation of the FAA's proposed SIDs/STARs until public outreach to affected communities could be completed as planned; 2) Local FAA Leadership, requesting local FAA personnel be placed in leadership positions to communicate with the community; 3) Holistic Outreach, calling for outreach to communities impacted by the partial implementation, as well as those to be impacted by the remaining implementation; 4) Early Coordination with Local Community Leaders, calling for outreach to community representatives of cities surrounding the airport, and addressing their specific concerns; 5) Adequate Resource Allocation, calling for FAA staff and consultant resources sufficient to adequately conduct the outreach and respond to community concerns.

On February 19, 2014, FAA issued a letter to MAC indicating the safety risk management analysis determined that partial RNAV SID implementation "….introduces unacceptable safety risks into the National Airspace System." The letter explained that the determination was driven by the following:

- Runway configuration changes 2-3 times daily.
- Requirement to use automation procedure referred to as the "deck" to change En Route Automation Modernization (ERAM) software preferential departure routes from RNAV procedures to legacy procedures, based on runway configuration.
- Runway configuration changes would require termination, or activation, of the deck with reissuance of revised departure instruction to each aircraft that has already pushed back from the gate or previously received its departure clearance prior to taxi.
- Reissued departure clearances after push back and taxi require head-down operations by the flight crews during a heavy workload time on the flight deck.

The NOC recommended 5 key provisions for how the FAA could conduct PBN design: 1) NOC support of RNAV STARs, 2) OPDs for STARs to all runways at MSP; 3) a case study of successful RNAV SID implementation at another airport with similar challenges, particularly, dense population surrounding the airport; 4) future RNAV SID designs and implementations incorporate previous outreach guidelines; 5) adequate time to prepare and conduct case study and community outreach plan. In March 2014, the FAA took the initiative to redesign all of the previous locally supported RNAV STARs and SIDs, enhancing the design and optimizing efficiency. In March 2015 the FAA implemented the RNAV STARs incorporating OPD at MSP. RNP STARs with OPD were implemented in April 2015.

The FAA reported that between March 24, 2015 and May 11, 2015 a total of 24,778 arrival operations at MSP used the new procedures. Based on the associated fuel burn and emission reduction estimates made by the FAA, over 1.2 million gallons of jet fuel were saved and carbon emissions were reduced by as much as 12.2 metric tons. Although not documented, the implementation of these measures will also reduce other pollutants.

Processes Used

The process used to initiate the preliminary design of the procedures was based on local collaborative effort between MAC, the local FAA, and Delta Airlines. The effort was taken over by the National PBN office after the NOC made the request for the development of the OPDs and SIDS. The FAA followed its 18-step process to develop the procedures for implementation. The NOC developed and initiated its own public outreach program and prepared its own noise contour analysis to inform the FAA's final design.

Criteria Development

No new criteria were developed as part of the MSP PBN project.

Project Communication and Public Outreach

The procedure design phase was a collaborative effort between FAA, NATCA, Delta Airlines, and MAC. The NOC was updated on a regular basis and was knowledgeable of the interactions and design trade-offs being made throughout the process.

The public outreach campaign planned by the NOC was multi-faceted. It included a web site, city council briefings, open houses, news channel presentations, and newspaper articles. The web site was to describe both PBN and the project. Two open houses were held with MAC and FAA representatives, and a Delta Airlines captain detailing the procedures and noise. A Star Tribune (Minneapolis local paper) publication and local TV coverage advertised the web site, the open house meetings, and other information. Briefings were to be given to mayors and other staff of communities. There were also additional presentations to the public.

Environmental Analysis

Neither an EA nor an EIS was conducted as part of this effort. The FAA prepared an environmental worksheet and issued a non-published Categorical Exclusion for the proposed PBN procedures. Further environmental analysis was conducted by the MAC staff. Analysis consisted of a comparison of the DNL contours of the existing flight procedures and the proposed flight procedures as well as modeled DNL and alternative metric noise levels at various locations around the airport.

While the FAA, in controlling and conducting the PBN development and implementation process should take the lead on community outreach and noise analysis, the airport can provide a supporting role in helping to translate local expectations relative to these activates.

Project Outcomes

Outcomes from the Minneapolis PBN departure, arrival, and approach implementation project include:

- The FAA prepared RNAV SIDs and STARs for all runways at MSP as part of this project.

- The MAC supported all procedures except the RNAV SIDs for Runways 30L and 30R. In November 2013, the FAA rejected the partial implementation recommendation based on safety and postponed the PBN implementation.
- Following the rejection of the partial implementation recommendation and the RNAV procedure postponement, the FAA worked to refine the design of the RNAV SIDs and STARs to improve efficiency and reduce environmental impacts.
- The MAC and the NOC established a framework for community engagement and impact analysis that was supported by all stakeholders as a roadmap for possible future RNAV SID design and implementation activities at MSP. In March 2015 the FAA implemented the RNAV STARs incorporating OPDs at MSP. RNP STARs with OPD were implemented in April 2015. This has significantly reduced aircraft fuel burn and emissions at the airport.

Post-Implementation Metrics

To prepare for the implementation of the STARs designed by the FAA, the MAC developed methods for post-implementation assessment of the PBN procedures. First and foremost, they are trying to evaluate how often OPDs are used at the airport. There have been few efforts at other airports to capture this type of data. The FAA's own assessment tools, such as the PBN Dashboard, do not adequately present the data.

The MAC is working with the FAA to get radar flight tracks 100 to 120 nm from the airport. MAC plans to develop target vertical profiles by aircraft type, and to conduct a spatial analysis on flight tracking data to identify aircraft conducting OPDs. Once the aircraft executing an OPD are identified, these data will be analyzed quantitatively in more detail. One particular evaluation metric of interest is the airspace dwell time of aircraft.

The FAA's PBN Dashboard provides analysis of the average daily number of IFR operations, the average daily usage levels of individual RNAV SIDs and RNAV STARs, and the usage levels of RNP AR approaches with RF legs for a specified calendar year for MSP (Federal Aviation Administration 2015). It indicates an average of 1,116 daily IFR operations. Average daily usage counts are listed for 4 RNAV SIDs, and sum to 17 departures. Average daily usage counts for the RNAV STARs indicate an average of 646 daily operations. RNP AR approaches were executed by 57 arrivals from July 2014 through June 2015.

Lessons Learned and Best Practices

The lessons learned from the Minneapolis/St. Paul case study include:

- Airports may initiate and sponsor PBN procedure development projects. Because MSP had initiated the PBN development task and process, the airport established itself as a key stakeholder and team player in PBN development with FAA.
- The FAA, as the agency controlling schedules and budgets for the design and implementation of PBN procedures, will ideally lead all elements of the process, including those elements intended to meet local expectations, such as noise analysis and public information components.
- FAA ATO will ideally recognize airports as a critical component to successful design and implementation efforts.
- Airport operators should focus their role in the PBN implementation on acting as a valuable resource to the FAA by defining local expectations of how the PBN design and implementation process should be conducted in order to ensure successful meeting of those expectations.

- By serving as an important resource to ATO in its formalization of a proactive community dialogue plan, airports can ensure that the local community perspective is understood.
- By airports advising ATO on the establishment of community and industry dialogue mechanisms, procedure design environmental and operational goals can be enhanced, a framework for planning and environmental review can be focused.
- In addition to providing a locally coordinated position on procedure design and environmental review expectations, airports bring data regarding their operations, air traffic characteristics, established procedures, and local technical knowledge to the process.
- Procedure design requirements are airport specific and should consider the demographics of the area and noise-sensitive land use surrounding the airport.
- If the community surrounding the airport is aware of and monitoring airport operations and aviation noise, more extensive outreach may be required to educate them regarding proposed PBN procedure development initiatives and their potential impacts, and to ultimately gain their acceptance of new or altered flight procedures.
- Airports wanting to participate in a PBN implementation project should have a team of people knowledgeable of PBN and capable of advising FAA in design, conducting community outreach, and coordinating between airport, airlines, and community and action groups.
- Local FAA airport representation working with airport management can be a more effective approach to outreach.
- Personnel from local FAA facilities can be quite helpful with outreach, but need to be able to effectively communicate technical issues and impacts to a wide array of interest groups.
- Airports and FAA need to establish and maintain a working relationship with community and local government groups.
- Sufficient time must be allocated to community outreach for a particular initiative, and outreach should be initiated early.
- If the community expects the impacts of the proposed procedures to be significant, they will ideally be allowed time to understand the impacts of, and respond to, proposed procedure changes. If there is no expected impact or it's minimal, less time may be required.

Seattle-Tacoma International Airport—PBN Departure, Arrival, and Approach Implementation

The Alaska Air Group and Port of Seattle—Seattle-Tacoma International Airport staff, The Boeing Company, and local FAA ATO personnel pursued the Greener Skies project to develop PBN flight procedures for the airport to reduce the environmental impact of air traffic. The approach procedures utilized radius-to-fix navigation capability of aircraft, and applied Established on RNP criteria permitting reduced separation between aircraft on RNP and ILS approaches to the airport's parallel runways. The airport supported placement of navigation waypoints in the arrival procedure to address known sensitives of the community to aviation noise. The FAA conducted its own public outreach campaign and encountered community opposition. SEA personnel assisted with outreach to engender community understanding of and support for the procedures.

Introduction

The Seattle Metroplex serves the Seattle/Tacoma metropolitan area of Washington and includes SEA, King County Airport—Boeing Field (BFI), Snohomish County Airport (PAE), and Tacoma Narrows Airport (TIW). SEA is a large hub international airport. Located 12 miles south of central Seattle, it was the fastest growing large hub airport in the U.S. in 2014. SEA is owned and operated by the Port of Seattle. The airport has three runways, one central and two satellite terminals and four concourses, as shown in Figure C-12, and is the main hub for Alaska Airlines and Horizon Air. In 2013, SEA had 16,690,295 enplanements with 657,664 operations.

Source: Federal Aviation Administration.

Figure C-12. *Plan view of Seattle-Tacoma International Airport.*

BFI is located approximately five miles south of central Seattle. It is categorized as a primary non-hub airport and is considered one of the busiest in the nation. BFI has some passenger service, but is mostly used for operations associated with Boeing aircraft manufacturing, general aviation, and cargo. FTY has two runways and an FAA-operated control tower. In 2013, the airport had 13,008 enplanements and 361,335 operations. PAE is located in unincorporated Snohomish County, between Mukilteo and Everett, Washington. It is categorized as a general aviation airport and is home to the Boeing Everett Factory, Aviation Technical Services, one of the nation's largest aviation maintenance facilities, and four flight schools. PAE has three runways (one is closed except for taxiing) and is served by an FAA-operated control tower. In 2013, PAE had 127 enplanements and 224,942 operations. TIW is located in Pierce County, approximately five miles west of central Tacoma. The airport is categorized as a general aviation airport and the county's primary business jet facility. TIW has one runway and is served by an FAA-operated control tower. In 2013, TIW had 93 enplanements with 95,165 operations.

The FAA's PBN Dashboard provides analysis of the equipage levels among general aviation, Part 121 major, regional and cargo aircraft, and IFR operations at SEA as of January 2015 (Federal Aviation Administration 2015). The results indicate that approximately 100% of Part 121 aircraft and IFR operations, and 35% of general aviation aircraft, are capable of RNAV 1 and RNP 0.3-1. Seventy percent or more of Part 121 major and regional aircraft and IFR operations, and fewer than 10% of Part 121 cargo aircraft, are capable of RNP AR. The FAA's PBN Dashboard indicates SEA has an inventory of four RNAV SIDs, two RNAV STARs and nine RNP approach procedures.

In 2009, Alaska Air Group (AAG), the holding company for Alaska Airlines and Horizon Air, and Port of Seattle—Seattle-Tacoma International Airport staff, in cooperation with The Boeing Company and local FAA ATO personnel, initiated development of a plan to investigate new PBN flight procedures for SEA that would utilize these latest navigational technologies and allow aircraft operators to fly optimal descent paths with radius to fix legs, while reducing their environmental impact during approaches to land. The program was ultimately named the "Greener Skies Over Seattle" or simply "Greener Skies." Greener Skies consists of procedural changes that begin in the Seattle ARTCC (ZSE), continue into the airspace of the Seattle TRACON (S46), and eventually end in the airspace controlled by Seattle ATCT as aircraft descend from cruising altitude all the way to landing on one of SEA's six runway ends. In 2010, the FAA NextGen Management Board authorized Greener Skies and took over responsibility for the development of criteria supporting simultaneous RNP operations, and the completion of the final design and implementation of the procedures, consistent with the Agency's functional role in controlling aircraft.

Demographics

The land use of the areas immediately adjacent to the airport boundary to the north is composed of commercial, industrial, and park areas. Residential areas exist beyond these areas further to the north. The areas to the south are primarily commercial, industrial, and park/recreation. Residential areas exist beyond these areas to the northwest. The demographics of the residential areas are mostly middle class, with pockets of upper class. Most of the community is knowledgable of the types of airplanes associated with the various operations at the airports in the Metroplex. There are no formal noise committees or noise groups in the areas. SEA receives approximately 1,000 noise complaints per year. SEA holds occasional open houses to inform and engage with surrounding community. Figure C-13 shows the areas surrounding SEA.

Figure C-13. *Seattle-Tacoma Airport and the surrounding area.*

Project Description

The Greener Skies project specifically involved development and implementation of multiple PBN procedures:

- A new STAR procedure for traffic arriving from the northwest to land on any of the six runway ends at SEA.
- A new STAR for aircraft arriving from the southwest that would reduce the number of flight miles flown when landing on any of the six runway ends.
- Implementation of 21 new RNP and RNP-to-ILS procedures utilizing RF legs northwest and south-west of SEA.
- Optimized Profile Descents from both the northwest and southwest.

A unique aspect of this project was the use of RF legs. At the time no other airspace design effort was attempting to implement RF legs due to the advanced equipage and training required for the airlines. However, the Alaska Airlines was fully equipped and certified for RNP procedures and RF legs.

The Greener Skies project was split into three initiatives: 1) Designing PBN procedures for implementation into the SEA Metroplex; 2) performing research and safety studies needed to validate ATC separation rule changes utilizing a technique called "Established on RNP," which allows for simultaneous operations on RNP approaches or RNP and ILS approaches; and 3) modification of ATC standards to allow applicable PBN standards to be implemented across the NAS based on the confirmed safety identified in initiative 2.

In 2011, the final draft designs of the PBN instrument flight procedures were completed. In 2012, the procedure designs were tested by Alaska Airlines in a 737 flight simulator and by Alaska Airlines, Horizon, US Airways, and SkyWest in flight trials. In 2013, the final procedures were implemented for use. The FAA final designs also included efforts to assure broad availability of the new procedures to all appropriately equipped aircraft, advancing the use of the technology in SEA's complex airspace that includes step-down approaches, confliction points, and frequent pilot/controller radio communications.

Processes Used

Greener Skies was a collaborative effort and a prime example of PBN implementation with airport involvement. The project ultimately transitioned to the FAA for implementation, however, the airport and Alaska Airlines (the representative carrier) remained deeply involved throughout the process. During the FAA's development process, airport representatives attended every meeting. The FAA met with the airport representatives, controllers, and airlines to decide on the placement of flight tracks of waypoint for each procedure. In many cases, the location of a waypoint shifted numerous times before the final design was settled upon. The FAA used the 18-step process in some form to develop the procedures, followed the Acquisition Management System Engineering and Safety Risk Management (SRM) processes for criteria development, and NEPA standards for the environmental analysis.

Criteria Development

Extensive criteria development was conducted in support of a procedure called "Established on RNP." The need for these new criteria arose from the lack of parallel operations criteria based on the use of RNP operations including the use of RF legs. When a leading aircraft on a straight in ILS approach to one runway, and a following aircraft on an RNP approach with RF turn onto final on other runway, there is the potential for the aircraft to be separated less than 3 nm apart. Criteria exist to allow the separation of aircraft on ILS final approaches to drop below 3 nm, but no criteria had been established for RNP operations in a similar scenario.

The FAA utilized the Systems Engineering 2020 program to acquire additional contract staff support as part of the effort to solve the separation standards issue. The Greener Skies team conducted evaluations and modeling to prepare criteria for the development of separation standards enabling the operation. The team established a project plan, concept of operation for the proposed procedures, and conducted modeling simulation and data analysis to evaluate the safety, flyability, and feasibility of the procedures in support of the SRM process required by FAA for the proposed rule changes.

The FAA completed the SRM in January 2013 and conducted HITL modeling to verify and validate the findings. The FAA Air Traffic Organization requested a waiver to standards in April, 2013 to enable the implementation of the procedures. On April 7, 2015, SEA implemented "Established on RNP" procedures allowing for the simultaneous use of the PBN and ILS procedures. The FAA is continuing to evaluate the procedures and perform analysis to address issues that have arisen with controller training, pilot training, and familiarity. SEA will stop using Established on RNP until October 2015 due to an airport construction project.

Project Communication and Public Outreach

The project study and design phase was a collaborative effort between FAA, airlines, The Port of Seattle, and the Boeing Company. Multiple meetings were held and all parties were invited to all of the meetings. Boeing, Alaska, and the Airport were invited to attend, however, were not able to participate in a significant or meaningful way.

The FAA conducted a public outreach as part of the EA. The process included two public scoping meetings—one held south of SEA on January 25, 2012 in Federal Way and one north of SEA on January 26, 2012 in Shoreline. A tribal scoping session was held at FAA's offices on January 26, 2012 in Renton. At each meeting the FAA presented an introductory workshop session, disseminated project information, made two formal presentations, and solicited comments.

Environmental Analysis

The FAA with support from a commercial contractor prepared an EA based on NEPA standards. A FONSI ROD was issued on October 31, 2012 for multiple procedures including:

- A new STAR for traffic arriving from the northwest to land on any of the six runway ends at SEA. The new procedure is expected to increase slightly the number of flight miles flown for some aircraft, taking them farther north than at present. Instead of overflying northern portions of Kitsap County as now, more of that traffic would approach the runways from over Hansville and Puget Sound south of Island County. However, compensating benefits derived from aircraft operating at slightly higher altitudes, undergoing fewer level-off segments, and maintaining lower thrust settings during the approach offset the penalty of increased flight miles.
- A new STAR for aircraft arriving from the southwest that would reduce the number of flight miles flown when landing on any of the six runway ends. In particular, the removal of a significant "dog leg" to the west over Olympia, Washington would be replaced by more direct routings generally over the former Fort Lewis Military Reservation and to either side of the former McChord Air Force Base, the two installations now collectively merged and known as Joint Base Lewis-McChord (JBLM).
- Implementation of new RNP and RNP-to-ILS procedures northwest and southwest of SEA. New approach procedures would provide high-precision extensions of the STARs onto curved approach paths and short straight-in final approaches to touchdown with less need for intervening interaction by air traffic controllers.
- Fifteen of the RNP procedures would provide instrument guidance for landings on runways 16L, 16C, and 16R (five to each runway end). Twelve of the 15 would lead aircraft in over Elliott Bay and the industrial area south of Harbor Island, and the other three would provide guidance to aircraft generally overflying areas of north Seattle subject to overflights now but guided by instructions from ATC.
- An additional six RNP procedures would guide aircraft along curved approach paths over the Port of Tacoma, keeping them north of Interstate Route I-5 and lining them up to land on runways 34L, 34C and 34R. Three other procedures represent transitions to longer straight-in instrument approaches very similar to now.

The airport was not included in the environmental process. Including the airport would have been instrumental in garnering public support and promoting the benefits of PBN to the community making the public outreach process smoother.

Project Outcomes

Outcomes from the Greener Skies project include:

- The overall outcomes of the Greener Skies initiative were considered to be positive in terms of improving flight efficiency, enabling Established on RNP operations and satisfying the majority of the communities' concerns regarding noise.

- As previously discussed, the effort included the implementation of multiple OPD STAR procedures, and multiple RNP and RNP to ILS approach procedures.
- Equally important is the development of criteria development associated with EoR procedures allowing simultaneous RNP and RNP/ILS procedures to occur.
- The benefits of these new criteria include shortened flight path miles flown, avoidance of highly populated residential areas, reduction in noise and emissions, flexible use of airspace, and increase in capacity. These criteria will also serve to provide similar benefits at airports throughout the NAS.

Post-Implementation Metrics

It is too early to say what the effects of Greener Skies are at this time. According to SEA data, there are 10 to 12 aircraft/day conducting Established on RNP procedures, most are Alaska Airlines flights. In a recent article (Environmental Leader 2015) concerning the Greener Skies initiative, post-implementation assessment focuses on impacts to industry and the local environment, including fuel burn, flight time, and emissions. Alaska Airlines predicts it will save 87 gallons of fuel, reduce flight time by nine minutes, and reduce carbon emissions by one metric ton for each arrival to SEA. Analysis of arrivals from the southwest when SEA is in a south flow configuration, assuming all aircraft can conduct EoR arrival procedures, estimates annual fuel savings of 2.7 million gallons and carbon emissions reductions of 25,600 metric tons.

Regarding local airport impacts, noise is a fundamental concern. SEA is installing a brand new noise monitoring and flight tracking system. A contractor to the airport is trying to implement the system to monitor tracks on per-aircraft and per-airline bases to understand and evaluate utilization and impact of PBN procedures. This is a new initiative to try to evaluate aircraft at a specific altitude and location. Flight tracks of participating and non-participating aircraft will be compared to determine the level of compliance to flight corridors in the original design of the procedures.

The FAA's PBN Dashboard provides analysis of the average daily number of IFR operations, the average daily usage levels of individual RNAV SIDs and RNAV STARs, and the usage levels of RNP AR approaches with RF legs for a specified calendar year at SEA (Federal Aviation Administration 2015). It indicates an average of 942 daily IFR operations. The average daily usage counts for the RNAV SIDs sum to 76 departures, and the RNAV STARs sum to 433 arrivals. RNP AR approaches were executed by 206 arrivals among 72,440 candidate aircraft, with usage concentrated to approaches to runway 16L and runway 16C.

Lessons Learned and Best Practices

The lessons learned from the Seattle case study include:

- Airports can successfully initiate and lead their own PBN development projects though aircraft operator and FAA involvement is also required.
- Knowledge of PBN supports meaningful engagement with the FAA in PBN development.
- Airports can contribute knowledge of local noise constraints and other considerations to the PBN development process.
- Airports can affect design changes to the proposed procedures to meet local noise constraints and other needs. However, this depends on the specifics of the project. In some cases, airports may be unable to affect change or the ability is limited due to project priorities and other factors.
- The FAA will lead its own environmental analysis and public outreach effort.

- Airports should be prepared to engage with the community concerning FAA-led initiatives and their impacts.
- Benefits and impacts of PBN procedures should be presented in community-understandable terms.

References

Environmental Leader. 2015. “Boeing Procedures Help Alaska Airlines Improve Efficiency, Cut Fuel Consumption.” http://www.environmentalleader.com/2015/07/06/boeing-procedures-help-alaska-airline-improve-efficiency-cut-fuel-consumption/. (As of July 8, 2015).

Federal Aviation Administration. 2004. “Airport Capacity Benchmark Report.”

Federal Aviation Administration. 2013. “Environmental Assessment for Houston Optimization of Airspace and Procedures in the Metroplex.” http://www.metroplexenvironmental.com/houston_metroplex/houston_introduction.html. (As of June 25, 2015).

Federal Aviation Administration. 2015. “NextGen Performance Success Stories.” https://www.faa.gov/nextgen/snapshots/stories/. (As of July 8, 2015).

Federal Aviation Administration. 2015. “Performance Based Navigation (PBN) Implementation and Usage.” https://www.faa.gov/nextgen/pbn/dashboard/. (As of July 7, 2015).

D Annotated Bibliography

Reviews and Recommendations on PBN Implementations

1. *The MITRE Corporation Center for Advanced Aviation System Development (CAASD). 2011. "Performance Based Navigation Capability Report."*

This report provides comprehensive information about the top 50 airports in the National Airspace System. Information includes runway configuration, taxi time, and delay characteristics; fleet and operator characteristics; quantities of types of published procedures; and current and forecast fleet equipage levels for different aircraft navigation capabilities. For each airport, the report provides the following information: 1) quantities of published instrument procedures, including conventional, RNAV 1 SIDs and STARs, and RNP AR SIAPs; 2) key performance metrics; 3) top carriers and aircraft types; 4) runway configurations and utilization; 5) distribution of operations by aircraft operator type and aircraft engine type; 6) current and forecasted percentages of operations capable of RNAV 1, RNAV 2, RNP 1, RNP 2, RNP 0.3, RNP 0.3 with Radius-To-Fix, RNP Approval Required, and RNP AR Operational Approval procedures.

2. *Office of Inspector General. 2012. "Challenges with Implementing Near-Term NextGen Capabilities at Congested Airports Could Delay Benefits."*

This report assessed the extent to which the FAA is responding to recommendations of the RTCA task force's 32 recommendations from September, 2009 for accelerating NextGen deployment and addressing barriers that hinder successful implementation of the recommendations. The report placed particular focus on the FAA's Metroplex program. The report found multiple deficiencies in an evaluation of 136 solutions proposed for 7 metroplex sites. The report found need for improvement in 1) implementing more advanced technologies and advanced procedures, 2) integrating use of other initiatives, and 3) streamlining procedures for implementation and deployment. The barriers remaining included 1) streamlining the process for implementing new flight procedures, 2) applying environmental regulations, and 3) training controllers. The FAA's Metroplex program was not leveraging advanced RNP procedures, only RNAV procedures and improved vertical profiles. The FAA's communication and collaboration with local airline and air traffic management has been limited. The FAA needs to develop a "best-equipped-best-served" policy. The FAA needs to establish a formal mechanism to communicate metroplex progress that allows continual feedback and coordination with the airlines and local FAA air traffic officials as work progresses at each metroplex site. The FAA needs to establish a process to select leads for the Metroplex team well in advance of the time that design and implementation teams are scheduled to begin. The FAA needs to include all stakeholders, including Flight Standards personnel, in implementing new flight procedures.

3. *RTCA NextGen Advisory Committee. 2013. "CatEx 2: Recommendation for Implementing the Categorical Exclusion in Section 213(c)(2) of the FAA Modernization and Reform Act of 2012."*

Identifies obstacles to and proposes remedies for implementing and using PBN procedures to support the FAA OAPM effort. Five major categories of obstacles to utilization of PBN procedures are identified: automation, design, environmental, regulations, and training. Proposes fifteen actions to overcome obstacles to PBN including: 1) prioritize, align, and apply time-based flow management adaptation to metroplexes where PBN has recently been implemented; 2) make effort to identify and address barriers to time-based flow management, 3) define a clear objective for the PBN implementation and communicate it to all stakeholders; 4) consider operating environment constraints in design, 5) develop a robust national simulation capability to test procedures for as many fleet types as possible; 6) develop a standard process to incorporate lessons learned; 7) permit broader operator participation; 8) rewrite 7110.65 and other documents to account for PBN-enabled operational changes, such as reduced separation standards; 9) develop and maintain a standardized national training program to include all operational stakeholders; 10) minimize the number of approach procedures in metroplexes to the extent possible; 11) widely disseminate procedure design criteria changes and use criteria waivers regularly, 12) eliminate operator validation of RNP AR databases, 13) implement RF legs for advanced RNP and terrain avoidance and streamline approval process, 14) expedite implementation of CatEx 2, and 15) provide vertical procedure design guidance.

4. *RTCA NextGen Advisory Committee. 2013. "NextGen Prioritization."*

Documents purpose for, approach to, and results of analysis to prioritize the thirty-six capabilities of the FAA's NextGen program to accommodate forecasted budget cuts. The analysis estimates 1) monetizable benefits, 2) non-monetizeable benefits, 3) implementation readiness, and 4) other criteria. The results identify Performance-Based Navigation (PBN) to be the highest priority capability. The thirty-six capabilities evaluated spanned surface operations, surface/terminal operations, low visibility approaches, multiple runway operations, PBN, Time Based Flow Management, Collaborative Air Traffic Management, Separation Management, On Demand NAS Information, Weather, and Core Infrastructure. Monetizable benefits evaluated included capacity, efficiency, air traffic control system productivity, and impact on environment. Non-monetizable benefits included access, flexibility, safety and security. Implementation readiness included standards and approvals, policy/operations, systems, institutional, roles and operational complexity, community perceived noise and emissions impact, and time for completion. Other criteria included global harmonization, confidence building, and critical infrastructure. Ranking was derived by a decision support tool process involving voting on the application of the four criteria for the 36 candidate consolidated capabilities. Rankings are PBN 0.82, Multiple Runway Operations – Reduced Separation Standards 0.75, PBN OAPM 0.65, ADS-B Out Separation Management 0.63, Data Comm Revised Pre-Departure Clearance 0.62, Low Visibility Approaches GLS I 0.57, ADS-B Interval Management 0.530, Low Visibility Approaches GLS II and III 0.51, Low Vis Approaches Enhanced Flight Vision Systems (EFVS) 0.49, PBN Advanced PBN 0.478, Low Vis Approaches Advanced EFVS 0.46.

5. *RTCA NextGen Advisory Committee. 2014. "Addendum to Recommendations for Increased Utilization of PBN in the NAS–Industry Barriers."*

RTCA NextGen Advisory Committee revisits its recommendations for increased utilization of PBN in the NAS to address industry barriers. The report lists numerous industry barriers and mitigations including 1) the need for a common view among technical pilots and planners regarding aircraft and system impacts of PBN procedures (including the TBFM system), and the need to consider these impacts during PBN design; 2) collaboration of industry and FAA on investment decisions, timelines, and priorities related to PBN initiatives, such as TBFM and automation; 3) the need to conduct flight simulation evaluation of designed PBN procedures for broad range of aircraft and Flight Management Computers before deploying them, and to enhance existing TARGETS or other tools for more rapid evaluation; 4) the need for training materials for industry, pilots, controllers, and other stakeholders to understand the differences among different PBN approach procedures (e.g., RNAV, VNAV, LNAV, and LPV) and aircraft capabilities, and the capabilities among the local community of users of PBN procedures at the airport or in the metroplex. This will help industry to develop training and education materials to enable better understanding and use of PBN procedures.

6. *United States Government Accountability Office. 2013. "NextGen Air Transportation System: FAA Has Made Some Progress in Midterm Implementation, but Ongoing Challenges Limit Expected Benefits."*

The GAO reviews the FAA's mid-term NextGen efforts. The GAO consulted documents and task force recommendations, interviewed airport officials and aviation experts in order to examine (1) planned NextGen operational improvements through 2018, (2) FAA efforts to address obstacles to implementation of operational improvements, and (3) FAA measurement and demonstration of benefits. The GAO found the FAA needs to integrate the NextGen efforts, develop a process for selecting PBN-appropriate procedures, and disseminate information to stakeholders. The GAO found that lengthy environmental reviews are an obstacle to timely PBN implementation. Environmental reviews typically take from 30 days to 2 years. Environmental assessments could be more narrowly focused on potentially significant impact categories. The FAA is working to enhance and integrate its environmental screening and analysis tools, including fuel burn and noise analysis, with a traffic simulator for PBN procedure design. The FAA is working to change the way flight procedure requests are prioritized and amended. The FAA created an office for PBN to oversee a coherent design, development, production, and implementation strategy for new procedures. The FAA is developing a toolbox to match the most appropriate PBN options such as RNAV or RNP to identified problems. The report defines roles and responsibilities in PBN procedure development. The FAA ATO designs and develops procedures and conducts environmental reviews. ATO also helps implement new procedures once published with documentation or training to air traffic controllers. The Office of Aviation Safety establishes design criteria for new procedures and conducts safety testing. AeroNav Products maintains existing procedures, tests new procedures against design criteria, and includes new procedures on published charts for pilots. The FAA OAPM has a 3-year implementation time frame for each site, including a 12-18-month environmental assessment process.

7. *RTCA NextGen Advisory Committee. 2014. "Blueprint for Success to Implementing PBN."*

The RTCA NAC recently published the Blueprint for Success to Implementing PBN procedures. This document specifies categories of stakeholders in PBN development and provides rich descriptions of and detailed recommendations to the FAA for conducting the 5-phase PBN procedure development process. This document provides useful descriptions of technical and non-technical stakeholders and recommendations for outreach to those groups. Non-technical stakeholders include the public, community groups and non-governmental organizations, airport authorities, airport advisory boards, and local, state, and federal government officials. Technical stakeholders include industry representatives, including the lead operator, A4A, the NBAA, the Regional Airlines Association, airport authorities, air traffic facilities, pilot unions, the Department of Defense, third-party procedure developers, and others. The document provides recommendations for working with or considering technical and non-technical stakeholders, and outreach strategies for non-technical stakeholders. For each of the 5-phases, recommendations account for capturing the needs of stakeholders, defining objectives and metrics for the PBN procedures, involving technical and non-technical stakeholders in the development process, planning and coordinating community outreach with PBN procedure development, managing data, and capturing lessons learned. While these recommendations are pending review and approval of the FAA, and may not be accepted and applied wholesale, they can help to further detail understanding of the nature and mechanics of each design phase, and potential contributions of the airport operator.

Background of PBN

8. *Federal Aviation Administration. 2012. "RNAV (GPS) Approaches."*

This briefing describes the different categories of RNAV GPS and WAAS approaches. Approaches include LPV, LP, LNAV, and LNAV/VNAV. It also defines advisory vertical guidance, approved vertical guidance, barometric aiding (Baro-Aiding), and Baro-VNAV.

9. *Federal Aviation Administration. 2013. "Fact Sheet –NextGen Goal: Performance-Based Navigation." http://www.faa.gov/news/fact_sheets/news_story.cfm?newsId=10856. (As of Au*gust 2013).

This web site provides a high-level summary of PBN including definitions of RNAV, RNP, RNP AR and OPDs; descriptions of benefits of PBN; and list of U.S. airports with RNAV and RNP procedures.

10. *The MITRE Corporation. 2010. "Flight Management Computer Systems (FMCS), Vertical Navigation (VNAV)." MITRE Document 10-1114, F064-B10-009.*

This slide package provides an overview of the VNAV capability of aircraft. This includes history, background, flight phases, descent path construction to satisfy the procedure lateral route and altitude and speed restrictions, types of descent paths planned by aircraft FMSs, tailwind and headwind influences on descent path planning and execution, and benefits of VNAV path planning and execution.

11. *Nolan, M. 2004. Fundamentals of Air Traffic Control. Thomson Brooks/Cole, Belmont, United States.*

This is a college-level textbook providing a comprehensive description of ATC in the United States. Subjects include the history of ATC, navigation systems, ATC system structure, airport ATC communications: procedures and phraseology, ATC procedures and organization, control tower procedures, non-radar en route and terminal separation, theory and fundamentals of radar operation, radar separation, operation in the national airspace system, oceanic and international air traffic control, the future of the National Airspace System, and an overview of the FAA.

12. *Ricondo & Associates. 2013. "Instrument Navigation."*

This slide package provides a comprehensive summary of instrument navigation. This includes types of navigation, types of ground-based navigation, types of space-based navigation, augmentations to space-based surveillance, RNAV and RNP, TERPS, Obstacle Clearance, SIDs, STARs, SIAPs, and the FAA information and procedures maintenance schedule.

PBN Plans and Status

13. *Federal Aviation Administration. 2011. "ADS-B Program Overview."*

Slide package providing overview of the FAA's ADS-B program. ADS-B periodically transmits aircraft position and velocity information with no pilot or operator input required. The position and velocity information are derived from GPS. ADS-B provides a method of determining the position of aircraft, vehicles or other assets. ADS-B information transmitted is available to anyone with appropriate receiving equipment. ADS-B supports air traffic control separation services in en route, terminal, and surface domains. It provides pilot advisory services including TIS-B and FIS-B. It supports situational awareness applications including enhanced visual acquisition, enhanced visual approaches, final approach and runway occupancy awareness, airport surface situational awareness, and traffic situational awareness with alerts. Supporting ground infrastructure is planned for deployment in 2010-2013 and supporting avionics equipage is planned for deployment in 2010-2020.

14. *Federal Aviation Administration. 2012. "Airport Capacity Benchmarks and Metroplex Airspace Optimization." Presented at the TRB 8th National Aviation System Planning Symposium, Galveston, TX.*

This presentation provides an overview of the FAA's 2012 Airport Capacity Benchmark assessment and OAPM efforts. Airport capacity is defined as the hourly throughput an airport's runways can sustain during periods of high demand. Rates are determined for specific runway configurations and Visual, Marginal, and Instrument weather conditions. PBN components specified in the FAA 2012 NextGen Plan, Appendix A include 1) RNP 10 in oceanic airspace for reduced separation; 2) RNP 4 in oceanic airspace for reduced separation with FANS 1/A; 3) RNAV 2 in en route airspace; 4) RNAV 1 in terminal airspace to fly more efficient routes and procedures; 5) RNP with curved path, providing the ability to precisely fly departure, arrival and approach procedures including repeatable curved paths; 6) LPV for improved access to many airports in reduced visibility, with an approach aligned to runway (Category 1); 7) RNP AR for improved access to airports in reduced visibility with an approach that can turn to runway, and improved procedures to separate traffic flows.

15. *Federal Aviation Administration. 2012. "Performance Based Navigation Implementation Plan for the 35 Operational Evolution Plan (OEP)/Core 30 Airports."*

This is a chart indicating the current and planned new PBN procedures for the 35 OEP and Core 30 airports in the US. Most airports had some quantity of RNAV SIDs or STARs, and even RNP AR IAPs, implemented as of Feb 8, 2012. The FAA had extensive plans for RNAV STAR, RNAV SID, and RNP AR implementation across numerous airports throughout 2013. The plans called for extensive implementation for a few specific airports in 2014/2015 (e.g., ATL and Charlotte (CLT)).

16. *Federal Aviation Administration. 2012. "Performance Based Navigation Implementation Plan for RNP AR Procedures at 35 Non-Operational Evolution Plan (OEP)/Non-Core Airports."*

Chart indicating current and planned new RNP AR approach procedures for 35 Non-Operational Evolution Plan/Non-Core 30 airports. Only a few airports had RNP AR approach procedures as of Feb 8, 2012, although many implemented some throughout 2012. 37 were procedures planned to be implemented during 2013.

17. *Federal Aviation Administration. 2013. "FAA NextGen Implementation Plan 2013, Appendix B, Delivering NextGen."*

This documents the FAA's plan for the ongoing transition to NextGen. NextGen integrates new and existing technologies, policies, and procedures to reduce delays, save fuel, and lower aircraft exhaust emissions. The NextGen Implementation Plan provides an overview of current and future benefits for aircraft operators and passengers. RNAV permits any flight path within coverage of ground- or space-based navigational aids. PBN defines the accuracy, integrity, continuity, and functionality requirements for aircraft to operate in airspace, and may define required sensors and equipment for aircraft. Metroplex is the FAA's fast-track initiative to implement PBN procedures and airspace improvements. Aircraft avionics, which enable PBN procedures at metroplexes include RNAV 1, RNAV 2, RNP 1 with Curved Path, VNAV, and RNP AR Approach. Aircraft avionics which enable PBN procedures at General Aviation airports include, RNAV 1, RNAV 2, and LPV. PBN-based airport enhancements include: PBN instrument flight procedures to improve arrival and departure efficiency, LPV approach procedures that provide Category I minimums (typically at general aviation airports), and RNP AR approach procedures. Business jets and air carriers are RNAV and RNP capable and can perform RNP AR approach minimums. The FAA may eliminate ILS CAT I installations and replace them with LPV and RNP approaches. In turn, the GBAS capability will boost ILS Category II and III operations. The NextGen Implementation Plan for Airport Enhancements includes reduced separation standards for CSPO and dependent runway operations, particularly in poor-visibility conditions. This depends on PBN implementation and aircraft equipage. It includes implementing RNAV approaches, including RNP and WAAS LPV approaches, in place of ILS approaches for parallel runways. Airport enhancements also include implementing combinations of RNAV and ILS approaches for dependent runways ≥ 2,500 feet apart and for independent runways.

18. *Federal Aviation Administration. 2013. "FAA NextGen Implementation Plan 2013."*

This provides an executive summary of the FAA's NextGen Implementation Plan. The Metroplex initiative is a fast-track effort to implement satellite-based procedures and airspace improvements. The FAA is publishing a significant number of satellite-based precision arrival and departure procedures and high- and low-altitude routes. The benefits include reduced flight delay and carbon dioxide emissions, fuel and passenger time savings, less aircraft noise, increased predictability and reliability of airport operations to enhance the airport's role as an economic engine for its community. The GPS WAAS enables LPV approach procedures for equipped general aviation aircraft to minimum altitudes as low as 200 feet. The FAA has published 3,123 approaches, and it will publish 5,128 by 2016. ADS-B and Data Communications will be leveraged with PBN to save time and fuel, decrease emissions, and improve the ability to address noise. The Environmental Management System (EMS) will be used to integrate environmental and energy objectives into the planning, decision making, and operation of NextGen Continuous Lower Emissions, Energy and Noise program with industry.

19. *Federal Aviation Administration. 2013. "NextGen for Airports."*

This publication concerns the NextGen components impacting general aviation and commercial airports. At general aviation airports, the WAAS-based approach procedures will increase access during low visibility by providing horizontal and vertical navigation accuracies to 7 feet, LPV decision altitudes 200 feet above runway, and ILS-like approaches. So far, 3,100 approaches have been published in the U.S. ADS-B Out will be required for most aircraft in controlled airspace by 2020. At commercial airports, PBN procedures are to be implemented at 13 metroplexes via FAA Metroplex, leveraging RNAV and RNP independent of ground-based navigational aids. Closely spaced parallel runway operations are to operate with reduced separation, allowing runways as close as 3,600 feet (now 4,300 feet) apart to operate independently. This requires an update to 7110.65 and impacts 16 runway pairs in the U.S.

20. *Federal Aviation Administration. 2013. "NextGen Implementation Plan 2013, Appendix B, NextGen Infrastructure."*

This publication concerns near-term implementation plans for NextGen infrastructure. ADS-B provides accurate and comprehensive surveillance via a broadcast communication link. ADS-B receives flight data from aircraft via a data link. Flight data is derived from on-board position-fixing and navigational systems. Aircraft position (longitude, latitude, altitude and time) is determined using GPS, an internal inertial navigational reference system, or other navigation aids. Data Communications (DataComm) implements capabilities providing new methods to deliver departure clearances, revisions, and taxi instructions in terminal environment. DataComm will be particularly useful to airport control towers.

21. *Federal Aviation Administration. 2013. "Optimization of Airspace & Procedures in the Metroplex (OAPM), OAPM FY 12 & FY 13 Milestones Summary and Dashboard Status."*

This presentation provides an overview and planned implementation dates of metroplexes included in the FAA's OAPM program. At the time of publication, the metroplexes and dates were: DC, North Texas, FY11-FY15; Houston, FY12-FY14; Charlotte, FY12-FY15; Atlanta, FY12-FY15; No. Cal, FY12 – FY15; So Cal, FY13 – FY16; Florida, FY13 – FY16; Phoenix, FY13 – FY16; Chicago, FY13 – FY17; Memphis, FY14 – FY 17; Cleveland/Detroit, FY14 – FY17; and Boston, FY15 – FY18.

22. *Federal Aviation Administration. 2014. "Performance Based Navigation Non-OAPM, PBN Milestones Summary and Dashboard Status as of Feb 28, 2013." http://mspfairskies.com/wp-content/uploads/2013/08/PBN.pdf. (As of December 18, 2014).*

This report summarizes the progress of the FAA's PBN implementation initiative across multiple sites, including program progress and per-site progress, as of Feb 28, 2013. The PBN process employed follows the 5-step Metroplex process of 1) Study and Scoping, 2) Design and Procedure Development, 3) Operational, Environmental, and SMS Review; 4) Implementation and Training; 5) Post-Implementation Review and Modifications. An explanation of each step is provided. Step 1 comprises project start, data collection, initial draft prototype designs, kickoff meeting. Steps 2 and 3 include Environmental Review Start, flight simulations, prototype designs draft, procedure design, post prototype design work, public meetings, and completion of environmental review. Steps 4 and 5 include procedures submitted to Flight Procedures Team (FPT), procedures submitted to AJV-3, quality assurance, flight inspection, charting, training, procedures published, procedures implemented, and post-implementation review. Published procedures included the Denver STARs and RNPs, Nashville procedures, Denver SIDs and St. Louis STAR & RNPs. Remaining procedures included the Seattle procedures, Portland STARs and Minneapolis STARs and SIDs.

23. *Informal Pacific Air Traffic Control Coordinating Group (IPACG). 2013. "38th Meeting Agenda Item 6: CNS Issues, Summary of U.S. ADS-B Activities."*

This report summarizes the ADS-B activities in the U.S. that may be of interest to IPACG participants. For ADS-B, aircraft with Version 2 avionics certified and installed in accordance with FAA AC 20-165 (or an equivalent approved by FAA Aircraft Certification) will receive ATC separation service in the U.S. ADS-R is a pilot advisory service that receives data from aircraft on one link and immediately rebroadcasts it on the other link. TIS-B is pilot advisory service for situation awareness, gathering data from U.S. ATC radars and multi-lateration systems. The FIS-B message set contains Airman's Meteorological Information, Aviation Routine Weather Report (METAR) and Unscheduled Specials, Next Generation Radar (NEXRAD) precipitation reflectivity, Pilot Reports (urgent and routine), Significant Meteorological Information, Terminal Area Forecast and unscheduled Amendments, Winds and Temperatures Aloft, NOTAMs important to flight safety, and Status of Special Use Airspace. IM is a new method for flight crews and ATC to achieve a desired spacing between aircraft in all phases of flight. Initial applications are to aircraft in en route airspace arriving to a terminal area metering fix meeting current IFR procedures and criteria. GIM-S schedules and manages arrival traffic flows. FIM-S allows aircraft to manage a separation interval assigned by ATC. GIM-S is included in the TBFM and ERAM programs.

PBN Design and Implementation

24. *LeighFisher et. al. ACRP Report 38: Understanding Airspace, Objects, and Their Effects on Airports. Transportation Research Board of the National Academies. Washington, D.C., 2010.*

This is a comprehensive description of the regulations, standards, evaluation criteria, and processes designed to protect the airspace surrounding airports. This supports aviation practitioners, local planning and zoning agencies, and developers in understanding and applying airspace design and evaluation criteria to ensure a safe operating environment for aircraft, to maintain airport operational flexibility and reliability, without limiting building development and economic growth in the surrounding community. The report provides background information and guidance. Background information includes fundamental airspace protection criteria of Federal Aviation Regulation 77, FA Order 8260.3B, and FAA Advisory Circular 150/5300-13, and presents mechanisms and processes for airspace protection. The report provides recommendations and best practices for airport management; local and regional planning agencies and municipal authorities; and building developers to minimize the impact of surrounding development on airport operations, flight procedures and future developments.

25. *United States Government Accountability Office, "FAA Airspace Redesign, An Analysis of the New York/New Jersey Philadelphia Project," July 2008.*

The report documents the GAO's assessment of the FAA's methodology in implementing a new airspace structure for the New York/New Jersey/Philadelphia metropolitan area. The GAO was asked to examine (1) the extent to which the FAA followed legal requirements for its environmental review, (2) the extent to which the FAA's methodology in assessing operational and noise impacts was reasonable, and (3) the likelihood the FAA will meet its projected time frames and costs of implementation. Among other things, the GAO found the FAA reasonably involved the public throughout the environmental review process. The FAA took actions required to ensure public outreach including conducting an early and open process, providing notice of and holding public meetings, and soliciting and responding to public comments. The Airspace Management Handbook describes the step-by-step procedures for airspace design management. After selecting the preferred alternative airspace design, the FAA began identifying measures to mitigate the noise impacts associated with the preferred alternative. An iterative process using operational and noise modeling tools was applied to identify potential noise mitigation strategies. Operational and noise models and simulations required substantial amounts of data, numerous assumptions, and extensive professional judgment. Supplemental noise metrics would have provided information that may be more readily understood by decision makers and the public than the DNL metric. FAA used U.S. Census Bureau block data to identify the areas that could be significantly impacted by noise. The FAA worked with congressional offices to determine the appropriate locations that would accommodate the specific needs of minority and low-income populations.

26. *Federal Aviation Administration. "Optimization of Airspace and Procedures in the Metroplex (OAPM) Study Team Final Report North Texas Metroplex."*

This report identifies operational issues in the North Texas metroplex and proposes PBN procedures to address them. The design included adding RNAV procedures, optimizing descent and climb profiles, segregating arrivals by airport and adding configuration-dependent RNAV departure procedures. The report outlines a 5-step process for PBN design and implementation. Step 1 identified and characterized issues. Step 2 proposed conceptual designs, including outreach meetings with local facilities and operators. Step 3 estimated the expected benefit, quantitatively and qualitatively, and explored potential solutions, including technical input from operational stakeholders. This step was supported by the OAPM National Analysis Team (NAT), which provides a centralized analysis and modeling capability for data collection, visualization, analysis, simulation and fuel burn modeling. Step 4 identified considerations and risks of proposed changes, with the support of the OAPM Specialized Expertise Cadre (SEC), which provides expertise from various FAA Lines of Business, including environmental, safety management, airports, and programs. Step 5 was documentation.

27. *Kim, Brian et al. ACRP Report 86: Environmental Optimization of Aircraft Departures: Fuel Burn, Emissions, and Noise. Transportation Research Board of the Natioanal Acadamies, Washington, D.C., 2013.*

This is a comprehensive guidebook concerning the design of Noise Abatement Departure Procedures (NADPs) to optimize the balance of noise exposure and emissions and fuel burn reduction in light of the ground tracks, flight profiles, aircraft types, and nearby populations of a particular application. The report includes a Departure Optimization Investigation Tool (DOIT), a spreadsheet-based program for the evaluation and design of departure procedures. Different types of noise abatement procedures are categorized as ground-track, profile, temporal, ground-based operational measures, and aircraft and air traffic control technology. Their benefits and drawbacks are presented. Ground track procedures include optimized ground tracks avoiding noise-sensitive areas, fanning of ground tracks over an area, area navigation overlays of existing departure procedures, and preferential routing for low-noise jet aircraft. Profile procedures are the FAA's close-in procedure, the FAA's distant procedure, and climbing over unpopulated land or water. Temporal procedures consist of varying ground tracks by time of day. Ground-based operational measures are single-engine taxi and preferential runways. Technology measures are automated thrust reduction, low-noise and low-emissions engines, and trajectory based operations. Each of these measures has benefits and drawbacks, and measures may be combined for increased effect. Case studies evaluate and compare the impact of each of these procedures on noise, emissions and throughput. An optimization tool is developed and described to support the design of departure procedures for a particular airport application.

28. *Airports Council International-North America (ACI-NA). 2013. "Airports' Role in the Development and Implementation of Performance Based Navigation (PBN) Flight Procedures."*

This position paper proposes involvement of U.S. airports in the FAA's implementation of NextGen PBN. RNAV and RNP are key PBN capabilities leveraged in the design of arrival and departure procedures at airports. Benefits of RNAV and RNP procedures may include reduced flight time, reduced flight distance, reduced fuel burn, increased efficiency, increased airspace and airport capacity, and increased safety. Environmental benefits may include reduced aircraft emissions, reduced noise, and aircraft routing flexibility. Section 213 of the 2012 FAA Modernization and Reform Act calls for coordinated and expedited review of PBN procedures. All procedures are CatEx'd from further detailed environmental review unless FAA administrator identifies extraordinary circumstances exist. The FAA Administrator's estimation of measurable reductions in fuel consumption, carbon dioxide emissions, and noise on a per-flight basis warrant CatEx. The ACI-NA is concerned by this, particularly noise on per-flight basis. Per the FAA 1976 Aviation Noise Abatement Policy, the community, airport and other stakeholders collaborate to mitigate noise impacts. Airport operators are primarily responsible for planning and implementing actions to reduce the effect of noise on residents. Airport operators have a long history working with community and reducing impacts. Airports need to understand how PBN may impact existing noise abatement procedures, develop an environmental strategy, and incorporate these into PBN design via an environmental review. Airports should advise the FAA ATO on community and industry dialogue mechanisms. Examples of positive outcomes of airport engagement in PBN procedure development include Portland, Denver and Louisville airports. Some stakeholders report that Minneapolis had a negative outcome.

29. *Federal Aviation Administration. 2013. "Order 8260.43B, Flight Procedures Management Program."*

This document describes the process for requesting the development, amendment, or cancellation of an IFP, and the FAA process for approving and prioritizing requests. The intended audience is the RAPT, the NAPT, and others requesting or amending an IFP. Any proponent may initiate a request for IFP creation, amendment, or cancellation. The proponent must contact the FPT in the respective Service Area. The proponent contracts with the FAA or with an AFS-approved IFP service provider. The FAA IFP development branch submits the procedure request to FPT for RAPT review. The service provider submits the procedure request to the Regional NextGen Branch (RNGB). Implementation depends on airport/obstacle data, environmental review, airspace and/or rulemaking action, installation/commissioning of navigational aids, concurrent modification of other flight procedures, data to support a deviation from standards (non-standard conditions), special flight evaluation, flight inspection, changes in runway/taxiway markings, charting intervals, and other criteria. The RAPT analyzes the procedure request, identifies possible conflicts, and considers implementation timing. The RAPT approves or disapproves a request and signs consensus forms documenting the collective decision. There is a process for the proponent to appeal the RAPT's decision if it is disapproved.

30. *Federal Aviation Administration. 2013. "Optimization of Airspace and Procedures in the Metroplex (OAPM), Los Angeles World Airports Community Noise Roundtable."*

This slide package provides an overview of the OAPM Southern California metroplex project as presented to the local community noise roundtable. Content includes the general design and implementation process, specific issues/inefficiencies in Southern California Metroplex to be addressed by the OAPM team, project progress, tasks and schedule, and a schedule of outreach meetings. For the OAPM process, the study team conducts study and scoping for approximately 3 months. The Design and Implementation (D&I) team conducts design and procedure development for 6-9 months; operational, environmental, and safety review for 16 months; implementation and training for 9-15 months, and post-implementation review and modifications for 3-6 months. This is an approximately 3-year process. Environmental involvement is required at all stages of the process. The initial study period of design and procedure development includes outreach, which entails design team meetings scheduled for each milestone in the design and procedure development phase.

31. *Federal Aviation Administration. 2013. "Third-Party Vendor Report."*

This slide package provides a progress report of a demonstration project for 3rd party development and delivery of RNP Instrument Flight Procedures at 5 FAA-selected mid-size airports. Vendors design, deploy and maintain public-use RNP approaches, including preparing environmental paperwork for environmental assessments. The process includes: 1) vendor work planning, 2) initial site coordination, 3) instrument flight procedure concept development, 4) implementation and training package development, and 5) pre- and post-implementation review and modifications. Step 2 includes site coordination, gathering of data, and an initial site visit. Step 3 includes an environmental impact briefing, RNP benefits estimation including limitations, and capabilities briefing; submitting a draft to RAPT; RAPT approval and assigned publication date; kick-off meeting; development of the instrument flight procedure concept; submission of the procedure draft for review; IFP design review; environmental review; obstacle evaluation; flight validation report development; and generation and review of final procedure design package. Step 4 includes an implementation and training package, ATC training, pre- and post-implementation reviews and analysis; Safety Management System documentation; quarterly PMRs and TIMs (Program Management Reviews, Technical Interchange Meetings). The five airports were: Syracuse Hancock (SYR), General Mitchell (MKE), Ted Stevens Anchorage (ANC), Dayton International (DAY), and Charles Wheeler Downtown (MKC).

32. *Federal Aviation Administration. 2014. "Order 7100.41, Performance Based Navigation Implementation Process."*

This document describes the process, the participants, and their roles and responsibilities in the PBN Implementation Process. The process is a standardized 5-phase implementation process for PBN routes and procedures. The process involves a Core Working Group (CWG) including the route/procedure proponent, a project facilitator, a TARGETS operator, the FAA ATO Service Center OSG, the regional NextGen branch, AeroNav Products, an airline representative, air traffic facilities; an airport authority; flight inspection services; and the PBN policy and support group. The Regional NextGen Branch supports "Reach Out" programs for new PBN routes/procedures. The 5 steps are 1) Preliminary Activities, 2) Development Work, 3) Operational Preparations, 4) Implementation, and 5) Post-Implementation Monitoring and Evaluation. A project tracking tool is used for management and documentation. The Preliminary Activities step defines and justifies the procedure. The Development Work step develops and verifies the PBN procedure. The Operational Preparations step identifies and addresses operational items for PBN route procedure implementation. The Implementation step publishes and implements routes and procedures on chart date. The Post-Implementation Monitoring and Evaluation step monitors operation of routes or procedures for 60 days, evaluates them against the project goals, and generates a PBN Post-Implementation Analysis Report.

33. *Federal Aviation Administration. 2014. "Process for Requesting PBN Procedures."*

This brief describes the process for accessing the FAA's IFP Request web link and processing a request for a PBN procedure or procedures. The FAA provides a web-based tool for requesting a new IFP to serve a particular airport. Request inputs include: 1) the airport's ICAO code; 2) the type of procedure requested, such as RNAV SIDs, RNAV STARs, RNP ARs, Q or T routes; 3) the details of the application, such as the runways or traffic flow served; and that 4) the Anticipated Benefit in Additional Remarks fields must be included. The request is forwarded to the FAA Service Center Operations Support Group, Flight Procedure Team. A local team representing this group can help with the request and initiation.

34. *Federal Aviation Administration. 2014. "Optimization of Airspace and Procedures in the Metroplex, Houston ZHU/I90, Implementation Play Book, Version 1.2."*

This report documents a phased approach for implementing OAPM-developed arrival and departure procedures in the Houston metroplex. It documents who does what in particular time frames prior to and during implementation. Time frames include 90-120 days prior, 60-90 days prior, 30-45 days prior, 30 days prior, 15-30 days prior, 7-15 days prior, and implementation day/phase in. The process calls for regular meetings among interested parties to coordinate planning and implementation. Parties include Implementation Team Core members, air traffic control facilities, control center and local traffic management unit personnel, industry representatives and pilots and internal facility departments. Topics include waiver processing, industry outreach, flight check results and validation flight planning, training and briefings, addressing procedure errors, and contingency plans.

35. *Metropolitan Airports Commission. 2014. "Resolution # 01-2014 Approved by the Minneapolis-St. Paul International Airport (MSP) Noise Oversight Committee (NOC) Regarding Future FAA Performance Based Navigation (PBN) and Area Navigation (RNAV) Standard Departure Procedure Design and Implementation Efforts at MSP."*

The resolution memorializes the entire experience of the MSP NOC in working with the FAA to implement PBN flight procedures for MSP, and provides lessons learned from the collaboration between the MSP NOC and the FAA. The letter first documents the timeline and steps of developing PBN procedures at MSP. The process begins with the NOC's efforts to leverage PBN to design noise abatement procedures. These initial efforts then expand to an initiative undertaken by local FAA for airspace-wide PBN procedure design. The letter then sites the insufficient time and effort allocated to community outreach regarding the new procedures as the main cause of the resulting public opposition to their implementation. The MSP NOC recommended 5 key provisions for how the FAA should conduct PBN design: 1) Obtain NOC support of proposed RNAV STARs, 2) Design OPDs for STARs to all runways at MSP; 3) conduct a case study of successful RNAV SID implementation at another airport with similar challenges, particularly dense population surrounding the airport; 4) future RNAV SID designs and implementations should incorporate previous outreach guidelines; 5) adequate time should be provided in future PBN implementations to prepare and conduct case study and community outreach plan.

PBN Metrics

36. *Federal Aviation Administration. 2011. "Optimization of Airspace and Procedures in the Metroplex (OAPM), Overview of Prototype Study Team Results." Presented at the RTCA Integrated Working Group.*

This slide package provides an overview of the initial findings from North Texas, Washington DC prototype studies. The studies identified inefficiencies, proposed mitigations, and evaluated operational, safety, airspace user benefits and environmental issues. Inefficiencies were identified in various configurations of each metroplex (e.g., north flow, south flow). RNAV and RNP AR enabled mitigations were proposed. Operational and safety benefits were 1) de-conflicting traffic flows via procedural separation; 2) repeatable, predictable flight paths; 3) reduced air traffic controller task complexity; 4) reduced pilot-controller communications; and, 5) reduced need for Traffic Management Initiatives. Operational and safety challenges include managing mixed equipage, in particular the sequencing of capable and incapable aircraft. Airspace user benefits are reductions in 1) fuel burn and emissions, 2) flight distance and time, 3) track length, 4) excess fuel carry, 5) pilot workload, and 6) reduced pilot-controller communications. Airspace and user benefits are increased capacity and improved connectivity to the en route structure. Airspace user costs are increase in flight distance (track length) and RNP AR qualification. Initial environmental screening included noise analysis. Tools used included Graphical Airspace Design Environment (GRADE), Monte-Carlo FMS Aircraft Simulation Tool (MFAST), and Base of Aircraft Data (BADA).

37. *Federal Aviation Administration. 2013. "Optimization of Airspace and Procedures in the Metroplex (OAPM)." Presented at the Los Angeles World Airports (LAWA) Community Noise Roundtable.*

This slide package provides an overview of the FAA's OAPM effort in the Southern California Metroplex. Benefits metrics presented include fuel costs ($6M - $53M), gallons of fuel (2.3M – 17.8M), metric tons of carbon (23k – 184k), and nautical miles of flight distance (648k – 5.4M).

38. *Federal Aviation Administration. "Report on NextGen Performance Metrics."*

This report defines 12 congressionally mandated metrics to measure NextGen improvements in safety, capacity, efficiency, and the environment. The metrics are reported publicly on 2 FAA websites. The metrics are 1) actual arrival and departure rates per hour measured against the currently published aircraft arrival rate and aircraft departure rate for the 35 Operational Evolution Partnership airports; 2) average gate-to-gate times; 3) fuel burned between key city pairs; 4) operations using advanced navigation procedures, including PBN procedures; 5) average distance flown between key city pairs; 6) time between pushing back from the gate and taking off (taxi-out time), and duration between gate out time and take off (wheels off) time; 7) continuous climb or descent, with level flight distance calculated from Top of Descent (TOD) to runway; 8) average gate arrival delay for all arrivals, 9) flown versus filed flight times for key city pairs; 10) implementation of NextGen capabilities designed to reduce emissions and fuel consumption; 11) unit cost of providing air traffic control services; and 12) runway safety, including runway incursions, operational errors, and loss of standard separation events.

39. *Timar, S., Hunter, G., Post, J. 2013. "Assessing the Benefits of NextGen Performance Based Navigation (PBN)." Presented at the 10th USA/Europe Air Traffic Management Research and Development Seminar, Chicago, IL.*

This report documents a method for and results of simulation-based evaluation of the throughput benefits of OAPM-proposed RNAV SIDs and STARs to mitigate different inefficiencies in the Northern California Metroplex. Applications of PBN include RNAV STARs to decouple fixes, routes, or airspace, shared with other SIDs or STARs; RNAV STARs with additional en route transitions; RNAV STARs permitting reduced in-trail separation minima between successive arrivals; and parallel RNAV STARs to relieve existing overloaded STARs. The study analyzes STAR/SID route data and flight tracking data to characterize particular metroplex inefficiencies identified in the OAPM reports. The study employs a queuing system-based approach to model the baseline SID or STAR capturing inefficiency, and the RNAV SID or STAR capturing the proposed mitigation mechanism. The study uses the models to evaluate the throughput impact of RNAV SIDs and STARs to mitigate each inefficiency type. Results showed

SID/STAR throughput increases for each type of inefficiency for specific instances documented in the OAPM Northern California Metroplex report.

40. *Bellamy, W. 2014. "United Airlines Starts NextGen Flight Procedures in Houston." Aviation Today. http://www.aviationtoday.com/av/commercial/United-Airlines-Starts-NextGen-Flight-Procedures-in-Houston_82359.html#.VgGkZN9VhBc. (As of 22 September, 2015).*

This article discusses implementation of satellite-based navigation procedures in the Houston Metroplex. Houston has 20 new RNAV STARs, 20 new RNAV SIDs, and 6 modified ILS transitions. The Houston traffic control center published notices to airmen for non-equipped aircraft. The procedures were developed with a high level of collaboration with FAA and industry. The first fully implemented new procedures permit United Airlines to use FMCs of aircraft to plan path descent. The legacy system permitted the FMC to plan lateral path, with air traffic controllers controlling the aircraft's descent with a sequence of descents and level-offs. The benefits of the new procedures are permitting aircraft to fly efficient, near-idle descent profiles, which save fuel, reduce noise, and reduce emissions; reduce communications by eliminating need to issue headings, speeds, and altitudes; and improve arrival rates (throughput). United Airlines was the lead carrier working with the FAA.

41. *Federal Aviation Administration. 2014. "NextGen: Performance Success Stories." http://www.faa.gov/nextgen/snapshots/stories/. (As of 19 September 2014).*

This web site summarizes the airport- and airspace-specific benefits of NextGen improvements. They include Improved approaches and low-visibility operations, improved surface operations, NAS infrastructure, PBN, separation management, and time-based flow management. The PBN section documents throughput, flight efficiency, access, safety, noise, controller workload, and airport maintenance benefits of various PBN procedures at airports across the U.S., including RNAV arrival and departure routes, and RNP AR and LPV approach procedures.

42. *Federal Aviation Administration. "Performance Assessment of NextGen Capabilities Implemented in CY2010."*

This report documents the assessment of recently fielded NextGen operational capabilities based on the ICAO Key Performance Areas (KPAs) using empirical data. The capabilities included PBN RNAV and RNP SIDs, STARs with OPDs, RNP AR approaches, and RNAV Q and T routes. Airports analyzed included Houston, Philadelphia, Logan International, and Anchorage. Measures of performance that may be of interest include airport and airspace capacity, throughput, capacity utilization and in-trail spacing. Measures also include Air Navigation Service Provider (ANSP) operational and capital investment costs. Measures also include flight distance, time, fuel burn, variability thereof, and difference from great circle distance, time, or fuel burn. Measures also include time in level flight below cruise altitude, distance between top of descent and the runway threshold. Measures also include environment number of people exposed to 65 DNL or higher, CO_2 and other emissions; safety separation conformance, loss rate, airport surface incidents. Flight times and distances for aircraft at study airports increased or decreased depending on the airport. Tailored arrivals demonstrated decreased time below 10,000 feet, higher average altitudes between 20,000 and 30,000 feet, reduced fuel burn and shorter flight times.

Airport Planning and Environmental

43. *Ricondo & Associates, Inc. et al. ACRP Report 20: Strategic Planning in the Airport Industry. Transportation Research Board of the National Academies, Washington, D.C., 2009.*

This guidebook presents a step-by-step process for the strategic planning of airports, including tools, techniques and information to develop and understand strategic plans that guide airport-related actions and decisions. Process steps include 1) creating a process plan and road map; 2) evaluating and understanding the organization; 3) defining and articulating the organization's mission, vision, and values; 4) scanning the environment and predicting developments; 5) identifying strategic issues, strategies, and long-term objectives; 6) formulating short-term objectives and creating action plans; 7) writing, communicating, and executing the plan; and 8) monitoring, evaluating, and modifying the plan. Case studies of different airports are presented in each process step to illustrate the principles and practices.

44. *Legal Research Digest 22: The Role of The Airport Sponsor in Airport Planning and Environmental Reviews of Proposed Development Projects Under the National Environmental Policy Act (NEPA) and State Mini-NEPA Laws. Transportation Research Board of the National Academies, Washignton, D.C., 2014.*

This is a comprehensive assessment of the airport sponsor's role in each phase of the environmental review process of NEPA for proposed development projects. The airport sponsor's role is described for pre-NEPA planning, categorical exclusions, environmental assessments, findings of no significant impact, environmental impact statements, records of decision and supplementation. Guidance is supported by surveys across a wide range of airport operators.

45. *Legal Research Digest 9: Case Studies on Community Challenges to Airport Development. Transportation Research Board of the National Academies, Washington, D.C. 2010.*

This is a comprehensive summary of strategies for and outcomes of municipality and community challenges to airport and FAA expansion and development projects. Content includes discussion of litigation avoidance, federal actions and state actions, and challenges to those proposed airport development actions. Challenges include existence of federal actions in NEPA; challenges to NEPA process; challenges to agency or consultancy that prepared the environmental evaluation; challenges to the standard of review under NEPA; challenges to the FAA determination of a FONSI; challenges to whether alternatives, cumulative effects or proposed mitigations were adequately considered by the FAA; challenges to whether the FAA properly supplemented the EIS; litigation brought under the environmental policy act, endangered species act, historic preservation act, department of transportation act, clean air act, or clean water act; constitutional law challenges; state law issues; jurisdictional issues; challenges to passenger facility charges; and others. A summary of the relevant cases, laws and rules is also provided.

46. *Infrastructure Mangement Groug, Inc. et al. ACRP Report 19: Developing an Airport Performance Measurement System. Transportation Research Board of the National Academies, Washington, D.C. 2010.*

This is a comprehensive guidebook for developing an airport performance measurement system as the basis for managing airport performance. The guidance includes an extensive list of areas for performance measurement and performance measures. Performance measurement areas proposed include safety and environmental sustainability. Safety measures include airfield violations of runway incursions, FAA safety compliance violations, and warning citations. Environmental sustainability measures include environmental compliance, including violations identified by a regulatory agency; air quality, including emissions per aircraft movement and air quality at the airport; and noise, including noise levels and noise complaints. Additional guidance concerns the development and implementation of the airport performance measurement system, and incorporating the measurements as feedback into a larger airport management system.

47. *Federal Aviation Administration. 2006. "Order 5050.4B, National Environmental Policy Act (NEPA) Implementing Instructions for Airport Actions."*

This order presents the guidelines for the FAA's Office of Airports to assess the environmental effects of a proposed airport action in complying with NEPA. The ARP reviews EAs or prepares EISs to assess the environmental effects of no action, the proposed action, and reasonable alternatives to the proposed action, and conceptual measures to mitigate those effects. Review of the EA may yield a FONSI to environmental resources, or that an EIS is needed. After completing the EIS, the FAA prepares a Record of Decision for the preferred alternative. The result is approval or disapproval of the airport action. Categorical exclusions are categories of actions that normally do not individually or cumulatively have significant adverse effects on the human environment. However, there may be extraordinary circumstances where a normally categorically excluded action may have a significant environmental effect. Impact on noise sensitive areas is an extraordinary circumstance. Significance thresholds are defined for assessing extraordinary circumstances. For example, a 1.5 dB increase in DNL of noise-sensitive areas at or above 65 dB, or an increase from 63.5 to 65 dB, or a 3 dB or less increase in DNL of parks, wildlife refuges, historic or cultural sites are considered significant. The EA documents a purpose and need of action, the proposed action, the alternatives, the affected environment, the environmental consequences, the mitigation, the cumulative impact analysis, and the agencies and people consulted. Coordination with appropriate resource agencies, industry groups, and affected communities is required to address issues of greatest concern. A scoping package is distributed to participants for engagement. A 30-day public review period is required. The EIS analyzes and discloses potential significant individual and cumulative environmental impacts of the proposed airport actions and alternatives.

48. *Federal Register. 2007. Vol. 72, No. 145, p. 41578.*

This registrar segment documents the FAA's requirements, policies, and guidance concerning air traffic control activities and adopting approach, departure, and en route procedures for air operations. In particular, it defines 3,000 feet AGL as the "mixing height," and states that aircraft emissions in that region have little impact on ground-level pollution concentrations. Furthermore, it states that air traffic procedures above 1,500 feet AGL and below the mixing height have little effect on emissions and ground-level contamination.

49. *Federal Aviation Administration. 2006. "Order 1050.1E, Change 1, Environmental Impacts: Policies and Procedures."*

This order presents policy and procedures to ensure compliance with CEQ regulations for implementing the provisions of the NEPA, 40 CFR parts 1500-1508; DOT Order 5610.1C, Procedures for Considering Environmental Impacts, and other related statutes and directives. Section 209 concerns public hearings, workshops and meetings. Section 214b designates the Associate Administrator for Airports as responsible for considering environmental impacts of proposed FAA approvals and FAA-funded airport actions, airport layout plans, and assuring compliance with NEPA requirements. Section 303 concerns Categorical Exclusions and charts the determination process. Section 304 defines extraordinary circumstances. Section 311 defines categorical exclusions for FAA actions involving establishment, modification, or application of airspace and air traffic procedures. Section 401 defines actions normally requiring an environmental assessment. Section 404 defines the environmental assessment process and components of EA. Chapter 5 concerns EIS and records of decision.

50. *Federal Aviation Administration. 2012. "Order 1050.1E, Change 1, Guidance Memo #5, Guidance for Implementation of the Categorical Exclusion in Section 213(c)(1) of the FAA Modernization and Reform Act of 2012."*

This order provides guidance to implement a legislative categorical exclusion 123(c)(1) CatEx established by the Congressional FAA Modernization and Reform Act of 2012, effective 6 December 2012.

Section 213(c)(1) states that navigation performance and area navigation procedures developed, certified, published or implemented under this section are presumed to be covered by CatEx under chapter 3 of FAA Order 1050.1E unless the FAA Administrator determines extraordinary circumstances exist. This is specific to the 35 OEP airports, medium or small hub airports within the same metroplex (at the Administrator's discretion), and 35 non-OEP airports. It calls out 1050.1E 401m and 401n normally requiring an EA, and states that RNAV/RNP procedures normally requiring EA under these provisions now fall within the scope of this categorical exclusion, absent extraordinary circumstances. Extraordinary circumstances may exist as described in paragraph 304 of 1050.1E. The FAA conducts screening and other consultation or analyses to determine if the potential for extraordinary circumstances applies to this CatEx. Screening is a first-order evaluation to determine the potential for significant environmental impacts. It calls for using FAA-approved lookup tables and screening tools. The documented CatEx should include screening results and other reviews supporting lack of extraordinary circumstances. Otherwise, the FAA must generate an EA or EIS.

51. *Federal Aviation Administration. 2012. "Order 1050.1E, Change 1, Guidance Memo #3, Considering Greenhouse Gases and Climate Under the National Environmental Policy Act (NEPA): Interim Guidance."*

This order provides guidance concerning consideration and evaluation of greenhouse gases (GHGs) and climate under NEPA. Guidance includes the NEPA evaluation process, considering the context of GHG emissions, and reducing GHGs. It includes an appendix citing NEPA text concerning the affected environment, environmental consequences (for airport and air traffic actions), and cumulative effects.

52. *Federal Aviation Administration. 2012. "Order 1050.1E, Change 1, Guidance Memo #4, Guidance on Using AEDT 2a to Conduct Environmental Modeling for FAA Air Traffic Airspace and Procedure Actions."*

This order provides guidance on the use of the AEDT Version 2a to conduct aircraft noise, fuel burn and emissions modeling for FAA air traffic airspace and procedure actions based on NEPA. It includes applicability, background, and a technical appendix. The technical appendix documents requirements for using AEDT 2a, including input of representative schedules, outputs (noise, criteria pollutant emissions, fuel burn and CO2 emissions), and non-default methods and data, use of weather information in analysis, atmospheric absorption, use of terrain for analysis, use of lateral attenuation for propeller aircraft and helicopters, and impact evaluation.

53. *RTCA NextGen Advisory Committee. 2013. "CatEx 2: Recommendation for Implementing the Categorical Exclusion in Section 213(c)(2) of the FAA Modernization and Reform Act of 2012."*

This report provides guidance to the FAA on how measurable reductions in noise for PBN procedures might be assessed on a per-flight basis, as described in Section 213(c)(2) CatEx 2 of the FAA Modernization and Reform Act of 2012. Assessment interprets "per-flight basis" for assessing noise as averaging the noise of a representative set of flights for a particular flight procedure. The report proposes the net noise reduction method. For this method, the PBN procedure is compared to the existing procedure to assess 1) the number of people who experience a reduction in noise compared to the number of people who experience an increase in noise, at noise levels greater than DNL 45 dB; 2) the increase in the number of people experiencing DNL 65 dB or greater, including a DNL increase from 63.5 to 65 dB. It describes applying the proposed methodology to the FAA noise screening analysis to determine if the procedure complies with CatEx 2. The report proposes a 3-step process for implementing CatEx 2: 1) identify area around airport where people might be impacted, 2) determine change in number of people exposed to noise in DNL bands with PBN versus conventional, and 3) apply the net noise reduction method. DNL is computed at census block centroids. Noise does not involve just sound energy, but exposure and experience of people to the energy. The committee considered a range of noise metrics, including DNL, aircraft noise certification levels, time above threshold, maximum sound level (LAMAX), and SEL. SEL captures noise level and duration; however, there are no accepted criteria or thresholds for evaluating the impact. Selection of points on the ground and noise thresholds complicates application of these alternative metrics.

54. *U.S. Environmental Protection Administration. 2014. "Six Common Air Pollutants." http://www.epa.gov/oar/urbanair/sipstatus/overview.html. (As of July 29, 2014).*

This web site defines six common air pollutants included in the NAAQS under the CAA. The six pollutants are ozone, particulate matter, carbon monoxide, nitrogen dioxide, sulfur dioxide, and lead. Comprehensive information for each pollutant is provided in additional linked web pages.

Airport Community Outreach

55. *Schaar, D., Sherry, L. "Analysis of Airport Stakeholders." Presented at the Integrated Communications, Navigation and Surveillance Conference."*

This research paper identifies, defines and specifies the goals of a comprehensive set of airport stakeholders, and proposes flowchart model of their relationships. Airport stakeholders include 1) passengers; 2) business, commerce, tourism, arts, sports, and education organizations that are customers of the airport; 3) air carriers, including passenger and cargo; 4) general aviation users; 5) airport organization, 6) investors and bond-holders, which fund general airport revenue bonds, 7) concessionaires in terminal buildings, 8) service providers in terminal buildings, 9) employees, 10) federal government; 11) local government, which elects airport board to oversee strategic direction and management of airport, 12) communities affected by airport operations; 13) non-governmental organizations, such as airport and environmental interest groups; 14) parking and ground transportation operators; and 15) airport suppliers. Flight operations of an airport may adversely affect the local community through increased noise, reduced air quality, reduced water quality, hazardous waste emissions and increased automobile traffic. The goals among numerous stakeholders are similar: maximizing passenger and traffic levels, maximizing destinations served and service frequency, maximizing economic impact, managing costs, and ensuring safety. The goals of the airport organization and community include these and also minimizing noise and achieving environmental sustainability.

56. *Woodward, Jon M. et al. ACRP Report 15: Aircraft Noise: A Toolkit for Managing Community Expectations. Transportation Research Board of the National Academies, Washington, D.C. 2009.*

This is a comprehensive guidebook for airport managers to address the impact of passenger jet traffic noise on the community surrounding the airport. It provides background information concerning aircraft noise and noise abatement, best practices and guidance for communicating and engaging with the public, and tools to develop and refine programs for communicating with public and private stakeholders regarding noise. The guidance focuses on exchange; that is, a bi-directional communication between the airport representatives and the community and other stakeholders. The guidance is targeted towards airports of all sizes; that is, small, medium, and large, beginning with basic communication methods, then extending to staffing approaches and techniques and strategies for communications. Best practices for effective communications include building trust through bi-directional communications, having senior airport leadership represent the airport, using graphics to illustrate key messages, openness and truthfulness in communications, airport noise staff who are equally skilled in public communications, and proactive communications that educate the community regarding future airport developments and changes that may impact them. Best metrics for evaluating noise include DNL for noise exposure patterns, SEL for sound impact on individuals and sounds attenuation requirements, Number of Events Above (NA) to evaluate alternative conditions and assess their impact on individuals, and Time Above (TA) to assess ground noise and its impact on the communications and cognition of students in school. Best practices for managing noise compatibility issues include shifting ground tracks, runway use programs, restricting run-up operations, pilot awareness programs, and planning to address and avoid land use conflicts.

57. *ACRP Report 26: Guide Book for Conducting Airport User Surveys. Transportation Research Board of the National Academies, Washington, D.C. 2009.*

This is a comprehensive guidebook for conducting user surveys at airports. Such surveys are often the primary source of information to support planning and operations. Surveys can be subject to a number of pitfalls, which can make them ineffective, such as poor continuity among surveys, poorly designed surveys, infrequency in surveying, inappropriate sample sets for accurate results, and weighting responses from individuals and large parties. Background information includes survey sampling concepts, survey planning and implementation, types of surveys, survey design, and results analysis. Applications include surveys of air passengers, employees, tenants, area residents, area business and cargo. Guidance for each survey category includes purpose, data to be collected, survey methodology; sampling, coverage and timing; questionnaire wording and length; measures to obtain adequate responses; and survey budget and survey summary.

58. *Chicago Sun Times. 2014. "Hearings On Runway Changes at O'Hare Out of Earshot of Affected Residents: Analysis."*

This article reports on the outreach efforts undertaken by the FAA in the O'Hare Modernization Program. The FAA hosted a public hearing about its Draft Environmental Impact Statement (Draft EIS) to obtain comments for the proposed modernization of O'Hare International Airport on a Tuesday afternoon at Avalon Banquets in Elk Grove Village. The modernization plan calls for using the parallel runways instead of the diagonal ones to expand airport flight capacity. The FAA is legally required to hold public hearings. Three public hearings were held by the FAA in areas not impacted by heavy traffic under the modernization plan. Instead, it held hearings in areas where noise was diminished. The hearings were held nine years prior to a change in the flight paths. The hearings were lightly attended relative to the population. Now the airport is receiving numerous noise complaints from Norridge and Itasca wards in wake of the FAA implementing the flight path changes; 24,000 Chicago residents are subjected to serious jet noise, an increase of 6267 people. U.S. Representative Mike Quigley, D-Ill., was getting involved.

59. *Port of Portland. 2015. "Community Outreach," http://www.portofportland.com/Cmnty_Outrch_Home.aspx. (As of 22 September 2015).*

This web site documents community outreach events related to Portland Airport (PDX) operations and community impacts. The citizen noise advisory committee is the official forum to address community's aircraft noise concerns, residential and business concerns; input to noise abatement projects, PDX Airport Noise Compatibility Plan, future airport noise plans, long-range airport planning, and citizen understanding of noise issues. The 15-member committee comprises representatives from cities and counties around PDX (e.g., Portland, Vancouver, Gresham; Multnomah, Clark, Washington, Clackamas). The Port of Portland Noise Management has a PDX Noise Alerts Twitter feed to notify citizens in advance of scheduled noise events. The PDX Noise Compatibility Study (Part 150 Study) identifies and evaluates measures to aid in reducing aircraft noise impacts to residential communities and other noise-sensitive areas. Stakeholder involvement includes airline, pilot, community, business, and environmental groups. The airport must update its noise exposure maps when a change in operations results in a significant change in noise exposure over areas categorized as non-compatible with aircraft noise.

PBN Flight Procedures, FAA Orders

60. *Federal Aviation Administration. 1998. "JO 7130.3A, Holding Pattern Criteria."*

This order prescribes criteria for determining holding pattern airspace area dimensions and instructions for their use. These criteria apply to all IFR holding operations conducted within airspace where domestic Federal Aviation Administration air traffic control procedures are used. Personnel responsible for planning holding airspace areas shall adhere to these criteria.

61. *Federal Aviation Administration. 2001. "JO 7110.79D, Charted Visual Flight Procedures."*

This order establishes criteria for developing charted visual flight procedures when required for environmental/noise considerations and/or, when necessary, for the safety and efficiency of air traffic operations.

62. *Federal Aviation Administration. 2005. "JO 8260.53, Standard Instrument Departures That Use Radar Vectors to Join RNAV Routes."*

This order provides the criteria to evaluate the use of radar vectors to join the initial departure fix of an RNAV SID.

63. *Federal Aviation Administration. 2006. "JO 8260.49A, Simultaneous Offset Instrument Approach (SOIA)."*

This order provides criteria and guidance for constructing and operating simultaneous offset instrument approaches to parallel runways spaced at least 750 feet apart, and less than 3,000 feet apart at airports identified by the FAA for SOIA.

64. *Federal Aviation Administration. 2009. "JO 8260.42B, United States Standard for Helicopter Area Navigation (RNAV)."*

These criteria are the FAA standards for developing helicopter RNAV instrument procedure construction based on GPS.

65. *Federal Aviation Administration. 2012. "JO 8260.58, United States Standard for Performance-based Navigation (PBN) Instrument Procedure Design."*

This order provides consolidated United States PBN procedure design criteria.

66. *Federal Aviation Administration. 2013. "JO 8260.43B, Flight Procedures Management Program."*

This order provides guidance for initiating and processing requests for public and special instrument and visual flight procedures including RNAV procedures. It establishes an RAPT at each FAA regional office as the point of contact for standardized consideration, prioritization, and processing of requests for new and amended flight procedures. It also establishes the NAPT.

67. *Federal Aviation Administration. 2013. "JO 7100.9E, Standard Terminal Arrival Program and Procedures."*

This order provides guidance and standardization for procedures development and management of the STAR program.

68. *Federal Aviation Administration. 2014. "JO 7110.65V, Air Traffic Control."*

This order prescribes air traffic control procedures and phraseology for use by persons providing air traffic control services. Controllers are required to be familiar with the provisions of this order that pertain to their operational responsibilities and to exercise their best judgment if they encounter situations that are not covered by it.

69. *Federal Aviation Administration. 2014. "JO 7400.2K, Procedures for Handling Airspace Matters."*

This order specifies procedures for use by all personnel in the joint administration of the airspace program. The guidance and procedures herein incorporate into one publication as many orders, notices, and directives of the affected services as possible. Although every effort has been made to prescribe complete procedures for the management of the different airspace programs, it is impossible to cover every circumstance. Therefore, when a situation arises for which there is no specific procedure covered in this order, personnel must exercise their best judgment.

FAA Order JO 7400.2K (Order 7400.2) is an internal agency document that gives administrative guidance to agency officials with jurisdiction over Obstruction Evaluation and Airport Airspace Analysis (OE/AAA). Part 2, Objects Affecting Navigable Airspace, and Part 3, Airport Airspace Analysis, contain relevant information pertaining to matters of physical objects and airspace navigation safety. Order 7400.2 refers to other documents, both regulatory and administrative, that provide the technical requirements for OE/AAA, and provides systematic guidance to administrators regarding the OE/AAA decision-making process. Order 7400.2 also provides diagrammatic clarifications to the regulations and standards found within it, and within other texts, including FAR Part 77.

70. *Federal Aviation Administration. 2014. "JO 7930.2P, Notices to Airmen (NOTAMs)."*

This order prescribes procedures used to obtain, format, and disseminate information on unanticipated or temporary changes to components of, or hazards in, the NAS until the associated aeronautical charts and related publications have been amended.

71. *Federal Aviation Administration. 2014. "JO 8260.3B, United States Standard for Terminal Instrument Procedures (TERPS)."*

This order contains the criteria used to formulate, review, approve, and publish procedures for instrument flight operations to and from civil and military airports.

Technical guidance is provided within this Order and its several derivative Orders to the agencies responsible for developing instrument flight procedures, which are specific to the navigation equipment available and the operating capacity of individual aircraft types. The TERPS guidance is highly technical in nature, and is intended for use by the agencies charged with developing safe and efficient operating procedures. For civil aviation, the FAA either prepares or must approve new and revised procedures. Instrument flight procedures are designed based on existing and known planned obstacles, among other factors.

Civil Airports: IFPs must be provided at civil airports open to the aviation public whenever a reasonable need is shown. No minimum number of potential instrument approaches is specified; however, the responsible FAA office must determine that a public procedure will be beneficial to more than a single user or interest. Private procedures, for the exclusive use of a single interest, may be provided on a reimbursable basis under Title 14 of the Code of Federal Regulations (14 CFR) Part 171, where applicable, if they do not unduly conflict with the public use of airspace. Reasonable need is deemed to exist when the IFP will be used by: (1) A certificated air carrier, air taxi, or commercial operator; or (2) two or more aircraft operators whose activities are directly related to the commerce of the community; and (3) military aircraft.

REQUESTS FOR PROCEDURES: Requests for military procedures are processed as described by the appropriate military service. Civil procedures may be requested by letter; therefore, no special form is required. Send requests to the appropriate Regional or Service Area Office. Requests are accepted from any aviation source, provided the request indicates that the airport owner/operator has been notified of the request.

(Such notification is necessary only when the request is for an original procedure to an airport not already served by an approach procedure.) The FAA will advise airport owners/operators of additional requests for procedures.

APPROVAL: Where a reasonable civil need has been established or a military requirement exists, a request for an IFP must be approved if the following minimum standards are met:

a. Airport. An airport airspace analysis conducted under Order JO 7400.2, Procedures for Handling Airspace Matters, or appropriate military directives, as applicable must find the airport acceptable for IFR operations. The airport landing surfaces must be adequate to accommodate the aircraft expected to use the procedure. The airport infrastructure requirements of FAA AC 150/5340-1, Standards for Airport Markings, and FAA AC 150/5300-13A, Airport Design, paragraph 317 must be met to achieve the lowest possible minimums.

Only circling minimums may be approved to airports where the runways are not clearly defined. Runway lighting is required for approval of night instrument approach operations. Do NOT deny takeoff and departure procedures at night due solely to the absence of runway edge lights.

b. Navigation Facilities. All instrument and visual navigation facilities used must successfully pass flight inspection.

c. Obstacle Marking and Lighting. Obstacles that penetrate 14 CFR Part 77 imaginary surfaces are obstructions and, therefore, should be marked and lighted, insofar as is reasonably possible under FAA AC 70/7460-1, Obstruction Marking and Lighting. Those penetrating the 14 CFR Part 77 approach and transitional surfaces should be removed or made conspicuous under that AC. Do NOT deny instrument approach procedures due to inability to mark and light or remove obstacles that violate Part 77 surfaces.

NOTE: In military procedures, the appropriate military directives apply.

d. Weather Information. Terminal weather observation and reporting facilities must be available for the airport to serve as an alternate airport. Destination minimums may be approved when a general area weather report is available prior to commencing the approach and approved altimeter settings are available to the pilot prior to and during the approach consistent with communications capability.

e. Communications. Air-to-ground communications must be available at the initial approach fix minimum altitude and where an aircraft executing the missed approach is expected to reach the missed approach altitude.

72. *Federal Aviation Administration. 2014. "JO 8260.16, Airport Obstruction Surveys."*

This order provides procedures for obtaining Airport Obstruction Surveys relating to ILS installations. Cancelled by Order 8260.3B, "United States Standard for Terminal Instrument Procedures (TERPS)."

73. *Federal Aviation Administration. 2014. "JO 8260.26F, Establishing and Scheduling Civil Public-Use Standard Instrument Procedure."*

This order provides policy and guidance for establishing public use SIAP and ODP effective dates. It ensures that aeronautical charts and supporting data will not be released to the public until it is known that the supporting navigation equipment will perform satisfactorily and that all procedural data are correct and confirmed by flight inspection.

74. *Federal Aviation Administration. 2014. "JO 8260.46E, Departure Procedure (DP) Program."*

This order provides the policy, guidance, and standardization for initiating, developing, processing, and managing the departure procedure program.

75. *Federal Aviation Administration. 2015. "JO 8200.1D, United States Standard Flight Inspection Manual."*

The purpose of this order is to prescribe standardized procedures for flight inspection of air navigation services.

76. *Federal Aviation Administration. 2015. "JO 8260.19F, Flight Procedures and Airspace."*

This order provides guidance to all FAA personnel for the administration and accomplishment of the FAA Flight Procedures and Airspace Program.

Requests for Public-Use IFPs:

Requests for approval and/or establishment of instrument flight procedures may originate from many different sources. See Order 8260.43, Flight Procedures Management Program. It may be a request from a state, city, airport manager, or an individual. It may also be from an air carrier, air taxi, military, commercial operator, ATC, or FAA Flight Standards Service (AFS) personnel. General information on the lifecycle process associated with IFPs can be found in appendix O.

Requirements for approval of instrument approach procedures are contained in Order 8260.3, U.S. Standard for TERPS, Volume 1, Chapter 1.

77. *Federal Aviation Administration. 2015. "FS 8260.57A, Oversight of Third Party Instrument Flight Procedure Service Providers."*

This order establishes FAA Flight Standards Service (AFS) policy, guidance, and standardization for the oversight of third party IFP service providers.

78. *Federal Aviation Administration. 2015. "JO 8260.60A, Special Instrument Procedures."*

This order provides the policy, guidance, and standardization for initiating, developing, processing, and managing Special [non-Title 14 Code of Federal Regulations (14 CFR) Part 97] Instrument Procedures. This guidance formerly resided in Order 8260.19, Flight Procedures and Airspace. Special instrument flight procedures authorized for use only by air carriers or some other segment of the aviation industry are not published in the Federal Register and are identified as "Special Procedures." Special Procedures may be developed for public and private use based on aircraft performance, aircraft equipment, or crew training, and may also require the use of landing aids, communications, or weather services not available for public use.

PBN Flight Procedures, FAA Advisory Circulars

79. *Federal Aviation Administration. 2014. "FAA-H-8083-16, Instrument Flying Handbook."*

This handbook supersedes FAA-H-8261-1A, *Instrument Procedures Handbook*, dated 2007. It is designed as a technical reference for professional pilots who operate under IFR in the NAS. This *Instrument Flying Handbook* is designed for use by instrument flight instructors and pilots preparing for instrument rating tests. Instructors may find this handbook a valuable training aid as it includes basic reference material for knowledge testing and instrument flight training.

80. *Federal Aviation Administration, 2007. "AC 70-7460-1, Obstruction Marking and Lighting."*

This document contains the Federal Aviation Administration's standards for marking and lighting structures to promote aviation safety.

81. *Federal Aviation Administration. 2007. "AC 90-100A, U.S. Terminal and En Route Area Navigation (RNAV) Operations."*

This AC provides operational and airworthiness guidance for operation on U.S. RNAV routes, SIDs, and STARs. Operators and pilots should use the guidance in this AC to determine their eligibility for these U.S. RNAV routes and procedures.

82. *Federal Aviation Administration. 2011. "AC 90-101A, Approval Guidance for RNP Procedures with Special Aircraft and Aircrew Authorization Required (SAAAR)."*

This AC provides airworthiness and operational approval guidance material for aircraft operators conducting Title 14 of the Code of Federal Regulations (14 CFR) part 97 Area Navigation RNAV RNP IAP with AR, charted as "RNAV (RNP) RWY XX."

83. *Federal Aviation Administration. 2011. "AC 90-110, Authorization Guidance for Development of RNP Procedures with AR by Third Party IFP Service Providers."*

This AC provides guidance material for third party IFP developers, referred to as "IFP Service Providers," to become authorized by the FAA to develop Title 14 of the Code of Federal Regulations (14 CFR) part 97 RNP IFPs with AR. IFPs are then referred to as "RNP AR." This advisory circular was cancelled on 13 February 2015.

84. *Federal Aviation Administration. 2015. "AC 90-113A, Instrument Flight Procedure Validation of IFPs."*

This AC provides guidance for conducting instrument flight procedure validation of satellite-based PBN IFPs for both fixed-wing and helicopter aircraft. This AC also addresses validation of helicopter WAAS special IFPs.

85. *Federal Aviation Administration. 2012. "AC 150/5200-28, Notices to Airmen (NOTAMs) for Airport Operators."*

This AC provides guidance on using the NOTAM system for airport condition reporting.

86. *Federal Aviation Administration. 2012. "AC 150/5300-13A, Airport Design."*

This AC contains the FAA standards and recommendations for airport design. Airport Design is the most widely utilized AC in the airport planning industry. Airport operators are advised in this AC regarding the standards of airport design that are known to maximize the safety and efficiency of the NAS. Within these guidelines are regulations and guidance for the clearance of obstacles. For off-airport obstacle clearance, this AC refers heavily to the regulatory standards set forth in FAR Part 77. The AC also provides guidance for those obstacle clearance concerns that would typically be on airport property, such as Runway Protection Zones, Object Free Areas, and Obstacle Free Zones. While this AC offers references to statutory requirements and provides quantitative guidelines for obstacle clearance that promote safe air navigation close to an airport, the document also provides qualitative guidance as responsible parties make decisions related to obstacle clearance. The principles within this AC related to obstacle clearance stem from an introductory premise that, "existing and planned airspace required for safe and efficient aircraft operations should be protected by acquisition of a combination of zoning, easements, property interests, and other means" (§201(a)(1)).

Appendix 2 of this AC ("Runway End Siting Requirements") describes, quantifies, and diagrams the sloped airspace clearance requirements for the critical points on the runway for arriving and departing aircraft. The emphasis of this appendix is that a new object that penetrates a critical runway end siting surface may result in serious impacts on the use of the runway by requiring the critical points to be moved, resulting in a reduction of usable runway length, which, in most cases, will incrementally reduce the capacity of that runway. As a companion to Appendix 2, Appendix 14 ("Declared Distances")

prescribes the usable length reductions that must be made in order for the runway to be in compliance with runway end siting and other airport design standards.

Chapter 3 covers Runway Design Standards and contains an interactive Runway Design Standards Matrix found on Page 93, Table 3-5, Runway design standards matrix, in the document.

87. *Federal Aviation Administration. 2007. "AC 150/5300-16A, General Guidance and Specifications for Aeronautical Surveys: Establishment of Geodetic Control and Submission to the National Geodetic Survey."*

This AC explains the specifications for establishing geodetic control on or near an airport. It also describes how to submit the information to the National Geodetic Survey for approval and inclusion in the National Spatial Reference System in support of aeronautical information surveys.

88. *Federal Aviation Administration. 2011. "AC 150/5300-17C, General Guidance and Specifications for Aeronautical Survey Airport Imagery Acquisition and Submission to the National Geodetic Survey."*

This AC provides the specifications for Airport Imagery acquisition and how to submit the imagery for review and approval in support of aeronautical information and airport engineering surveys.

89. *Federal Aviation Administration. 2009. "AC 150/5300-18B, General Guidance and Specifications for Submission of Aeronautical Surveys to NGS: Field Data Collection and Geographic Information System (GIS) Standards."*

This AC provides the specifications for the collection of airport data through field and office methodologies in support of the FAA. It also explains how to submit data to the FAA, who will forward the safety critical data to the National Geodetic Survey for independent verification and validation. This AC provides standards for documenting airport geographic information using both field survey and remote sensing data gathering methods, and mapping using GIS, in such a manner that survey data generated by any entity conforming to the standard will be usable by the FAA and the National Geodetic Survey. Chapter 16 of this AC considers the requirement to identify, with precision and accuracy, the presence of obstructions on and around an airport. The AC details the regulatory requirements for airspace obstruction limitations from FAR Part 77 both quantitatively and diagrammatically for each type of runway approach and for non-approach areas around an airport. While FAR Part 77 requires notification of construction for all structures that meet the requirements in §77.13, this AC provides guidance regarding the types of obstructions that must appear on airport aeronautical survey charts. This AC provides checklists for the data required to chart obstructions on or around an airport. Also contained within this AC is guidance for charting the numerous declared distance considerations (as outlined in AC 150/5300-13), which may have an impact on the obstruction evaluation process.

90. *Federal Aviation Administration. 2013. "AC 150/5340-1L, Standards for Airport Markings."*

This AC contains the FAA standards for markings used on airport runways, taxiways, and aprons.

PBN Flight Procedures, Title 14, Code of Federal Regulations

91. *Federal Aviation Administration. 2015. "Part 77, Safe, Efficient Use and Preservation of the Navigable Airspace."*

This part establishes: (a) the requirements to provide notice to the FAA of certain proposed construction, or the alteration of existing structures; (b) the standards used to determine obstructions to air navigation, and navigational and communication facilities; (c) the process for aeronautical studies of obstructions to air navigation or navigational facilities to determine the effect on the safe and efficient use of navigable airspace, air navigation facilities or equipment; and (d) the process to petition the FAA for discretionary review of determinations, revisions, and extensions of determinations.

FAR Part 77 provides the statutory requirements for notification to the FAA of proposed construction or alteration; defines physical airspace obstruction standards; and outlines FAA's obstruction evaluation procedures. FAR Part 77 outlines procedures available for additional review when the effect of a proposed structure on airspace navigation safety or efficiency is questionable, or when the public need for the proposed development justifies acceptable modifications to existing airspace procedures. As a regulatory document, FAR Part 77 provides limited technical information. Interpretation of the regulation may require the review of other technical guidance documents.

In addition to a general introduction, FAR Part 77 consists of five subparts. Subparts (1) and (2) comprise the substantive regulations while subparts (3) and (4) are procedural regulations. Subpart (5) provides special regulations for the broadcasting industry. (1) FAR Part 77 outlines the specific conditions that require notice to the FAA prior to new construction or alteration of an existing structure. This provision includes instructions and time requirements for the notification process. (2) FAR Part 77 provides the criteria that the FAA uses to determine whether an object constitutes an "obstruction to air navigation." These criteria, including heights above ground, civil or military "imaginary surfaces," and effects to flight procedures, are the three-dimensional boundaries by which the FAA classifies an object as an obstruction. (3) FAR Part 77 describes the process for conducting an aeronautical study, and potential rulings that may result. An aeronautical study may be necessary if a proposed construction exceeds obstruction standards, and the entity proposing the development seeks a favorable determination from the FAA. This section outlines the rights and responsibilities of parties involved in an aeronautical study. (4) FAR Part 77 prescribes "rules of practice for hearings," in the event that an aeronautical study ruling is contested. This subpart, like the preceding subpart, clarifies rights and responsibilities, as well as rules of representation of all parties involved in an airspace obstruction hearing. (5) FAR Part 77 includes special provisions and recommendations for maximizing the compatibility of airspace navigation and broadcasting infrastructure.

92. *Federal Aviation Administration. 2015. "Part 97, Standard Instrument Procedures."*

(a) This part prescribes standard instrument approach procedures to civil airports in the United States and the weather minimums that apply to landings under IFR at those airports. (b) This part also prescribes ODPs for certain civil airports in the United States and the weather minimums that apply to takeoffs under IFR at civil airports in the United States.

PBN Flight Procedures, Other Publications

93. *Federal Aviation Administration. 2015. "Aeronautical Information Manual (AIM), Change 3."*

This manual is designed to provide the aviation community with basic flight information and ATC procedures for use in the NAS of the United States.

94. *Federal Aviation Administration. "Airport Facility Directory (A/FD)."*

The A/FD is a 7 volume set plus Alaska and Pacific Territories of printed paper books containing data on public and joint use airports, seaplane bases heliports, VFR airport sketches, NAVAIDs, communications data, weather data sources, airspace, special notices, and operational procedures. The seven volumes cover the conterminous United States, Puerto Rico, and the Virgin Islands.

Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FAST	Fixing America's Surface Transportation Act (2015)
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TDC	Transit Development Corporation
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation

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