ACRP

REPORT 86

AIRPORT COOPERATIVE RESEARCH PROGRAM

Sponsored by the Federal Aviation Administration

Environmental Optimization of Aircraft Departures: Fuel Burn, Emissions, and Noise

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

AIRPORT COOPERATIVE RESEARCH PROGRAM

ACRP REPORT 86

Environmental Optimization of Aircraft Departures: Fuel Burn, Emissions, and Noise

Brian Kim, Ben Manning, and Ben Sharp
WYLE LABORATORIES, INC.
Arlington, VA

John-Paul Clarke, Isaac Robeson, and Jim Brooks
GEORGIA INSTITUTE OF TECHNOLOGY
Atlanta, GA

David Senzig
VOLPE CENTER–U.S. DEPARTMENT OF TRANSPORTATION
Cambridge, MA

Subscriber Categories
Aviation • Economics • Environment

Research sponsored by the Federal Aviation Administration

TRANSPORTATION RESEARCH BOARD

WASHINGTON, D.C.
2013
www.TRB.org

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). The ACRP carries out applied research on problems that are shared by airport operating agencies and are not being adequately addressed by existing federal research programs. It is modeled after the successful National Cooperative Highway Research Program and Transit Cooperative Research Program. The ACRP undertakes research and other technical activities in a variety of airport subject areas, including design, construction, maintenance, operations, safety, security, policy, planning, human resources, and administration. The ACRP provides a forum where airport operators can cooperatively address common operational problems.

The ACRP was authorized in December 2003 as part of the Vision 100-Century of Aviation Reauthorization Act. The primary participants in the ACRP are (1) an independent governing board, the ACRP Oversight Committee (AOC), appointed by the Secretary of the U.S. Department of Transportation with representation from airport operating agencies, other stakeholders, and relevant industry organizations such as the Airports Council International-North America (ACI-NA), the American Association of Airport Executives (AAAE), the National Association of State Aviation Officials (NASAO), Airlines for America (A4A), and the Airport Consultants Council (ACC) as vital links to the airport community; (2) the TRB as program manager and secretariat for the governing board; and (3) the FAA as program sponsor. In October 2005, the FAA executed a contract with the National Academies formally initiating the program.

The ACRP benefits from the cooperation and participation of airport professionals, air carriers, shippers, state and local government officials, equipment and service suppliers, other airport users, and research organizations. Each of these participants has different interests and responsibilities, and each is an integral part of this cooperative research effort.

Research problem statements for the ACRP are solicited periodically but may be submitted to the TRB by anyone at any time. It is the responsibility of the AOC to formulate the research program by identifying the highest priority projects and defining funding levels and expected products.

Once selected, each ACRP project is assigned to an expert panel, appointed by the TRB. Panels include experienced practitioners and research specialists; heavy emphasis is placed on including airport professionals, the intended users of the research products. The panels prepare project statements (requests for proposals), select contractors, and provide technical guidance and counsel throughout the life of the project. The process for developing research problem statements and selecting research agencies has been used by TRB in managing cooperative research programs since 1962. As in other TRB activities, ACRP project panels serve voluntarily without compensation.

Primary emphasis is placed on disseminating ACRP results to the intended end-users of the research: airport operating agencies, service providers, and suppliers. The ACRP produces a series of research reports for use by airport operators, local agencies, the FAA, and other interested parties, and industry associations may arrange for workshops, training aids, field visits, and other activities to ensure that results are implemented by airport-industry practitioners.

ACRP REPORT 86

Project 02-12
ISSN 1935-9802
ISBN 978-0-309-25903-3
Library of Congress Control Number 2013935788

Published reports of the

AIRPORT COOPERATIVE RESEARCH PROGRAM

are available from:

Transportation Research Board
Business Office
500 Fifth Street, NW
Washington, DC 20001

and can be ordered through the Internet at

http://www.national-academies.org/trb/bookstore

Printed in the United States of America

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

The **National Academy of Sciences** is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. On the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Ralph J. Cicerone is president of the National Academy of Sciences.

The **National Academy of Engineering** was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Charles M. Vest is president of the National Academy of Engineering.

The **Institute of Medicine** was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, on its own initiative, to identify issues of medical care, research, and education. Dr. Harvey V. Fineberg is president of the Institute of Medicine.

The **National Research Council** was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Ralph J. Cicerone and Dr. Charles M. Vest are chair and vice chair, respectively, of the National Research Council.

The **Transportation Research Board** is one of six major divisions of the National Research Council. The mission of the Transportation Research Board is to provide leadership in transportation innovation and progress through research and information exchange, conducted within a setting that is objective, interdisciplinary, and multimodal. The Board's varied activities annually engage about 7,000 engineers, scientists, and other transportation researchers and practitioners from the public and private sectors and academia, all of whom contribute their expertise in the public interest. The program is supported by state transportation departments, federal agencies including the component administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation. **www.TRB.org**

www.national-academies.org

COOPERATIVE RESEARCH PROGRAMS

CRP STAFF FOR ACRP REPORT 86

Christopher W. Jenks, *Director, Cooperative Research Programs*
Crawford F. Jencks, *Deputy Director, Cooperative Research Programs*
Michael R. Salamone, *ACRP Manager*
Lawrence D. Goldstein, *Senior Program Officer*
Anthony P. Avery, *Senior Program Assistant*
Eileen P. Delaney, *Director of Publications*
Hilary Freer, *Senior Editor*

ACRP PROJECT 02-12 PANEL
Field of Environment

John C. Williams, *Ricondo & Associates, San Francisco, CA* (Chair)
Kim Marie Berry, *General Mitchell International Airport - Milwaukee County (WI), Milwaukee, WI*
Eric Freed, *John Wayne Airport, Irvine, CA*
Scott C. Herndon, *Aerodyne Research Inc., Billerica, MA*
Jason L. Schwartz, *Port of Portland (OR) - Portland International Airport, Portland, OR*
Janet K. Tinoco, *Embry-Riddle Aeronautical University, Daytona Beach, FL*
Ebad Jahangir, *Pratt & Whitney, East Hartford, CT*
Sandy Liu, *FAA Liaison*
Christine Gerencher, *TRB Liaison*

AUTHOR ACKNOWLEDGMENTS

The research team would like to express our gratitude to various individuals who have contributed to the successful completion of this project, particularly the previous project managers for this project, Clint Morrow and Fabio Grandi. Mr. Morrow provided the initial leadership in directing the project, and Mr. Grandi was instrumental in managing the development of the electronic tool.

FOREWORD

By Lawrence D. Goldstein
Staff Officer
Transportation Research Board

Airport operators use noise abatement departure procedures (NADP) to minimize the impact of noise on surrounding communities; however, while decreasing noise impacts, these procedures may result in other adverse environmental and operational effects. Possible effects include increased fuel burn, increased air emissions, and reduced airport capacity. In turn, reduced capacity can result in travel delays, especially during adverse conditions. With the advent of quieter aircraft and improved modeling capabilities, there is an opportunity to re-evaluate NADPs to take into account potential environmental effects and fuel consumption while continuing to minimize noise impacts on surrounding communities. *ACRP Report 86* was conceived in response to this opportunity, with the objective of creating a protocol for evaluating and optimizing aircraft departure procedures in terms of noise exposure, emissions, and fuel burn. This research concludes that, although noise, emissions, and fuel burn are often thought to increase or decrease in opposite directions, this is not always the case. In fact, depending on a variety of factors that include ground tracks, flight profiles, aircraft type, and nearby population, simultaneous reductions in noise, emissions, and fuel burn can be achieved.

In addition to the report, the product of the research includes a spreadsheet-based electronic tool, the Departure Optimization Investigation Tool (DOIT), which allows users to understand and test tradeoffs among various impact measures, including noise levels, rate of fuel consumption, and emissions. The overall approach is based on changes in aircraft departure tracks, manipulating airport fleet mix, and varying other operational parameters. The audience for this research and the spreadsheet tool consists of airport operators, their supporting consultants, the Federal Aviation Administration, and other research institutions. The topic is timely and especially important as the FAA's "Next Generation Air Transportation System" (NextGen) technologies come on line and as more and more airports invest in developing sustainability programs while they push to improve capacity and maintain, if not decrease, environmental impacts.

With continued introduction of significantly quieter aircraft, it is becoming increasingly possible to optimize or potentially eliminate NADPs without generating adverse noise impacts and while increasing fuel efficiency and minimizing adverse air emissions. Introduction of these new technologies may allow a change from NADPs to more direct routing, which can help increase airport capacity through more efficient operations. In addition, given an increasing focus on climate change, a decrease in fuel consumption coupled with a decrease in greenhouse gas emissions can help improve the overall carbon footprint of an airport.

Efforts to reduce fuel consumption can broadly fit in two categories: aircraft/engine design improvements and air traffic optimization. With respect to optimization of air traffic, effort to date has primarily focused on the enroute flight phase. In contrast, this report focuses on how variations in departure procedures can affect airports and airport communities more directly. For air traffic optimization, the focus of FAA's NextGen has been on reducing flight time. Reduced flight times generally translate into aircraft engines burning less fuel and emitting fewer pollutants; however, for short-haul flights, fuel consumed enroute can be less than 50% of the total fuel burn. Arrivals and departures have received less attention, despite the possibility that they can achieve significant reductions in fuel use as well as reductions in noise exposure and air quality impacts. Application of departure optimization procedures can help respond to these continuing and growing concerns.

CONTENTS

SUMMARY

Environmental Optimization of Aircraft Departures: Fuel Burn, Emissions, and Noise

As airport operations continue to expand as infrastructure is modified to meet the growing demand for air travel, they need to balance their growth with environmental constraints. Although the main environmental concern continues to be noise, a more comprehensive approach needs to be implemented to better understand the effects of airport growth and changes. Indeed, the implementation of new aircraft and navigation technologies under the Next Generation Air Transportation System (NextGen) will require both noise and emissions, as well as fuel burn, to be assessed in order to fully understand the effects from such complex new technologies.

Although the tradeoffs between noise, fuel burn, and emissions have been extensively analyzed for Optimized Profile Descents (OPD), much less has been accomplished for noise abatement departure profiles (NADPs). As quieter airframe and engine technologies are developed, more direct flight tracks may be used with minimal (or no) effect on noise but noticeable reductions in fuel burn and emissions. To assess such cases requires methods to analyze a range of possibilities to identify optimum scenarios.

Starting with approximately 100 documents, literature reviews were conducted to examine existing studies on tradeoffs dealing with noise, fuel burn, and emissions, especially those dealing with airport growth and capacity impacts. The reviews included data gap identification to address the following issues:

- Different variations of NADPs;
- Interrelationships between takeoff profiles and ground tracks; and
- Airport throughput impacts on noise, fuel burn, and emissions.

The literature reviews revealed that any study involving noise abatement tracks needs to consider the local community's reactions to changes in noise versus other environmental impacts. Although an established noise abatement procedure cannot be significantly altered, it may be optimized to help ensure that maximum reductions in fuel burn and emissions are achieved for each scenario.

Based on the literature reviews, protocols were developed for analyzing the tradeoffs between the environmental impacts (i.e., noise, fuel burn, and emissions) and airport capacity. The protocols were developed as follows:

1. Collect necessary airport data,
2. Develop ground tracks and profiles, and
3. Perform tradeoff analysis.

The protocols were used to assess nine airports as part of a set of case study analyses. The selected airports constituted a good mixture of airport size, different types of NADPs, aircraft types, and population densities. The case studies showed that, in general, even relatively small changes in noise exposure can appreciably affect reducing fuel burn and emissions, although the benefits to runway throughput may be minor and, in some cases, negligible (except for fanning). The effect on local population varied from airport to airport, and, in some cases, a small impact on community noise could be traded for larger reductions in emissions. On the basis of the data generated from such case studies, tradeoff curves can be developed between the various impacts (e.g., noise versus emissions). Depending on the location of noise-sensitive populations, the direct tracks may produce the most noise impacts while producing the most reductions in fuel burn and emissions.

A spreadsheet-based, electronic tool was also developed—the Departure Optimization Investigation Tool (DOIT)—to enable users to better understand the tradeoffs among noise, fuel burn, and emissions when conducting optimization assessments focusing on manipulating airport fleet, operations, and the use of different departure tracks. Although airport capacity/throughput is not a directly adjustable option in the tool, the tool's allowance for changes in operations and track utilization can be used to consider such effects.

DOIT provides a hypothetical airport scenario that can be used to analyze various what-if cases involving different NADPs and allows for changes to the fleet mixes, track utilizations, and future technologies as represented through changes in aircraft source noise, fuel burn, and emissions characteristics. The output results are presented as reductions (or increases) in noise, fuel burn, and emissions, which can be used to identify optimum conditions for each modeled scenario.

CHAPTER 1

Introduction

1.1. Background

The aviation industry has been at the cutting edge of technology since its inception, benefiting various other industries. Transformational changes through the Next Generation Air Transportation System (NextGen) include the introduction of new vehicles, the integration of advanced information technologies into the National Airspace System (NAS), and the implementation of new operational models by air carriers. Such advances call for systemwide approaches to environmental sustainability and innovative solutions to fuel utilization and airport capacity optimization.

Despite notable technological advances, aviation noise is expected to remain the biggest impediment to the expansion of airport capacity in the next 20 years. Virtually all major environmental campaigns against airport and air traffic expansion have centered on community concerns over noise exposure. That said, concerns over climate change and local air quality are gaining momentum and prompting calls for new regulatory schemes to curb emissions of CO_2 and other air pollutants—although aviation contributes less than 3% of global greenhouse gas emissions (Kim 2009).

Furthermore, the recent increases in fuel prices have pushed the economic viability of airlines to a breaking point and caused major shifts in demand for air travel. For the foreseeable future, aviation will have to continue contending with volatile oil prices. Despite the potential of alternative and renewable sources of energy, such shifts for air transportation will require changes in terms of aircraft technology that are not immediately available.

There is also a concern that forecast levels of air traffic growth may outpace the introduction of environmentally friendly and fuel-efficient aircraft technology over time. There are design tradeoffs among aircraft-generated noise, emissions, and fuel burn. The introduction of new aircraft technology is only part of the solution. Seeking integrated approaches to the optimization of aircraft operations—along with technological innovation and NAS modernization—can produce a more sustainable growth strategy for aviation while achieving meaningful reductions in both environmental impacts and airline operating costs.

Although Optimized Profile Descent (OPD) procedures have attracted considerable attention for their tradeoff benefits, there has been little discussion of the environmental and operational interdependencies of departure procedures, notably what are known as noise abatement departure profiles (NADPs). Yet, it is in the interest of all stakeholders, particularly members of the community, to evaluate the costs and benefits of operational alternatives, including NADPs, carefully. Stakeholders need such information to decide, for example, whether an incremental improvement in noise exposure justifies an increase in total emissions or vice versa.

Despite current challenges, the aviation industry must continue implementing the NextGen plan and invest in NAS modernization, operational improvements, and new technology. NextGen is an opportunity to resolve longstanding bottlenecks in system capacity and implement more environmentally and energy-efficient operational concepts at airports and in the NAS.

1.2. Project Scope and Goals

The focus of this project was to develop a departure optimization method to (1) quantify potential reductions in noise, fuel burn, and emissions; (2) estimate increases in air traffic capacity that could be achieved by optimizing departure procedures while continuing to address noise exposure for communities around airports; and (3) account for existing and future fleet mixes and improvements envisioned under NextGen. In the context of current departure noise abatement procedures (NAPs), this project reports on environmental and capacity-related benefits associated with the following localized contributors: (1) source noise reduction in future engine/

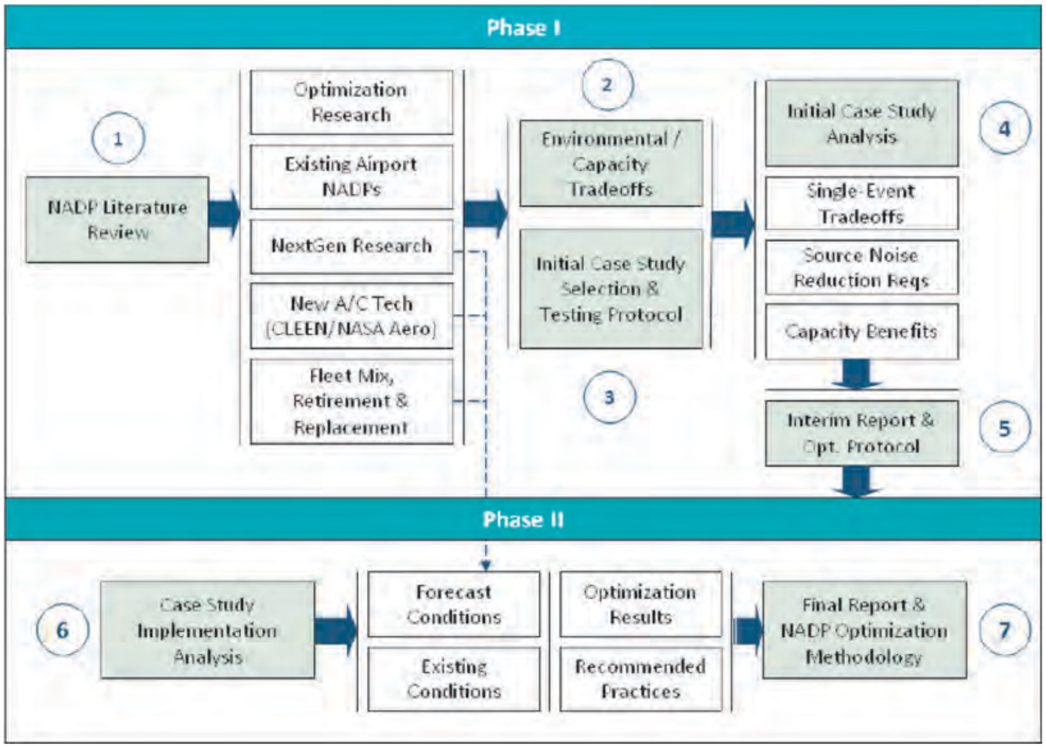


Figure 1-1. Project tasks and phases.

airframe technologies, and (2) realistic alterations to present noise abatement departure procedures to help regulators and airport management make environmentally optimal decisions. Overall, this project consists of two phases and seven tasks (see Figure 1-1).

This ACRP project complements the goals of NextGen and furthers the ability of airports to pursue sustainable environmental solutions while gaining the operational benefits of new aircraft and NAS technology. This project's goals are to provide a method for NADP optimization through the exercise of an analysis framework that combines advanced environmental modeling capabilities and refined optimization techniques. The optimization framework uses data from extensive FAA airport, flight trajectory, and fleet mix databases. The use of such tools and databases ensures a well-researched and practical protocol to help guide airport decisions on NADP optimization.

In addition to the protocol, an electronic (spreadsheet-based) tool—the Departure Optimization Investigation Tool (DOIT)—was developed to demonstrate the tradeoff potential among noise, emissions, and fuel burn. By allowing manipulation of a realistic airport scenario, DOIT enables users to better understand the sensitivities of each of the output results to the input data on airport fleet mix, track utilization, and technological advances.

1.3. Report Structure

The report reflects the research plan specified by ACRP—starting with the literature review and culminating in the development of the electronic tool. The body of the report summarizes the work conducted and its outcomes while the appendices provide details and background materials.

Chapter 2 provides an overview of the literature review, including definitions of terminologies and some qualitative discussions on tradeoffs. Chapter 3 provides optimization case study overviews of selected single-event departures at various airports. Chapter 4 presents the electronic tool that can be used to assess tradeoffs among noise, emissions, and fuel burn under a departure NAP optimization scenario.

Appendix A provides details on the literature review. Appendix B contains details on optimization protocols. Appendix C presents capacity modeling protocols. Appendix D provides an example to illustrate the impacts of NAPs on airport throughput. In Appendix E, use of the electronic tool is explained through various examples.

CHAPTER 2

Project Background

This chapter discusses the framework for initiating and developing the research, including key terminology, a summary of the literature review, and a qualitative discussion of departure NAPs. This background information provides the foundation for the analytical assessments and methods presented in Chapters 3 and 4.

2.1. NADPs and Other Terminology

In order to frame the discussion in this report, several key terms are defined below. Additional terms are defined in Appendix A.

Noise Abatement Departure Profile (NADP). The FAA's Advisory Circular AC 91-53A, dated July 22, 1993, provides acceptable criteria for safe NADP operations for civil transport jet aircraft. The Advisory Circular (AC) presents two departure methods—one intended to provide noise relief for communities close to the airport (the *close-in* procedure) and the other to provide relief for communities farther from the airport (the *distant* procedure). The FAA provided this guidance to aircraft operators so that operators would not have to support unique noise abatement procedures at each airport. Although the burden of developing the procedures and supporting the training of those procedures was considered to be high, the FAA's main concern was that lack of standardization resulting from unique departure procedures was a potential safety issue. The Air Line Pilots Association (ALPA) formally supports this policy (Deeds 1996).

In addition to the FAA's recommended procedures, ICAO has also promulgated NADPs in the fourth edition of their PAN-OPS document (ICAO 1993). Instead of using the nomenclature of close-in and distant, the ICAO document refers to Procedure A and Procedure B, respectively. These procedures are usually referred to as the ICAO – A and the ICAO – B procedures. The primary difference between the FAA and ICAO methods is that the FAA's AC assumes the use of a thrust cutback early in the procedure (at an altitude not less than 800 feet AGL) followed by a thrust restoration at 3,000 ft AGL, while the ICAO PAN-OPS assumes the thrust is reduced from takeoff power to climb power at a higher altitude and that climb thrust is maintained throughout the remainder of the departure (no thrust restoration is required).

In addition, the National Business Aircraft Association (NBAA) provides a recommended procedure for close-in community relief. NBAA does not explicitly recommend a procedure for distant communities, but does recommend a standard departure procedure, which uses the same techniques as the AC 91-53A distant procedure and the ICAO – B procedure. The NBAA procedures can be found at http://www.nbaa.org/ops/environment/quiet-flying/.

The remainder of this section summarizes the procedures contained in AC 91-53A and the ICAO PAN-OPS document. Note that ICAO – A and ICAO – B nomenclature include noise-designated terms (Noise 1 and Noise 2) as indicated below.

Close-in (ICAO – A/Noise 1) NADP. The close-in procedure works by delaying the normal retraction of the aircraft's flaps until the aircraft reaches a *clean-up* altitude. By maintaining the deployment of the flaps, the aircraft increases its climb gradient so that it reaches a given altitude at an earlier distance from the airport. This increases the distance from the aircraft to the receptors on the ground, decreasing the noise received on the ground. Because the flaps are extended, the aircraft cannot perform a normal acceleration and will typically maintain the original climb speed (e.g., V2 + 10 knots) to the altitude where the procedure ends, and the flaps are retracted and the aircraft accelerates.

The reduction in airspeed at the end of the procedure means that the aircraft needs to spend thrust accelerating to normal climb speed. Because of the loss of available thrust to climb the aircraft (as well as the increased drag from the extended flaps), an aircraft that has flown a close-in procedure will be lower. A lower aircraft can be louder than an aircraft that has performed a standard procedure at a greater distance from the airport.

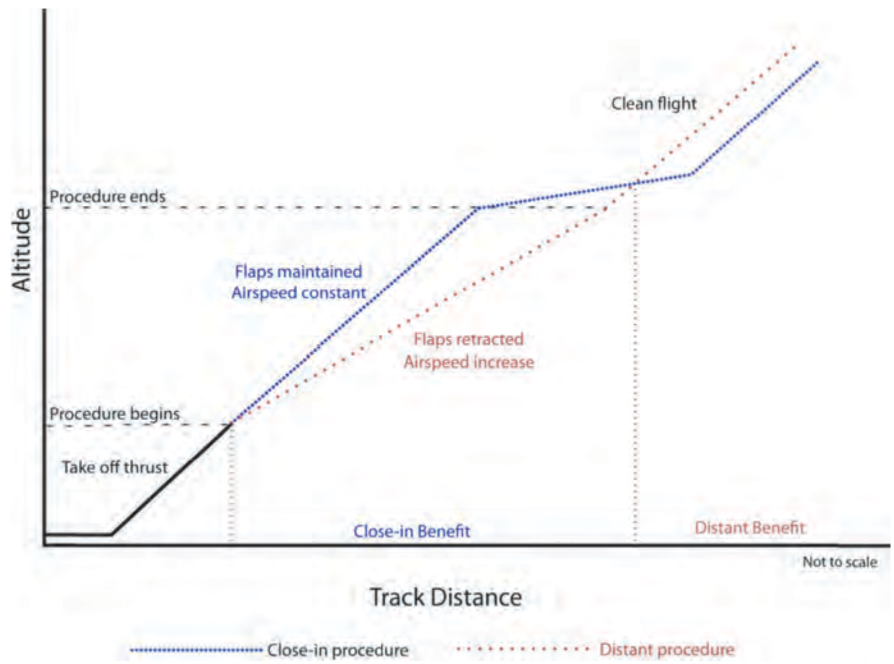


Figure 2-1. NADP schematic.

Distant (ICAO – B/Noise 2) NADP. In a distant procedure, the aircraft retracts flaps according to the normal flap retraction schedule. The differences from the standard procedure are usually minor when a thrust reduction is not implemented – these differences are typically in the altitude at which the aircraft transitions from takeoff thrust to climb thrust, in the initial flaps selected, or relatively minor procedural changes. The difference in the climb gradients of the two procedures is presented in Figure 2-1.

In addition, the following terms are used frequently in this report:

Noise Abatement Procedure (NAP). A general term for a flight procedure used by airports, operators, and/or air traffic control for arrivals or departures, including ground tracks and profiles. This study focuses on departure NAPs. For example, an NADP is a type of NAP.

Profile. The vertical component of an aircraft trajectory (altitude) combined with the corresponding speed and power settings (thrust). Typically defined at distances from aircraft takeoff or landing; sometimes defined by time from takeoff or landing.

Ground Track. The projection of an aircraft's trajectory onto the ground (i.e., the X-Y location of an aircraft trajectory).

2.2. Literature Review

The research team conducted a thorough review of relevant literature, existing research, published practical guidance, and other appropriate material to identify, list, and describe current or proposed types of noise abatement departure procedures. This review was limited to departure procedures only, from takeoff queuing through climb to cruise. Generation of ground noise during taxi-out was also considered to the extent addressed by existing and proposed noise abatement departure procedures. Published guidance was reviewed for several airports, although there was little available on taxi procedures. The full literature review is presented in Appendix A.

In summary, nearly 50 works were reviewed in three relevant subject areas: capacity, airspace, and operations; studies of environmental interdependencies which examine the tradeoffs between environmental factors; and studies focusing only on noise impacts. In addition to providing valuable information, the review of these studies identified gaps in the current research and the need for this project to fill the gaps. The literature review revealed the following:

- Many of these studies were conducted outside the United States and focus on non-U.S. airports. Although these studies provide relevant data, they do not address the same operational environment, regulatory standards, and socio-political environment found in the United States.
- Most of these studies provided detailed technical information, but lack practical guidance for the implementation of suggested procedures.
- There is considerable approach/arrival procedure research, but limited analysis of departures and runway capacity that details the implementation of procedures and impacts on airport operational environments.

- Little of the research addresses the environmental impacts of future aircraft technology such as that described under NextGen, CLEEN, and the NASA Fundamental Aeronautics Research Program (i.e., N+1, N+2, and N+3 generation aircraft).
- Any study of noise abatement procedures must consider and address the public's likely reactions to changing NAPs. The reality of increased operations equating to increased noise and emissions may result in considerable local community objection and only thorough and valid mitigation strategies will gain acceptance. Although it is not feasible for an airport to completely remove an established set of NAPs, it is possible to optimize the existing procedures to improve emissions and fuel burn.

In addition, the literature review highlighted several key modeling issues, including the need to

- Model realistic variations of NADPs, which can vary by aircraft type and airport (as discussed in ICAO 2007, SOURDINE II, and others).
- Study the interrelations between ground tracks and profiles (as discussed in Clarke 2000, Prats 2008/2009, and Forsyth 2009).
- Model ground operation noise and emissions resulting from decreased delays via improved runway throughput when using optimized NAPs.

These conclusions from the literature review served as a basis to initiate the research. The following sections address the different types of departure NAPs and a qualitative discussion of tradeoffs.

2.3. Qualitative Assessment of Tradeoffs

The goal of the qualitative assessment of tradeoffs was to identify various types of NAPs and the potential interdependencies among fuel burn, emissions, noise, and capacity. Quantifying such relationships is addressed in Chapter 3 which presents the airport case study analysis. This quantification uses the protocols established in Appendix B, which presents the airport scenario modeling. Appendixes C and D provide information on airport capacity impacts.

A comprehensive listing of the various types of NAPs in use and proposed for the future was developed based on the literature review. Known and potential benefits and drawbacks of each individual procedure were discussed, considering qualitatively the range of noise, fuel burn, emissions, and capacity metrics. Next, the Tradeoffs Chart (Table 2-1) was developed, with the goal of ranking the benefits and drawbacks of each procedure considering five key factors:

- Community Noise (N)
- Local Emissions (E)
- Fuel Burn (F)
- Runway Throughput (T)
- Airspace Capacity (C)

Each factor was assigned a score relative to existing (non-NAP) departure procedures. The scores ranged from "++" (high benefit) to "−−" (high drawback). A score of "0" indicated no impact and a score of "+/−" indicated a mixed benefit/drawback. Table 2-1 shows the overall Weighted Score of each procedure computed using a weighted scoring model:

Weighted Score = $2*N + E + F + T + C$

Community noise was double weighted (multiplied by two) for two reasons: (1) to counter the fact that emissions/fuel burn and capacity each have two scores and (2) to account for the higher importance of noise for assessing the effectiveness of a NAP. The individual scores for each factor were determined based primarily on the literature review and also on professional experience. Community noise scores were assigned considering both the tradeoffs involved and magnitude of change in noise. In terms of tradeoffs, fanning and RNAV/RNP SID overlays can reduce noise in some areas, but concentrate and increase noise in other areas; whereas an optimized ground track can be designed to reduce noise in all noise-sensitive areas. In terms of magnitude, single-engine taxi reduces noise without tradeoff, but the magnitude of noise reduction is much less than that of optimized ground tracks.

Most scores for emissions and fuel burn were equivalent because changes in fuel burn usually result in the same directional change in emissions. Also, many of these scores are "+/−" because there are inherent tradeoffs in fuel burn: the total energy to takeoff and climb an aircraft does not change—only the balance of fuel used in various stages of flight. Scores for runway throughput and airspace capacity are also often equivalent; however, there are cases when a NAP may have a higher impact on airspace capacity than runway capacity. For example, SID overlays are designed to have a beneficial impact on airspace capacity—they can also improve runway efficiency, but to a lesser degree. In general, NAPs that decrease the efficiency of takeoff and climb phases (e.g., noise-optimized tracks and NADP-1) negatively impact runway and airspace capacity.

Table 2-1 also shows that most of the highest-scoring NAPs involve new technology and NextGen. These NAPs are not currently implementable, but will come on line over time. The implementation timeframe was estimated based on the literature review. Aside from future procedures, the highest-scoring implementable NAPs include single-engine taxi (which has mild benefits but no drawbacks); NADP-2 (which is already

Table 2-1. Tradeoffs chart.

Category	NAP	Qualitative Assessment: Community Noise	Local Emissions	Fuel Burn	Runway Throughput	Airspace Capacity	Weighted Score[1]	Estimated Implementation Timeframe	Relevant Literature/ Example Airports
Ground Track	Optimized ground track which avoids noise sensitive locations	++	+/-	-	-	--	0	Now	Prats 2008; LGA; BOS; SFO
	Distribute ground tracks over area (fanning)	+/-	+/-	+/-	+	+	+2	Now	Capozzi 2003 PHL; EWR; MSP
	RNAV/RNP overlays of SIDs	+/-	+/-	+/-	+	+	+2	Now	Mayer 2008 DFW, ATL
	Preferential routing for low-noise jet aircraft	+	+/-	+/-	+	+	+4	NextGen	Rachami 2008, JPDO 2007
Profile	NADP 1 Close-in procedure	+	-	-	-	-	-2	Now	ICAO 2007; PBI, SNA
	NADP 2 Distant procedure	+/-	+/-	+	+	+	+3	Now	ICAO 2007; MSP
	Climb over unpopulated land or water near airport to gain altitude	++	-	-	+/-	-	+1	Now	BOS
Temporal	Vary ground tracks by time-of-day	++	+/-	+/-	-	-	+2	Now	Prats 2008; SDF
Ground-Based Operational Measures	Single-engine taxi	+	+	+	0	0	+4	Now	
	Preferential runway system	++	+/-	+/-	-	--	-1	Now	Heblij and Winjen 2008; BUF, LGA, SFO
Aircraft/ ATC Technology	Automated thrust reduction for NADP 1	++	-	-	-	-	0	Now + 5 Years	Forsyth 2009; SNA
	Low-noise and emissions engines	++	++	++	0	0	+8	5 - 10 Years	Rachami 2008
	Trajectory-Based Operations (TBO)	+/-	+/-	+	+	+	+3	NextGen	JPDO 2007, Visser 1992

Note 1. Noise score is multiplied by a weight of 2 and all other scores are multiplied by a weight of 1, then the individual scores are summed.

Legend:

++	High Benefit
+	Low Benefit
0	No Impact
-	Low Drawback
--	High Drawback
+/-	Mixed Benefit/Drawback

Table 2-2. NAP descriptions.

Ground Track Procedures			
NAP	**Benefits**	**Drawbacks**	**Implementation Control**
Optimized ground track which avoids noise-sensitive locations	▪ Contains noise exposure to specific areas, and avoids noise-sensitive receptors ▪ Can optimize procedure to minimize noise-exposed population	▪ May concentrate noise in selected areas ▪ Not always possible to avoid all populated areas ▪ May cause reduction in airspace capacity if path is not optimal ▪ May cause increase in fuel burn and emissions if path is not optimal	▪ Recommend: Airports (via planning studies) ▪ Implement: FAA
Distribute ground tracks over area (fanning)	▪ Distributes noise over broad area ▪ Can be designed to create a “fair” share of noise among communities ▪ Allows for airspace flexibility ▪ Improved capacity and runway throughput	▪ Noise increases in some areas ▪ May not provide any benefit for fuel burn or emissions	▪ Recommend: Airports (via planning studies) ▪ Implement: FAA
RNAV/RNP overlays of SIDs	▪ More accurate than conventional navigation ▪ Accurate routing can improve airspace capacity ▪ Contains noise exposure to specific areas ▪ Can be designed to avoid noise-sensitive receptors	▪ Concentrates noise in selected areas where flights occur ▪ Emissions and fuel burn have negligible or small change compared to conventional navigation ▪ Not all aircraft have necessary navigational equipment	▪ Implement: FAA
Preferential routing for low-noise jet aircraft	▪ Allows lower-noise aircraft to fly direct routing to departure fix, reducing fuel burn and emissions ▪ Increases airspace and runway capacity for existing aircraft types ▪ Provides incentive for operators to upgrade to low-noise technology	▪ Cannot implement until NextGen ▪ Capacity benefits proportional to the number of low-noise aircraft ▪ No improvement in noise, fuel burn and emissions for existing types of aircraft	▪ Implement: FAA via NextGen

(continued on next page)

Table 2-2. (Continued).

Profile Procedures			
NAP	**Benefits**	**Drawbacks**	**Implementation Control**
NADP 1 Close-in procedure	▪ Redistributes noise away from areas near the airport (from brake release to 5-10 miles away depending on aircraft type) ▪ Tradeoff of larger noise reduction than corresponding noise increase farther from airport ▪ Useful where ground tracks cannot be changed ▪ When compared to NADP2, lower NO_x	▪ Airlines and most airports prefer NADP 2 (distant procedure) ▪ Only in use at few airports with exceptional close-in residential areas, noise monitors, or geographic features ▪ Takes more time to reach top of climb altitude when compared to NADP2 due to delayed acceleration segment to retract flaps (reduction in capacity) ▪ When compared to NADP2, higher GHG due to shorter time to climb to 3000’	▪ Recommend: Airports ▪ Implement: Airlines/operators
NADP 2 Distant procedure	▪ Redistributes noise away from areas farther from the airport (beyond 5-10 miles away from brake release depending on aircraft type) ▪ Useful where ground tracks cannot be changed ▪ Airlines and most airports prefer this NADP. In some cases, airlines have adopted NADP 2 as their standard procedure ▪ Takes less time to reach top of climb altitude compared to standard profile (due to increased acceleration at lower altitudes) ▪ Increase in runway and airspace capacity due to increased acceleration during initial climb	▪ When compared to NADP1, higher NO_x but lower GHG due to longer time to climb to 3000’ but shorter time to reach cruise altitude	▪ Recommend: Airports ▪ Implement: Airlines/operators
Climb over unpopulated land or water near airport to gain altitude	▪ Reduce noise exposure in noise-sensitive areas by climbing to higher altitude first ▪ Shift higher noise exposure levels to non-noise-sensitive areas	▪ Increase in emissions due to longer flight time ▪ Increase in fuel burn due to longer flight time ▪ May have impacts on runway throughput ▪ Can only be implemented at certain airports with adjacent land or water	▪ Recommend: Airports (via planning studies) ▪ Implement: FAA

Temporal			
NAP	**Benefits**	**Drawbacks**	**Implementation Control**
Vary ground tracks by time-of-day	▪ Flexibility to reduce noise during sensitive periods such as nighttime ▪ Typically lower traffic levels at nighttime, thus low impact on capacity ▪ Minimize reductions in capacity by implementing only at certain times of day	▪ Noise abatement flight tracks may be longer and increase fuel burn and emissions	▪ Recommend: Airports (via planning studies) ▪ Implement: FAA
Ground-Based Operational Measures			
NAP	**Benefits**	**Drawbacks**	**Implementation Control**
Single-engine taxi	▪ Reduced noise during taxi ▪ Reduced fuel burn and emissions	▪ No benefit to runway or airspace capacity ▪ FAA safety concerns at some airports	▪ Recommend: Airports ▪ Implement: Airlines and Operators
Preferential runway system	▪ Minimize noise by directing flights towards less sensitive areas ▪ Can implement at specific times such as nighttime, when traffic levels are lower	▪ Decrease in airspace capacity compared to most optimal configuration ▪ May increase fuel burn and emissions if distance to departure fix is increased	▪ Recommend: Airport ▪ Implement: FAA
Aircraft/ATC Technology Measures			
NAP	**Benefits**	**Drawbacks**	**Implementation Control**
Automated thrust reduction for NADP 1	▪ Optimal use of NADPs which reduce noise at sensitive locations ▪ Provides automatic cutback to minimum required thrust at specific user selected altitude or noise-sensitive location on ground	▪ Technology under development/ not widely in use; will take time for operators to upgrade fleets ▪ Tradeoff of noise close and distant from airport	▪ Implement: Manufacturers and Airlines
Low-noise and emissions engines	▪ Decreases noise and emissions impacts throughout all phases of flight ▪ Engines also consume less fuel	▪ Although under development, not currently available ▪ Will take time for operators to upgrade fleets ▪ No inherent effect on capacity, unless preferential routing is possible	▪ Implement: Manufacturers and Airlines
Trajectory-based operations (TBO)	▪ Can be adjusted with time and traffic levels ▪ Optimized to improve capacity and reduce delays and fuel burn ▪ May decrease noise by combination of ground tracks and profiles	▪ NextGen technology needed to implement (4-dimensional trajectories) ▪ May increase noise during peak traffic levels	▪ Implement: FAA via NextGen

Table 2-3. NAP combinations matrix.

	Ground Track	Profile	Temporal/Traffic Level	Ground-Based Operations	Aircraft/ATC Tech
Ground Track					
Profile	NADP 1 or 2, to reduce effect of increased noise in new areas due to changed ground track				
Temporal/Traffic Level	Combine ground track with peak demand procedures	NADP 1 or 2, to reduce effect of increased noise			
Ground-Based Operations	Queue aircraft according to low-noise versus existing types to more efficiently route aircraft on ground tracks	NADP can add to environmental benefits of ground-based operations	Implement preferential runways on a time of day basis, depending on demand and noise sensitivity		
Aircraft/ATC Tech	In future, low-noise engine technology can allow for smaller increase in noise and more-direct routing	Automated thrust reduction for NADP 1	In future, low-noise engine technology can allow for smaller increase in noise	Preferential routing for low-noise aircraft to increase capacity	

used by many operators); RNAV/RNP overlays of SIDs (which have high benefits to airspace and runway capacity but mixed environmental benefits); and, varying ground tracks either temporally or over an area using fanning (both of which have weighted scores of +2). All other NAPs in Table 2-1 have scores of +1 or below, with preferential runways and NADP-1 having negative scores.

Table 2-2 describes each NAP in greater detail and includes a list of the benefits and drawbacks considered in assigning the individual scores shown in Table 2-1. Thus, a more detailed description of the decision process behind the development of the weighted scores is provided. In addition, Table 2-2 discusses the entity that controls implementation of each NAP—given that control affects an airport's ability to implement NAPs successfully, this is a key consideration.

Finally, Table 2-3 provides an assessment of NAPs that can be used in combination to further reduce or counteract negative environmental impacts. This table provides a basis for understanding how several types of NAPs can be used in conjunction to best optimize procedures for a given airport.

CHAPTER 3

Case Study Analyses

3.1. Approach

The goal of the case study analysis was to provide detailed data on the tradeoffs among noise, emissions, fuel burn, and capacity by modeling single departure events at several airports. Although it is unlikely that an airport would remove an existing NAP, an airport could optimize that NAP in terms of emissions, fuel burn, or capacity at the expense of noise exposure (i.e., given that an existing NAP is already optimal for noise exposure in the eyes of both airport and community, any changes to a NAP would be undesirable, unless supporting data can be used to show the benefits of making such changes).

The Testing Protocol included in Appendix B specifies the parametric optimization process in which many combinations of departure ground tracks and profiles were modeled for each airport. These tracks covered variations of existing NAPs, as well as the most direct ground track from takeoff to a departure fix. Environmental analysis was carried out for each case study and capacity was modeled by simulating runway throughput for each airport. Assessments of tradeoffs were then compiled by comparing each of the result sets against the existing NAPs for all modeled variables. Figure 3-1 illustrates the process detailed in the Testing Protocol.

After an individual review of 81 U.S. airports with existing NAPs, 9 airports were selected for case study analysis. These airports represent different types of airports with various NAPs and local noise and air quality issues. These airports are listed in Table 3-1 along with a description of the NAP and additional information on why the airport is of interest (e.g., airport type, air quality concerns, annual operations, and proposed baseline aircraft type). Although details are provided, descriptions are generalized and the actual airport names have been replaced with code names (e.g., APRT1) to respect airport sensitivities to the presentation of such information. A detailed explanation of the airport selection process is provided in Appendix B.

The airports listed in Table 3-1 were used to determine the tradeoffs for different types of NAPs. In the following sections, NAPs are discussed as detailed in Table 3-2, which shows the type of NAP studied in each section and highlights the way each was implemented in the case studies. This chapter presents a summary of results for each type of NAP studied; the impacts of airport capacity are presented in Appendixes C and D. The population data used for these analyses were obtained from Arc GIS data.

3.2. Turn Restrictions

A turn-restriction NAP puts a constraint on the departure ground tracks used for a given runway at a given airport. This constraint is typically used to keep aircraft flying at runway heading after takeoff until reaching a certain distance (or altitude) relative to the runway end, after which the aircraft can turn toward the destination or fix as directed by air traffic control. Such procedures are in use at APRT6, APRT1, and APRT5 (distance based) and at APRT9 and APRT8 (altitude based).

To model the effects of optimizing these procedures, alternate ground tracks were created for each of these airports following the schematic shown in Figure 3-2. Beginning with the distance or altitude location where the NAP allows turns to be initiated, additional ground tracks were developed at 0.5 NM intervals working back toward the runway end. Each of the tracks was constructed to reach a common convergence point representing the destination fix of the existing NAP ground track. The most-direct ground track represents an immediate turn from the runway end. For example, Figure 3-3 shows the ground tracks and NAP for APRT6, and Figure 3-4 shows the tracks for APRT9.

The procedure at APRT6 for runway 7L is designed with a “gate” located 5 NM east of the runway. Turns made after the gate may head north or south; however, for this analysis, a south turn was modeled, converging at a point southeast of the airport. The differences in noise, emissions, fuel burn,

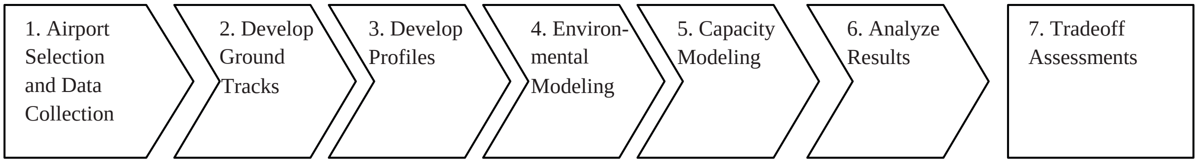


Figure 3-1. Case study analysis process.

Table 3-1. Case study airports.

Airport	Type of Airport	Existing Departure NAP [1]	Air Quality Concerns[2]	Approx. Annual Operations[3]	Baseline Aircraft Type[3]
APRT1	Cargo Hub	- Airport goes to single direction operation at night - Departure turns based on distance from airport	Ozone, PM2.5	100,000 – 200,000	A300
APRT2	Hub, Coastal	- RNAV NAP procedures	Ozone, CO	300,000 – 400,000	757-200
APRT3	Hub	- Community close to airport	Ozone, CO, PM2.5	300,000 – 400,000	MD-88
APRT4	Hub	- Fanning NAP	CO, SO2	400,000 – 500,000	DC9-30
APRT5	Hub, Coastal	- Multiple turn restrictions on departure	Ozone, CO, PM2.5	300,000 – 400,000	747-400
APRT6	Hub	- Departure heading gate (distance-based turns)	Ozone, CO, PM10	500,000 – 600,000	737-700
APRT7	General Aviation	- Distance-based turns	Ozone, CO, PM10, PM2.5, NO2	< 50,000	Gulfstream GIIB (Noise Stage 2)
APRT8	Regional	- Heading restriction based on altitude	Ozone	< 50,000	CRJ-200
APRT9	Regional	- Altitude-based headings	Ozone	100,000 – 150,000	EMB-145

Sources: (1) Boeing NER Database 2009;
(2) VALE Airport Status List 2009;
(3) ETMS 2006

Table 3-2. NAP studies matrix.

Sec.	NAP Study	Airport(s)	Method	Utilization
3.2	Runway-heading Turn Restrictions	APRT1, APRT5, APRT6	Study varies initial turn by distance from runway end, progressively reducing distance	Alternated NAP with straight-out ground track to represent flights in other directions
		APRT8, APRT9	Study varies initial turn by altitude of aircraft, progressively reducing altitude	All aircraft follow NAP
3.3	Multi-turn NAP track	APRT2, APRT3, APRT5	Study varies NAP ground track geometry for more-direct routing	All aircraft follow NAP
3.4	Climb Procedures	APRT2	Study lengthens ground track over water to increase altitude reached at shoreline crossing	All aircraft follow NAP
3.5	Close-in NADP	APRT3, APRT5, APRT7	Determine how close-in NADP can mitigate noise increases due to a different ground track	All aircraft follow NAP
3.6	Fanning	APRT4	Noise abatement fanning procedure distributes noise to different areas	Alternated use of fanning tracks

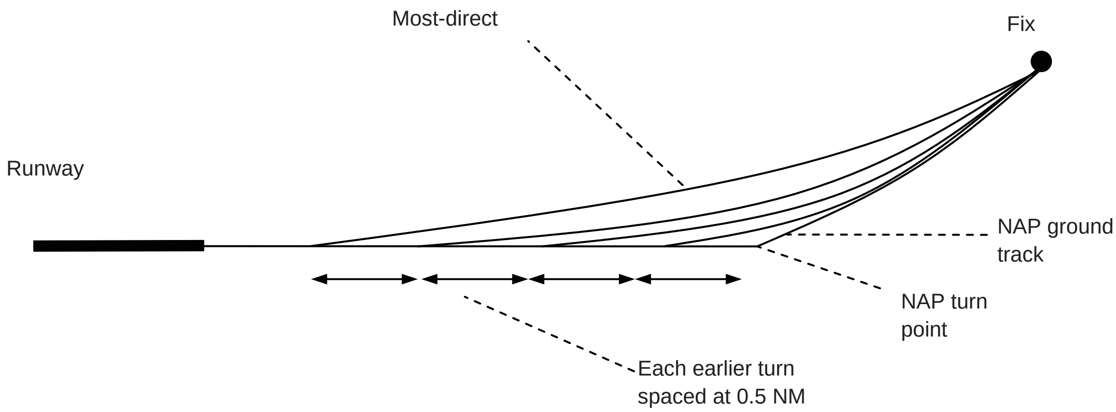


Figure 3-2. Illustration of turn-restriction ground tracks.

and capacity resulting from each ground track turning earlier than the existing NAP are discussed below.

Noise level analysis was conducted by computing the difference in single-event SEL contours for each ground track. The difference in SEL values and population counts for each track were computed in comparison with the existing NAP track. As an example, the difference in SEL comparing the track which turns 2.5 NM sooner than the NAP is shown in Figure 3-5. This map shows the range of SEL increase and decrease over the local area, including a maximum increase of 18 dB and a maximum decrease of 14 dB. Noise differences were also computed for the other ground tracks modeled for APRT6, and maps of these differences showed similar trends with different values of increase and decrease. Throughout this chapter, noise difference maps are presented using different color scales to reflect varying levels of noise change appropriate to each airport and aircraft type.

Figure 3-6 shows the capacity curves for APRT6. The modeled ground tracks affect runway throughput according to the length of the common path shared by successive departures. The capacity simulation was used to alternate aircraft flying south along the modeled ground tracks (DIR, NAP, and INT) and aircraft flying in other directions through the departure gate (STR). The direct ground track, DIR, increases runway throughput by approximately 1.5 to 2 departures per hour (x-axis), depending on the arrival rate (y-axis). This increase is due to the fact that once a departure turns immediately south on the direct track, the following departure can be more quickly cleared to take off.

Noise, emissions, fuel burn, and capacity were then plotted on a graph designed to summarize the tradeoffs. Figure 3-7 shows the population exposed to SEL greater than 75 dB, which increases by varying amounts over the baseline of 59,167 persons for the NAP. Each ground track is indicated on the x-axis. Emissions of CO_2 and fuel burn are shown in terms of total kilograms (from beginning of takeoff roll to reaching the departure fix). Capacity is shown in terms of the number of hourly departure operations for the runway for a constant level of arrival operations. Although not shown, SEL increases from 0 dB for the NAP (left side of graph) up to 29 dB for the direct ground track. Figure 3-7 illustrates the same trends exhibited by fuel burn and CO_2 emissions. Although not as closely as CO_2 emissions, NO_x emissions also follow fuel burn and, therefore, would show similar trends. NO_x emissions are often used as an indicator of impacts on local air quality.

There are several conclusions which can be drawn from Figure 3-7. First, the tradeoffs between increasing noise and decreasing emissions and fuel burn are readily apparent. Comparing the extremes of the ground track nearest to the NAP (which turns 0.5 NM before the gate) and the direct track, CO_2 emissions decrease from 1,363 kg to 961 kg – a decrease of 30%. In addition, fuel burn decreases from 432 kg to 305 kg, also a 30% decrease. An increase in capacity is expected: there is an improvement from 37 operations to 39 departures per hour. In terms of the effect on the local area, the population count must also be considered, and, unlike the other variables, there is not a steady rate of increase or decrease. For APRT6, the baseline for the NAP is 59,167 persons within the single-event 75 dB SEL contour. The population counts for all other modeled tracks are higher; however, the greatest increases occur between the 2.5 and 4 NM turns. In fact, the direct-track population count is 61,362 – only 4% higher than the NAP population count.

Certainly, the decision to change an existing NAP would have to be weighed carefully against decreases in emissions. For example, selecting the "NAP minus 2 NM" ground track would increase the population exposed to 75 dB SEL by 13%; however, this would decrease the CO_2 emissions by 11%. Local airport decisions can be better informed by considering the tradeoffs and trends in noise levels, population counts, emissions, fuel burn, and capacity.

Similar results were generated for APRT9, a much smaller airport with a fleet consisting mainly of regional jets. The NAP consists of a runway-heading turn-restriction of 3,000 ft

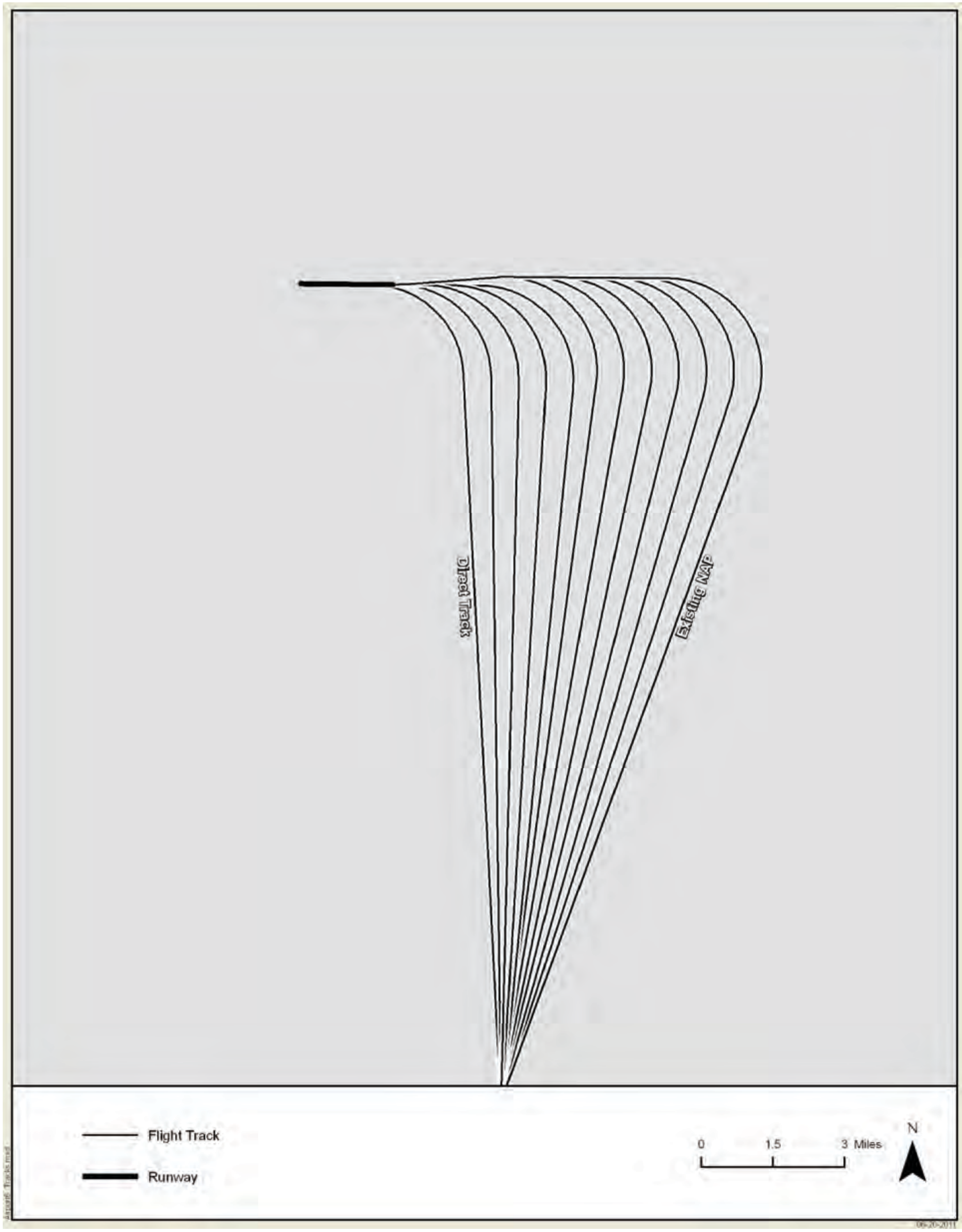


Figure 3-3. APRT6 ground tracks.

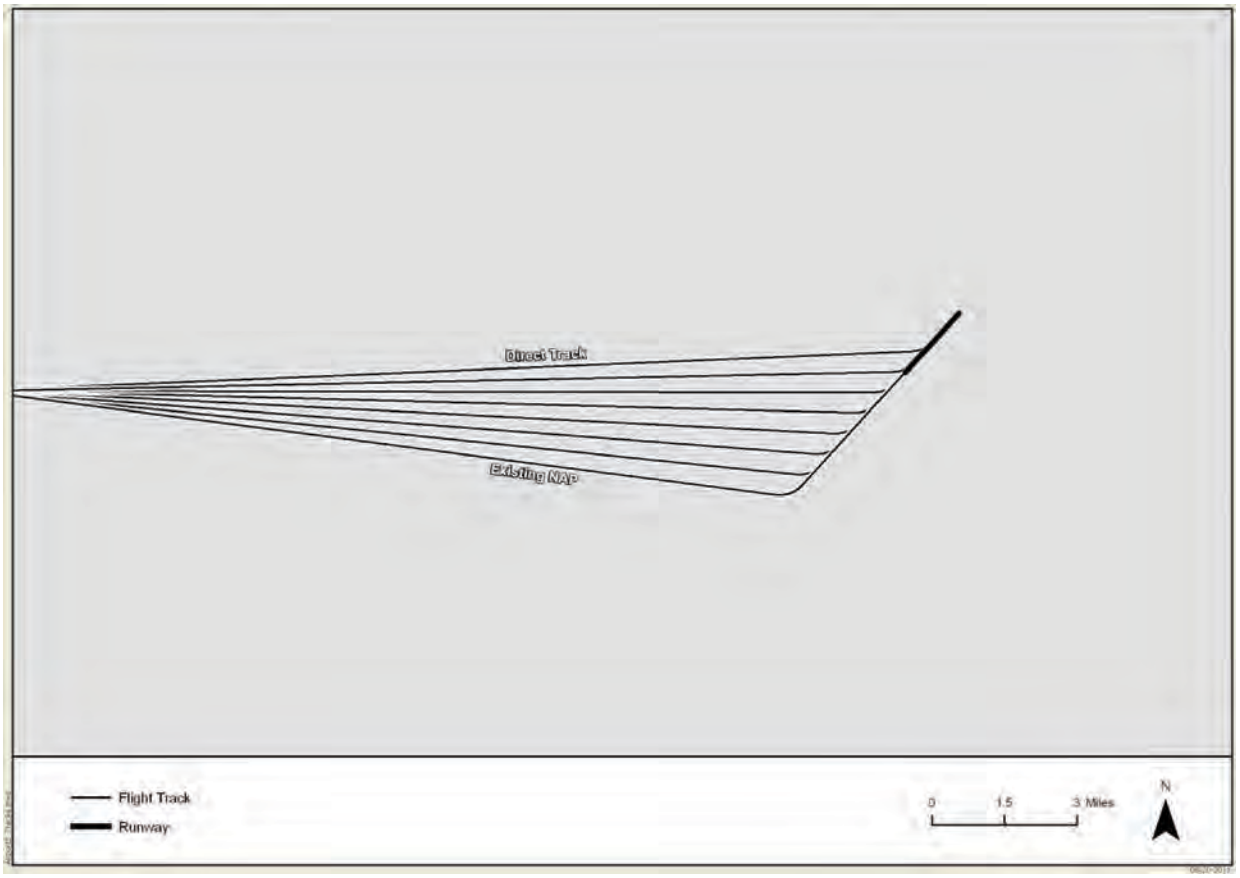


Figure 3-4. APRT9 ground tracks.

MSL. For this procedure, it was assumed in the model that all operations would follow the procedure before turning westbound. The noise difference map shown in Figure 3-8 shows the areas of noise decrease and increase when shifting an EMB-145 departure operation from the NAP to the direct track, and Figure 3-9 shows the tradeoffs summary chart. Both figures reflect the maximum noise increase of 17 dB SEL comparing the NAP to the direct track. For the intermediate tracks, the increase in population exposed to SEL above 75 dB increases gradually at first, from 6,342 for the NAP to 6,632 for the "NAP minus 1.5 NM." The difference between these ground tracks is a reduction of 11 kg of CO_2 and 4 kg of fuel, and 0.5 operations per hour impact on throughput. Overall, the relative differences shown for APRT9 are much less than for APRT6 due to the smaller aircraft type and different ground track geometry modeled.

3.3. Multi-Turn NAP Routing

A multi-turn NAP ground track is designed to avoid densely populated and noise-sensitive areas near airports. The modeling of such NAPs was performed on the basis of published information for APRT3, APRT2, and APRT5. Similar to turn restrictions, once multi-turn NAPs terminate, ground tracks proceed to a destination-specific fix in the airspace. To model the effects of optimizing these procedures, alternate ground tracks were created following the schematic shown in Figure 3-10. The airspace between the existing NAP and the most-direct feasible ground track was filled with alternate tracks spaced 0.5 NM apart. Figures 3-11 and 3-12 show the specific ground tracks modeled for APRT3 and APRT2, respectively.

For APRT3, a tradeoffs summary chart was developed to determine the optimal alternate flight tracks for the utilized runway using an MD-88 aircraft type for analysis (see Figure 3-13). The direct track, which turns immediately left instead of following the NAP initial right turn, results in a noise increase; however, the total population exposed to 85 dB SEL is lower. Although CO_2 and fuel burn are reduced by 27%, there are significant changes in noise exposure. In addition, capacity is affected by the varying ground tracks, due to the interactions between the multi-turn trajectory near the runway end and the departure profile of the MD-88. Effects of profiles at APRT3 are discussed further in Section 3.5.

The ground tracks modeled for the APRT2 runway RNAV NAP departure procedure vary from the published NAP to a

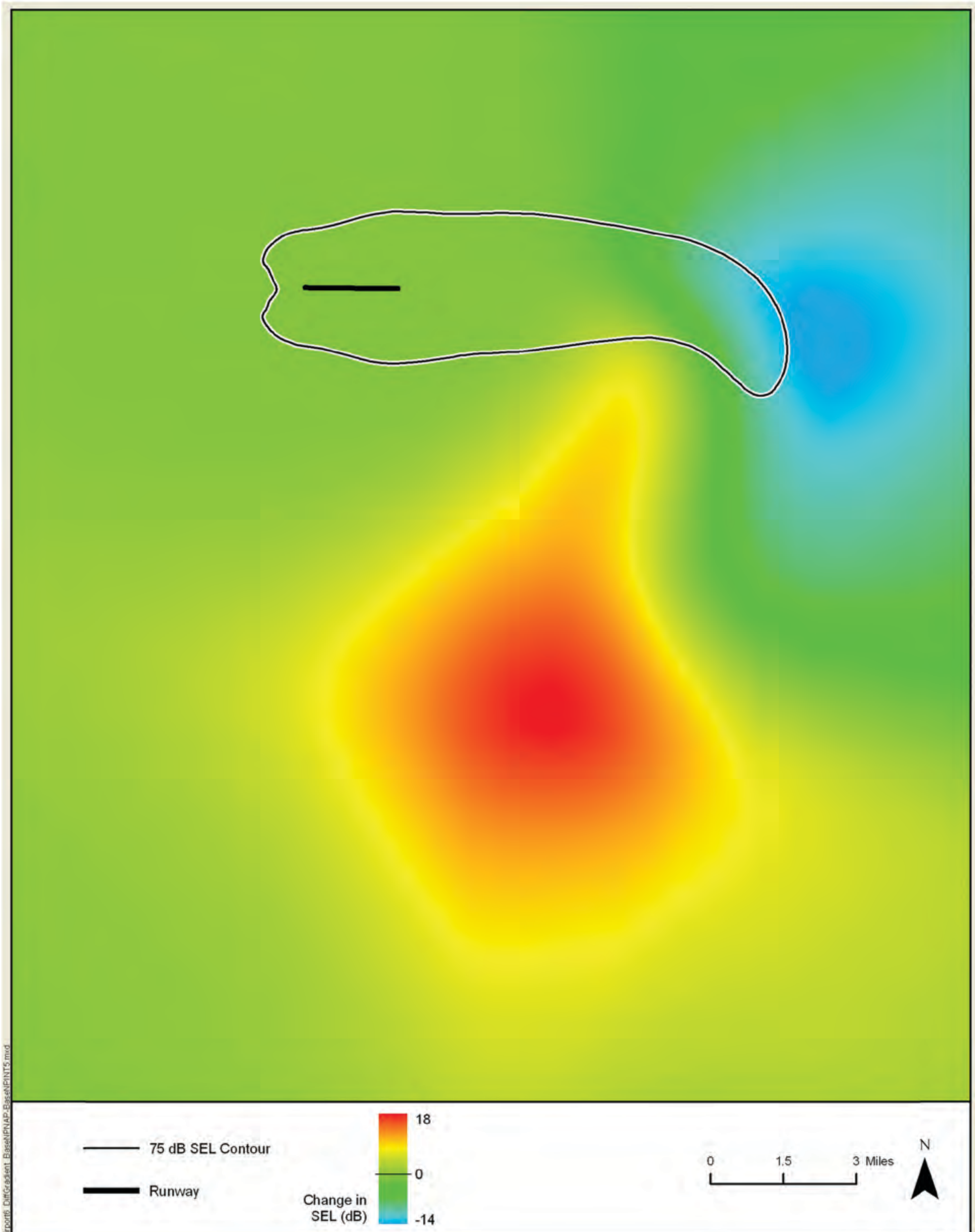


Figure 3-5. APRT6 noise difference map.

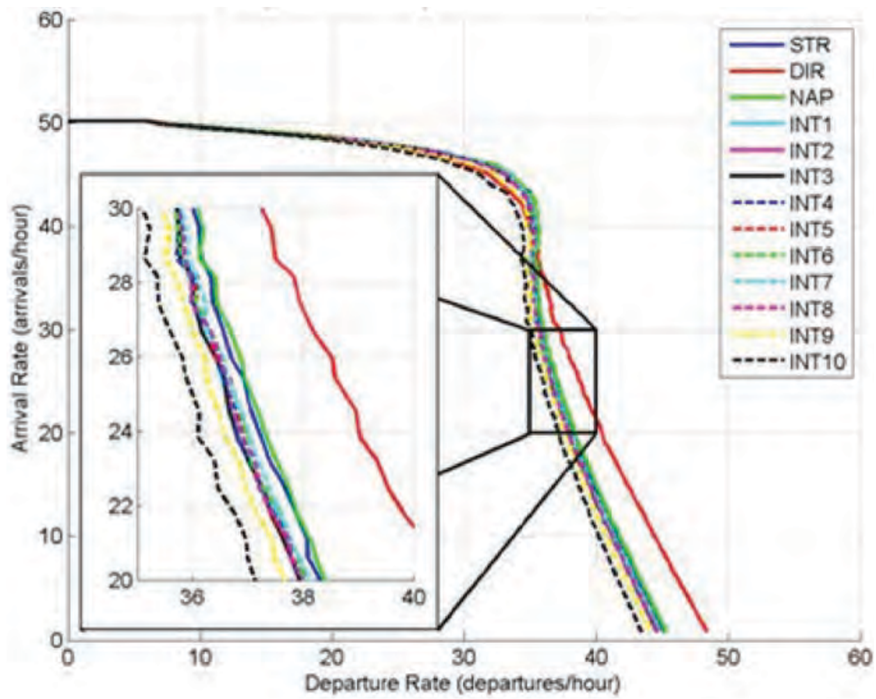


Figure 3-6. Capacity of runway pair at APRT6 with base departure profiles.

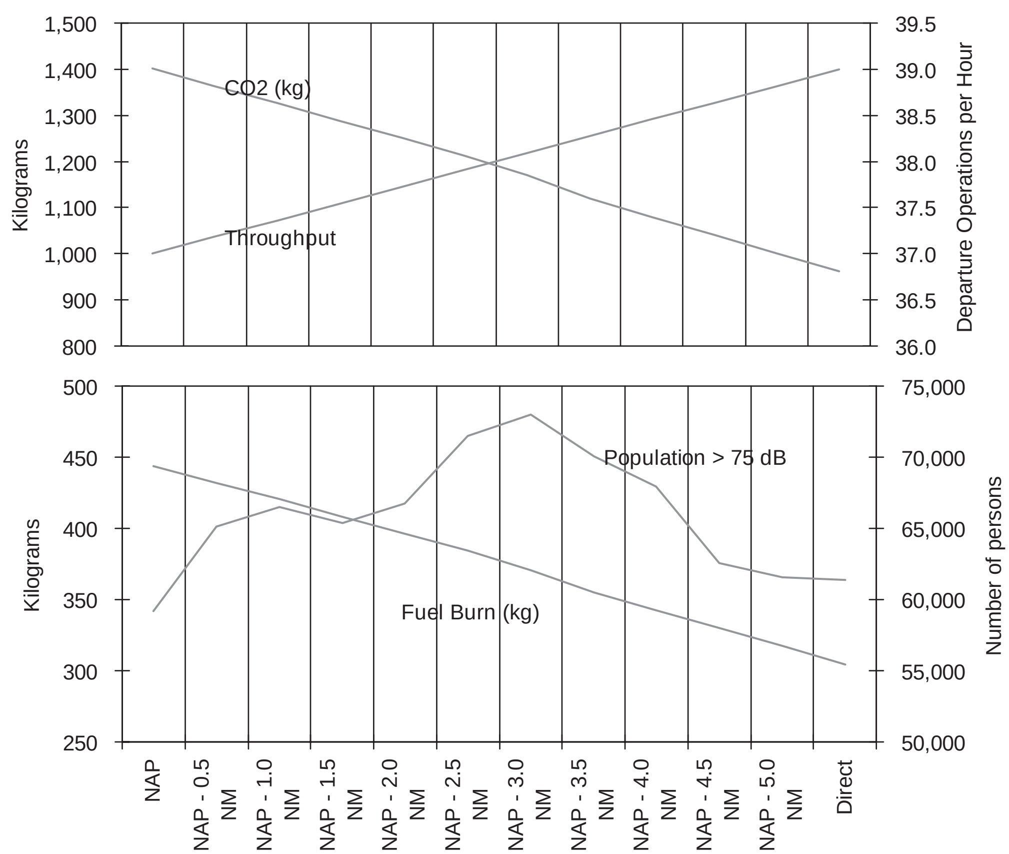


Figure 3-7. APRT6 tradeoffs summary.

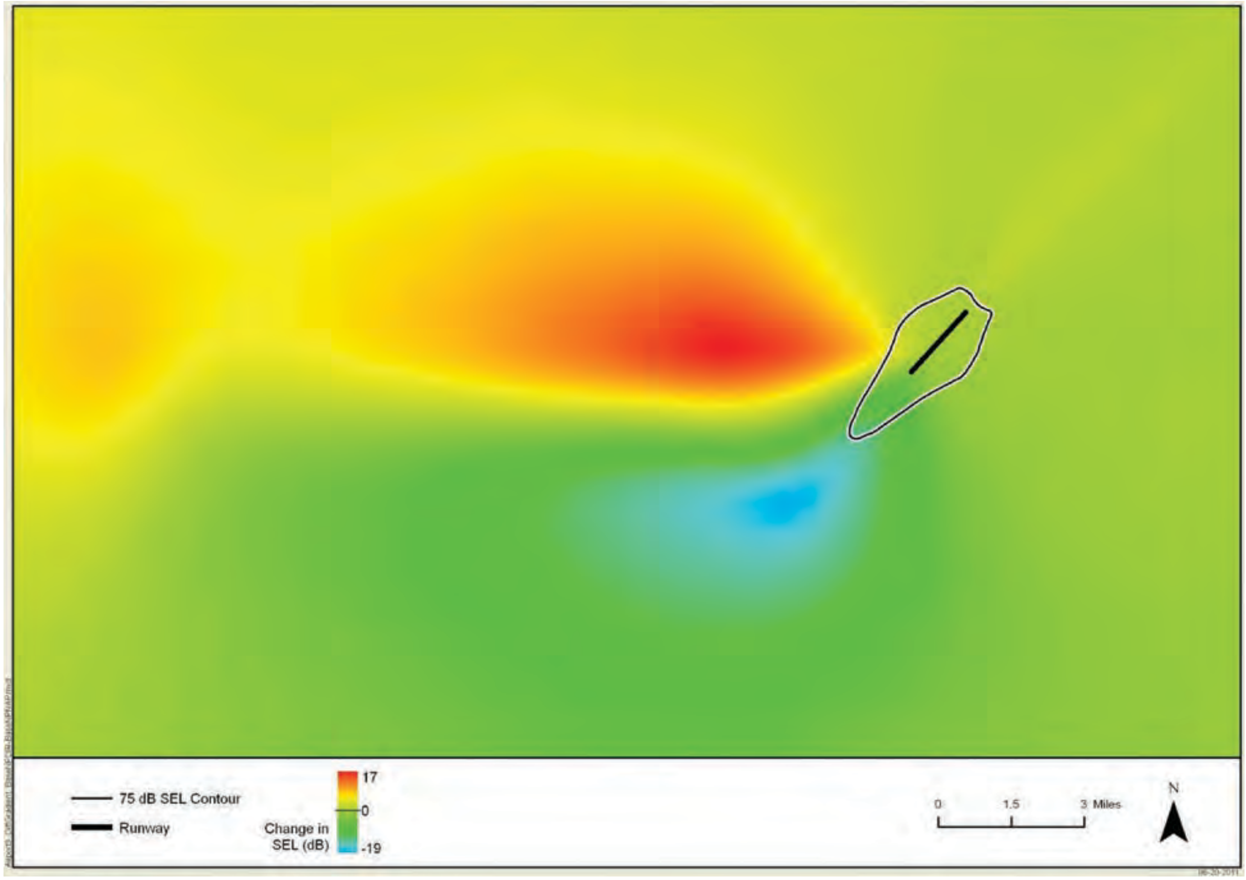


Figure 3-8. APRT9 noise difference map.

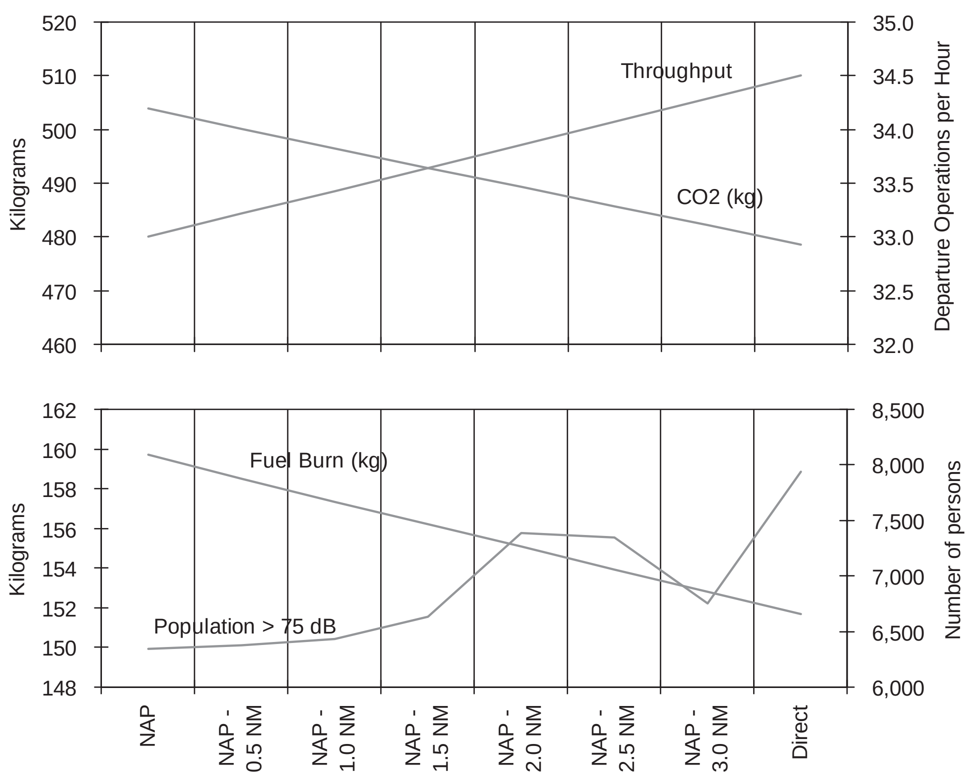


Figure 3-9. APRT9 tradeoffs summary.

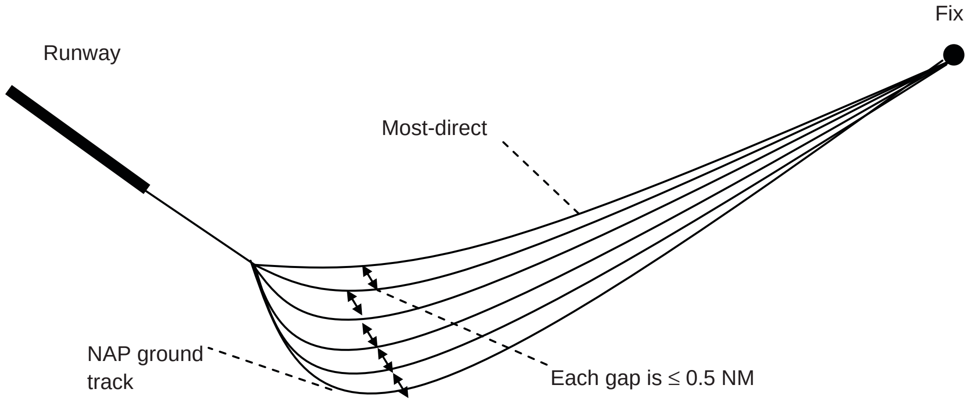


Figure 3-10. Illustration of multi-turn ground tracks.

direct ground track. The resulting changes in SEL are shown in the noise difference map in Figure 3-14. This map indicates that the maximum increase of 35 dB is located northwest of the airport, while corresponding noise decreases to 32 dB are located southwest of the airport. The intermediate noise increase values are shown in the tradeoffs chart in Figure 3-15.

Both APRT2 and APRT3 are airports surrounded by dense populations, as shown in Figures 3-13 and 3-15. Therefore, there is great sensitivity of population counts to changes in ground track locations at these airports. Although there is a potential to reduce emissions and fuel burn at each of these airports, a balance must be struck with changes in noise levels. For example, the population exposure for APRT2 increases gradually until after the "NAP minus 3 NM" alternate track; up to this point, reductions in CO_2 and fuel burn are 23% and there would be a 0.6 operations per hour increase in runway throughput.

3.4. Climb Procedures

The NAPs studied in the previous section are designed to avoid noise-sensitive areas by turning at several points along a ground track. However, a multi-turn ground track can also be used when a runway is near an unpopulated area or body of water. For example, APRT2 has implemented a procedure for runway departures because the airport is contiguous with an ocean. As shown in Figure 3-16, the existing conventional departure procedure was previously used to direct departing aircraft with a destination to the north. A new RNAV procedure was implemented recently to extend the segment of the ground track located over the water, so that aircraft can climb to a higher altitude before turning north and crossing the shoreline. A peninsula (not shown) to the northeast of the airport is still exposed to departing flights, but the longer flight track allows aircraft to climb higher before crossing this area, thus reducing noise.

However, the longer RNAV ground track results in higher fuel burn and emissions. Figure 3-17 shows the tradeoffs chart for each ground track out to a cutoff near the point where the tracks converge towards the fix. The result of the longer RNAV departure track (left side of the chart) is a 10% increase (243 kg) in CO_2 emissions (with a similar increase in NO_x emissions) compared to the conventional departure (right side of chart). Conversely, the RNAV departure reduces noise levels by as much as 16 dB for a single event. Thus, the benefit of reducing noise in the vicinity of the airport comes at the cost of increased emissions and fuel burn, although there is no measurable effect on capacity.

3.5. NADP Profiles

In addition to the NAP ground track procedures discussed above, Noise Abatement Departure Profiles (NADP) are also used to mitigate noise near airports. This section discusses the effects of NADPs on noise, emissions, fuel burn, and capacity. First, NADPs will be discussed independently of flight tracks. Then, the interactions between profiles and ground tracks will be discussed, particularly the case in which an NADP can mitigate noise increases that result from changing ground track locations.

In practice, the distant NADP-2 procedure is very similar to aircraft manufacturer's standard procedures—many airlines have adopted NADP-2 as their standard procedure. The close-in NADP-1 is different than standard procedures, particularly below 3,000 feet above field elevation (AFE). Figure 3-18 shows a schematic diagram of these profiles, with NADP-2 assumed to be similar to the standard procedure. The noise benefit of NADP-1 occurs above at least 800 feet AFE and below 3,000 feet AFE: the aircraft climbs higher sooner and reaches 3,000 feet AFE sooner than the standard profile. NADP-1 also

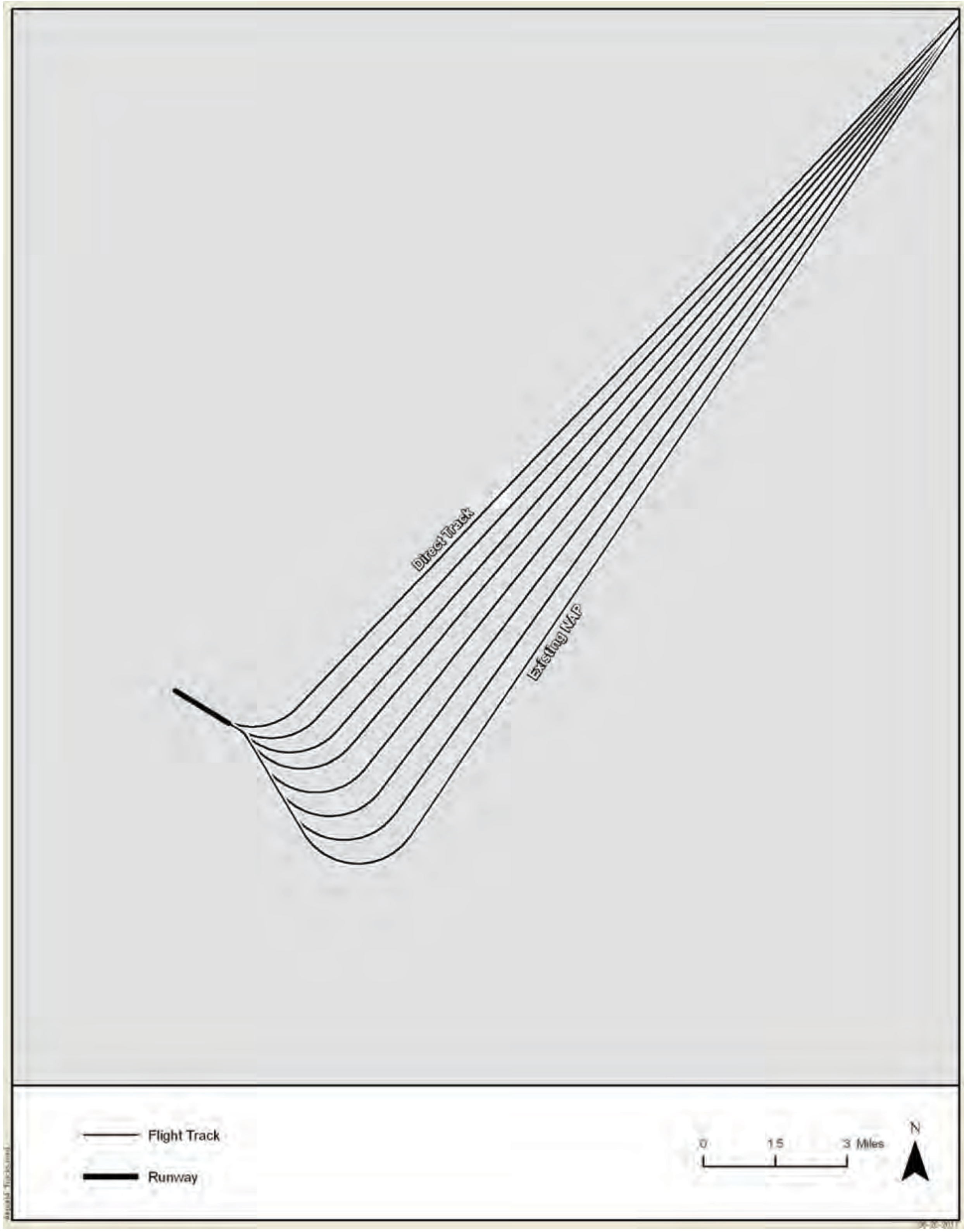


Figure 3-11. APRT3 ground tracks.

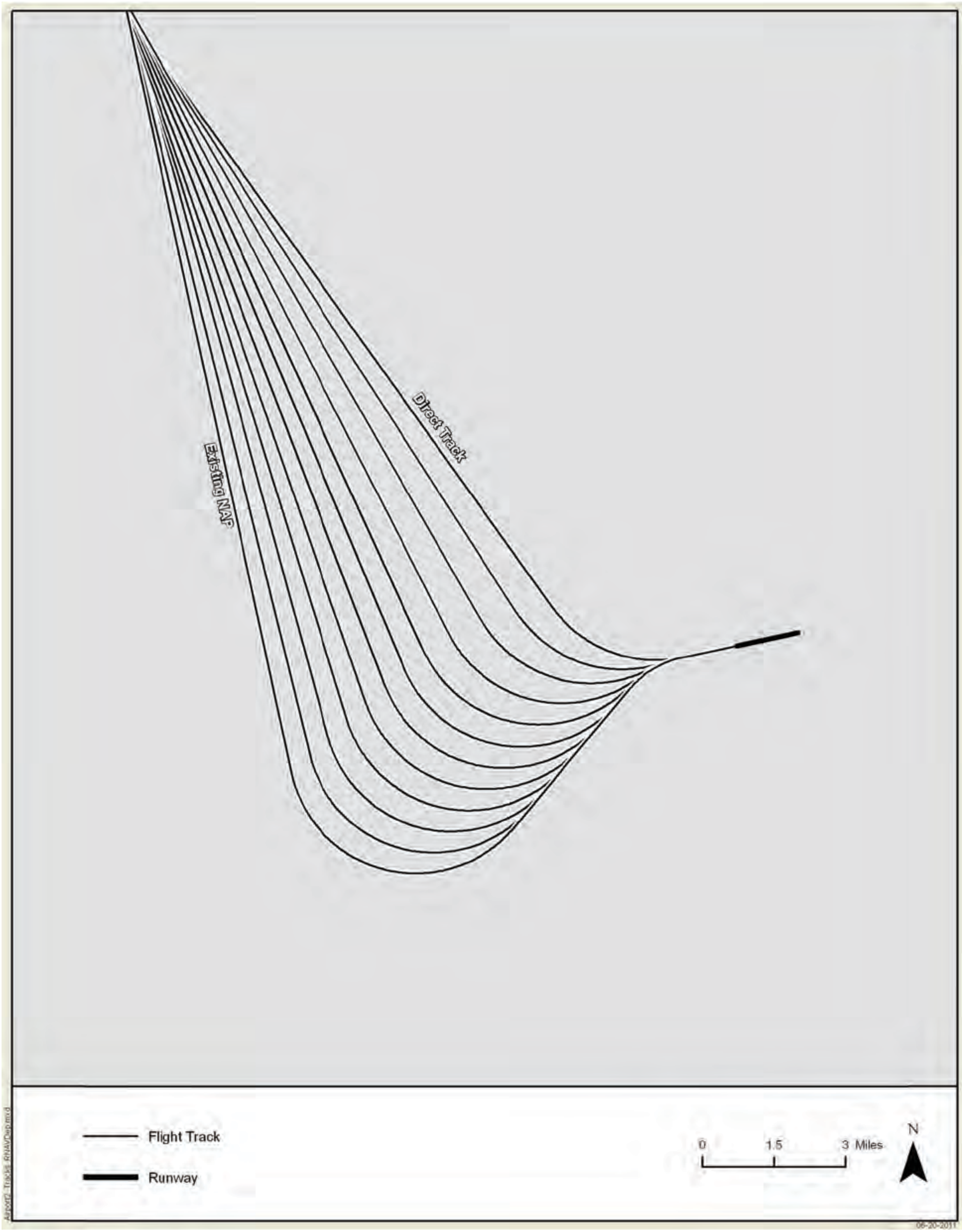


Figure 3-12. APRT2 ground tracks.

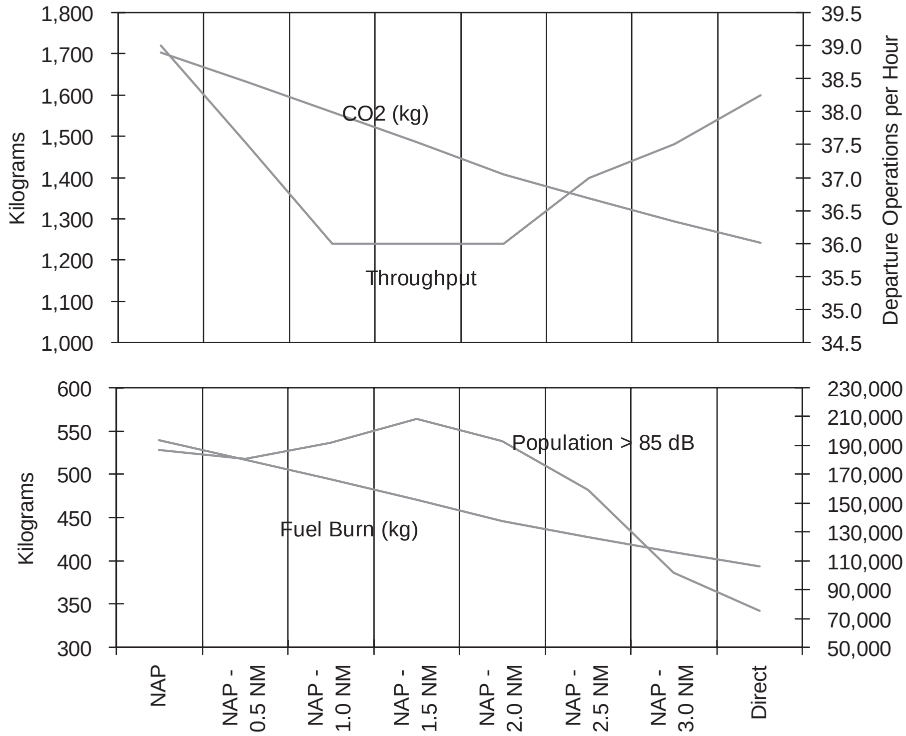


Figure 3-13. APRT3 tradeoffs summary.

entails a thrust reduction at the beginning of the procedure, from takeoff thrust down to climb thrust. However, this thrust reduction is not as drastic as the "deep cutback" or minimum thrust level used in some special cases. It is far more typical for aircraft to reduce thrust to climb power early than to reduce thrust to the minimum level.

In addition to the effect of reducing noise, emissions are also reduced for below 3,000 feet AFE, which is the mixing layer cut-off used for computations of air emissions for a local area (for pollutants such as CO, PM, HC, and SO_x). Figure 3-19 shows that CO emissions and fuel burn accumulated to 3,000 feet AFE are less for NADP-1 than for the standard (base) procedure at APRT3.

However, as shown in the schematic, after the procedure ends, the NADP-1 must retract flaps and accelerate, resulting in lower altitude farther from the airport. When the aircraft reaches a common departure fix, the total fuel burn and emissions are greater than the standard procedure, as shown on the right side of Figure 3-19. This tradeoff is important to consider when weighing the benefits of NADP-1: this trend was also found for other aircraft types and airports.

The lower airspeed of NADP-1 below 3,000 feet AFE, while allowing for reductions in noise and local emissions, affects runway capacity. Figures 3-20a and 3-20b compare the runway throughput for APRT3 for standard (top) and NADP-1 (bottom) profiles. The departure curves are lower for the NADP-1 case, with approximately four fewer operations per hour; this is due to the lower airspeed of NADP-1 near the runway end. This tradeoff must also be considered when assessing NADPs.

The combination of changing ground tracks and using NADP-1 can be used to develop an optimized 3-dimensional trajectory. That is, implementing an NADP can partially mitigate the noise increases due to a change in a ground track and can reduce the local air emissions below 3,000 feet AFE. Continuing with the APRT3 case study as an example, Figure 3-21 shows the noise differences for a combination of NADP-1 and an alternate ground track which turns to the fix 1 NM sooner than the NAP. A noise reduction of 5 dB is shown at the location of the NAP track and a noise increase of 5 dB is shown at the location of the alternate early-turn track. In addition, the noise reduction of the NADP can be seen close to the runway end directly under the flight track during the initial segment of the ground track.

However, there is a noise tradeoff involved in the use of NADP-1. Directly south of the runway end there is an area of noise increase; this is due to the lower airspeed of the aircraft during the climb to 3,000 feet AFE. Although the aircraft is at a higher altitude than the standard profile during this climb segment, the lower airspeed results in more accumulated noise added to the SEL metric in areas to the side of the ground track near the runway end. This effect is highly dependent on ground track geometry; however, there is always a tradeoff between reducing noise directly under the ground track and increasing noise on the sidelines when using an NADP-1. This

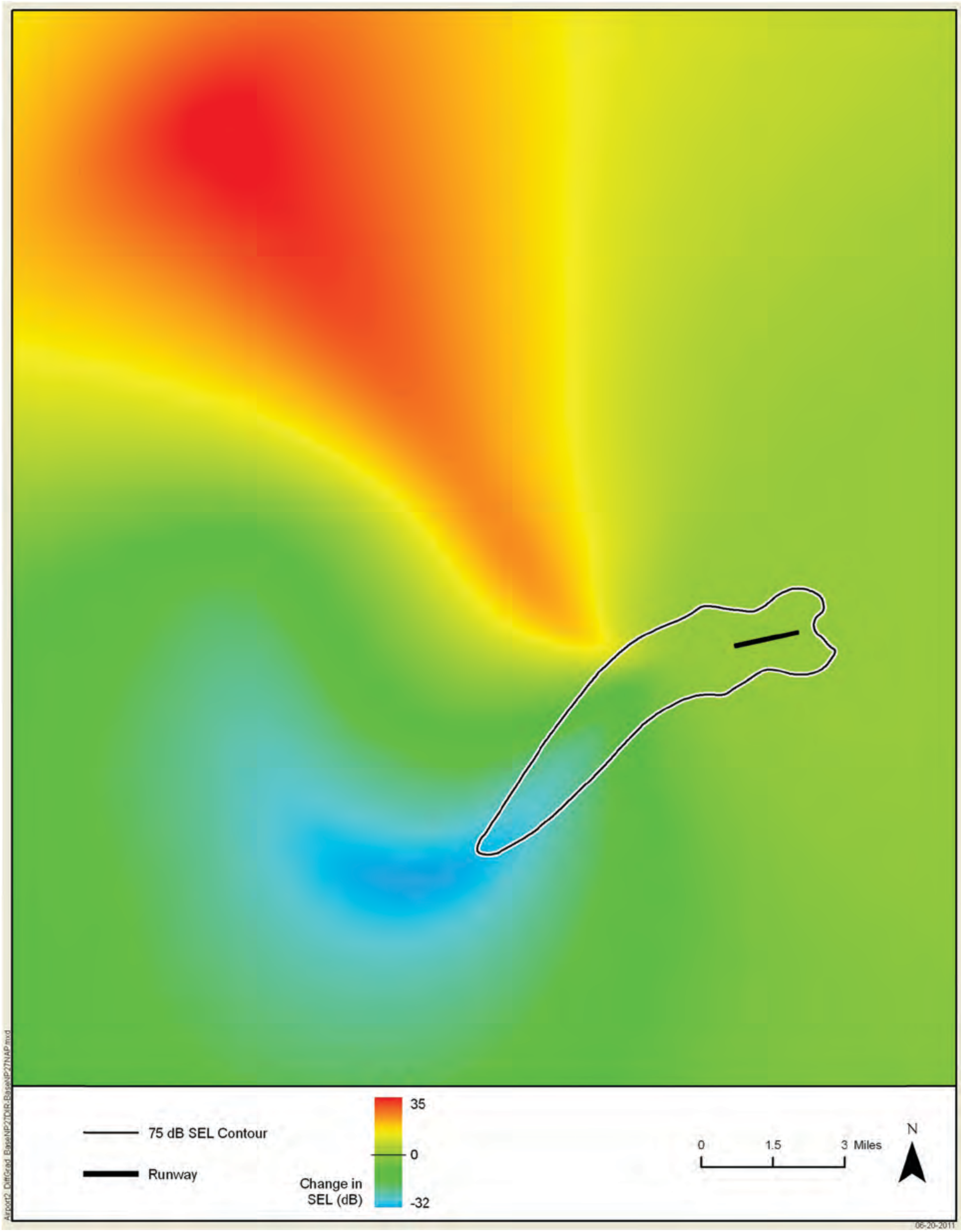


Figure 3-14. APRT2 noise difference map.

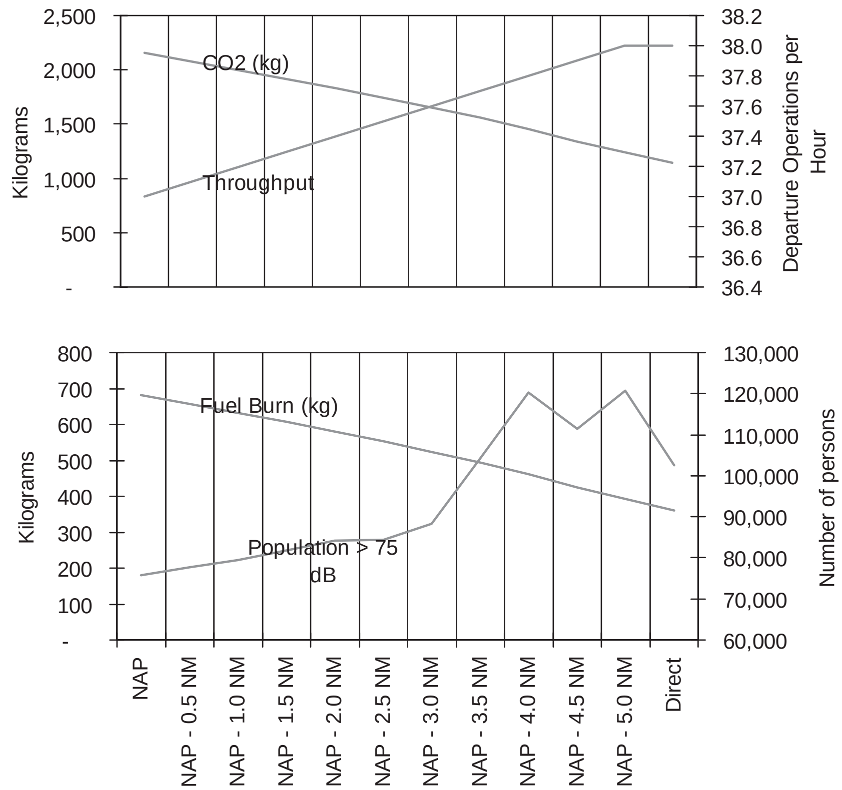


Figure 3-15. APRT2 tradeoffs chart.

noise tradeoff must be considered in any situation when an NADP-1 is implemented.

3.6. Fanning

Fanning procedures are implemented by FAA air traffic control to improve runway throughput, particularly for periods of high traffic levels at an airport. In addition, airports such as APRT4 use fanning as a noise abatement procedure in order to distribute noise more widely over an area. For one of the runways at APRT4, a fanning departure procedure is in place because areas directly in line with the runway are affected by arrivals to the opposite runway end. Figure 3-22 shows the departure tracks from the runway, including straight-out departures, left and right fanning headings immediately at the runway end, and left and right fanning headings 1 NM from the runway end. These ground tracks were modeled to assess the changes in noise and capacity when using fanning procedures. Emissions were not computed because the tracks do not converge at any point beyond the terminal area.

Figure 3-23 shows the SEL difference between a straight-out departure ground track and fanned tracks and shows this difference when switching from the fanned tracks to the straight-out departure ground track. Although the maximum SEL difference is 36 dB, the differences closer to the airport are smaller. Nonetheless, the increase in noise along the extended centerline of runway 30L is significant. Furthermore, the capacity curves in Figure 3-24 show that only the immediate-turn fanning tracks result in an increase in throughput because a departure must be on a heading 15 degrees off of the previous departure profile by 1000 ft. above the runway for the trajectories to be considered to diverge immediately. The 1 NM turns modeled for APRT4 did not meet this condition. Thus, an important conclusion is that fanning can improve runway throughput only when the turns are made immediately after takeoff, which is not possible for some larger aircraft types.

3.7. Conclusions

Nine airports were modeled using single-event case studies to determine the tradeoffs of noise, emissions, fuel burn, and capacity. These airports represent a sample of different sizes and types of airport, with varying levels of population density and different types of aircraft. The case studies showed that even relatively small changes in noise exposure have an appreciable impact on reducing fuel burn and emissions, although the benefits to runway throughput were minor and, in some cases, negligible (with the exception of fanning). The impact on local population varied from airport to airport, and, in some cases, a small population impact could be

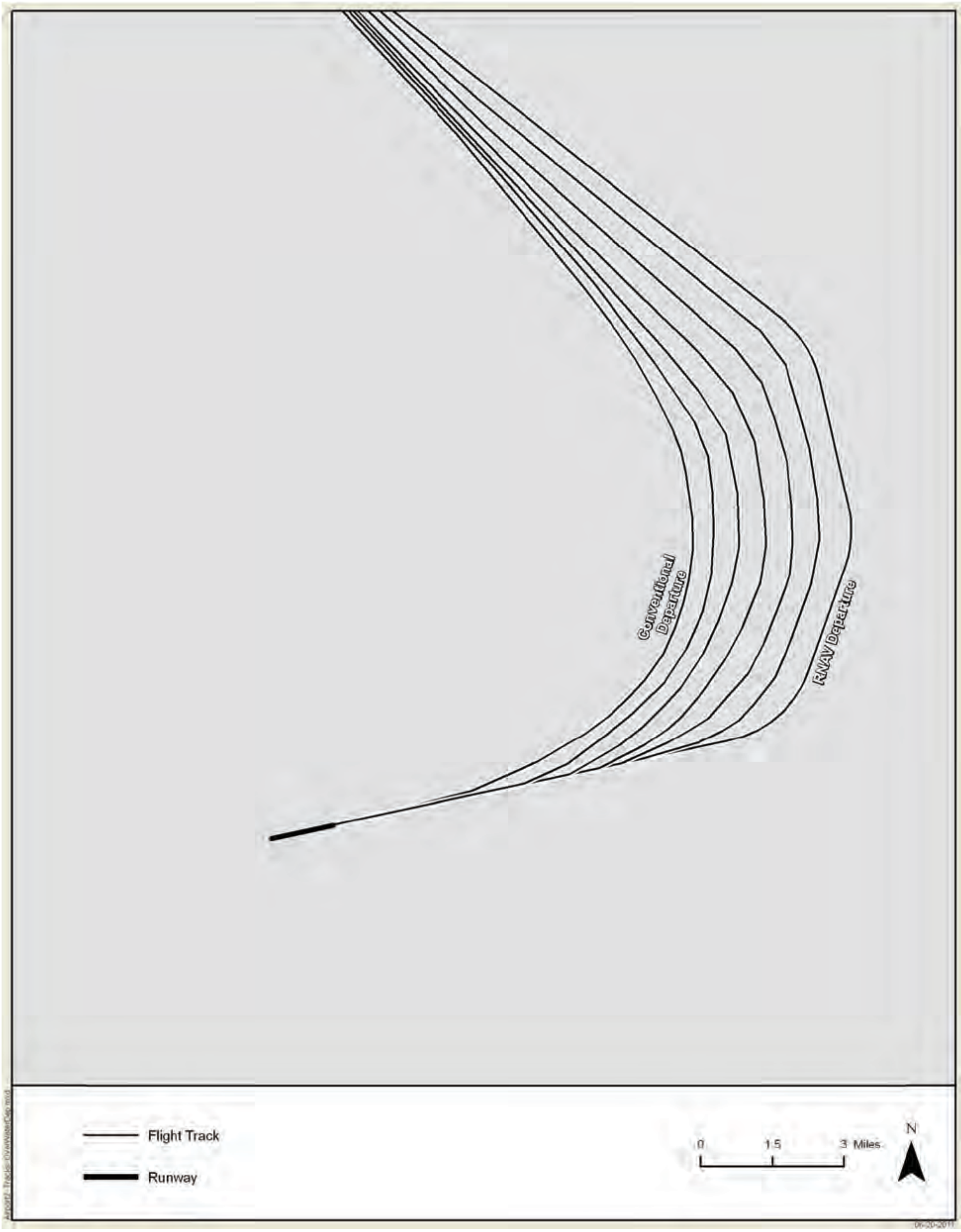


Figure 3-16. APRT2 climb procedure ground tracks.

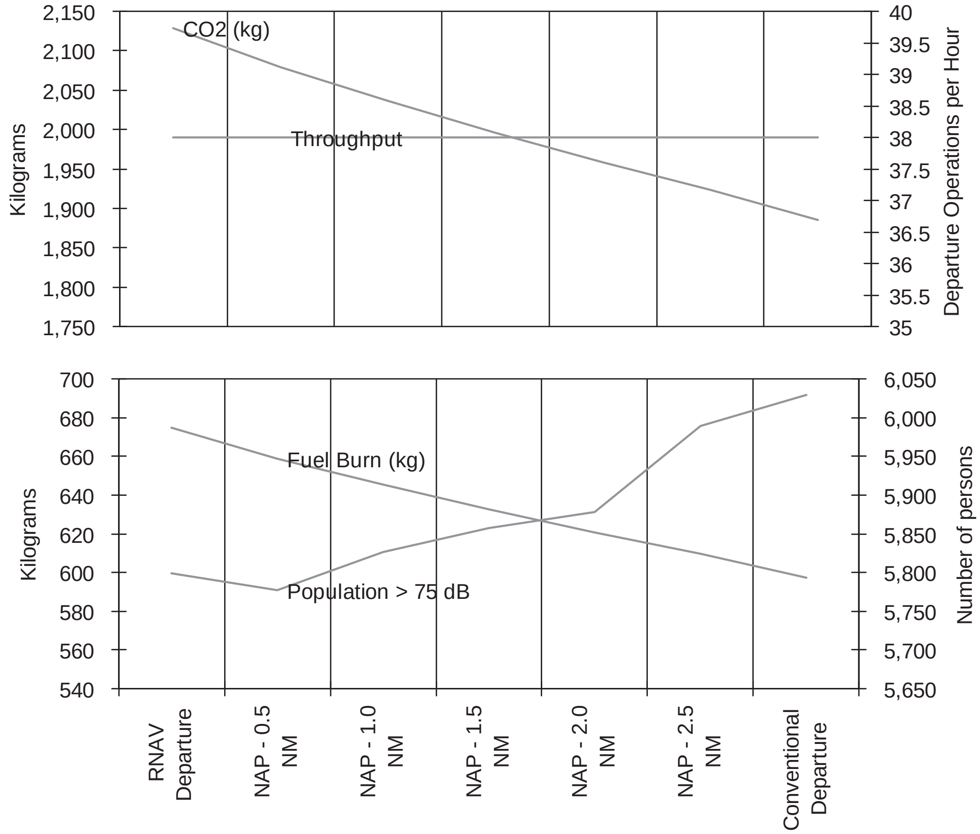


Figure 3-17. APRT2 climb procedure tradeoffs chart.

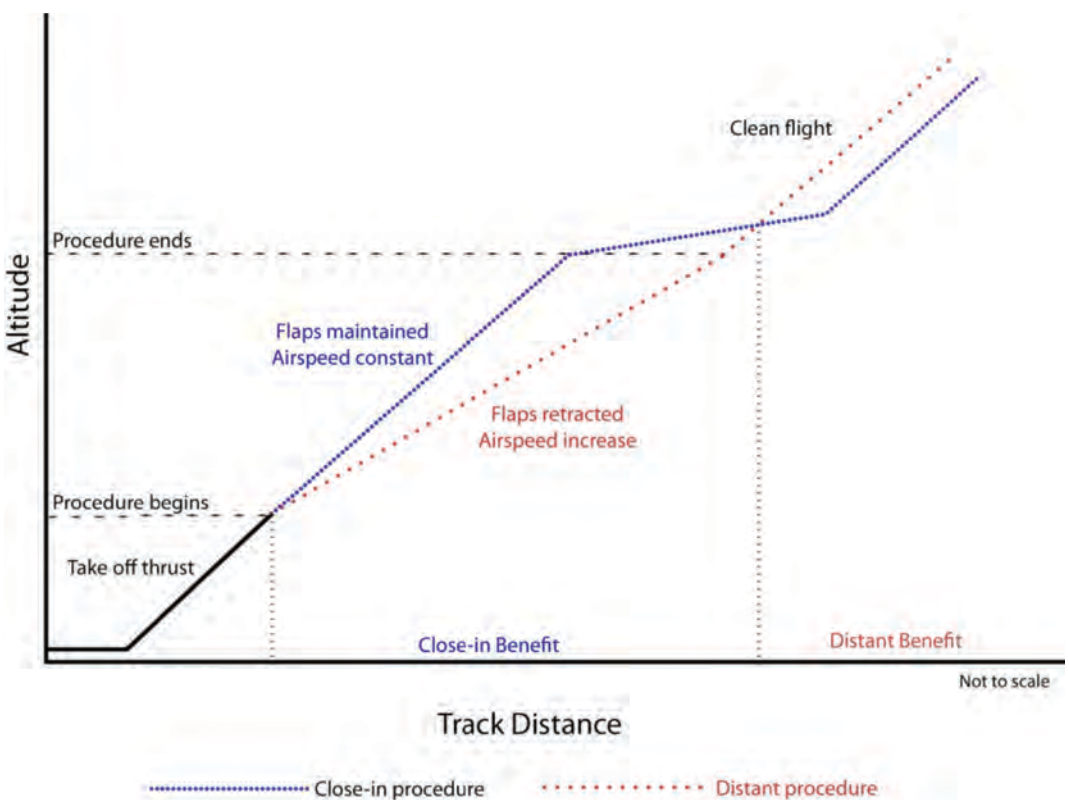


Figure 3-18. NADP schematic.

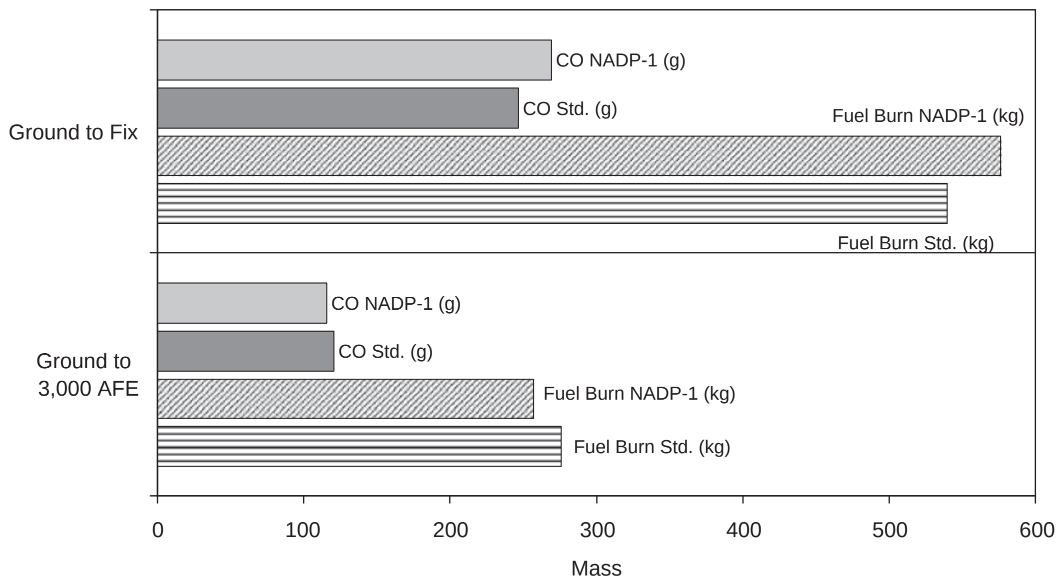


Figure 3-19. Emissions and fuel burn for MD-88 at APRT3.

traded for larger reductions in emissions. In terms of profiles, NADP-1 was found to have tradeoffs in noise and emissions, but consistently reduced throughput.

In addition to the conclusions drawn in each preceding section, an analysis which considers all airports together was completed. Figure 3-25 summarizes tradeoffs in terms of noise increase in decibels versus CO_2 emissions decrease in kilograms. A curve was plotted for most of the airports using the data generated for the ground tracks modeled relative to the existing NAP, with the direct track resulting in the greatest noise increase and corresponding CO_2 reduction.

The variability of the curves results from three factors unique to each airport: aircraft type, ground track geometry, and departure fix (cutoff) location. For example, regional jet emissions are much lower in overall magnitude than heavy jet emissions, so the potential for reduction is also smaller. Ground track geometry was also an important factor: large, sweeping NAP turns (i.e., APRT2, APRT1, APRT3, and APRT6) showed greater changes when compared with smaller, incremental track changes (i.e., APRT5, APRT9, and APRT7).

To characterize the range of noise changes shown in Figure 3-25, a list of noise reductions due to fleet replacement using various existing and planned aircraft technology was tabulated. Table 3-3 shows the approximate ranges of noise reductions relative to existing marginal noise stage 3 aircraft. The differences in cumulative noise level for stage 3 and 4 are based on FAA certification requirements and the future aircraft cumulative levels were reported by Rachami (2008). Takeoff and sideline levels were assumed to be equivalent and were approximated from existing certification data trends. Overall, this analysis shows that, for single-departure operations modeled in the case studies, replacing a stage 3 with stage 4 would result in a 3 to 4 dB reduction throughout all noise contour levels, with even greater reductions possible with future technology. Therefore, fleet replacement, limited to a single-event basis, has the potential to mitigate the increases in noise reported in Figure 3-25.

The case studies generated single-event data from which the most optimal procedures were determined by comparing results with the existing NAPs. Although the goals of the case studies were met, there were some limitations to the analysis. Given that the case studies focused on single-departure events, the following limitations were observed:

- Cumulative effects, such as daily or annual average noise and emissions inventories, could not be computed based on the case studies. The environmental and capacity effects of departures on other runways and arrivals were not included.
- The runway throughput model was simplified to focus on individual runway operations and ground tracks. In addition, the effects on throughput reported in this chapter are representative of IFR conditions; VFR conditions results showed no changes as a result of NAPs because the separation limits are smaller.
- The ground tracks and profiles modeled for single events are idealized to match precise procedures; in practice, there are deviations from these procedures (e.g., the dispersion of ground tracks throughout an airspace corridor).
- Each case study considered only one aircraft type per airport, limiting the ability to compare aircraft with different noise levels directly.

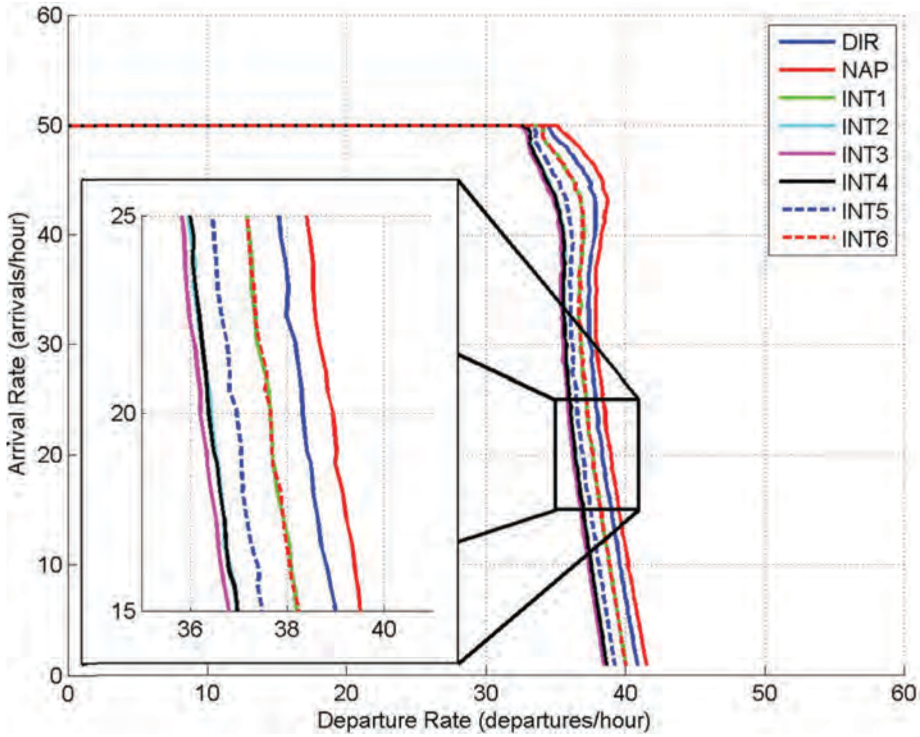


Figure 3-20a. Runway capacity for MD-88 at APRT3 with base profiles.

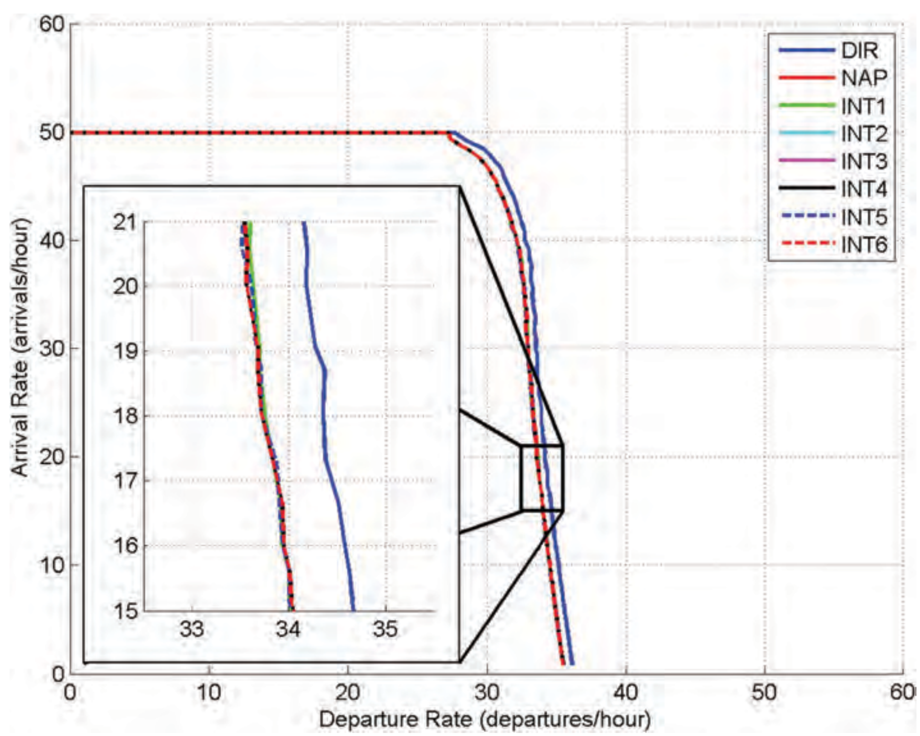


Figure 3-20b. Runway capacity for MD-88 at APRT3 with Noise1 profiles.

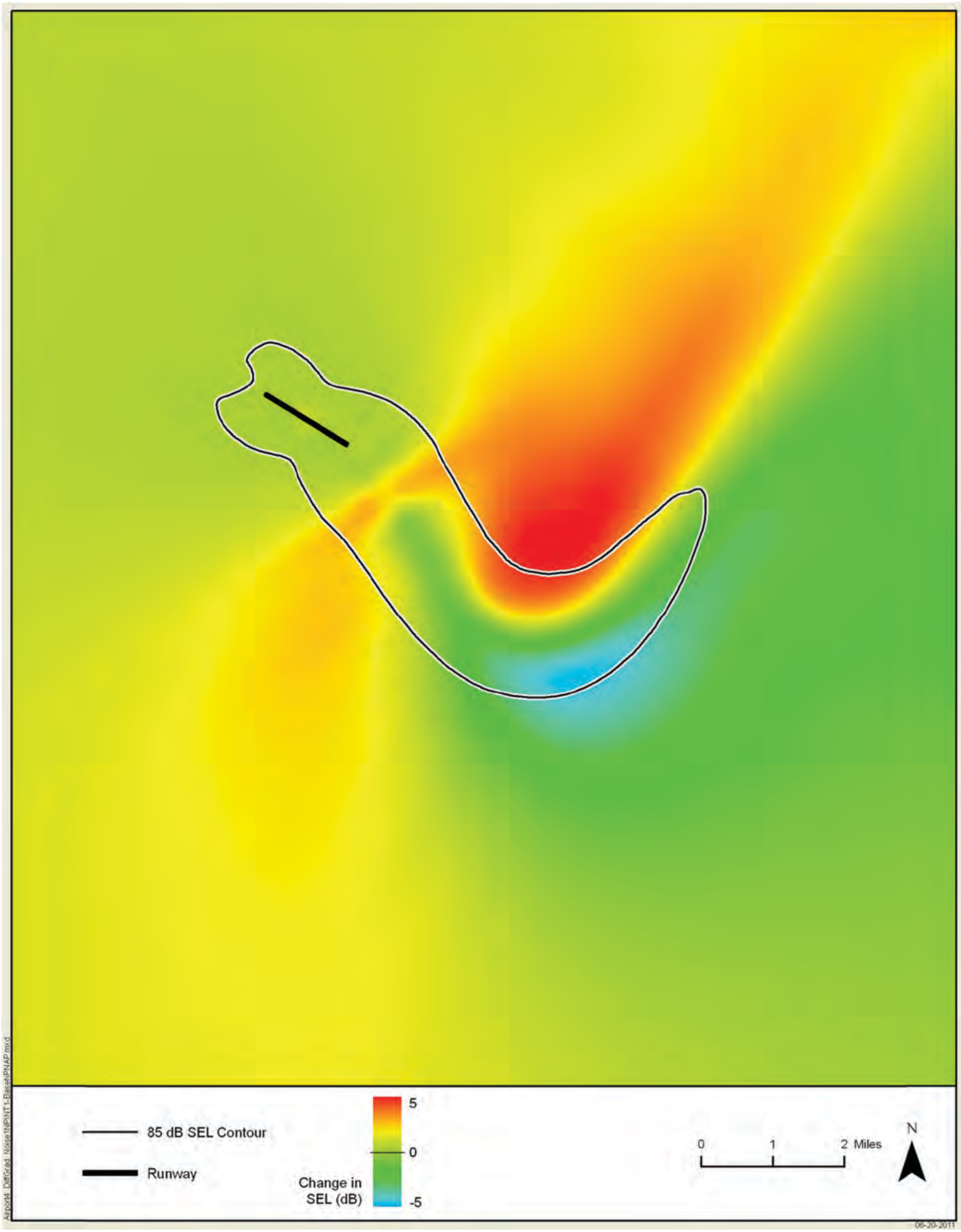


Figure 3-21. APRT3 noise difference for NADP-1 (1 NM turn).

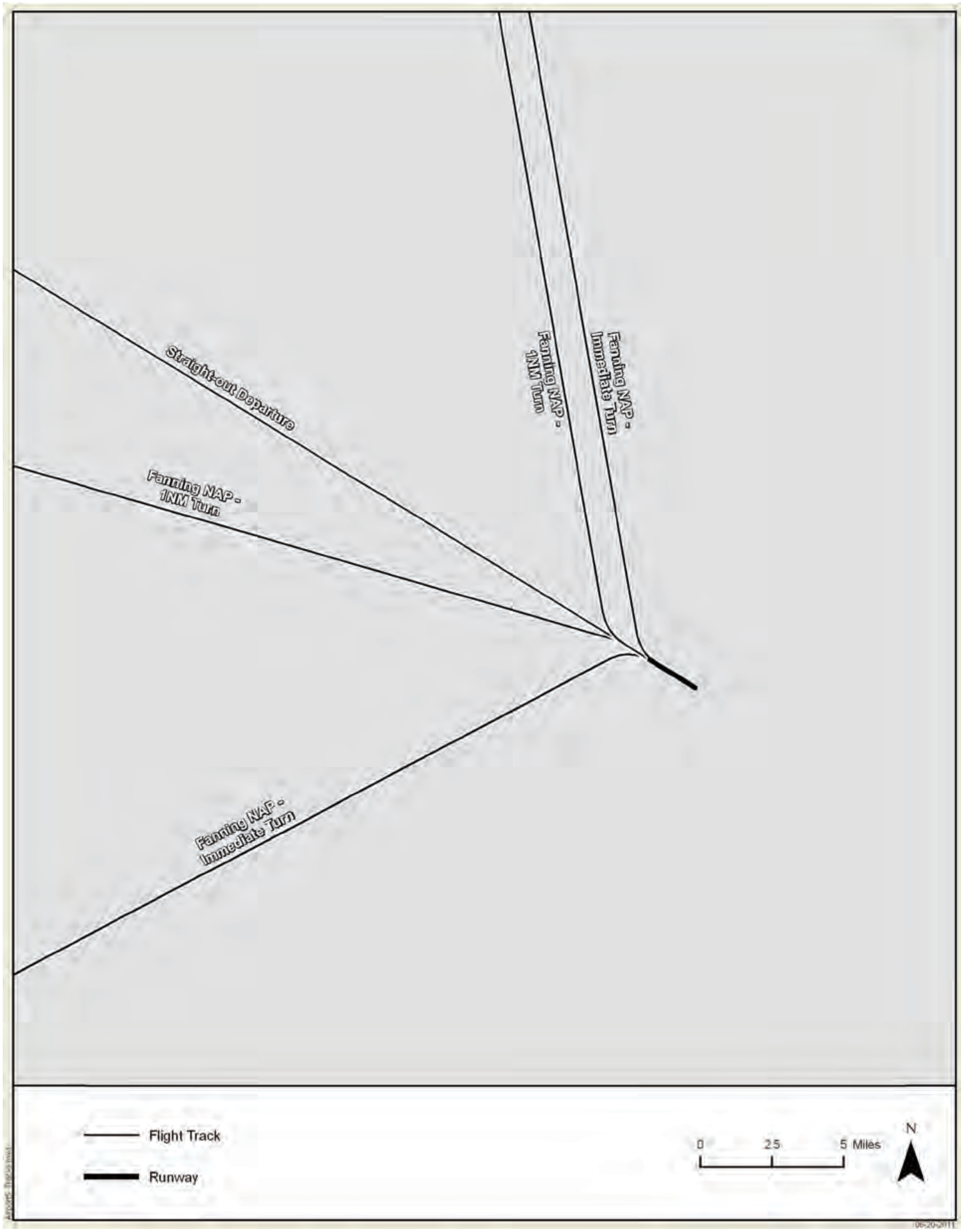


Figure 3-22. APRT4 ground tracks.

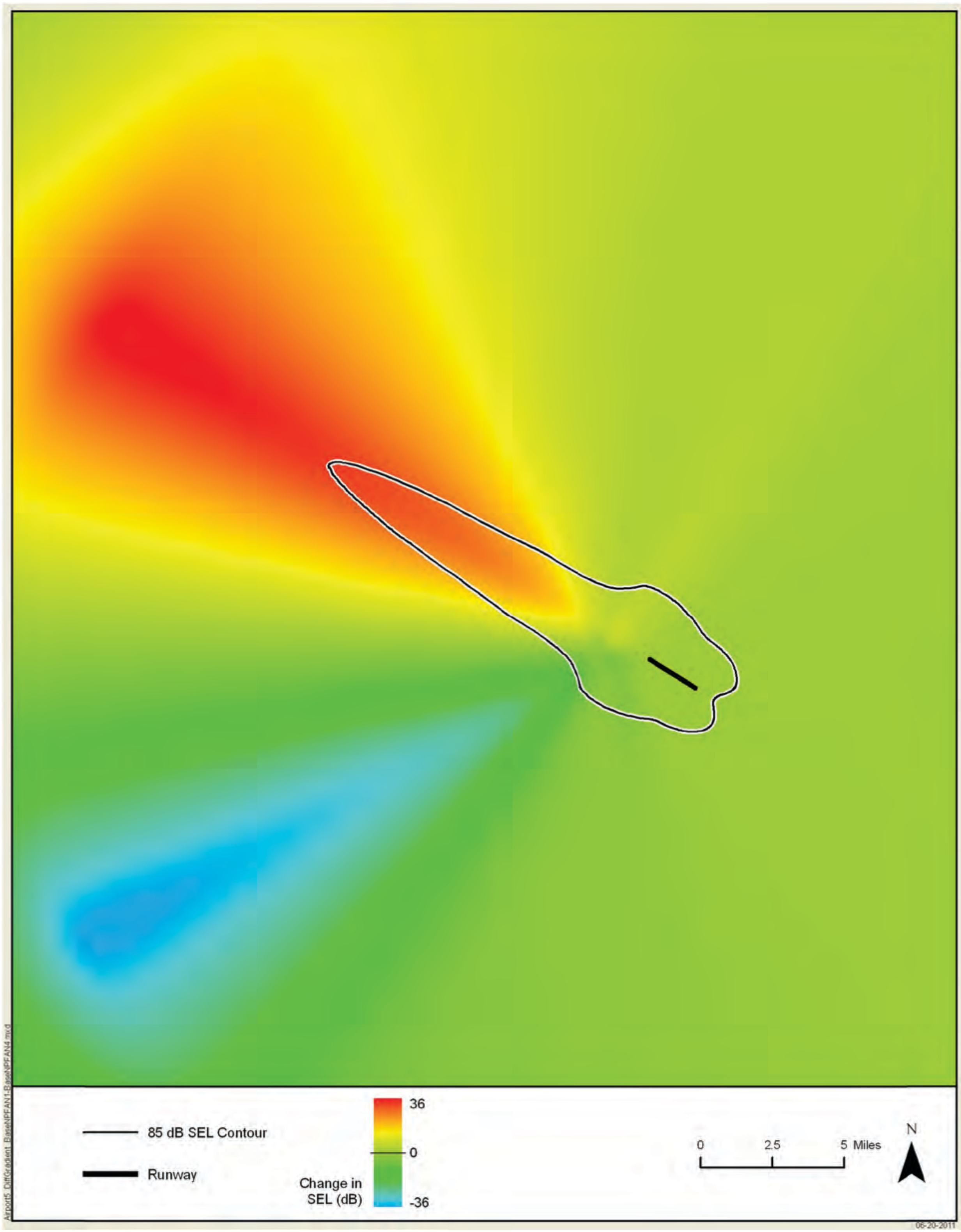


Figure 3-23. APRT4 noise difference.

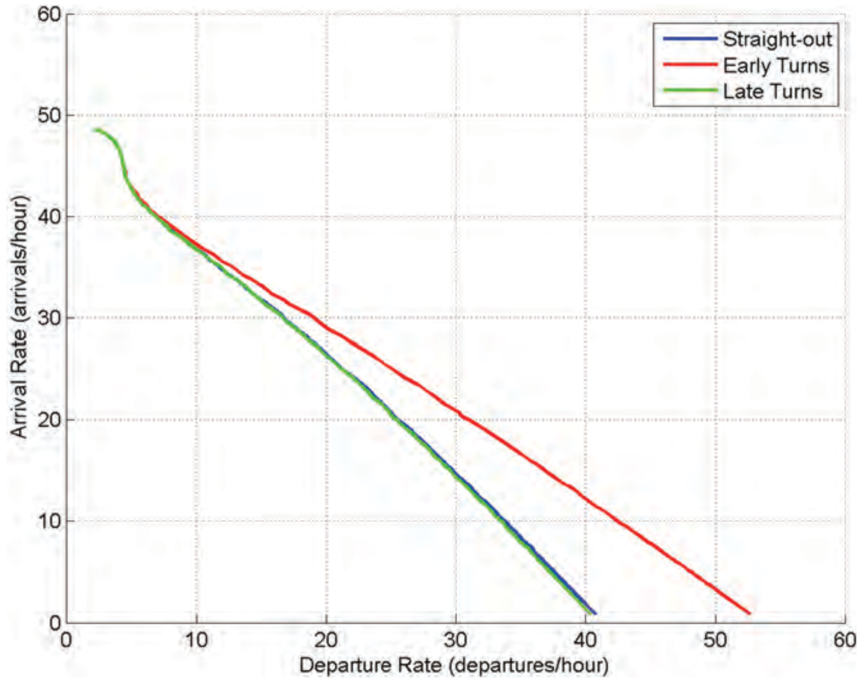


Figure 3-24. APRT4 runway capacity with base profiles.

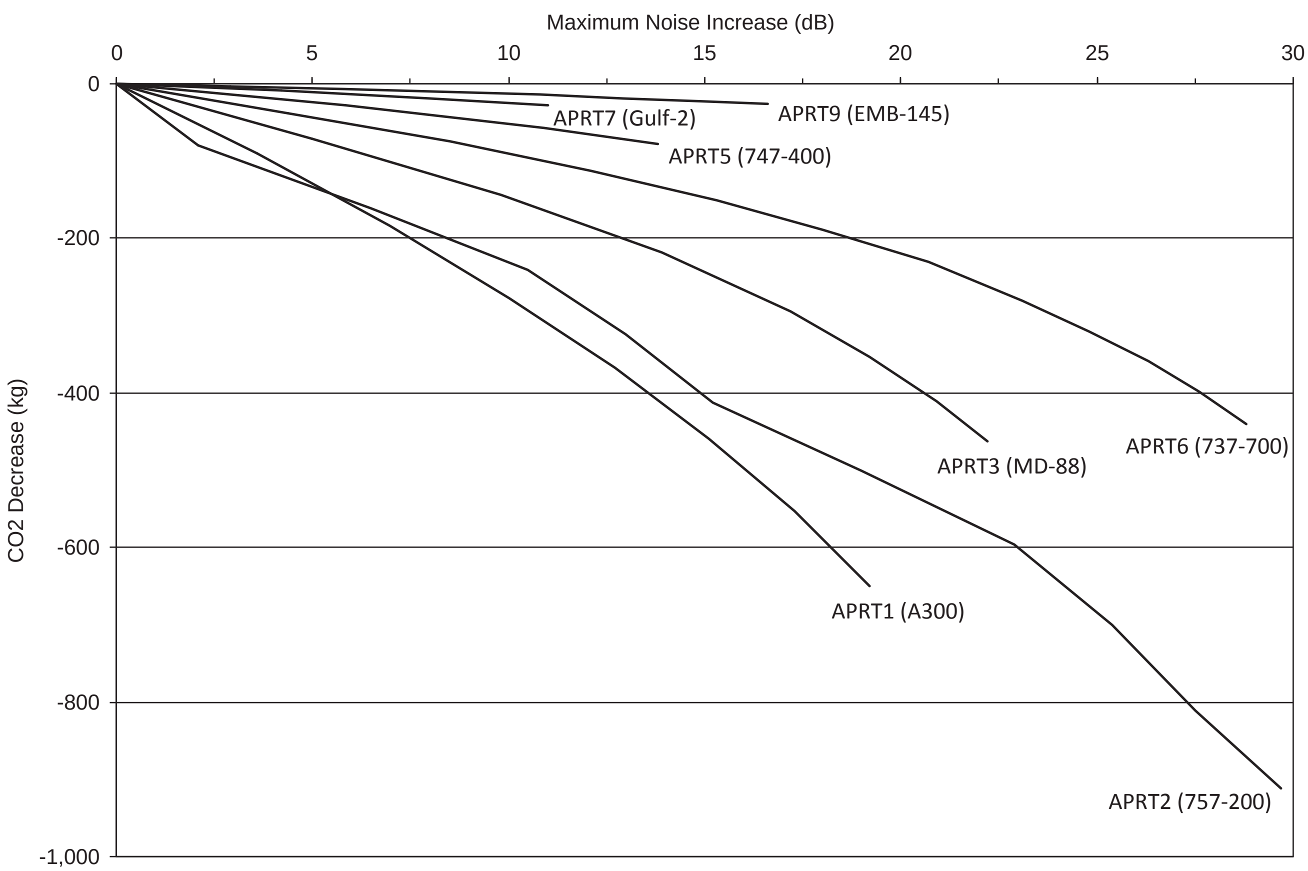


Figure 3-25. Comparison of noise and CO_2 change levels for multiple airports.

Table 3-3. Noise reduction levels for aircraft technology horizons.

Aircraft Technology	Difference in Cumulative[1] Noise Level Relative to Stage 3 (dB)	Approximate Difference in Takeoff and Sideline Noise Level Relative to Stage 3 (dB)
Stage 3	0	0
Stage 4	-10	-3 to -4
Advanced Stage 4[2]	-30	-9 to -11
N+1[2]	-42	-12 to -15
N+2[3]	-52	-16 to -18
N+3[4]	-81	-24 to -28

1: Cumulative noise certification levels are based on the sum of takeoff, sideline, and approach noise measurements. Typically, takeoff accounts for 30-35% and sideline accounts for 30-35% of cumulative.
2: Currently under development.
3: Development through 2020.
4: Development through 2035.
Sources: Rachami 2008; FAA Advisory Circular AC36-1H

CHAPTER 4

Optimization Tool

4.1. Introduction

In support of helping airport operators to better understand the tradeoffs among aircraft noise, fuel burn, and emissions from departure track optimizations, an electronic tool was developed to help facilitate scenario assessments. The focus of the tool is to allow the assessment of departure trajectory optimizations through the use of methods that allow

- Calculation of noise exposure;
- Quantification of fuel burn and emissions;
- Modeling of changes in air traffic capacity resulting from the implementation of optimized departure procedures; and
- Accounting for future fleet mixes and technologies, including those envisioned as part of NextGen.

The primary difficulty in developing a method applicable to all airports is that most airports are unique in terms of the aircraft fleet they serve, in the nature and location of the communities that surround them, and, consequently, in the flight trajectories and procedures they use. For the previously discussed case study analyses, several specific airports were selected to serve as examples of the types of departure noise abatement procedures that are commonly implemented. Although some of the airports presented combinations of several of the procedures of interest, no single airport could be used as an example that covered all noise abatement procedures (NAPs). Given the range of variability of possible individual situations, the approach selected for developing the method was to create an interactive tool that exemplifies a generalized framework for assessing environmental optimization of departure flight operations. Section 4.2 provides details on the hypothetical airport layout used in the tool while Appendix E discusses scenario modeling and provides some detailed example uses of the tool.

The tool is in the form of a Microsoft Excel-based interactive application that computes noise, fuel burn, and emissions results on the basis of various user inputs within the context of a set of fixed parameters. For simplicity and ease of use, the tool's overall modeling scenario is based on a set of fixed tracks that allow the user to model various scenarios depending on how the operations of a user-defined fleet mix is allocated to the tracks. This allows airport operators to study what-if scenarios that most closely resemble their airport flight tracks in an attempt to better understand the effects (e.g., sensitivities) of choosing different combinations of flight tracks, operations, and fleet mixes.

4.2. Tool Description and Design

4.2.1. Software and Hardware Requirements

The Departure Optimization Investigation Tool (DOIT) is a spreadsheet-based analysis tool that integrates (1) a multiple-tab input interface; (2) integrated function-based computation engines; and (3) a database of aircraft noise, fuel burn, and emissions characteristics. DOIT was developed as a self-contained Microsoft (MS) Excel macro-enabled workbook compatible with MS Excel 2007 and higher; compatibility with previous versions was not possible because of limitations in worksheet size and capabilities. The macro execution functionality is required for loading results from different scenario workbooks; not enabling macro execution effectively disables the tool's results function. The workbook size is relatively large (about 24 MB) and varies slightly based on the amount of input provided; the large size is primarily due to the presence of the underlying noise and emissions data. The single-file, self-contained design was chosen to keep the tool simple—there is no need for external data (outside of the spreadsheet) or location dependencies for installing the tool or storing data. Loading time varies depending on the computer's drive and processor capabilities, but results computations are seemingly instantaneous on most current hardware.

4.2.2. Tool Structure

4.2.2.1. Interface

The tool interface consists of multiple sheets that provide information, input, and output results. In addition, the workbook contains several data and computation sheets that have been hidden from the user to protect the data and formulas they contain. All sheets have been organized to provide a logical and easy-to-use organization of the information they present for input or review, and access to the internal data and formatting has been locked for protection from accidental data changes.

Consistent color coding is used throughout the interface to facilitate visual navigation of the data tables. Column and row navigation and referencing for tables that extend over wide areas is supported by the use of fixed panes that allow scrolling data fields while maintaining the visibility of the related headers. Data integrity for user-provided inputs is also supported by some data verification functionality that gives visual feedback when the values entered do not conform to the appropriate input validation parameters.

4.2.2.2. Computation Infrastructure

The computations required to generate noise exposure, fuel burn, and emissions results are performed within dedicated calculation sheets (tabs) with the results referenced to the output sheet of the application interface. The results computations are seemingly performed instantaneously—which provides immediate feedback to the user—and the necessary speed is achieved through the use of direct cell referencing between the computation sheets and input data cells. Although this approach avoids computationally costly lookup procedures, it is completely dependent on a fixed cell framework; the locks implemented in the interface and the hiding of the data and calculation components have all been introduced to protect the integrity of this framework.

4.2.2.3. Noise Computation Method

Calculation of aircraft noise is based on the single-event addition method, a noise computation approach that uses pre-computed single-event Sound Exposure Level (SEL) data generated using the FAA Integrated Noise Model (INM) Version 7.0b (FAA 2009) to calculate noise exposures. This method allows very quick computations without requiring any actual noise modeling to be performed, which is time consuming and requires complex sets of data and software components. The time and complexity savings are achieved by performing the noise computations for all desired combinations of aircraft and flight track off line and by storing the results, which can be recombined to compute the final noise levels resulting from any combination of aircraft operations.

The noise calculations are conducted by quantifying the noise exposure at the points of interest by multiplying each aircraft and track combination's single-event acoustic energy by the number of operations and then by summing all the contributions and converting the total acoustic energy into a SEL value. The computation engine can also account for overall changes in source level by adjusting the number of operations by which the single-event levels are multiplied. The adjustment factor is computed using the following formula, which relates number of operations (Ops) to decibel (dB) changes:

$$Ops_{Adj} = Ops \times 10^{\frac{\Delta dB}{10}}$$

In this formula, the decibels of noise change provided by the user for an aircraft are converted into a multiplier used to scale the original operations and mimic the desired change in source noise level. Within the tool, the user can review the worksheet providing the noise data summary to identify the effects of these adjustments on the final number of operations used for the calculations.

4.2.2.4. Emissions Computation Method

The aircraft fuel burn and emissions computations within the tool are performed with an approach similar to that used for noise. The fuel burn and emissions outputs for every aircraft on every flight track were pre-computed and the output data stored in the application. The emissions data were generated using a method developed by Wyle that takes as input the INM 7.0b aircraft performance data (i.e., flight profile data) and the length of the section of track to analyze and compute the resulting fuel burn and emissions (NO_x, CO, HC, CO_2, H_2O, and SO_x). Given that this type of analysis requires segment-level emissions data with an interpolation scheme for "cutting" segments based on the length of the assessed tracks, neither the FAA's Emissions and Dispersion Modeling System (EDMS v5.1.3) (FAA 2007) nor the Aviation Environmental Design Tool (AEDT) (FAA 2012) could be used. Future versions of AEDT may allow for the flexibility of using its results within the tool. Although EDMS and AEDT were not used, the fuel burn and emissions calculation methods employed in the tool are identical with those used in the FAA tools, including the use of the Boeing Fuel Flow Method 2 (BFFM2) (DuBois 2006) and Eurocontrol's Base of Aircraft Data (BADA) (EEC 2011).

The fuel burn and emissions assessments rely on operations adjustments to model the changes in fuel burn and emissions provided by the user. Given that the fuel burn and emissions reduction parameters are expressed in term of percentages, the adjusted operations are computed by simply scaling the original operations by the appropriate percentages. As with noise, the model provides the user a view of the effects of these adjustments for each of the parameters within the worksheet that contains the fuel burn and emissions data summary.

The fuel burn and emissions computations are conducted up to a total horizontal ground distance of 12 NM radius from the start of runway roll. Therefore, all fuel burn and emissions reduction (or increase) results are based on comparing up to the 12 NM limit. The purpose in choosing the 12 NM radius was to select a point that was far enough to capture the full breadth of the differences between each track. That is, all of the different characteristics of the compared tracks occur within the 12 NM radius, and beyond the 12 NM radius, the trajectory points are similar (the flight tracks would be the same for aircraft traveling to the same destination).

As a result, the 12 NM radius serves as the basis for any resulting reductions (or increases). Using a different but greater radius (e.g., 13, 14, or 15 NM) will likely provide similar magnitudes of reductions. However, the percent differences can be significantly different depending on what radius is used. As a result, any percent reductions (or increases) resulting from the 12 NM analysis should be understood to represent just the near-terminal differences. For a full flight analysis, the user must determine the fuel burn and emissions so as to develop percent reductions.

4.2.2.5. Airport Layout Scenario Used in the Tool

The airport layout used in the tool does not represent any real airport and was developed to enable the user to explore the various noise abatement procedures covered in the case study analyses chapter of this report. As presented in Figure 4-1, the runway system in this airport scenario is made of two parallel runways capable of supporting concurrent take-off and landing operations of any of the aircraft in the fleet. A two-runway system was selected to support modeling of more complex temporal track use and preferential runway scenarios. A cross runway was not added to this layout for simplicity.

Among the most location-dependent variables of an airport system are the locations of the noise-sensitive areas around the airport, which are the reason noise abatement procedures are developed. As such, the airport layout includes two notional population centers near the airport to the North-East and North-West. These population centers were located so that the flight tracks for the airport could be logically designed to cover various noise abatement procedures.

The flight track layouts were also tailored to modeling of the NADP types addressed in the case study analyses. As shown in Figure 4-1, Runway 09 has been assigned the set of tracks

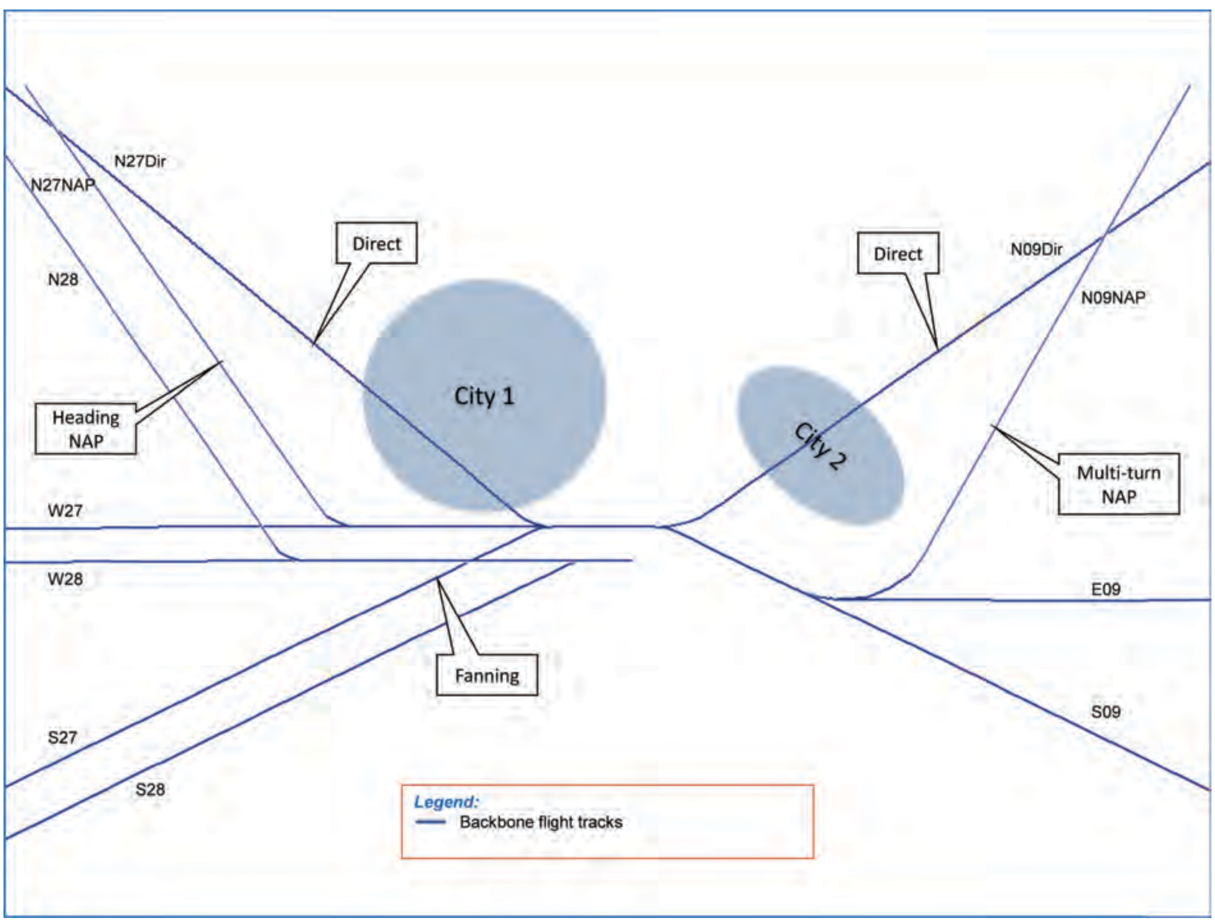


Figure 4-1. Sample airport flight tracks.

necessary to model multi-turn noise abatement procedures, which include the NAP and direct tracks, plus two additional tracks for modeling of operations heading East and South of the airport. Runway 27 includes tracks that support both heading and fanning NAPs; these tracks include the heading NAP and direct tracks plus the tracks with West and South headings. These last two tracks, in conjunction with the direct track, allow modeling of fanning operations. Finally, the three tracks on Runway 28 have been designed to support operations heading north, west, and south and accommodate operations modeled to simulate preferential or temporal operational scenarios. All tracks can be easily identified by their IDs (composed of a letter code for the heading [e.g. "N" for north] followed by the runway ID). The heading NAP flight tracks have an additional 3-letter code to distinguish the original NAP track (extension "NAP") and the direct track (extension "Dir").

For the study of multi-turn and heading NAPs, the airport tracks layout also includes a set of intermediate tracks located between the NAP and direct tracks. These intermediate flight tracks, shown in Figure 4-2, are spaced at an interval of 0.5 NMs at the apex of the primary turn and are shaped to provide flight paths that move gradually closer to the direct flight track. The intermediate tracks can be easily identified by their IDs, which include the track heading followed by runway ID and the number indicating the order of the track starting from the NAP track, with 02 being the intermediate track closer to the NAP flight path.

These tracks give the ability to assess the benefits quieter fleets can afford by being able to fly more direct routes without adversely affecting noise exposure. As aircraft are moved from the outer, longer flight tracks to the inner ones, the operations total fuel burn and emissions are reduced due to the shorter path, which, however, also decreases the distance to the noise-sensitive areas resulting in potentially higher exposure levels. By iteratively changing the aircraft flight paths and/or their noise output, the model can be used to find the optimal compromise where the most emissions and fuel savings can be achieved without significantly affecting noise exposure.

Noise resulting from aircraft operations is computed in the model at a fixed set of location points placed directly under the flight path of each track as well as the location where noise

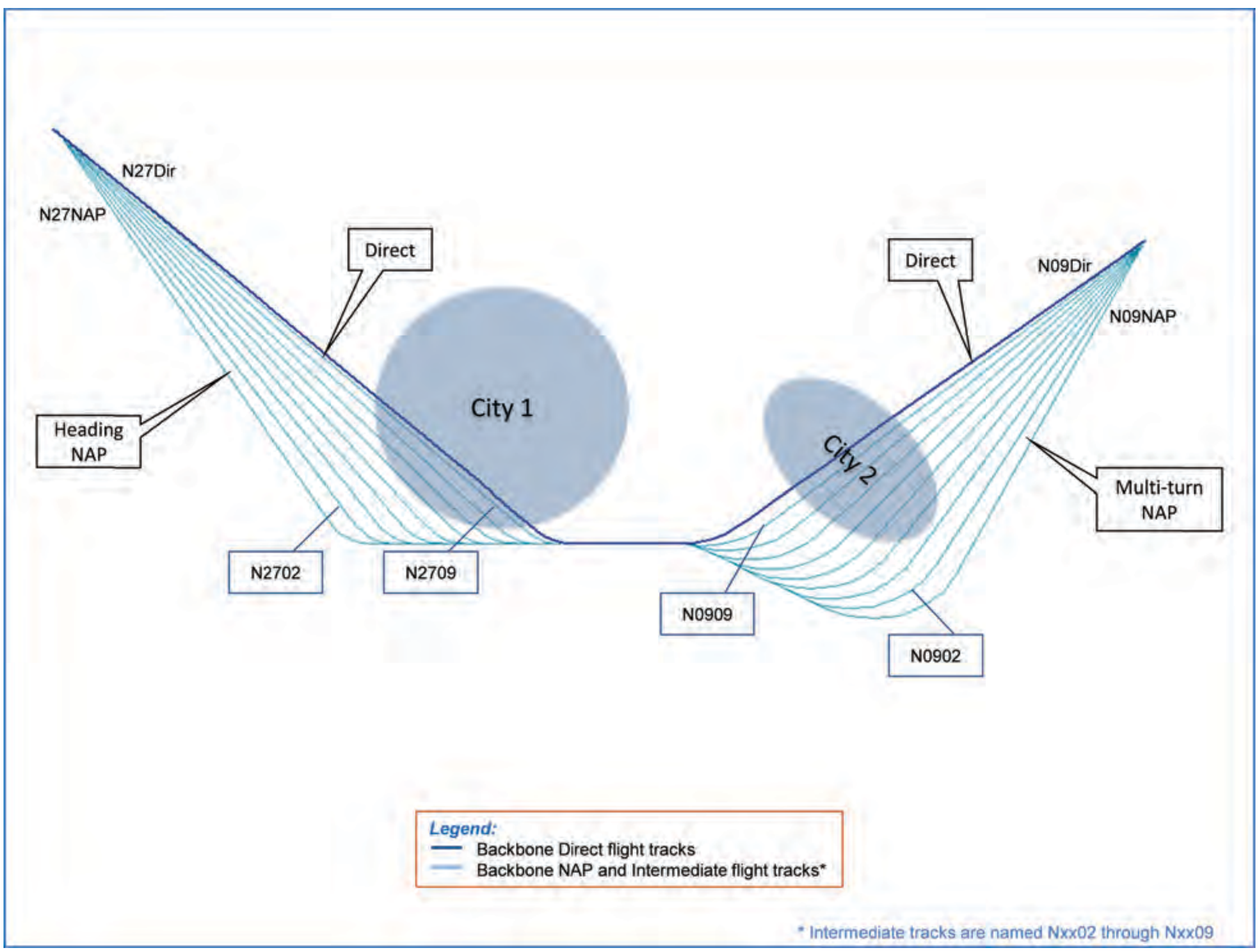


Figure 4-2. Sample airport intermediate flight tracks.

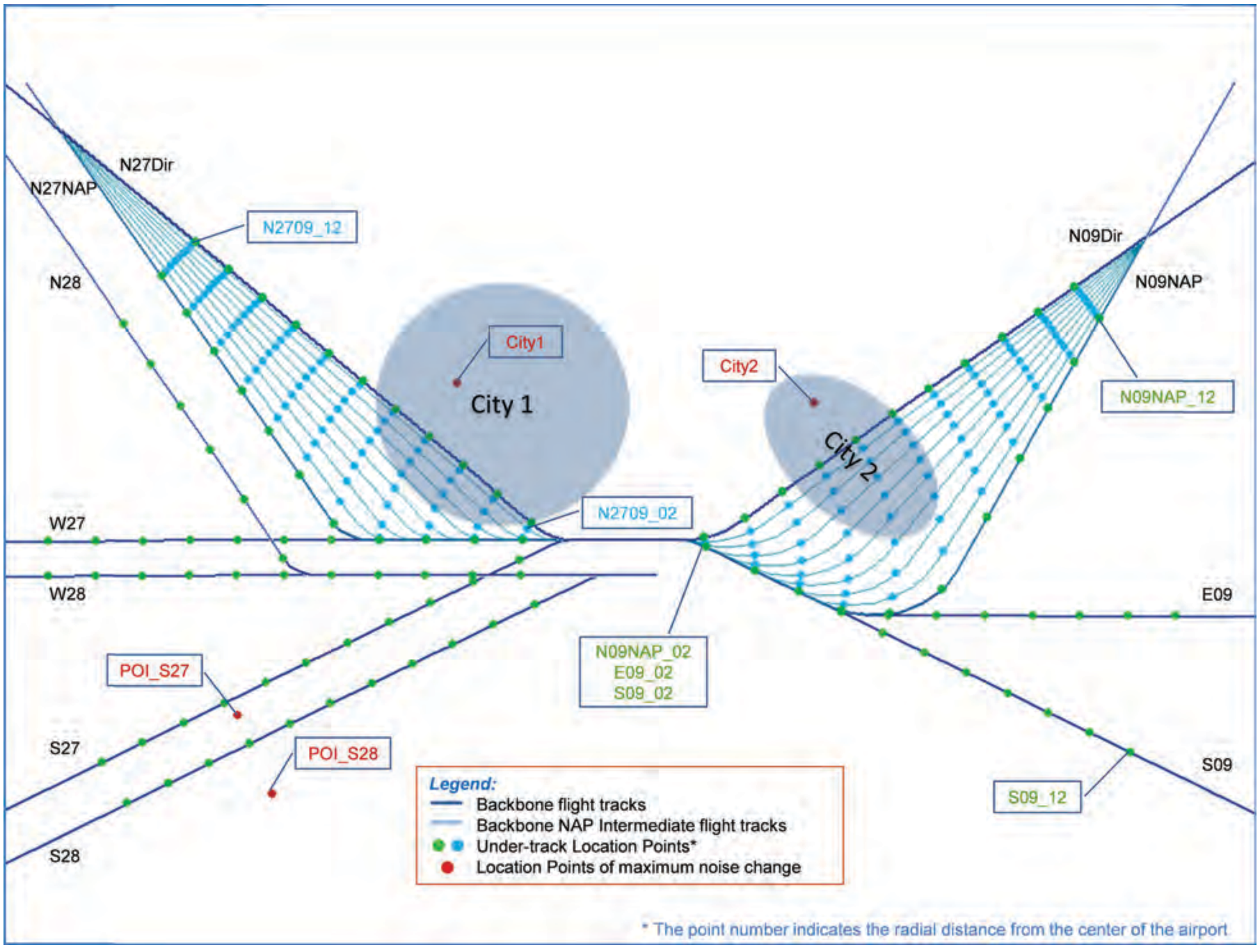


Figure 4-3. Location of the points where noise exposure is computed.

level is most affected by the sum of the influences from all tracks. Figure 4-3 shows the location of the points for which noise exposure is calculated. In the figure, the blue and green points indicate the under-track locations, which are placed at 1-NM radius from the center of the airport study. The first point is located at a distance of 2 NM while the last point is at 12 NM. The point-naming convention allows easy identification of both the location and distance by consisting of the flight track ID followed by a number, from 02 to 12, indicating the distance from the airport center.

Various reference points were also created to allow gauging of the changes in noise from one scenario to another. The reference points where the noise exposure is most affected by the combined changes in the airport flight path utilization are shown in maroon (dark, brownish red). Although all could be affected by changes in any of the flight tracks, the most significant contributors are those located closer to them. The City1 point is most affected by changes to the operations off of runway 27, while the point City2 is affected predominantly by changes in use of the runway 09 flight tracks. The noise level at the points named POI_S27 and POI_S28 is instead most influenced by flight tracks heading due west and southwest from both runways 27 and 28. By observing the changes in noise exposure at these four points the user can assess the overall effect of a scenario's assumptions.

Up to this point, the previous figures have only shown backbone flight tracks in the study, but the model also includes two sets of flight tracks with built-in dispersion. The backbone-only flight tracks allow modeling of the ideal condition where every aircraft can follow the exact same path without any deviation. This mode of operation is useful when the intent is to explore the effects of different scenarios without the smearing effect introduced by dispersion. In contrast, the two sets of dispersed tracks provide a realistic framework given that they are both based on dispersion patterns derived from radar data for an actual airport before and after the implementation of RNAV procedures. The first set, shown in Figure 4-4, reproduces the dispersion about the nominal track before the implementation of the new procedures while Figure 4-5 shows the dispersion observed after the RNAV implementation. These figures only show the primary flight tracks for clarity; however, the two sets of dispersion are applied to the intermediate flight tracks

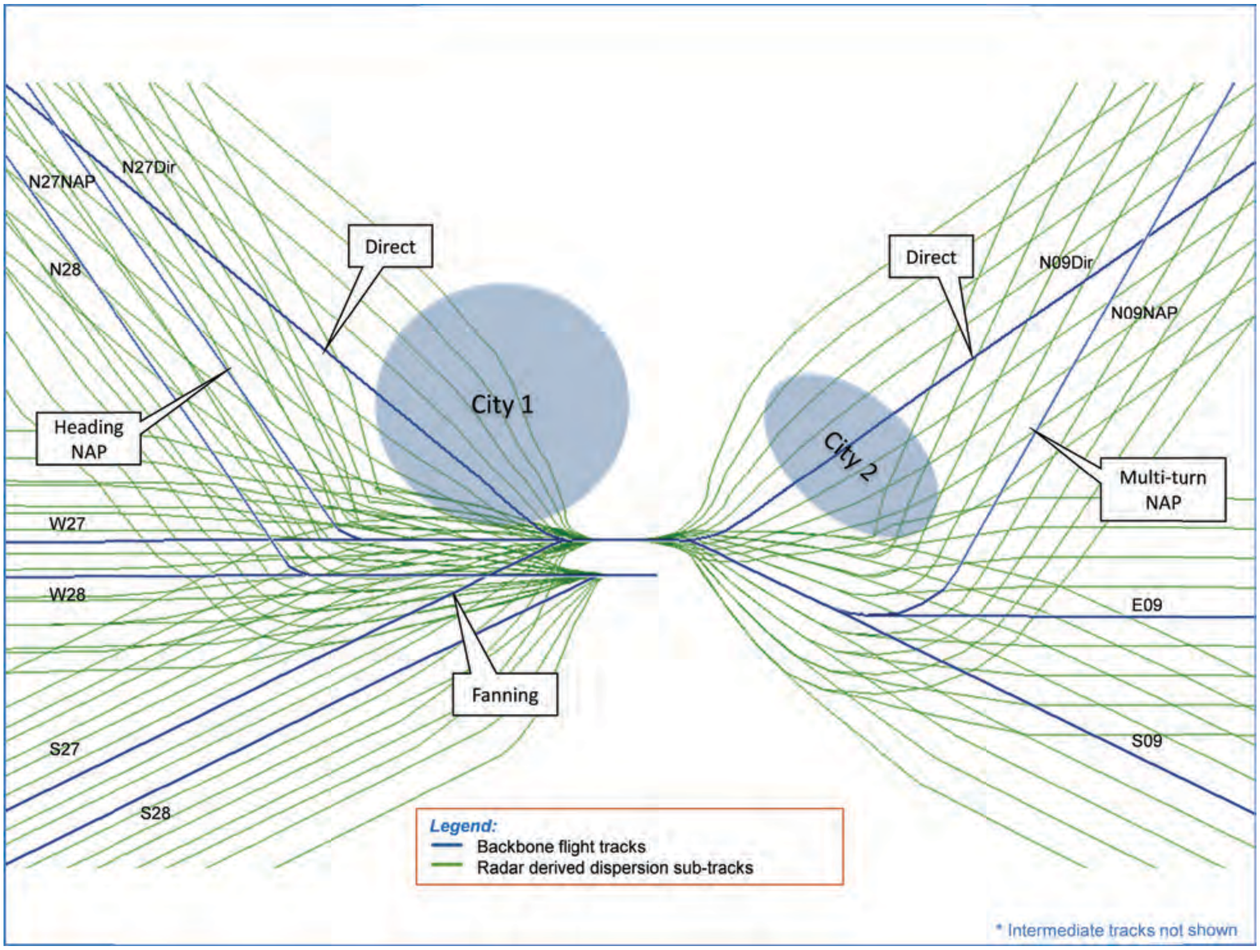


Figure 4-4. Flight track dispersion for standard departure procedures.

as well. Comparing the two figures highlights the difference RNAV procedures can make to the dispersion pattern of aircraft following a particular flight path. The inclusion of these two sets of tracks allows the user to account for the effects of RNAV procedures as well as compare their contribution to a scenario where such procedures are not in place.

Although the two sets of flight tracks with dispersion are different in their layout about the backbone track, the use of each sub-track is the same. Both the standard and RNAV flight tracks with dispersion use the standard operations distribution percentages, shown in Table 4-1. The table shows that flight Sub-tracks 1 and 2, for example, each receive 19.1% of all operations assigned to that ground track.

4.3. Tool Interface

4.3.1. Introduction

The tool's interface is organized based on Excel's multiple sheets, or tabs, structure which it uses to provide dedicated input data output results, and information sections. Both the organization of the tabs within the workbook, which are numerically ordered, and the layout of each individual sheet are designed to provide an intuitive framework that facilitates the user's navigation of the different sections. A help function is also available by clicking on the "Help" button at the top left of every sheet.

4.3.1.1. Input Sections

The input-related tabs, colored green, cover all information necessary to define a scenario's fleet and operations, the aircraft technology, and the airport operational characteristics. The order of the input sheet within the workbook (and the numbering) has been designed to provide a logical flow to entering the information required by the tool. The input section includes the following tabs:

- "2. Technology" – allows users to enter noise, fuel burn, and emissions modifiers that alter the aircraft environmental performance characteristics.
- "3. Operations" – provides the framework for specifying the scenario's operations.

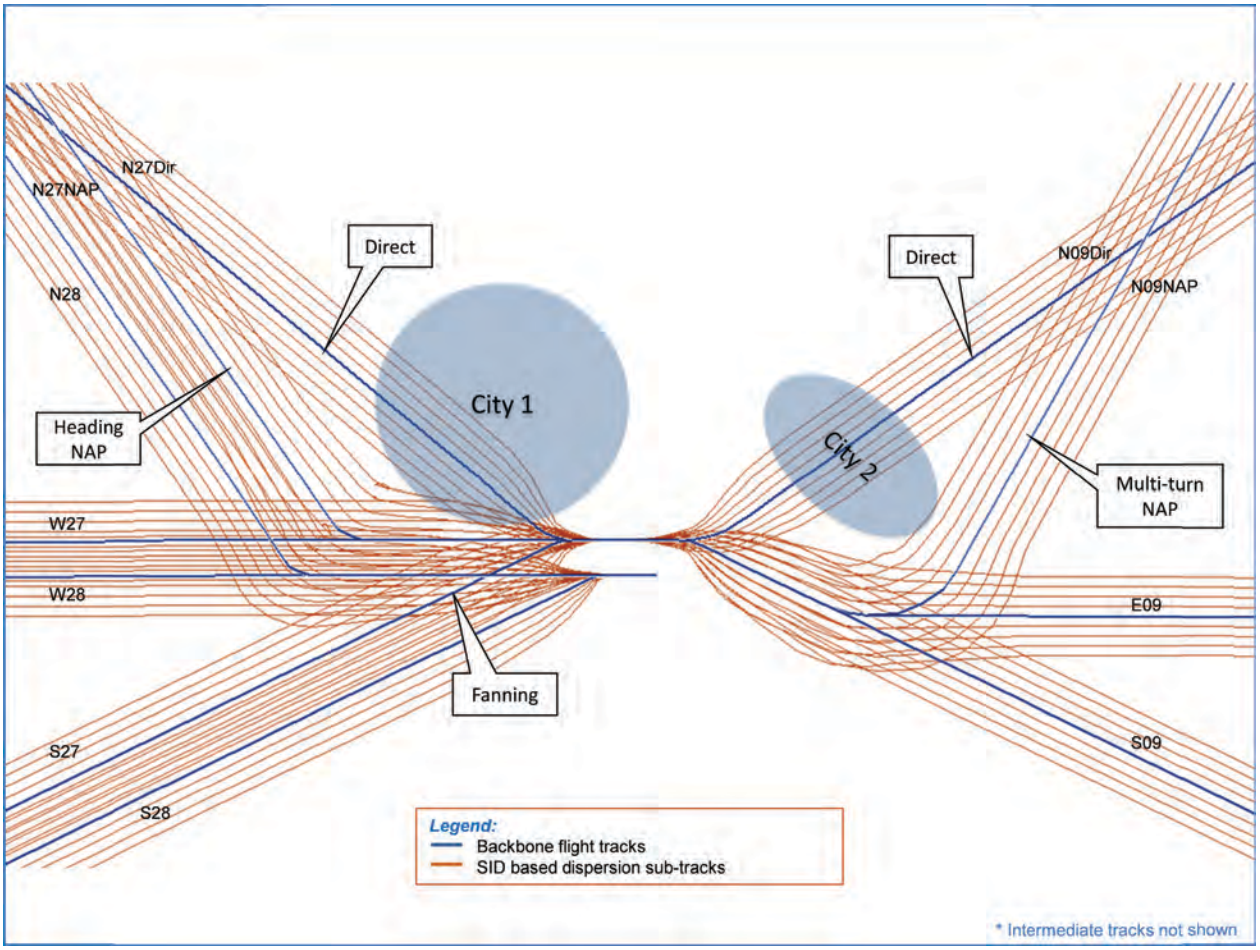


Figure 4-5. Flight track dispersion for RNAV procedures.

- "4. Utilization by AC Category" – allows defining the runway and flight track utilization on the basis of aircraft category.
- "5. Utilization by Aircraft" – allows entering runways and flight track utilizations for each individual aircraft (optional input).
- "6. Dispersion by AC Category" – provides the framework to control flight track dispersion by aircraft category.
- "7. Dispersion by Aircraft" – allows defining the flight track dispersion for each individual aircraft (optional input).

In all of the input section tables the tool provides the ability to specify all information for two independent sets of fleets (referred to as Technology Groups): a 'Current' fleet and a 'Future' fleet. The purpose of having two sets of aircraft defined in the model is to enable the user to define two different versions of each aircraft to handle situations where different environmental performance and facilities utilization need to be modeled concurrently. Although these fleets are discussed distinctly, they together represent one scenario, i.e., the aircraft defined as part of the Current fleet and the Future fleet are all used together for each modeled scenario.

Generally, the Current fleet should be used to fine-tune the fleet currently operating at an airport by modifying each aircraft's environmental performance to either more closely match the actual aircraft or act as a more accurate substitute for an aircraft that does not appear in the mix. Although the preference is to adjust the noise, fuel burn, or emissions

Table 4-1. Sub-tracks utilization percentages.

Sub-track ID[1]	Backbone	1/2	3/4	5/6	7/8
Percentage	22.2	19.1	12.1	5.7	2.0

[1] *Odd ID numbers indicate sub-tracks left of the backbone and lower numbers represent sub-tracks closer to the backbone.*

characteristics of an existing aircraft within the tool's fleet in order to derive a substitute aircraft, a simpler substitution can be performed by assuming an existing aircraft is representative of another aircraft (i.e., a surrogate). In such a case, no adjustments to the noise, fuel burn, or emissions characteristics would be conducted and the user would need to take that into account as part of the uncertainties (errors) in the overall modeling work. For this simpler substitution method, the FAA's substitution list from INM can be used (FAA 2011).

The Future fleet is intended to enable the user to define the aircraft expected to begin operating at the airport and whose capabilities may enable the creation of more efficient departure procedures. However, because this differentiation between the two fleets is simply conceptual and has no bearing on the actual computations, the user can elect to use the two sets of aircraft in any manner that best fits the requirement of the scenario. A user modeling a scenario where only the number of operations is changing could decide, for example, to use the second set of aircraft (Future fleet) to extend the modeled fleet detail. This can be accomplished by substituting the listed aircraft in the Future fleet with other existing aircraft types. Essentially, the user would ignore the "Future" term and treat the fleet as another set of aircraft within the Current fleet. This includes assigning current operations and making runway assignments to the "Future"-labeled fleet as if they were an extension of the Current fleet.

4.3.1.2. Output Sections

The output tabs, in red, provide the user with the noise, fuel burn, and emissions levels computed based on the inputs as well as the comparison to those produced by a different scenario stored in a separate workbook. The results for the current scenario and related comparisons are computed in real time as the user enters or modifies the data in the input sheets. The output section consists of the following tabs:

- "10. Ref Scenario Results" – allows users to select and import the results from a different (baseline) scenario for comparison purposes.
- "11. Results" – provides the scenario output and the values that differ from the results of the selected baseline.
- "12. Emission Results Summary" – provides users with the aggregated amounts of fuel burn and emissions for each runway.

4.3.1.3. Information Sections

The information tabs provide the user with information regarding the application, the scenario, and the provided input. These tabs are in yellow with the exception of the one that holds the scenario's description which is in purple. The information section includes the following tabs:

- "Introduction" – contains the tool's header information and a brief tutorial on its use.
- "1. Scenario Info" – allows users to enter descriptive information for the scenario.
- "8. Noise Data Summary" – provides an integrated view of the input data used for noise calculations.
- "9. FB & Emissions Data Summary" – provides an integrated view of the input data used for fuel burn and emissions calculations.
- "Airport Layout" – contains a schematic representation of the sample airport runways and flight tracks layout as well as the location of the points of interest for which noise exposure is computed.
- "System Data" – contains the characteristic information for the aircraft included in the tool's fleet and the links to where certification data for other aircraft can be found.

4.3.2. Interface Tab Descriptions

This section covers each of the tabs found within the tool interface and describes the information they contain and required user input; additional background information is also provided to support the user's understanding of underlying concepts and assumptions.

4.3.2.1. Tool's Information and Brief Tutorial Tab ("Introduction")

This tab provides the user with the Tool's header information as well as a "Quick Start" brief tutorial on its use. The tutorial only provides the list of steps the user needs to take to create a new scenario. Each step is qualified by a description of its purpose, but does not cover each topic to the level of detail found in this documentation.

4.3.2.2. Scenario Information ("1. Scenario Info")

The Scenario Information tab is designed to provide a space where the creator of the scenario can document its purpose and underlying assumptions. Although the tab is not part of the model's input structure and its only role is to provide information, it has been placed as the first step in the creation of a scenario to help document its use. Given the amount of information, a scenario without a proper description could be difficult to interpret and understand. Additionally, the information contained in the first three fields of this section is used to reference a scenario output when imported into a different spreadsheet. This feature enables the user to identify the source of the comparison data quickly, but only if such information has been entered when comparison scenario was properly documented. Table 4-2 describes the fields in this tab.

The Date field should be updated every time a change is made to the scenario data. Keeping this field current can help

Table 4-2. Scenario information tab fields description.

Field Name[1]	Description
Date*	Date of completion of the scenario.
Name*	Name of the scenario.
Description*	A brief description of the scenario.
Notes	Any information necessary to describe the scenario's purpose and underlying assumptions.

[1] *Fields marked with "*" are imported in the Baseline Results tab when a scenario is loaded as the reference of a different scenario.*

in resolving version issues that might arise when multiple versions of the same scenario have been created in different locations without appropriate file naming management.

The entry for the Name field should give a user familiar with the analyses underway at the airport a clear understanding of the context of the scenario at hand, which can help an analyst quickly differentiate among files. A more detailed explanation can be entered in the Description field, which should provide a concise understanding of the genesis of the study and of its purpose. Finally, all modeling details, assumptions, and any other information necessary to fully understand the scenario should be included in the Notes field.

The Notes field can accommodate up to 32,767 characters and hard returns can be entered by pressing ALT+RETURN. If the number of lines exceeds the size of the visible area of the field, the entire content can be viewed in the formula bar by expanding its size and using the scroll bar (the formula bar can be extended by hovering over the line separating the bar from the worksheet until the pointer turns into an up-down double arrow, pressing the mouse left button, and dragging the separator downwards). Alternatively, the content of the Notes field can be copied to a text document by selecting the Notes field, executing the copy command, and pasting to the destination document. A user can also choose to write the modeling notes in a separate document for ease of editing and referencing, and then add those notes to the study by selecting and copying the text and then selecting the Notes field and executing the paste command.

4.3.2.3. Aircraft Technology ("2. Technology")

The Aircraft Technology tab is used to modify the environmental characteristics (i.e., noise, fuel burn, and emissions) of the aircraft in the fleet from their default specifications as defined within the modeling software and information used to generate the data (i.e., INM 7.0b and BADA 3.9). The input table is divided into two main sections based on technology group—Current and Future—to allow the user to define two independent sets of aircraft. The Current group can be used to fine-tune the fleet currently operating at an airport. Each aircraft's environmental performance can be modified to either more closely match the actual aircraft or to act as a more accurate substitute for an aircraft that does not appear in the mix. The Future fleet allows defining aircraft expected to be operating at the airport or aircraft expected to enter service in the near, or distant, future or to provide additional aircraft modeling options for a single fleet. Hence, the term, "substitute" is used to denote an aircraft not currently in the tool's fleet that can be used to more accurately represent the baseline fleet at an airport or an aircraft (i.e., new technology) as part of a Future fleet. These substitute aircraft are implemented by changing an existing (original) aircraft's noise, fuel burn, or emissions characteristics. However, as previously indicated, a simpler substitution can be conducted by assuming an existing aircraft can serve as a surrogate for an aircraft not within the tool's fleet without any changes to the existing aircraft's noise, fuel burn, or emissions characteristics. A substitution list like that found in the FAA's INM can be used for this simpler substitution method (FAA 2011).

The fields included in the Aircraft Technology tab are listed in Table 4-3. The values in Technology Group and Aircraft Category fields provide a level of grouping that is reflected throughout the tool's input section. The aircraft assignment to groups reduces the input requirement to the user by allowing parameters to be set at the group level. The Noise, Fuel

Table 4-3. Aircraft technology tab fields description.

Field Name	Description
Tech Group	The fleet technology group.
Aircraft Category	The aircraft category based on size.
Aircraft	The aircraft ID (correspond to the INM 7.0b IDs).
Noise Reduction (dB)	The noise reduction in decibels to be applied to the base aircraft. A negative value results in an increase in noise output.
Fuel Burn Reduction (%)	The fuel burn reduction in percentage to be applied to the base aircraft. A negative value results in an increase of fuel burn.
Emissions Reduction (%)	The reduction in emissions produced by the base aircraft expressed as a distinct percentage for each of the pollutants (CO_2, CO, NO_x, THC, SO_x, and H_2O). A negative value results in an increased output of the specific pollutant.
Notes	A description of the aircraft defined by the given technology parameters.

Burn, and Emissions fields allow independent setting of each parameter for every aircraft in both sets of fleets. When no reduction or increase in value is desired, the appropriate fields can be either set to zero or the cells' contents deleted.

The techniques to be used for computing the noise, fuel burn, and emissions adjustment values require that information is available for both the aircraft in the tool and the aircraft being modeled using the tool. Table 4-4 lists the required values for the fleet available in the application while Table 4-5 lists internet sources where the same information can be retrieved for most of the aircraft currently operating. The techniques for computing the adjustment values are described in the following subsections.

Noise adjustments are framed in terms of decibel reductions from the standard aircraft. A positive value causes the model to compute a lower noise output, while entering negative values produces the opposite effect. The value entered should represent the difference in source noise level between the aircraft in the database and the future aircraft being approximated.

The method for adjusting for different engines or creating an aircraft substitution should mirror the procedure defined in the ICAO Doc 9911, 1st Ed (ICAO, Doc 9911, "Recommended Method for Computing Noise Contours Around Airports - First Edition," 2008), and the ECAC Doc 29, 3rd Ed (ECAC, Doc 29, "Report on Standard Method of Computing Noise Contours around Civil Airports - Third Edition: Volume 1: Applications Guide," 2005). In order for the two aircraft to have comparable performance, the substitute should have a similar weight, the same number of engines and installed thrust-to-weight ratio, and, ideally, be produced by the same manufacturer. The differences in noise footprints can then be taken into account by applying an adjustment based on the difference in certification noise levels, which the tool's computation engine performs in accordance with the ICAO and ECAC documents. The noise reduction value is computed by subtracting the original aircraft combined departure certification value (the arithmetic average of the lateral and flyover levels) from the substitute value for the aircraft:

$$dB_{Change} = \left(\frac{dB_{Substitute,Flyover} + dB_{Substitute,Lateral}}{2} \right) - dB_{Original,Average}$$

The convention adopted for this tool is that a negative (−) dB_{Change} denotes an increase from the original to the substitute aircraft, whereas a positive (+) dB_{Change} denotes a decrease (or reduction) from the original to the substitute aircraft. This convention was chosen because, in most cases, modeled future aircraft will tend to have lower noise, fuel burn, and/or emissions. This would allow calculated differences to be described as "reductions" without a negative sign.

The average departure certification values for the aircraft available in the tool are provided in Table 4-4 while the values for other aircraft can be found on the internet from the sources listed in Table 4-5. When the aircraft that needs to be modeled is a future aircraft for which only a projected value is available, that value can be used as the noise reduction parameter. If the aircraft to which the value has to be applied already has an adjustment, then the two can be added if the future aircraft value is given as being the expected source noise reduction above the current level. The following two examples illustrate how to determine the decibel difference when only the engine is different and when the aircraft are different.

Example 1: Calculation of noise adjustment values for airframes with different engines. *If an aircraft operating at an airport has a matching airframe in the tool's fleet but different engines, the adjustment factor is computed by using the two aircraft departure certification levels.*

Aircraft	Model	Engine	Cert Level Avg Dep (dB)	Cert Level Fly-over (FO) (dB)	Cert Level Sideline (SL) (dB)
Original	A320-211	CFM56-5-A1	91.7	---	---
Substitute	A320-233	V2527E-A5	---	83.1	91.4

Adjustment Computation:

$$dB_{Change} = \left(\frac{83.1\ dB + 91.4\ dB}{2} \right) - 91.7\ dB$$

$$dB_{Change} = -4.4\ dB$$

Example 2: Calculation of noise adjustment values for creating an aircraft substitute. *If an aircraft operating at an airport does not have a matching aircraft in the tool's fleet, a replacement aircraft should be picked that has a similar weight, the same number of engines and installed thrust-to-weight ratio, and ideally be from the same manufacturer.*

Aircraft	Model	Engine	MTOW (lbs)	Cert Level Avg Dep (dB)	Cert Level Fly-over (FO) (dB)	Cert Level Sideline (SL) (dB)
Original	737-800	CFM56-7B26	174,200	90.6	---	---
Substitute	737-900	CFM56-7B24	164,000	---	86.7	92

Adjustment Computation:

$$dB_{Change} = \left(\frac{86.7\ dB + 92\ dB}{2} \right) - 90.6\ dB$$

$$dB_{Change} = -1.3\ dB$$

In both of these examples, the negative values for dB_{Change} actually imply an increase in noise given that the convention used in the tool is to specify reductions as positive values and

Table 4-4. Fuel burn and emissions parameters.

Aircraft ID	INM Aircraft Description	EDMS Engine Description	ICAO UID	BADA ID	Number of Engines	Max Gross Takeoff Weight (lb)	Static thrust per Engine (lb)	Dep Avg Certification Level (db)	Fuel Burn (TO)	NO_x (TO)	CO (TO)	THC (TO)
717200	Boeing 717-200/BR 715	BR700-715C1-30	4BR007	B712	2	121000	18000	86.5	0.984	27.92	0.8	0.01
727EM2	FEDX 727-200/JT8D-15	JT8D-15	1PW010	B722	3	208000	15500	97.7	1.178	19.4	1.03	0.24
737300	Boeing 737-300/CFM56-3B-1	CFM56-3-B1	1CM004	B733	2	135000	20000	88.4	0.946	17.7	0.9	0.04
737700	Boeing 737-700/CFM56-7B24	CFM56-7B18/3	8CM061	B737	2	154500	24000	89.5	0.842	14.81	0.17	0.03
737800	Boeing 737-800/CFM56-7B26	CFM56-7B26	8CM051	B738	2	174200	27300	90.6	1.221	28.8	0.2	0.1
747400	Boeing 747-400/PW4056	CF6-50C1, -C2	1GE007	A343	4	875000	56800	100.6	2.487	36.3	0.5	0.6
757RR	Boeing 757-200/RB211-535E4	RB211-535E4	5RR038	B752	2	255000	40100	89.9	1.85	22.31	0.26	0.03
767300	Boeing 767-300/PW4060	PW4060	1PW043	B763	2	407000	60000	95.1	2.647	32.8	0.37	0.1
777200	Boeing 777-200ER/GE90-90B	GE90-90B	T97084	B772	2	656000	90000	93.6	3.414	53.21	0.15	0.04
777300	Boeing 777-300/TRENT892	Trent 892	2RR027	B773	2	660000	77000	95.6	3.91	45.7	0.28	0.01
A300-622R	A300-622R\PW4168	PW4158	1PW048	A306	2	378533	58000	94.2	2.481	30.2	0.4	0.09
A300B4-203	Airbus A300B4-200/CF6-50C2	CF6-50C1, -C2	1GE007	A308	2	364000	52500	95.5	2.487	36.3	0.5	0.6
A310-304	A310-304\GE CF6-80 C2A2	CF6-80C2A2	2GE037	A310	2	346126	53500	94.2	2.152	22.35	0.04	0.05
A319-131	A319-131\IAE V2522-A5	V2522-A5	3IA006	A319	2	166449	22000	88.1	0.971	24.5	0.57	0.041
A320-211	A320-211\CFM56-5A1	CFM56-5-A1	1CM008	A320	2	169756	25000	91.7	1.051	24.6	0.9	0.23
A320-232	A320-232\V2527-A5	V2527-A5	1IA003	A320	2	169756	26500	88.4	1.053	26.5	0.53	0.041
A321-232	A321-232\V2530-A5	V2530-A5	1IA005	A321	2	196211	30000	91.6	1.331	33.8	0.45	0.045
A340-211	A340-211\CFM56-5C2	CF6-50C1, -C2	1GE007	A343	4	566588	31200	94.8	2.487	36.3	0.5	0.6
A380-841	A380-841\RRtrent970	Trent 972B-84	9RR048	A388	4	1254430	70000	*94.9*	2.69	38.8	0.4	0
CL600	CL600/ALF502L	ALF 502L-2	1TL001	CL60	2	36000	7500	*94.9**	0.3999	13.43	0.4	0.02
CL601	CL601/CF34-3A	CF34-3A	1GE034	CL60	2	43100	9220	82.3	0.407	11.61	0	0.06
CNA55B	Cessna 550 Citation Bravo / PW530A	PW530	PW530	C550	2	14800	2863	*96.4**	0.1785	11.04	9.07	0.7
CNA750	Citation X / Rolls Royce Allison AE3007C	AE3007C	8AL025	C750	2	35700	6407	77.5	0.301	16.88	0.94	0.254
CRJ9-ER	CL-600-2D15/CL-600-2D24/CF34-8C5	CF34-8C5	8GE110	CRJ9	2	82500	13625	*86.3*	0.648	14.69	0.64	0.02
DC1030	DC10-30/CF6-50C2	CF6-50C1, -C2	1GE007	DC10	3	572000	53200	97.9	2.487	36.3	0.5	0.6
DC95HW	DC9-50/JT8D17 w/ ABS Heavyweight hushkit	JT8D-17	1PW013	DC94	2	121000	16000	94.1	1.245	20.6	0.95	0.22
DHC6	DASH 6/PT6A-27	PT6A-27	PT6A27	D228	2	12500	2000	---	0.0515	7.6	0.9	0
DHC8	DASH 8-100/PW121	PW121	PW121	DH8A	2	34500	4750	83.2	0.1353	14.5	2	0
DHC830	DASH 8-300/PW123	PW123	PW123	DH8C	2	43000	4918	83.6	0.1486	17.7	1.9	0
EMB145	Embraer 145 ER/Allison AE3007	AE3007A1/3	6AL013	E135	2	45420	7500	82.6	0.3589	15.42	0.5	0.03
EMB14L	Embraer 145 LR / Allison AE3007A1	AE3007A1	6AL007	E145	2	48500	7500	83.0	0.3826	16.17	0.75	0.03
FAL20	FALCON 20/CF700-2D-2	CF700-2D	CF700D	FA20	2	28700	4500	94.9*	0.3285	5.6	22	0.1
GV	Gulfstream GV/BR 710	BR700-710C4-11	6BR010	LJ45	2	90500	14750	84.8	0.747	19.52	1.04	0.02
HS748A	HS748/DART MK532-2	RDa.7	RDA7	ATP	2	46500	5150	---	0.178	5.57	3.15	0.97
IA1125	ASTRA 1125/TFE731-3A	TFE731-3	1AS002	FA10	2	23500	3700	94.9*	0.225	19.15	1.13	0.062
LEAR35	LEAR 36/TFE731-2	TFE731-2-2B	1AS001	LJ35	2	18300	3500	96.4*	0.205	15.25	1.394	0.114
MD11GE	MD-11/CF6-80C2D1F	CF6-80C2D1F	2GE049	MD11	3	682400	61500	95.5	2.629	28.12	0.05	0.04
MD82	MD-82/JT8D-217A	JT8D-217A	4PW069	MD82	2	149500	20900	92.8	1.32	17.54	0.42	0
MD83	MD-83/JT8D-219	JT8D-219	4PW071	MD82	2	160000	21700	94.2	1.354	18.72	0.42	0
MU3001	MU300-10/JT15D-5	JT15D-5, -5A, -5B	1PW037	C560	2	14100	2500	96.4*	0.2054	11.13	0	0

* Based on aircraft class data developed for ICAO/CAEP8 Analyses

Table 4-5. Additional sources of aircraft noise and emissions parameters.

Noise Certification Data	
Source	European Aviation Safety Agency (EASA), Certification directorate
Reference	Type Certificate Data Sheets for Noise (TCDSN): Jet, Heavy Propeller, and Light Propeller aeroplanes
Link	http://www.easa.eu.int/certification/type-certificates/noise.php
Source	Direction générale de l'Aviation civile (DGAC)
Reference	NoisedB - certified noise levels of civil transport aircraft types (a project supported by the International Civil Aviation Organization)
Link	http://noisedb.stac.aviation-civile.gouv.fr/
Fuel Burn and Emissions Indices	
Source	FAA's Emissions and Dispersion Modeling System (EDMS) Emissions System Table
Reference	Federal Aviation Administration (FAA) (2010). Emissions and Dispersion Modeling System (EDMS) User's Manual, EDMS 5.1.3. FAA-AEE-07-01. Revision 8.
Link	http://www.faa.gov/about/office_org/headquarters_offices/apl/research/models/edms_model/
Source	International Civil Aviation Organization (ICAO) Jet Engine Emissions Databank
Reference	International Civil Aviation Organization (ICAO), ICAO Emissions Databank.
Link	http://www.caa.co.uk/default.aspx?catid=702

increases as negative values. For future aircraft/engine technologies, the surrogates are expected to have lower characteristic values resulting in positive dB_{Change} values. Similarly, fuel burn and emissions reductions are all specified in terms of positive percentage changes while increases are defined using negative percentage values. The values used should represent the difference in the fuel consumption or emissions output between the aircraft in the database and the aircraft being modeled.

Calculating the fuel burn and emissions percentage reduction values for better approximating an aircraft with a different engine or creating a substitute is done by first subtracting the original aircraft parameter from that of the substitute, and then by dividing the result by the original and converting to a percentage value. Fuel flow (FF) and emissions indices (EI) generally include four numbers, each representing a different mode of flight: Take-off (TO), Climb-out (CO), Approach (AP), and Idle (ID).

$$\%Change = \left(\frac{FF\ or\ EI_{Substitute} - FF\ or\ EI_{Original}}{FF\ or\ EI_{Original}} \right) \times 100$$

For simplicity, this percentage change calculation method only requires the fuel flow and emissions indices of NO_x, CO, and THC corresponding to the Take-off mode. This provides a first-order approximation of the characteristics of the substitute aircraft. Take-off values were deemed easier to use in part because of their availability for most pollutants over other values. If characteristic values for NO_x are available from the ICAO emissions databank or other sources, then these values should be used because they will provide more accurate results.

In contrast, CO_2, SO_x, and H_2O emissions are modeled on the basis of the composition of the fuel such that the emissions indices for these pollutants are constant across all modes of operation:

$$CO_2\ EI = 3{,}155\ g/kg$$
$$SO_x\ EI = 1{,}237\ g/kg$$
$$H_2O\ EI = 0.8\ g/kg$$

As such, these constant EI values should be applied in the above equation as the original values. The substitute values can be derived from a fuel chemical composition analysis, mainly involving an understanding of the carbon (C) and hydrogen (H) contents of the fuel.

The user can modify the adjustment (% change) factors for both the fuel burn and emissions. The adjustments are conducted independently—hence, there is no potential for "double-counting" the adjustments, i.e., the % change applied to fuel burn will not affect emissions (and vice versa) because the adjustments are performed on two independent sets of predeveloped data rather than being applied to a method that calculates fuel burn and emissions from the precursor data (i.e., FFs and EIs).

Although these parameters allow the user to generate more precise results for the aircraft technology being modeled, these parameters are not necessary to determine the reductions in fuel burn and emissions that can be afforded by adopting more efficient departure procedures. If a user is interested only in determining the percentage reduction achieved by new procedures and there are no technology changes, the technology adjustment fields for fuel burn and the different pollutants can be left blank. The values for the Fuel Burn and Emissions parameters for the fleet included in the tool are listed in Table 4-4 while the sources for the other aircraft are listed in Table 4-5.

4.3.2.4. Aircraft Operations ("3. Operations")

The Aircraft Operations tab holds all the operations information for the scenario being developed. The operations data are organized by aircraft category and have to be provided for both the daytime and nighttime periods (7:00 to 22:00 and 22:00 to 7:00 respectively) with nighttime operations receiving a 10dB penalty. The table also allows setting the split between Current and Future fleets by entering percentage distributions for both time periods. To ensure the correctness of the percentage input data, the table includes built-in error checking that provides visual feedback by highlighting cells with incorrect values (e.g., a total Current and Future fleet split greater or smaller than 100%).

In addition to totaling fields for each of the aircraft, the table provides summaries by group for all the fields. For the technology mix columns, the totals for each category display the assignment mix for the Day and Night operations and the overall mix for all operations. The grand total row at the bottom of the table gives the overall summary across all categories. The fields in the Aircraft Operations tab are described in Table 4-6.

In a scenario where all operations are performed by the existing fleet, the operations for each aircraft would be assigned to the Current fleet. However, if the airport existing fleet has been developed by taking advantage of the aircraft in both technology groups, the operations should be split between the pairs of aircraft so that the desired number of operations is assigned to each version. In a scenario where the two technology groups represent the Current and Future fleets, the percent assignment to the Future fleet should reflect the number of operations expected for the new aircraft. The assignments can be developed to match the expected penetration of the new aircraft into the overall fleet or that in the fleet of the airline or airlines operating at the airport. In the latter case, the percentage could also be further refined by assessing each airline's expected service routes deployment plan for the new equipment, which may result in a higher or lower presence at a specific airport.

4.3.2.5. Airport Runways and Flight Tracks Utilization by Aircraft Category ("4. Utilization by AC Category")

The information in this tab defines how the operations are distributed among the available runways and flight tracks on the basis of aircraft category. The input framework is organized in two tables: one to define how the runways are used and one to assign their operations to specific flight tracks; both tables also include dedicated input sections for the Current and Future fleets. All values have to be provided in terms of percentage splits with the data validation infrastructure highlighting cells not meeting the necessary data integrity requirements. Total rows are provided for each data subset to aid in the entering or troubleshooting of the data.

The Runways Utilization table is used to assign the operations of each aircraft group and fleet. For each Technology group, the user has to provide the day and night percentage split which must total to 100% within each aircraft category and day period combination. Each aircraft within each group will have its operations assigned based on these group-level values.

The Flight Tracks Utilization table determines how the operations assigned to each runway are further split among the available flight tracks. The data in this table are organized by technology group, aircraft category, time of day, runway, and related flight tracks. The percentage values have to be specified independently at the runway level with the percentages for each track adding to 100% for each runway. As with the runway

Table 4-6. Aircraft operations tab fields description.

Field Name	Description
Aircraft Category	The aircraft category based on size.
Aircraft	The aircraft ID (correspond to the INM 7.0b IDs).
Operations: Day	The aircraft's day (7:00 – 22:00) operations.
Operations: Night	The aircraft's night (22:00 – 7:00) operations.
Operations: Total	The total number of operations.
Technology Mix: Day Ops	The day operations split in percentage between the Current and Future fleets.
Technology Mix: Night Ops	The night operations split in percentage between the Current and Future fleets.
Technology Mix: Total Ops	The total operations split in percentage between the Current and Future fleets.

Table 4-7 Runways and flight tracks utilization tab fields description.

Field Name	Description
Tech Group	The fleet technology group.
Runway	The runway ID.
Track[1]	The flight Track ID.
Aircraft Category ID: Day	The aircraft category (Heavy, Large, Small, and Propeller) runway or flight track utilization percentages for the Day operations (7:00 – 22:00).
Aircraft Category ID: Ngt	The aircraft category (Heavy, Large, Small, and Propeller) runway or flight track utilization percentages for the Night operations (22:00 – 7:00).

[1] The Track field appears in the Flight Tracks Utilization table only.

table, the defined distribution is applied to all aircraft in the category. Table 4-7 describes the fields found in these two tables.

Noise is one of the principal reasons airports encounter strong resistance to efforts to optimize their operations. However, the introduction of new navigation, airframe, and engine technologies in the near and medium term could allow airports to optimize the use of their infrastructure without causing significant changes to the adjacent communities' noise environment. The presence in the table of individual sections for each of the technology groups allows the user to tailor the way aircraft with different environmental performance use the airport's infrastructure and, therefore, model the gains that such optimizations could afford. In a scenario where quieter equipment is being introduced, experimenting with different runways and flight track assignments will allow the analyst to identify which combination provides the greatest decrease in fuel burn and emissions without significantly affecting the noise level experienced by the communities.

For example, in a scenario where the Future fleet category includes new aircraft that outperform the current equivalent equipment in terms of source noise level, the new aircraft can have their departures assigned to flight paths that are more efficient. The aircraft, for instance, could be quiet enough to be moved from heading or multi-turn noise abatement flight tracks to their direct counterparts, which, given their shorter lengths, would allow for decreased flight time, resulting in fuel burn and emissions reductions.

4.3.2.6. Airport Runways and Flight Tracks Utilization by Aircraft ("5. Utilization by Aircraft")

This tab allows the user to fine-tune the airport utilization on a specific aircraft basis for both Current and Future fleets. The input structure is the same as that of the utilization by aircraft group tab with the difference that, in this table, the aircraft group categorization is replaced by the actual aircraft types. Completing the information in this table is not a requirement as the default is for aircraft to follow the distributions defined in the previous table for their respective category. This table is provided for the user to implement ad hoc variations to the generic patterns to accommodate aircraft that in the scenario require different handling.

To model an alternative use for a specific aircraft, the user first needs to enable the functionality for the target aircraft and time period; the Runway Utilization table in this tab includes an Enable field for the day and night columns of each aircraft of the two technology groups. To switch the functionality on, select the field that displays the Off caption on the red background. Click the drop-down menu list box that appears when the field is selected, and choose the On or Off option in the drop-down menu. When activated, the field turns from red to green, the related data entry fields become active, and their background turns from gray to white. Once activated, the data requirements are the same as those in the utilization by category tables (in the previous tab). The information in this table can be edited at any time, but the information is actually used only if the related Enable field has been set to On, which is confirmed by the cell background color.

The ability to control the runway and flight tracks assignment at the aircraft level allows the analyst to properly model situations where one or few of the aircraft in a category are equipped with technology that would allow them to use more efficient flight paths without having a negative effect on the overall exposure levels. For example, a Future fleet for an aircraft group could be modeled where most of the newer aircraft only have a marginal evolutionary improvement in source noise, but a couple have much higher improvements because of the adoption of a new type of engine, as in the case of a geared turbofan engine. In such a scenario the flight paths for most of the fleet could be slightly tweaked to make use of the small improvement, but the two other aircraft in the group could be individually reassigned to take advantage of the most efficient flight tracks, thus realizing the maximum benefit.

4.3.2.7. Flight Tracks Dispersion by Aircraft Category ("6. Dispersion by AC Category")

The information in this tab allows the user to define the mix of dispersion patterns expected on each individual flight track by fleet, aircraft category, and time of day. All values are expressed in percentage by individual flight track and a total

Table 4-8. Flight tracks dispersion tab fields description.

Field Name	Description
Tech Group	The fleet technology group.
Runway	The runway ID.
Track	The flight Track ID.
Dispersion	Dispersion type ID.
Aircraft Category ID: Day	The aircraft category (Heavy, Large, Small, and Propeller) dispersion percentages for the Day operations (7:00 – 22:00).
Aircraft Category ID: Ngt	The aircraft category (Heavy, Large, Small, and Propeller) dispersion percentages for the Night operations (22:00 – 7:00).

field is provided along with data validation functionality to facilitate entering the data. Three dispersion patterns are available: (1) "None," where all aircraft fly the backbone track as in the case of precision GPS navigation; (2) "Standard," where the dispersion was derived from actual radar data; and (3) "SID," where the modeled dispersion represents the expected extent using advanced RNAV procedures. The descriptions of the fields found in the Flight Tracks Dispersion tab are provided in Table 4-8.

The ability to select different types of dispersion patterns allows the user to take into account the introduction of more precise navigation technology in the assessment of possible optimization approaches. Given that the introduction of advanced navigation reduces the width of the corridor flown by aircraft along the flight paths, it also affects the noise exposure on the ground. Narrower dispersions concentrate the noise exposure closer to the nominal flight path which allows for flight tracks to be moved without affecting a change as compared to a scenario where the dispersion is wider.

4.3.2.8. Flight Tracks Dispersion by Aircraft ("7. Dispersion by Aircraft")

This tab allows the user to fine-tune the flight tracks dispersion utilization on a specific aircraft basis for both Current and Future fleets. The input structure is the same as that of the dispersion by aircraft group tab with the difference that, in this table, the aircraft group categorization is replaced by the actual aircraft IDs. Completing the information in this table is not a requirement because, by default, aircraft follow the dispersion utilization defined in the previous table for their respective category. This table is provided for the user to implement ad hoc variations to the generic patterns to accommodate aircraft-specific scenarios.

To model an alternative dispersion utilization for a specific aircraft, the user first needs to enable the functionality for the target aircraft and time period; the table in this tab includes an Enable field for the day and night fields of each aircraft in both fleets. To switch the functionality on, select the field that displays the Off caption on the red background. Click the drop-down menu list box that appears when the field is selected, and choose the On or Off option in the drop-down menu. When activated, the field turns from red to green and the related data entry fields lose the gray background. Once activated, the data requirements are the same as those in the category table (in the previous tab). Grayed-out fields can still be edited, but only fields that have been activated affect the calculations.

Setting the dispersion associated with individual aircraft can be used in a manner similar to that of setting the flight track utilization by aircraft. The fine level of control allows designing scenarios that target assessing the benefits afforded by the introduction of more advanced technology on specific aircraft in the fleet served by the facility. In the case of the introduction of new equipment, the two capabilities will need to be used simultaneously to be able to model the advantage introduced by both the airframe/engine technologies and the navigation technologies.

4.3.2.9. Noise Modeling Input Data Summary ("8. Noise Data Summary")

This table allows the user to more easily review the effects of the input parameters provided in terms of the actual aircraft operations assigned to each individual track and dispersion option. To facilitate the navigation of the data, the table highlights the active information by dimming the font in fields with no data. The interface also provides the capability to display only subsets of data using filtering based on the aircraft category and type, as well as the runway and track IDs. The filtering can be applied based on a value, a set of values, or on the font color, which allows easily selecting only the active records. The table displays three sets of data: (1) the actual operations, which are the operations entered and distributed by the user; (2) the noise-adjusted operations, which represent the equivalent number of operations after applying the adjustments needed to model the noise technology changes provided by the user; and (3) the total modeled noise operations, which shows the total operations assigned to each set of dispersion tracks after taking into account the nighttime penalty.

Comparing the number of operations listed in the actual operations section to those in the adjusted section can illustrate the overall magnitude of the prescribed noise reductions in a more readily understandable format. The two sets of numbers highlight the magnitude of the change in noise output by showing how many flights of the original aircraft would have to be dropped (or added) to produce the same noise levels as the revised aircraft. Expressing the improvements in terms of number of flights change can be a very effective communication tool when addressing audiences that have limited understanding of decibel units.

4.3.2.10. Fuel Burn and Emissions Input Data Summary ("9. FB & Emissions Data Summary")

This table allows the user to more easily review the effects of the input parameters provided in terms of the actual aircraft operations by fleet. To facilitate the navigation of the data, the table highlights the active information by dimming the font in all that do not contain information. The design also provides the capability to display only subsets of data using filtering based on the fleet, aircraft category, and aircraft type. The table displays two sets of data: (1) the actual operations, which are the operations entered by the user; and (2) the adjusted operations for Fuel Burn and each of the pollutants, which represent the equivalent number of operations after applying the adjustments needed to model the technology changes provided by the user.

4.3.2.11. Reference Scenario Results Setup ("10. Ref Scenario Results")

This tab allows the user to load results from an existing scenario to use as a reference (baseline) for computing the amount of change reported in the Results sheet. The source scenario file is loaded by selecting the Load Scenario button and then selecting the appropriate file in the Open File dialog box. The baseline scenario information can be removed by pressing the Clear button. If the selected file is a valid scenario, the related description information is copied into the scenario information table along with the name of the source file and its location. This tab does not require any manual inputs from the user because all input is automatically retrieved from the source (baseline) scenario file selected. The results are copied into the results table as values and no link is preserved between the original file and this tab. As such, if any of the baseline scenario data is changed in the original file, the information in this tab must be updated (or reloaded) if the goal is to keep the two sets consistent.

4.3.2.12. Scenario Results ("11. Results")

This tab contains the table that shows the noise, fuel burn, and emissions results generated based on the provided input. The noise results are computed at several points along the flight tracks as well as the points near the airport where the most change is expected based on the geometry of the airport flight tracks. The emissions results present the total fuel burn and emissions results by runway. The sheet contains two tables: the current scenario result and the total change between the current scenario and the reference scenario.

For analyses where reference scenario data have also been loaded, the table also displays the reduction between the two scenarios for each of the results data sets. Given that the changes are expressed in terms of reductions, positive values represent the current scenario having a decrease from the reference, while negative values represent an increase. Although the table for the current scenario is always populated, the change results table reports information only when a reference scenario has been loaded in the reference scenario results tab. To facilitate review of the results, the table provides filtering capabilities based on the runway, track, and point ID.

4.3.2.13. Scenario Results ("12. Emissions Results Summary")

This tab provides the user with aggregated fuel burn and emissions for each runway. When a reference (baseline) scenario is loaded, the summary sheets also display the results for the baseline and the amount of reduction for each pollutant. The comparison by runway facilitates the assessment of the overall effect of the modeled scenario (i.e., in comparison with the baseline scenario).

4.3.2.14. Airport Layout Tab ("Airport Layout")

This tab contains pictures of the sample airport runway and flight track layouts. The images are intended to provide the user with an easily accessible reference during the development of a scenario. The full description of the airport layout was covered in Section 4.2.2.5; brief descriptions are provided below:

- **Backbone Flight Tracks:** Includes backbone tracks not including the full array of flight tracks located between the single-turn and multi-turn noise abatement flight tracks and their respective direct tracks.
- **Single and Multi-Turn NAP, Intermediate, and Direct Flight Tracks:** Single-turn and multi-turn noise abatement flight tracks, their respective direct tracks, and the intermediate tracks are included.
- **Backbone Flight Tracks and Noise Computation Location Points:** The location of the under-track location points and the location of the points where the maximum noise change is experienced.

- **Backbone Flight Tracks and Radar-Derived Dispersion Flight Tracks:** Backbone tracks and sub-tracks using flight track dispersion parameters derived from radar (NAP intermediate flight tracks not included).
- **Backbone Flight Tracks and SID-Derived Dispersion Flight Tracks:** Backbone tracks and sub-tracks using the SID flight track dispersion parameters (NAP intermediate flight tracks not included).

4.3.2.15. System Data Tab ("System Data")

This tab contains characteristic information on the aircraft types available in the tool and information on publicly available sources of information for most aircraft currently operating. The tool's fleet information is presented in a table listing the following data:

- Aircraft and engines descriptions;
- ICAO engine ID;
- BADA aircraft ID;
- Number of engines;
- Aircraft maximum take-off weight;
- Static thrust per engine;
- Departure average noise certification level;
- Fuel flow; and
- Emissions indices (NO_x, CO, and THC).

The second table in the sheet lists sources of noise certification and emissions data for most of the aircraft fleet currently in operation and the related internet addresses. This system data can aid the user in comparing different aircraft and engine types, thereby helping in the development of adjustment factors.

References

Ausrotas, R. A., and R. W. Simpson. (1992) "Impacts of Technology on the Capacity Needs of the US National Airspace System."

Bly, E. (2009) "*Effects of reduced IFR arrival-arrival wake vortex separation minima and improved runway operations sequencing on flight delay*" (Master's Thesis). Available from DSpace@MIT Database. Retrieved from http://hdl.handle.net/1721.1/28908.

Capozzi, B., S. Augustine, and T. R. Thompson. (2003) "Dynamic Noise Avoidance Routing Through Terminal Airspace." AIAA.

Clarke, J.-P. (2003) "The role of advanced air traffic management in reducing the impact of aircraft noise and enabling aviation growth." *Journal of Air Transport Management,* 161–165.

Clarke, J.-P., and C. S. Draper. (2000) "Systems Analysis of Noise Abatement Procedures Enabled by Advanced Flight Guidance Technology." *Journal of Aircraft* 37[2], 266–273. AIAA.

Clarke, J.-P., and R. J. Hansman. (1997). "Systems analysis of noise abatement procedures enabled by advanced flight guidance technology." AIAA.

Competitive and Sustainable Growth Programme. (2006) "SOURDINE II," D9-1, Final Report. Report GRD2-2000-30105.

Daniel, J. (2002) "Benefit-cost analysis of airport infrastructure: the case of taxiways."

de Muynck, R. (2000). "The SOURDINE Project developing environmentally friendly arrival and departure procedures." *Air Transport,* 282–284.

Deeds, D. (1996) "Noise Abatement versus Safety." *Air Line Pilot,* November/December 1996, 39–40.

DuBois, D. and G. C. Paynter. (2006). "Fuel Flow Method2" for Estimating Aircraft Emissions. Society of Automotive Engineers (SAE) Technical Paper Series. 2006-01-1987.

Elmer, K. (2002) "A Study of Noise Abatement Procedures using AMES B747-400 Flight Simulator."

Erkelens, L. J. J. (1998) "Research on Noise Abatement Procedures."

——— (1999) "NLR Development of noise abatement procedures in the Netherlands."

Eurocontrol Experimental Centre (EEC). (2011) "User Manual for the Base of Aircraft Data (BADA)," Revision 3.9. *EEC Technical/Scientific Report No. 11/03/08-08.*

European Civil Aviation Conference. (1999) "EU Dialogue with the European Air Transport Industry–Airport Capacity–Challenges for the Future."

FAA. (1993) "Advisory Circular 91-53A: Noise Abatement Departure Profiles."

——— (2007) "Emissions and Dispersion Modeling System (EDMS) Version 5 Technical Manual." FAA-AEE-07-07. Draft.

——— (2008) "FAA NY/NJ/PHL Metropolitan Area Airspace Redesign Operational Assessment Report."

——— (2008) "Implementing Tomorrow's Solutions Today NEXTGEN."

——— (2009) "Integrated Noise Model (INM), Version 7.0b User's Guide." FAA-AEE-07-04.

——— (2011) "Integrated Noise Model (INM), Version 7.0c User's Guide." Page 287, "acft_sub.dbf." FAA-AEE-07-04.

——— (2012) "Aviation Environmental Design Tool." http://www.faa.gov/about/office_org/headquarters_offices/apl/research/models/aedt/. Updated June 6.

FAA. *Air Traffic Control.* (Order JO 7110.65S). Retrieved from http://www.faa.gov/air_traffic/publications/.

FAA, Mitre Corporation, et al. (2004). *Airport Capacity Benchmark Report 2004.* Retrieved from http://www.faa.gov/about/office_org/headquarters_offices/ato/publications/bench/.

Forsyth, D. (2009) "Modeling Noise Abatement Procedures with Variable Thrust Restoration." Presentation to the SAE A-21 Committee.

Gershzohn, G., et al. (2002) "Advanced Noise Abatement Procedures: An Experimental Study of Flight Operational Acceptability."

Girvin, R. (2009) "Aircraft noise-abatement and mitigation strategies."

Heblij, S. J., and H. G. Visser. (2007) "NLR Air Traffic Control Decision Support for Integrated Community Noise Management."

Heblij, S. J., and R. A. A. Wijnen. (2008). "Development of a runway allocation optimization model for airport strategic planning."

Hebly, S. (2007) "Advanced Noise Abatement Departure Procedures: Custom Optimized Departure Profiles."

Huber, J. (2003) "Aircraft Noise Impact Under Diverse Weather Conditions."

ICAO. (1993) "Procedures for Air Navigation Services–Aircraft Operations." Doc. 8168-OPS/611, Volume 1, Flight Procedures, Fourth Edition, Part V, "Noise Abatement Procedures," November 11, 1993.

——— (2007) Circular on NADP Noise and Emissions Effects. CAEP/7-WP/25.

——— (2007) "Review of Noise Abatement Procedure Research and Development and Implementation Results - Discussion of Survey Results."

Janic, M. (1999) "Aviation and externalities: the accomplishments and problems."

——— (2003) "Modelling operational, economic and environmental performance of an air transport network."

Joint Planning and Development Office (JPDO). (2007) "Concepts of Operations for the Next Generation Air Transportation System–Version 2.0."

Jung, Y. (2002) "Design Concept and Development Plan of the Expedite Departure Path (EDP)."

Kim, B., et al. (2009). *ACRP Report 11: Guidebook on Preparing Airport Greenhouse Gas Emissions Inventories.* Transportation Research Board of the National Academies.

King, D., and I. Waitz. (2005) "Assessment of the effects of operational procedures and derated thrust on American Airlines B777 emissions from London's Heathrow and Gatwick airports. PARTNER-COE-2005-001."

Lu, C. (2008) "The implications of environmental costs on air passenger demand for different airline business models. *Journal of Air Transport Management* 2008, 1–8.

Mitsuhashi, H. (2000) "Pilots' Endeavor for Aircraft Noise Abatement." InterNoise, 2000.

Prats, X. (2009) "Trajectory Management for Aircraft Noise Mitigation."

Prats, X., et al. (2008) "Hierarchical and Sensitivity Analysis for Noise Abatement Departure Procedures." AIAA 2008[8867].

——— (2008) "Optimal departure aircraft trajectories minimising population annoyance."

Rachami, J., et al. (2008) "Simultaneous Improvements in Environmental Performance and Operational Efficiency Enabled by Significantly Quieter Aircraft." AIAA ICAS/ATIO Anchorage, Alaska.

Schwanke, S., et al. (2007) "Support of Cost-Benefit Analyses of Noise Control Measures Around a Generic Airport." 45th AIAA Aerospace Sciences Meeting and Exhibit, 1–10.

Suzuki, S. (2009) "Trajectory Optimization for Safe Clean and Quiet Flight."

Upham, P. (2003) "Environmental capacity and airport operations: current issues and future prospects."

Visser, H. G. (1991). "Terminal Area Traffic Management." *Prog. Aerospace Sci.* 28, 323–368.

——— (2005) "Generic and site-specific criteria in the optimization of noise abatement trajectories." Transportation Research Part D [10], 405–419.

Visser, H. G., and R. A. A. Wijnen. (2002) "Optimal departure trajectories with respect to sleep disturbance."

APPENDIX A

Literature Review

A-1. Overview of Literature

A-1.1. Review Process

The research team gathered approximately 100 papers, articles, and other materials. Searches were performed using several sources, including Science Direct, the Pennsylvania State University online library, the Georgia Institute of Technology library, conference proceedings, and internet searches. The research team reviewed all materials to determine relevance to this project and narrowed the field to approximately 50 items. Then, each item was further reviewed to determine the specific topic areas, keywords, level of relevance, currency (existing operations vs. future/NextGen) and airports studied (domestic vs. international). This data was entered into a database using the Reference Manager™ software. The database was used to organize and prioritize the literature and generate a bibliography.

A-1.2. Overview Matrix

As an initial step, the literature was summarized into tables to provide a quick review of the most pertinent items. Table A-1 presents the interdependencies studies, including scope and variables optimized. These studies are similar to the ACRP research because they include several environmental factors (e.g., noise, emissions, and fuel burn) and/or capacity and optimize the tradeoffs among them. Table A-2 presents the most-relevant environmental studies reviewed and the metrics and quantitative results as applicable. This table is useful to compare and contrast each study and the results presented.

A-1.3. Key Terms

In order to frame the discussion in this appendix, several key terms are defined below.

NAP (Noise Abatement Procedure). A general term for a flight procedure used by airports, operators, and/or air traffic control for arrivals or departures, including ground tracks and profiles. This study focuses on departure NAPs.

Profile. The vertical component of an aircraft trajectory (altitude) combined with the corresponding speed and power settings (thrust). Typically defined at distances from aircraft takeoff or landing; sometimes defined by time from takeoff or landing.

Ground Track. The projection of an aircraft's trajectory onto the ground (i.e., the X-Y location of an aircraft trajectory).

NADP (Noise Abatement Departure Profile). Departure profiles designed to reduce noise levels either close to an airport or farther from an airport. In the United States, NADPs are defined and regulated per FAA Advisory Circular 91-53A (which includes two NADP types: close-in and distant). For non-U.S. airports, the ICAO PANS OPS Part V, Chapter 3, defines equivalent close-in and distant NADPs. These documents define the minimum requirements for safe flight and do not specifically define procedures for any given aircraft. Thus, NADPs can vary according to aircraft type, airline, and airport.

NADP-1/ICAO-A Profile. The close-in community NADP, which is designed to reduce noise levels near the airport, with the tradeoff of increasing noise in areas farther away from the airport.

NADP-2/ICAO-B Profile. The distant community NADP, which is designed to reduce noise levels farther from the airport, with the tradeoff of increasing noise in areas near the airport.

NPR (Noise-Preferred Routing). A ground track optimized to reduce noise at sensitive receptors.

A-2. Discussion of Literature

The relevant literature reviewed was divided into three categories: reports on capacity, airspace, and operations which set the context for this ACRP project and also informed its analysis of runway capacity; studies of environmental interdependencies (similar to this ACRP research) which examine the tradeoffs among environmental factors for

Table A-1. Interdependencies studies matrix.

Reference	Scope of Analysis	Objective function	Constraints	Variable	Optimization method
ICAO (2007)	profile optimization for departure flights	noise	N/A	N/A	flight procedure, spatial management, and ground management
SOURDINE (2006)	overall assessment of departure and arrival procedures on noise, emission, safety, capacity, user acceptance	N/A	N/A	N/A	compare several landing and takeoff procedures
King and Waitz (2005)	calculate emissions for derated takeoff profile	emission	N/A	profile	N/A
Rachami (2008)	trajectory optimization	noise, emission	N/A	trajectory	test of alternative trajectories
Visser (2005)	trajectory optimization	fuel, noise	aerodynamic	trajectory segments	nonlinear programming
Hebly and Visser (2008)	profile optimization for departure flights	noise, fuel	aerodynamic, thrust cutback	profile	nonlinear programming
Prats (2008)	trajectory optimization	noise, fuel, delay	aerodynamic, event, path and box	trajectory segments	nonlinear programming, lexicographic
Suzuki et al. (2009)	online optimal navigation	noise, fuel	aerodynamic, terminal, and inequities	trajectory segments, time	multi stage direct allocation
Heblij and Wijnen (2008)	Runway allocation	noise, delay	non negative flight number	runway use	mix-integer programming
Janic (2003)	air transport network operations	noise, emission, capacity	total flight number <=airport capacity	network flow	integer programming

airport operations; and studies focusing on noise impacts which study departure procedures, including effects of ground tracks and profiles.

A-2.1. Capacity, Airspace, and Operations Studies

The need to increase the capacity of the National Airspace System (NAS) because of projected traffic increases has been recognized for almost two decades and some technical papers have addressed this issue. Although some investigations simply state the need for increased capacity (citing various sources of traffic growth predictions), others provide suggested means of achieving the needed capacity growth. In almost every case, it is recognized that it is imperative to mitigate the increases in noise and emissions associated with both existing air traffic levels and future increases in traffic.

Aircraft noise is identified as the prevalent deterrent to the construction of new airports and the expansion of existing airports (Austrosas 1992 and Upham 2003). Given that local communities often form the opposition to expansion, airports must adopt "good neighbor" policies while recognizing that significant social and cultural factors can affect the perception of what levels of noise are considered a nuisance. Although aircraft and engine technology improvements have reduced operational noise and emissions, a growing reality is that the projected increase in operations will outstrip the reductions provided by technology (ECAC Conference 1999 and Upham 2003).

The conclusions of the investigative reports reviewed propose actions ranging from strategic initiatives with regard to emissions (e.g., improved intermodal transportation between airports and city centers) to ground delay reductions by improvements in high-speed turnoffs and increases in existing ramp areas and gates (ECAC Conference 1999 and Upham 2003). Tactical initiatives predominantly propose development of automation to support changes in the way the airspace is managed.

One of the first published investigations recognizing the need for increased capacity (Visser 1992) focused on terminal area traffic management proposing time-based procedures using existing and future airborne and ground equipage. Time-Based Operations (TBO) are seen as a way to absorb delay in a more fuel-efficient manner while increasing capacity by minimizing the actual aircraft separations. Implementation of these types

Table A-2. Environmental metrics and results matrix.

Reference	Scope of Analysis	Metrics				Quantities/Benefits				Notes
		Noise	Emissions	Fuel Burn	Capacity	Noise	Emissions	Fuel Burn	Capacity	
Interdependencies Studies										
ICAO (2007)	Single flights	Lmax (plot dB vs. track dist.)	percent NOx; percent CO2	N/A	N/A	See Note	See Note	N/A	N/A	Compares NADP1 and NADP2 to one another.
SOURDINE (2006)	Single flights	Noise Sensitivity Depreciation Index (NSDI); percent change in population exposed	percent	N/A	hourly arrivals	N/A	N/A	N/A	N/A	A Yes/No metric is used for all the assessments.
King and Waitz (2005)	Single flights	N/A	kg CO2, kg HC, kg NOx	kg	N/A	N/A	derated procedure created 14.5% reduction in NOx, 99% reduction in HC and 20% reduction in CO	derated procedure caused 12.3% increase in fuel consumption	N/A	
Rachami (2008)	Single flights	SEL (contour area)	kg CO2	kg	time to fixed point at ~ 10NM	70% reduction in 75 SEL contour areas	20-30% reduction in CO2	100-250 kg reduction	6 - 21% time savings	analysis of future engine technology allowing for direct flight paths, compared to existing aircraft and procedures
Visser (2005)	Single flights	% awakenings; population above 65 dB; area above 65 dB	N/A	kg	N/A	N/A	N/A	N/A	N/A	the different noise metrics and fuel burn metric are not optimized at the same time
Hebly and Visser (2008)	Single flights	% awakenings	N/A	kg	N/A	15% reduction in awakenings	N/A	5% reduction	N/A	
Prats (2008)	Single flights	Lmax; normalized annoyance	N/A	N/A	N/A	Minimization	N/A	N/A	N/A	
Suzuki (2009)	Single flights	N/A	N/A	pounds	N/A	N/A	N/A	N/A	N/A	no detailed metrics are used in this paper
Heblij and Wijnen (2008)	Runway allocation	Population noise annoyance	N/A	N/A	N/A	30% decrease in noise annoyed population	N/A	N/A	N/A	delay and safety are considered qualitatively
Janic (2003)	Airport network	dB	ton	N/A	flights per day	increase noise to allow higher capacity	increase emission to allow higher capacity	N/A	N/A	
Noise Studies										
Capozzi (2003)	All airport arrivals	SEL; DNL				5% to 50% fewer pop. > 55DNL				
Elmer (2002)	Single flights	Lmax (contours; plot dB vs. track dist.)				5% reduction in 90 dB contour area				
Mitsuhashi (2000)	Single flights	Lmax (plot dB vs. track dist.)				plot dB vs. track distance; not specific				Includes steepest-climb profile used in Japan
Forsyth (2009)	Single flights	dB; time history				Not specific				
Clarke (2000)	Single flights	Lmax (contours; area)				15% reduction in pop. > 60 Lmax				
Winjen and Visser (2002)	Single flights	Probability of Awakening; SEL				20% fewer awakenings				

of operations requires an air/ground data link which permits the rapid exchange of data between the airborne and ground-based automated systems. Although the airborne capability of the Flight Management System (FMS) is considered acceptable, development of a ground-based system is deemed necessary to couple with the FMS in order to optimize available aircraft trajectories so as to de-conflict traffic, thereby ensuring a safe and efficient merge into the existing traffic flow. The result of this investigation identifies improved systems and procedures along with new technologies to eliminate present limitations with regard to communication, navigation, and surveillance, which will enable improved efficiency in the management of terminal area airspace. Many of the capabilities defined in this report are included in the JPDO Concept of Operations (Version 2, 2007) which is the envisioned strategic blueprint for the overhaul of the National Airspace System (NAS).

Visser (1992) defined capacity as the ability to accommodate demand and separated capacity into three distinct elements: airspace, runway, and control. A distinction between "theoretical" and "practical" capacity is also made with "theoretical" corresponding to the maximum number of aircraft that can be accommodated within a period of time and "practical" as the level of capacity corresponding to a specific level (average) delay. Available runway capacity is stated to be dependent on the operating configuration of the runway(s) and limitations of the surrounding airspace, including ceiling and visibility which dictate required ATC separation standards.

Given that arrival operations are considered the most limiting with regard to increasing airspace capacity, most of the investigative reports are focused on mitigation strategies involving improved arrival procedures along precise ground tracks avoiding noise-sensitive areas.

The continuous descent arrival (CDA), now more generally referred to as optimized profile descent (OPD), is recognized as a procedure that can provide both noise and emission benefits, maintaining the required lateral separation with existing automation requires increased separation between the leading and trailing aircraft because of the differences in speed as the leading aircraft decelerates. Restoring existing capacity requires development of automation relying on improved aircraft trajectory method to conduct operations with existing standards of separation (Erkelens 1999).

Another proposed mitigation procedure was to extend the current 3-degree ILS glide slope to an altitude of 6,000 feet above the runway elevation and use GPS-aided FMS to conduct the arrival and approach accurately (Clarke 2003). Here again, the problem of separation during a decelerating approach is recognized with development of new automation identified as a solution.

As with arrival/approach operations, existing investigative reports regarding departure operations primarily address noise and/or emission mitigation strategies. Again the emphasis is on conducting the departure via accurately flown ground tracks and avoiding noise-sensitive areas with FMS-equipped aircraft flying published SIDs (Clarke 2003 and Erkelens 1998). An extension of this mitigation strategy is a proposal to develop multiple transitions to a common arrival path, pre-determining the noise impacts along the path for each aircraft type, and then sequencing the arrival stream to either minimize the required separation spacing for capacity or minimize the resulting noise impact (Heblij 2007).

The Expedite Departure Path (Jung 2002) is a description of an automated decision support tool that would increase airspace capacity with respect to departure operations by providing controllers with conflict-free altitude, heading, and speed advisory. The objective is to minimize the altitude holds that characterize many of the departure vertical profiles allowing the aircraft to complete a more efficient transition to the en route phase of the operation. This report proposes additional development to integrate the tool with the existing decision support tools for management of aircraft departure queues and departure runway load balancing.

Given that separation requirements apply to departure operations, a possible increase in the runway capacity for departures can be realized with the implementation of divergent or dispersed headings. A summary published as part of an Operational Assessment Report for the FAA's NY/NJ/PHL Airspace Redesign (2008) compared departure efficiency rate (scheduled departures/actual departure rate) for a year prior to implementation of dispersed heading with the efficiency rate for a year following implementation. Newark (EWR) Runway 22 reported an increase in efficiency rate from 88% to 107% while Philadelphia (PHL) reported an increase from 107% to 110%.

No published literature was found linking the environmental impacts of departure operations with runway capacity effects. The only capacity-related study for departures was primarily associated with airspace only briefly mentioning future integration with existing decision support tools.

A-2.2. Interdependency Studies

Environmental mitigation of airport operations has been studied using various optimized procedures. A focal point is airport operating procedures for arrival flights, primarily OPD. However, there is a growing body of literature on the optimization of departure procedures which establish methods to operate aircraft to minimize environmental impact at sensitive receptors.

A summary of the current state of the art and the issues for implementation of procedures were given in an ICAO report in 2007. This report gives the results of a survey of established arrival and departure noise abatement procedures. In addition to technical requirements for modeling noise, emissions, and fuel impacts, the report stresses that better collaboration among research organizations, airports, airlines, manufacturers, and governments is needed. The report concedes that most research has focused on the effects and implementation of arrival procedures. NADP use by various U.S. and international airlines for many aircraft types is collected in a survey. A total of 14 different departure profiles, all conforming to the definitions of NADP-1 and NADP-2, are listed in detail for the relevant aircraft types (including many common air carrier jets and two regional jets). This data was valuable to this ACRP project.

Following this report, the ICAO working group completed an environmental analysis of the varying NADPs presented in the survey report (Circular on NADP Noise and Emissions Effects–Working Paper CAEP/7-WP/25, 2007). This analysis was commissioned to resolve a major limitation of the PANS OPS (and the FAA Advisory Circular) which lacks quantitative data to assist an operator or airport in selecting and designing a specific NADP. Unique elements of this research include determination of the "cross-over point" where an NADP changes from reducing noise to increasing noise and analysis which includes full-thrust profiles as well as reduced-thrust profiles. Reduced thrust is an important feature of the study, because it relates more directly to actual flight procedures used most often by airlines. Comparisons are made among four types of NADPs and the relative differences in noise and emissions are computed. The study concludes that close-in noise differences are generally greater than distant noise differences and that the magnitude of noise difference is less for reduced-thrust takeoffs than for full-thrust takeoffs. For emissions, the study concludes that NO_x generally increases while CO_2 generally decreases when flying NADPs. As such, tradeoffs must be made on a per airport basis, as no single procedure can reduce both noise and emissions. This study is limited to the analysis of flight profiles and does not investigate changes in ground tracks and does not focus on any specific airport.

Several different methods are evaluated for noise abatement for airports in the SOURDINE project (Muynck 2001). Existing rules in flight management and new rules are investigated and the procedures for taking off and landing are updated based on the chosen rule for certain airports. For departure flights, gradual increase of cutback thrust during climb out helps to maintain a low noise at ground level. In the following SOURDINE II Final Report (2006), methods are reported to mitigate noise impact and emissions around airports by defining new departure and approach procedures. The project aims to develop optimized departure/takeoff trajectories to minimize noise impact without loss in capacity/safety and other environmental benefits including emissions. The new procedures are then validated through the air transport management lifecycle. Four European airports are chosen and capacity is modeled using TAAM and SIMMOD, noise is modeled in INM, and emissions are modeled in TBEC. Three departure and five approach procedures are assessed. The departure procedures include ICAO-A, SII close-in, and SII distant. The effects on environmental impact as well as feasibility are assessed for all the procedures.

Recently, emission mitigation has become increasingly important. In current models, emissions are calculated based on full-thrust assumption for departure flights. King and Waitz (2005) discussed the emissions from de-rated departure flights. Although most flights use reduced thrusts when taking off, the emissions are calculated at full thrust in most emission models, and this leads to overestimated emissions. The study uses the actual flight trajectory to estimate the actual thrust and uses this thrust to calculate fuel flow and emissions. When using this method for the flights at London-Heathrow (LHR) and Gatwick (LGW), a 10% overestimation of emission is found. This study indicates the necessity to use realistic power settings for departure flights to calculate emissions.

For departure and arrival flights, certain practices can reduce both emissions and noise levels, due to progress in engine designs. Rachami et al. (2008) reported a series of technical assessments of the relationships among various aviation environmental and operational factors, including noise at the source, aircraft emissions, fuel burn, and flight trajectories. The study includes an initial phase focusing on single-event operations and a second phase focusing on all airport operations. Alternative trajectories are assessed for emission reduction and noise impact through Integrated Noise Model (INM) and emission calculation based on INM trajectory for two individual airports. This study shows how fuel burn, emission, and capacity can be improved without worsening noise impact.

Mathematical methods have been used to find the optimal solutions regarding the different aspects of airport operations (e.g., noise, emissions, capacity, economy, and safety). For an actual airport operation, all these factors have to be considered, and there are various strategies in handling these multiple objectives mathematically. As an optimization issue, some of the factors considered are the objective function that needs to be minimized (or maximized) and other factors that can be treated as constraints. The most common variable to adjust for better environmental impact is the flight trajectory (usually segmented into smaller pieces either spatially or temporally).

Visser (2005) developed the NOISHHH model, including a noise model, a geographic information system, and a dynamic trajectory optimization algorithm. Fuel consumption, site-specific noise impact (probability of awakenings), and generalized noise impact (population within contour areas) are weighted and summed into one objective function, and tradeoff analysis is performed by adjusting the weights. The variables are the segments of the trajectory, but the optimization is subjected to constraints of aerodynamics so the trajectory will be realistic. The optimization process consists of cycles among several modules, including an optimization engine that implements a nonlinear programming method, a performance model and noise model, and a database to store all the data. The author states that the method is not ideal for real-time navigation purposes and proposes a database of optimal and sub-optimal profiles for operators to select. Hebly and Visser (2008) used the NOISHHH model to minimize noise impact in terms of total awakenings and fuel consumption by finding the optimal profile for a departure flight; the optimal profile is then compared with ICAO-A reference profile.

Prats (2008) introduced a similar model to NOISHHH to optimize trajectories to minimize noise impact. The major difference from NOISHHH is that a hierarchical optimization problem (Pareto type) is used, rather than the weight and sum method. Airliner cost and Air Traffic Management (ATM) efficiency are taken into account in addition to noise to form a multi-objective optimization problem.

Suzuki et al. (2009) developed trajectory and 4D navigation applications to study safe, clean, and quiet operations. Their model optimizes the trajectory for the total fuel burn of a B747 and a B737 descent. The single-flight optimization confirms that flying higher for longer time results in better fuel savings. Although when two aircraft are considered, the best solution is to let the heavier aircraft be close to its single-flight optimal trajectory.

The above methods are designed for the best trajectory or profile for a given runway. For airports with more than one runway, flights can be allocated to different runways to mitigate environmental impact. Heblij and Wijnen (2008) proposed a multi-objective optimization solution of runway allocation at a generic airport. The objective function consists of noise, third-party risk, and delay. The multiple objectives are summed using weights automatically adjusted. When reaching the final optimum, the three objective functions will be equally important. The optimizing process is interactive so users can adjust the weights. The optimization problem is solved by a mix-integer programming method.

At a higher level, for an air transport network, including airports and air routes connecting them, Janic (2003) describes the use of integer programming techniques to maximize the total network profits for given environmental constraints and operational capacity. The decision variable is the maximum number of flights in the network. The objective function is the net profit expressed as the difference between revenue and cost. The constraints include capacity, noise impact, and air pollution. The air transport network with London-Heathrow airport as the center is chosen as a case study. To reduce the decision variables, the high diversity of air routes was collapsed into seven clusters and four aircraft types. By varying the constraints level, the impact on profit is investigated. The model has found the noise constraints had more effect on profit than the emission constraints.

A-2.3. Noise Studies

As noise has traditionally been the most studied environmental concern for airports, many studies were found in which, while discussing the optimization of ground tracks or profiles, the environmental analysis was limited to noise. Some studies also include qualitative discussions of navigation or capacity effects of noise abatement procedures. Furthermore, because of the advanced stage of research into OPD procedures, many studies focus on approach procedures with less information on departure procedures. This section discusses the noise analysis studies in three categories: studies of ground track optimization; studies of vertical profile optimization; and studies discussing both ground tracks and profiles together.

Several studies analyze ground tracks and specific effects on noise. Erkelens (1999) sets forth the essential points regarding ground track locations: advanced navigation capabilities allow for more precise locations of ground tracks, which can contain noise exposure to specific areas. Erkelens discusses both approach and departure procedures, including Precision Navigation Instrument Departure (PNID), in which RNAV is used to define departure ground tracks with greater precision. RNAV is now used at several U.S. airports to “overlay” SIDs, thereby making them more precise.

Capozzi (2003) explores the optimization of ground tracks to improve noise exposure. Although the research focuses on approach procedures, the method is relevant to this ACRP research. The goal of the optimization process used by Capozzi is to minimize both noise and delay. The focus is on ground track geometry; altitude and speed are not varied in the analysis. Capacity is discussed in terms of the tradeoff between airspace efficiency and noise impacts for arrivals. Several noise metrics are used to compare and contrast the effects of varying trajectories, including population impacts. A set of arrival paths fill in the “boundaries” set by the most direct (least delay) ground track and noise abatement (higher delay, more circuitous) ground track. These varying ground tracks are overlaid on a map showing population density at Census centroids. Then, the noise impacts of each ground track are compared according to SEL values. In addition, an attempt is made to integrate all arrival events over a day to minimize the population exposed to DNL above 55 dB. This is accomplished using various optimized ground tracks judged by overall DNL impact (and not individual flight impact). The goal is to reduce population exposed to DNL above 55 dB at the expense of increasing population below DNL 55 dB. One interesting conclusion is that the best method for improving noise exposure is to select abatement ground tracks based on difference in sound level due to individual events compared to a baseline procedure.

Several noise studies focus on profiles and NADPs. Elmer (2002) discusses a study of departure and arrival procedures flown using a flight simulator replicating a Boeing 747 operating at London-Heathrow airport. Noise impacts are assessed for the ICAO-A NADP and two variations. L_{max} contours for single flights are compared and the L_{max} is plotted as a function of track distance on Cartesian coordinates, similar to the results presented by ICAO (2007). In addition to noise, pilot flying accuracy and workload are studied. This study lends valuable data on noise effects of different reduced-thrust profiles as compared to standard NADPs. Mitsuhashi (2000) also discusses a comparison of varying profiles, using L_{max} versus track distance to compare profiles. Mitsuhashi focuses on noise abatement profiles used in Japan, where the primary procedure is steepest-climb profile. The author determines that a thrust-cutback procedure similar to the close-in NADP is in some instances louder than the steepest-climb. Although this is country-specific, steepest-climb may be possible in the United States under NextGen.

Forsyth (2009) adds a new element to the discussion of NADPs: the focus is made on cutting back thrust when the aircraft is at a noise-sensitive ground location and not a set altitude. This can be accomplished using the Boeing Quiet Climb System (QCS) cockpit software, which automates departure profiles for the close-in NADP. This software is an on-board thrust management function to reduce noise at specific points on the ground. Typically, NADPs are defined and executed based on aircraft height: thrust is reduced when a certain altitude is reached. However, altitude will vary according to aircraft weight, as a lighter aircraft (less fuel/passenger/cargo load) will climb faster, reaching a noise-sensitive point on the ground at a higher altitude than a heavier aircraft. The QCS has already been deployed to some Boeing aircraft. The author also notes that airlines prefer the distant NADP because it saves fuel and time (as the aircraft can make initial climb more efficiently and quickly).

Several noise studies focus on the interrelations among ground tracks and flight profiles. Clarke (2000) investigates the tradeoffs between noise abatement profiles and ground tracks. A NOISIM model is developed to use flight simulator performance data to feed noise and population impact models. Three profiles are modeled: a baseline full-thrust takeoff, the ICAO reduced-thrust takeoff, and a deep thrust-cutback departure. Peak A-weighted sound level contours are plotted for each profile for varying aircraft altitudes to compare the noise levels at different stages of flight. A specific study of noise exposure at Boston Logan International Airport is conducted. A combination of a thrust-cutback procedure and a modified ground track results in lower population exposed to noise. One key element of the study is the determination of the ideal altitude for thrust cutback specific to the airport and corresponding adjustments to the ground track. Huber (2003) also used NOISIM to assess weather effects on aircraft noise. A Boeing B767 flight test is used to show that weather can affect the climb rate of an aircraft and, therefore, noise exposure.

Two studies by Prats (2008, 2009) also focus on the noise impacts of modified ground tracks and profiles for departures. A novel scheme is developed to design ground tracks based on sensitivity to noise in terms of L_{max} levels at different times of day. "Fuzzy logic" and optimization are used to create the most equitable ground track in terms of noise sensitivity: different tracks are optimized for specific receivers (hospital, residential, industrial – for varying hours of day and night). For example, since schools are only in use during daytime hours, they can be subjected to higher levels of overflight noise during nighttime. However, the author does not consider that flying various procedures based on time of day and noise sensitivity would not be possible under the current U.S. air traffic system. Currently, procedures are defined as day or night and cannot be modified in real time or over finer time intervals. NextGen would allow for customized and time-varying trajectories. In addition, Winjen and Visser (2002) contribute to this topic by using a different noise metric, based on probability of awakening. This work laid the foundation for Visser's later papers which used the NOISHHH tool to perform interdependencies modeling for flight trajectories.

A-3. Conclusion

The literature reviewed covered three relevant subject areas: capacity, airspace, and operations; studies of environmental interdependencies that examine the tradeoffs among environmental factors; and studies focusing only on noise impacts. In addition to providing valuable information, the review of these studies identified gaps in the current research and the need for this project to fill the gaps.

First, many of these studies were conducted outside the United States and focus on non-U.S. airports. Although these studies provide relevant data, they do not address the same operational environment, regulatory standards, and socio-political environment found in the United States. This project will fill a need for detailed analysis of U.S. airports.

Second, most of these studies have provided detailed technical information, yet lack practical guidance for the implementation of suggested procedures. Although some guidance is discussed for airlines, this ACRP project will fulfill the need for guidance for airports.

Third, due to the predominance of OPD-related research, there is a lack of analysis of departures and runway capacity that details the implementation of procedures and impacts on airport operational environments. This project will link the potential for environmental benefits to the constraints of runway and airspace capacity.

Fourth, little of the research addresses the environmental impacts of future aircraft technology such as that described under NextGen, CLEEN, and the NASA Fundamental Aeronautics Research Program (i.e., N+1, N+2, and N+3 generation aircraft). This ACRP project will provide such forward-thinking analysis and discussion.

Finally, any study of noise abatement procedures must consider and address the public's likely reactions to changing NAPs. The simple reality of increased operations equating to increased noise and emissions will result in considerable local community objection and only thorough and valid mitigation strategies can hope to gain their acceptance. This project will focus on the implementation of procedures at airports and the potential for environmental benefits, beyond changes in noise exposure. Although it is not feasible for an airport with an established set of NAPs to abolish them, it is possible to optimize the existing procedures to improve emissions and fuel burn.

In addition, the literature review has highlighted several key modeling issues that the environmental analysis conducted during this study will need to address, including the need to

- Model realistic variations of NADPs which can vary by aircraft type and airport (as discussed in ICAO 2007, SOURDINE II, and others).
- Study the interrelations between ground tracks and profiles (as discussed in Clarke 2000, Prats 2008/2009, and Forsyth 2009).
- Model ground operations noise and emissions due to the effect of decreased delays with better runway throughput when using optimized NAPs.

APPENDIX B

Testing Protocol for Case Studies

B-1. Introduction

The purpose of this task was to identify representative noise-sensitive airports where one or more of the various types of NAPs have been implemented and develop a testing protocol to determine the impact of NAPs on noise, fuel burn, emissions, and capacity. The goals of this case study analysis are to

- Generate a large amount of results data from which the most optimal procedures will be determined by comparing results to the existing NAPs.
- Present results without qualification, instead providing information on the tradeoffs between all modeled variables.
- Model single-event environmental effects and quantify potential effects in capacity.

Note: The case studies will not be able to address ground operations (taxiing) because only single-departure events will be modeled.

B-2. Case Study Airport Selections

This section describes the process of analyzing and selecting airports for the case study analysis performed under Task 4.

B-2.1. NAP Information

The Boeing Commercial Airplane Company maintains a Noise and Emissions Regulations database ("Boeing NER database") with 643 of the world's airports which have some type of environmental restrictions on aircraft operations. The Boeing NER database shows basic airport information (i.e. where the airport is located, the IATA airport code, etc.) and provides details of the associated environmental restrictions. Note that in many cases these restrictions are voluntary. Boeing makes this airport database publicly available at http://www.boeing.com/commercial/noise/list.html. As the first step in this task, we transferred the entire Boeing NER database to a Microsoft Excel spreadsheet ("extraction spreadsheet") so we could manipulate the data more easily.

B-2.2. Flight Track Information

The AEDT airports database contains flight track information for a number of airports. The flight track data for these airports generally comes from the International Commercial Aviation Organization's Committee on Aviation Environmental Protection (ICAO/CAEP) MAGENTA (Model for Assessing Global Noise Exposure to the Noise of Transport Aircraft) project, which estimates airport noise around the world. The track data was extracted from the AEDT airports database using a SQL query. Although flight track data may exist in the AEDT database, the quality of that data was not documented at this point in the process; only the existence of the data was of interest.

There were 220 airports extracted from the AEDT airports database which have flight track information. However, not all of the airports from the AEDT airports database were in the Boeing NER database, so we noted on the Boeing database spreadsheet which airports in the Boeing NER database also existed in the AEDT flight track database. Since some of the airports had slightly different names between the two databases, the IATA airport code was used to ensure airports with slightly different names between the two databases were the same airport. There were 172 airports that were both in the Boeing NER database and that had tracks in the AEDT airport database.

B-2.3. Operational Information

For each of the United States airports in the Boeing NER database with a Noise Abatement Procedure (NAP) or a preferential runway program, we extracted the total operations

Table B-1. Seat class definitions.

Seat class	Number of passenger seats
1	<20
2	20-50
3	51-99
4	100-150
5	151-210
6	211-300
7	301-400
8	401-500
9	501-600
10	600+

(both arrivals and departures) by seat class category from the FAA Enhanced Traffic Management System (ETMS) database of operations for 2006. These extracted operations data were added to the extraction spreadsheet. The operational data from 2006 for each of the airports (including detailed fleet mix) were separated into departures and arrivals according to their seat class following the ICAO seat class definition, as listed in Table B-1. The seat class data were used to help determine which of the airports we should further examine while maintaining a balance between general aviation airports (primarily served by aircraft in the lower seat classes), regional airports (primarily served by aircraft in the middle seat classes), and international and hub airports (served by aircraft in the top seat classes).

We also separated departure operations by distance traveled; this may be useful since distance flown is a reasonable surrogate for aircraft weight, which in turn directly influences aircraft performance. Aircraft weight as a function of distance traveled will be determined using the AEDT concept of stage lengths, where the weight of the aircraft increases in discrete increments at 500 or 1000 nautical miles (NM) great circle trip distance increments. Table B-2 below shows the AEDT stage lengths.

B-2.4. Air Quality Information

Information on the status (nonattainment, maintenance, or attainment) of local air quality for criteria pollutants was collected for the airports in the extraction spreadsheet. This data was derived from a list of all U.S. commercial airports maintained by the FAA's Voluntary Airport Low Emissions Program (VALE). VALE aids commercial airports in reducing airport emissions by using Airport Improvement Program (AIP) funds and Passenger Facility Charges (PFC) to finance improvements. The VALE "List of U.S. Commercial Service Airports and their Nonattainment and Maintenance Status" is available at: http://www.faa.gov/airports/environmental/vale/.

Table B-2. Stage length definitions.

Stage Length	Minimum Range (NM)	Maximum Range (NM)
1	0	499
2	500	999
3	1,000	1,499
4	1,500	2,499
5	2,500	3,499
6	3,500	4,499
7	4,500	5,499
8	5,500	6,499
9	6,500	11,000

B-2.5. Selection of Airports

Next, we noted the airports which met these criteria: departure NAP information on the Boeing NER website, AEDT track information, and located in the United States. There were 81 airports that met all three criteria, each of which was examined in more detail by returning to the Boeing NER website and reviewing the available information.

In this intermediate down-selection, we removed airports from further consideration if they had a NAP which could not be well modeled by single operations, was vaguely defined, or was not significantly different from the NAP at another airport. In general, airports with relatively few operations were dropped from further consideration since the effectiveness of NAP operations would be relatively low.

After an individual review of the 81 airports, 20 of the airports were considered for further analysis. From that list, 9 airports were selected for analysis and are listed in Table B-3. Although specifications on the NAP and other information of interest (airport type, air quality concerns, annual operations, and proposed baseline aircraft type) are presented, they have been generalized ("sanitized") in light of sensitivities the airports may have regarding presentation of such information.

B-3. Testing Protocol

The Testing Protocol defines the process for analyzing the case study airports to compute noise, emissions, fuel burn, and capacity. The goal of the case studies analysis is to provide detailed data on the tradeoffs between these variables for different types of NAPs. This approach is necessary because it is unlikely that an airport would remove an existing NAP, but it is feasible that an airport could optimize its existing NAP to provide an emissions, fuel burn, or capacity benefit at the expense of changes in noise exposure. That is, since an existing NAP is already optimal for noise exposure in the eyes of both airport and community, any changes to a NAP would be undesirable, unless supporting data can be used to show the benefits of making changes.

The Testing Protocol specifies a parametric optimization process in which many combinations of ground tracks and profiles will be modeled for each airport. These tracks will

Table B-3. Proposed case study airports.

Airport	Type of Airport	Existing Departure NAP (1)	Air Quality Concerns(2)	Approx. Annual Operations(3)	Baseline Aircraft Type(3)
APRT1	Cargo Hub	- Airport goes to single direction operation at night - Departure turns based on distance from airport	Ozone, PM2.5	100,000 – 200,000	A300
APRT2	Hub, Coastal	- RNAV NAP procedures	Ozone, CO	300,000 – 400,000	757-200
APRT3	Hub	- Community close to airport	Ozone, CO, PM2.5	300,000 – 400,000	MD-88
APRT4	Hub	- Fanning NAP	CO, SO2	400,000 – 500,000	DC9-30
APRT5	Hub, Coastal	- Multiple turn restrictions on departure	Ozone, CO, PM2.5	300,000 – 400,000	747-400
APRT6	Hub	- Departure heading gate (distance-based turns)	Ozone, CO, PM10	500,000 – 600,000	737-700
APRT7	General Aviation	- Distance-based turns	Ozone, CO, PM10, PM2.5, NO2	< 50,000	Gulfstream GIIB (Noise Stage 2)
APRT8	Regional	- Heading restriction based on altitude	Ozone	< 50,000	CRJ-200
APRT9	Regional	- Altitude-based headings	Ozone	100,000 – 150,000	EMB-145

Sources: (1) Boeing NER Database 2009;
(2) VALE Airport Status List 2009;
(3) ETMS 2006

cover variations of existing NAPs, as well as the most-direct ground track from takeoff to a departure fix. Capacity will be modeled by determining runway throughput for each airport. NAPs only have an impact on airport capacity in as much as they enable or result in changes in the speed of departing aircraft, the length of the common path that is shared by successive departures, or the time between departures and arrivals. By comparing each of the result sets against the existing NAPs, we will determine the most optimal solutions. It is important to note that although many of the studies in the literature review employed detailed computer models which optimized ground tracks and profiles, such a model is beyond the scope of this project.

Figure B-1 illustrates the 7-step process detailed in the Testing Protocol.

B-3.1. Airport Data Collection

The purpose of Step 1 is to review, for each airport, the airport and airspace layout, fleet mix, and existing NAPs. In addition, we will collect data to feed the AEDT model and GIS analysis. A base map was created for each airport.

1. Collect general airport data: runway layout and configurations (assume optimum configuration), and average weather (assume visual conditions).
2. Collect and review navigational charts and departure fix locations.
3. Compare published procedures, including NAPs, to the AEDT airports database. Review AEDT ground tracks and profiles per runway and terminal airspace. Determine

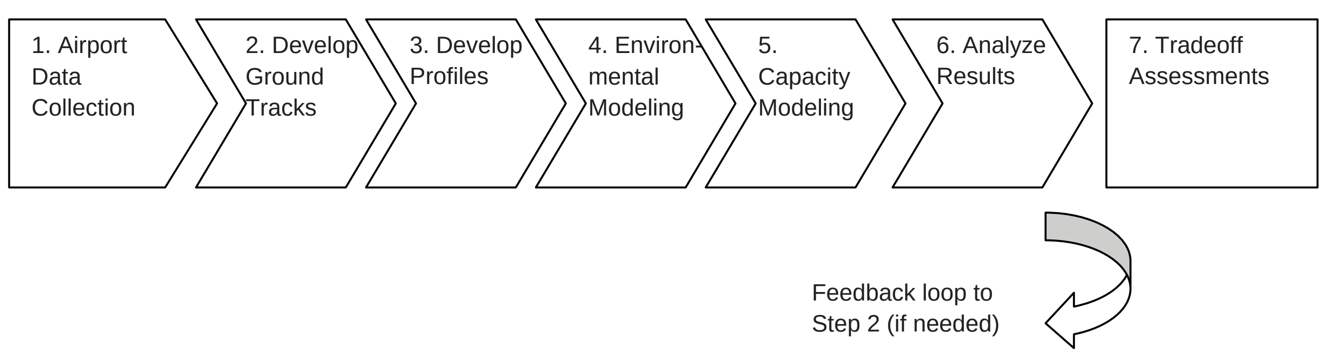


Figure B-1. Overall process.

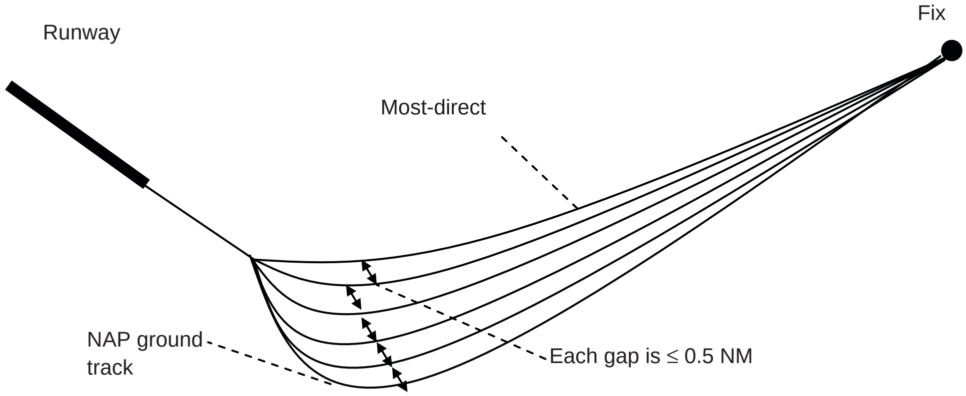


Figure B-2. Illustration of NAP turn restriction ground tracks.

quality and appropriateness of AEDT tracks and profiles for modeling NAP effects.

4. Identify NAP procedures as modeled in the AEDT airports database (see Table B-3 for each airport's defined NAPs). Determine if additional modeling is necessary to capture existing NAP.
5. Use ETMS operational data to determine fleet mix, number of operations, and departure stage lengths. Classify aircraft by size (small, large, B757, or heavy). Set up AEDT to model the correct baseline aircraft type and baseline stage length (see Table B-3).
6. Collect geographic data into a GIS database. Will include airport runways and boundary, local features (roads, bodies of water), and census population data. Create a base map for each airport. Land use data will not be collected.

B-3.2. Develop Ground Tracks

The purpose of Step 2 is to develop, for each airport, a set of ground tracks which represent the existing NAP, a track flying directly to the departure fix, and multiple intermediate tracks which fill the airspace between them.

1. Define the NAP ground track in AEDT. In some cases, the AEDT airport database will suffice. In other cases, an NAP ground track may need to be created based on published procedures.
2. Define the most-direct possible ground track which uses the same runway as the NAP and reaches the same departure fix, in the shortest possible length/time. This ground track (series of X-Y points) will be built in GIS then imported to AEDT. For each aircraft type the minimum safe distance from takeoff before a turn can be initiated, and the minimum radius of turn, will be determined.
3. Define a set of alternate ground tracks (each a series of X-Y points) which fill a range of possible trajectories bounded by the NAP and most-direct ground track. This will include: tracks making turns off of initial runway heading at a variety of distances from takeoff; tracks which follow an NAP to a variety of positions then turn to the departure fix. The set of alternate ground tracks will be spaced such that the farthest distance between each track is no more than 0.5 NM. See Figures B-2 and B-3.
4. Once all ground tracks are defined in GIS, convert to AEDT format. Input to AEDT databases. See flow chart in Figure B-4.

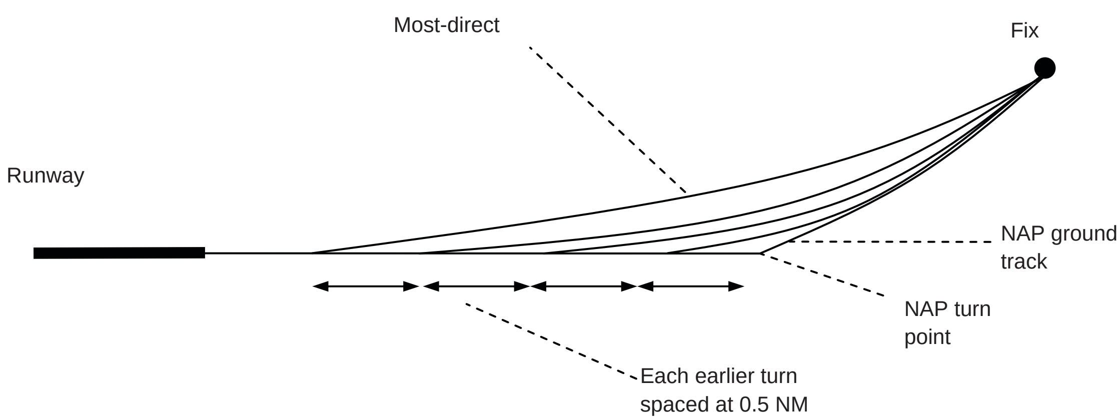


Figure B-3. Illustration of DME turn restriction ground tracks.

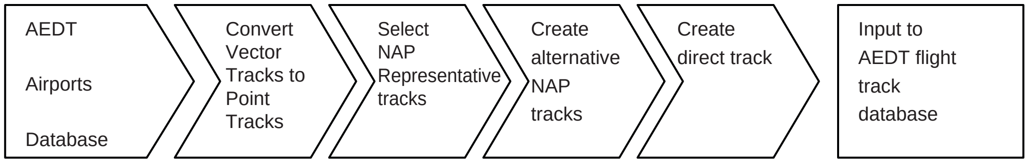


Figure B-4. Track creation process.

B-3.3. Develop Profiles

The purpose of Step 3 is to define NADP-1 and NADP-2 profiles for each aircraft type. Since the current AEDT alpha version does not yet have a user interface, INM version 7.0b will be used to edit and create profiles using procedure steps.

1. For each aircraft type, select the AEDT default Standard, NADP-1 and NADP-2 profile for the appropriate stage length(s). Note that the AEDT default profiles are the same as those in INM version 7.0b (see Figure B-5).
2. Review the AEDT default NADP-1 and NADP-2 profiles compared to the ICAO 2007 NADP survey (see Appendix C). Based on this review, take one of the following actions (listed in order of preference):
   - Use AEDT default NADP's, if both exist for given aircraft type.
   - Modify the default NADP's, using the ICAO 2007 NADP survey data and using the INM interface and guidance from the INM User's Manual. See Figure B-6.
   - If no default NADP's exist in AEDT, build ICAO 2007 NADP procedure steps using the INM interface and guidance from the INM User's Manual. See Figure B-6.
   - For business jets, use National Business Aviation Association (NBAA) Close-In Departure Procedure (available at: http://www.nbaa.org/ops/environment/quiet-flying).
3. If necessary, extend profile above the AEDT cutoff altitude of 10,000 feet AGL.
4. Input all modified/new NADP profiles to AEDT fleet database.

B-3.4. Environmental Modeling

The purpose of Step 4 is to execute the FAA's AEDT to compute noise, fuel burn, and emissions for every possible

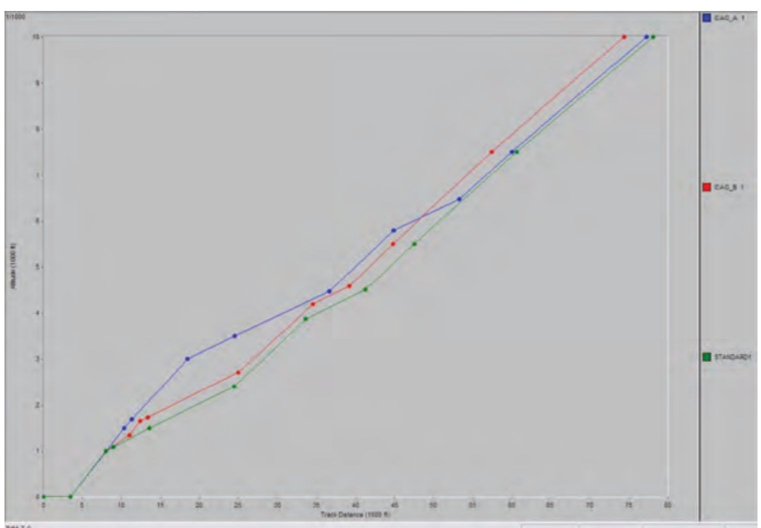


Figure B-5. Example of AEDT standard and NADP altitude profiles.

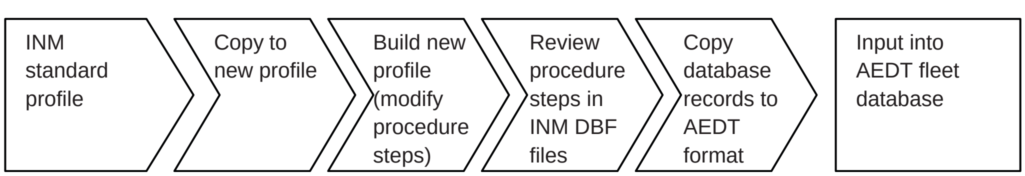


Figure B-6. NADP creation process.

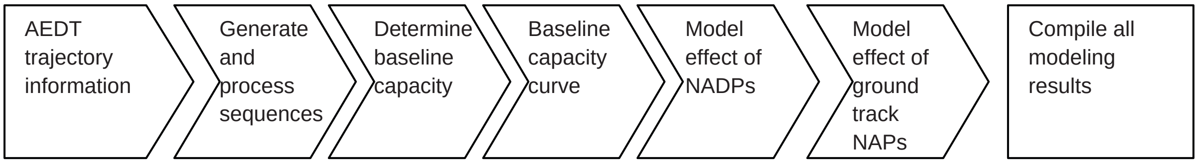


Figure B-7. Capacity modeling process.

combination of ground tracks and profiles (including NADPs and standard profiles). Each unique combination will be referred to as a "case."

1. Organize all inputs (ground tracks and profiles) for all airports within the AEDT databases. Perform quality control of all inputs.
2. Define departure operations for the correct aircraft type for each case.
3. Set up AEDT Configuration files (separate files for standard profile fleet database, close-in and distant NADP fleet databases).
4. Final quality control and bug check.
5. Run AEDT results processor module; query results database to confirm completion.

B-3.5. Capacity Modeling

The purpose of Step 5 is to perform an analysis of runway throughput for each airport to determine the effects of NAPs on capacity (see Figure B-7). See Appendices C and D for details on capacity impacts.

1. AEDT will output 4-dimensional trajectories in the performance database (i.e., speed, ground track position, and altitude of aircraft for each segment of departure flight path).
2. Generate and process sequences for each runway separately.
3. Determine baseline capacity for each runway separately, then weight each runway and sum the total airport capacity. Assume no runway interactions for simplicity.
4. Create baseline capacity curve (Pareto frontier) showing arrivals per hour vs. departures per hour. See example in Figure B-8.
5. Determine effect of using noise abatement profiles: Model the effect of NADP-1 and NADP-2 (which affect departure speeds) on capacity for one given runway. Then weight this new capacity against the rest of the airport runways. Create alternate capacity curves.
6. Determine effect of using noise abatement ground tracks: Model ground tracks, which affect length of common

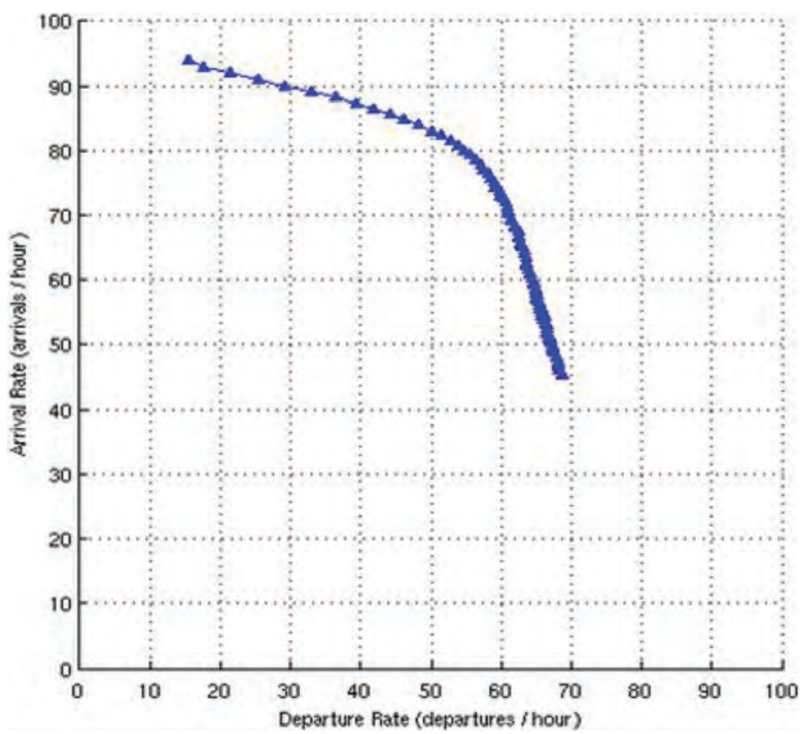


Figure B-8. Example of calculated runway capacity Pareto frontier.

departure paths, for one given runway. Then weight this new capacity against the rest of the airport runways. Create several alternate capacity curves (one for each modeled noise abatement track).

B-3.6. Analyze Results

The purpose of Step 6 is to compile results databases for each airport.

1. Noise Results – Regularly-spaced noise grids will be output from AEDT for each case.
   - Noise contour maps:
     – SEL 85 dB contour maps (level based on speech and classroom speech interference research which uses L_{max} 75 dB; however AEDT does not output L_{max} metric at this time)
   - Difference grids will be computed using NMPlot. These grids will show the difference as increase and decrease in noise from the existing NAP.
     – Population changes within difference areas.
   - Tables of population within noise contour and contour area (for all cases) and difference compared to existing NAP.
2. Emissions & Fuel Burn Results – AEDT results processor will be used to output tables of all available pollutants, fuel burn, and performance data for each case.
   - AEDT will output the following pollutants for local air quality:
     – CO; HC; $PM_{2.5}$; SO_x
     – AEDT cannot compute ozone directly; instead AEDT will compute pollutants which are precursors to ozone such as NO_x and VOC
   - AEDT will output the following pollutants for greenhouse gases (GHG):
     – CO_2
   - AEDT will output the following performance data:
     – Fuel burn (FB) and time of flight
   - We will set a cutoff point for all cases within each airport. The purpose of the cutoff is to compute emissions and performance across all cases in a consistent manner by comparing the results from equal distances/altitudes flown.
     – Low Cutoff: Mixing layer 3,000 feet AFE
     – High Cutoff: Distance to fix (i.e., common point of convergence of ground tracks)
   - Emissions inventory tables will be developed for each case showing total mass of emissions. Summary tables will be created to show the percent differences from the existing NAPs.
3. Capacity Results – The metrics used will include throughput (number of arrivals and departures per hour on a runway) and time (between consecutive departures).
   - Compare and contrast all capacity curves. Graphically assess how the Pareto frontier shifts for each noise abatement procedure compared to baseline capacity curve.
   - Tables of throughput and time for each case.
   - Summary tables of percent differences in throughput and time comparing each case to the existing NAP.
4. Technology Assessment – Determine the source noise reduction theoretically needed to result in no increases in noise. This will be automated using the Noise Source Reduction Optimizer (NSRO). See Figure B-9 below.
   - Use noise difference grids from Step 6.1 to determine the greatest value of noise increase (for each case).
   - Compute equivalent reduction of operations required to model reduced source noise level (per ECAC 2005):

$$N = 10^{\Delta L/10}$$

   (N = Number of aircraft operations; ΔL = Noise reduction in dB)
   - Run new source noise through AEDT.
   - Re-compute noise difference grids.
   - Once NSRO has determined the source noise reduction level, classify the reduction according to technology goals specified under NextGen, CLEEN, and NASA

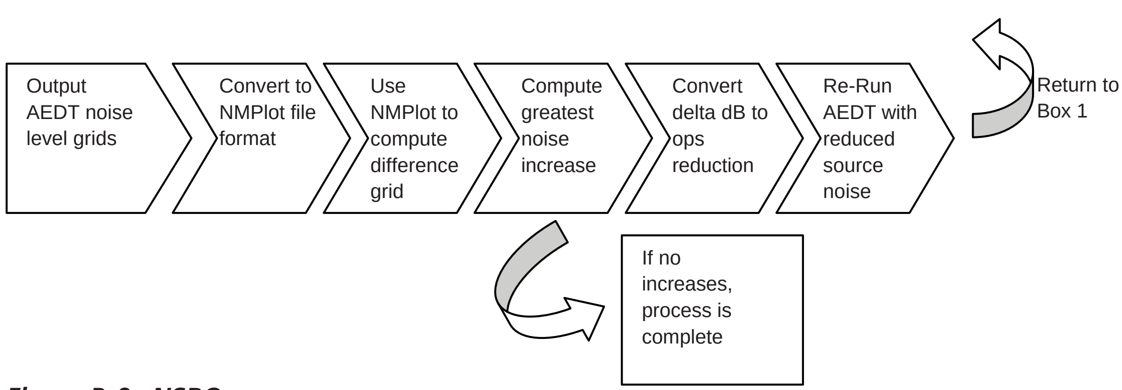


Figure B-9. NSRO process.

Fundamental Aeronautics Research Program (i.e., N+1, N+2, N+3).

5. Feedback to Step 2 – Perform a feedback loop, if deemed necessary by the team, to develop and analyze additional ground tracks and/or profiles. The decision will be based on the results analysis. The goal is to allow for further refinement of ground track or profile procedures to better model the most optimal procedures. For example, ground tracks may be added to the analysis to study the effect of noise on specific locations; or, a variant of NADP-1 may be added to the analysis to compare thrust cutback at different altitudes.
   - Additional procedures/ground tracks modeled at SFO, BOS.

B-3.7. Tradeoff Assessments

The purpose of Step 7 is to synthesize all case study results, for each airport and across the set of all airports. This will include additional tables and charts, and a discussion of the accuracy of the results. The most optimal procedures will be selected based on noise level, emissions, fuel burn, and capacity. Population impact will not be used as a selection criterion since it may vary locally.

1. Selection of most optimal procedures based on results of Step 6
   - Combine ground track and NADP into optimal procedure
   - Discuss day vs. night procedures
   - Emissions – pollutants of concern vary by airport
   - Selection of optimal procedures:
     – Minimal change in noise levels (population and area)
     – Greatest FB and emissions reduction
     – Greatest capacity increase
2. General accuracy of modeling results (as compared to real operations)
   - Full thrust modeling assumption vs. reduced thrust used in practice
     – Reference to ICAO (2007) which presented results with and without reduced thrust
   - Single-event modeling does not consider real-world dispersion of flights around a published procedure
   - Phase 2 will address capacity and ground operations more completely

APPENDIX C

Capacity Modeling Protocol

C-1. Introduction

With the increase in traffic in the National Airspace System (NAS), the effects of any changes to air traffic procedures on the capacity of airports must be considered, as airports are one of the major areas of congestion in the NAS. If new proposed procedures decrease the capacity of an airport, a trade-off must be done to examine the other benefits from the procedure and to determine if those benefits outweigh the cost of decreasing capacity. Decreased environmental impacts are some of the benefit that has resulted in decrease in capacity due to restrictions on flight paths of aircraft into and out of airports. Noise Abatement Departure Procedures (NADPs) historically have resulted in decreases of capacity because they normally restrict where aircraft can fly around airports.

However, with the development of quieter engines and aircraft, new NADPs may be able to gain these losses in capacity back. Because aircraft now create less noise, new NADPs could allow for a wider range of flight paths around airports while still maintaining low noise levels. By designing NADPs to balance the need for increased efficiency but less noise, fuel burn, and emissions, optimal procedures can be created that can actually improve an airport's efficiency. When performing trade-offs on airport efficiency, calculating the airport capacity allows any changes in efficiency to be quantified.

The airport capacity is shown as a Pareto frontier, as seen in Figure C-1, which describes the maximum departure rate for a given arrival rate under a given set of conditions. These conditions include the weather, which affects the airport configuration and the flight rules being used, and the type of aircraft being considered. The standard method for calculating the capacity of an airport is to pick a set of conditions and then use the FAA procedures for the terminal area to determine how many departures can leave for a given arrival rate. The arrival rate is varied so as to calculate the entire boundary, while still ensuring the required minimums are maintained. This document will describe the methods used for calculating the capacity of a single runway at an airport and then apply those principles to calculating the capacity of an entire airport.

As seen in Figure C-1, the capacity curve is only the theoretical description of the relation between arrival and departure rates. Very often these rates are not achieved due to less than optimal conditions or not enough traffic to maximize the airport's resource. In Figure C-1, most reported rates occurred at well below the calculated Pareto frontier. However, the actual rates can exceed the calculated capacity curve, as seen in Figure C-1 as the few data points outside of the curve. This can indicate over-utilization of the airport or a high level of optimization by controllers and airlines.

C-2. Single Runway Capacity

C-2.1. Overview

When calculating the capacity of a single runway, a set of initial conditions must first be chosen. This set of conditions includes the fleet mix using this runway and the type of flight rules being used. Once the fleet mix has been determined, arrival and departure sequences can be created. The arrival sequence is spaced out and threshold crossing times are created. Once these times and spacings have been determined, the arrival and departure sequences are iterated through allowing a departure to take off every time that there is a large enough gap between arrivals. Once the arrival sequence has been completely iterated through, the arrival and departure rates are calculated based on the total number of arrivals and departures that occurred in the time it took for all of the arrivals to land. The spacing is then varied to determine the departure rates at varying arrival rates.

C-2.2. Initial Conditions

The two major initial conditions that influence the capacity of a runway are the flight rules being applied and the fleet mix

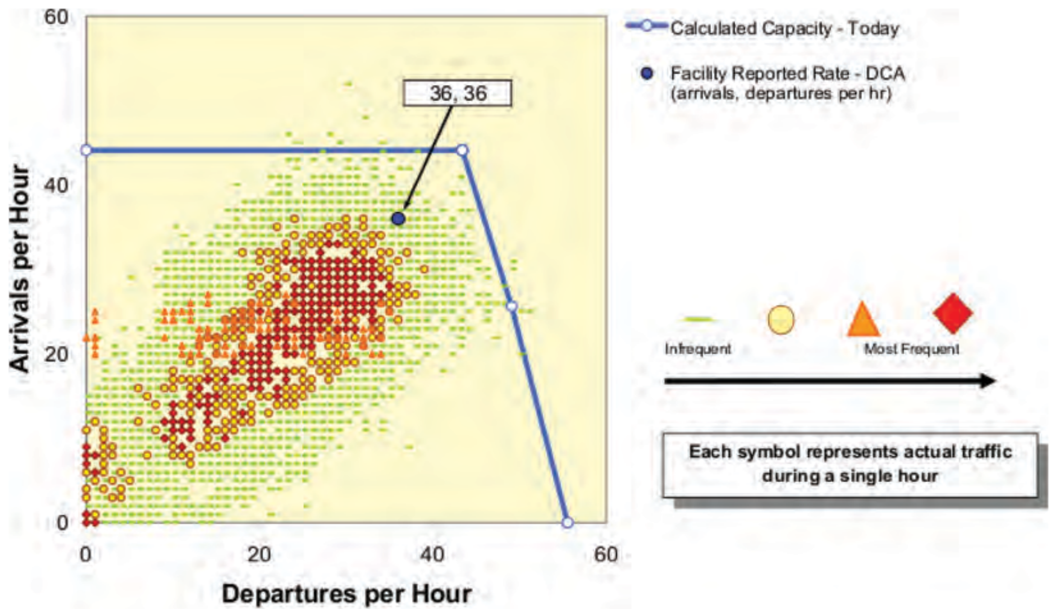


Figure C-1. FAA reported capacity curve for Reagan Washington National Airport with actual data shown from Airport Capacity Benchmark Report 2004.

used on the runway under consideration. Whether aircraft are being flown under Visual Flight Rules (VFR) or Instrument Flight Rules (IFR) greatly affects the capacity of a runway and by extension an airport. The decision between IFR and VFR is determined by the weather conditions. Normally, when calculating capacity, instead of setting the weather conditions, the set of flight rules being used is decided upon.

For example, when the FAA performed their benchmark of the capacity of airports in 2004, they picked three sets of conditions to examine each airport under. First, they considered the case of optimal conditions, where visual approaches were used. Then, they calculated the capacity under marginal conditions with instrument approaches but visual separation was still maintained. Finally, they determined the capacity under IFR conditions.

The other set of initial conditions that must be initialized is the fleet mix, which determines the sequence of aircraft types for the runway. The types of aircraft can be simplified into the four types of aircraft listed in the FAA regulations. These types are small, large, Boeing 757, and heavy. Further detail is not needed as all separation requirements can be determined from these types.

These sequences can be set in a variety of ways. A sequence can be created by determining the percentages of each type of aircraft that frequent the airport under consideration. These percentages can then be used along with a uniform random number generator to create a random sequence with the correct percentages of aircraft types. Another way to initialize each sequence is to use true sequences observed at the airport.

C-2.3. Set Arrival Times

The next step in calculating the capacity is to set the times at which each arrival in a sequence will arrive at the specified runway. This process is done by applying the FAA required spacing. The minimum IFR separation between aircraft in an arrival sequence due to wake vortices is specified in FAA Order JO 7110.65S, Para 5-5-4. These minimum separations are described below in Table C-1.

The minimum separation between aircraft when applying visual separation is not specified by the FAA. Pilots are given latitude to maintain a safe separation between each other. As a result, the visual separations tend to be smaller. The observed average separation between aircraft is shown in Table C-2. These separation distances are the distance between the two arrivals when the leading arrival is crossing the runway threshold.

Another restriction on whether or not an arrival can land is that the runway must be clear. To take this into account, the observed runway occupancy times in Table C-3 can be used.

Table C-1. IFR minimum wake vortex separation between arrivals.

		Trailing Aircraft			
	(nm)	**Small**	**Large**	**B757**	**Heavy**
Leading Aircraft	**Small**	2.5	2.5	2.5	2.5
	Large	4	2.5	2.5	2.5
	B757	4	4	4	4
	Heavy	6	5	5	4

Table C-2. Observed average separation between visually separated arrivals.

	Trailing Aircraft				
	(nm)	**Small**	**Large**	**B757**	**Heavy**
Leading Aircraft	**Small**	1.9	1.9	-	1.9
	Large	2.7	1.9	-	1.9
	B757	-	-	-	-
	Heavy	4.5	3.6	-	2.7

The arrival time for each aircraft in the arrival queue is said to be the time at which the aircraft crosses the runway threshold. To determine the arrival time of each arrival, the previous requirements are applied to the arrival sequence. Because the separations are in terms of distances, they must be converted to times. In order to do so, the average approach speeds in Table C-4 are used to convert the distances into times.

In addition to the calculated arrival times, an additional time is added to each arrival time to allow for varying the arrival rate. This additional time is found from a random number generator with an exponential distribution defined by $f(x) = \lambda e^{-\lambda x}$ where $f(x)$ is the probability density function and x is the random variable, which is in this case time. This distribution is varied to create a range of arrival rates. Thus, when λ approaches infinity, the resulting times from the distribution approach zero and so the maximum arrival rate is obtained.

The departure times are not set initially. It is not known when a departure will be able to take off until the related arrival and departure sequences are set.

Once the airport configuration and flight rules have been set and the arrival times calculated, all of the arrival and departure sequences must be iterated through following the FAA procedures according to first in/first out. The arrivals cross the threshold at the set arrival times and as many as possible departures are allowed to take off. The processing stops as soon as the arrival sequence is iterated to the end. Once this happens, the number of arrivals is summed to determine the total number of arrivals and then divided by final arrival time to calculate the arrival rate. The same calculations are done on the departures to determine the departure rate.

The departure sequence is assumed to be always full so that the limit on departure rate is not dependent on a lack of departures in a sequence. Therefore, if a departure sequence is ever emptied during the processing, additional departures must be added using whatever method was used to generate the original sequence or a departure can be generated during the processing each time a departure is needed.

Table C-3. Average arrival runway occupancy time.

	Aircraft Type			
Occupancy Time (sec)	**Small**	**Large**	**B757**	**Heavy**
	50	60	60	70

Table C-4. Average arrival speed.

	Aircraft Type			
Average Speed (knots)	**Small**	**Large**	**B757**	**Heavy**
	90	130	130	150

The arrival sequences must be sufficiently long so as to remove noise due to the randomization, or the processing must be repeated multiple times for a given exponential distribution in order to average out the noise. Once a departure rate has been determined for a given exponential distribution and thus a given arrival rate, the process must be repeated with a different distribution. In this way, the entire capacity curve can be calculated for an entire range of arrival rates.

The rules governing when a departure can take off are described in FAA Order JO 7110.65S, Section 9. When examining Noise Abatement Departure Procedures (NADPs), the key regulations involved deal with the spacing between departures. A departure is allowed to begin takeoff roll once the preceding departure "has crossed the runway end or has turned to avert any conflict [JO 7110.65S 3-9-6.a]" as shown in the diagram in Figure C-2.

However, if distances can be determined, the preceding departure needs to only be airborne and a minimum distance from the current departure. The minimum distances are listed in Table C-5. The categories used in the table are defined as follows: Category I are small single propeller driven aircraft weighing less than 12,500 lbs.; Category II are small twin engine propeller driven aircraft weighing less than 12,500 lbs.; Category III are all other aircraft.

The arrival times must also be taken into account when determining if a departure can take off. Because the arrival times are fixed, if a departure is allowed to take off, any

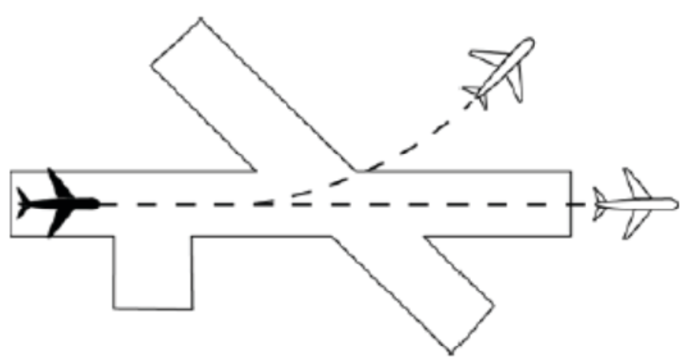


Figure C-2. Same runway separation.

Table C-5. Minimum distance between departing aircraft.

	Trailing Aircraft			
	(ft.)	Category I	Category II	Category III
Leading Aircraft	Category I	3000	4500	6000
	Category II	3000	4500	6000
	Category III	6000	6000	6000

spacing requirements between arrivals and departures must be satisfied. For an arrival to land, the previous departure on the runway must have crossed the runway end (JO 7110.65S 3-10-3.a.2). However, if distances can be determined, the distances in Table C-5 can be applied where the leading aircraft is the departure and the trailing aircraft is the arrival.

To determine how long it will take a departure to cross the end of the runway, the following assumptions can be made about the departure profile. The departure can be assumed to accelerate linearly for 5000 ft. down the runway until it reaches its average departure speed shown in Table C-6. After that the departure can be assumed to maintain a ground speed equal to its average departure speed.

Other restrictions are based on wake turbulence constraints. An IFR/VFR aircraft departing behind a heavy jet/B757 must be separated by 2 minutes, when both are departing from the same runway. If a departure follows a heavy/B757 arrival or an arrival follows a heavy/B757 departure, these aircraft must be separated by 2 minutes if they are on a runway with a displaced landing threshold if the projected flight paths will cross. Small aircraft must be separated from "a large aircraft taking off or making a low/missed approach when utilizing opposite direction takeoffs on the same runway by 3 minutes unless a pilot has initiated a request to deviate from the 3 minute interval (JO 7110.65S 3-9-6.i)." All aircraft departing "behind a heavy jet /B757 departing or making a low/missed approach when utilizing opposite direction takeoffs or landings on the same or parallel runways separated by less than 2,500 ft. (must be separated by) 3 minutes (JO 7110.65S 3-9-6.j)."

C-3. Multi-Runway System Capacity

C-3.1. Overview

The capacity of a multi-runway system (i.e. an airport) is determined in a similar manner to that of a single runway. However, because there are multiple runways, events on one runway can affect events on other runways. Yet, the steps for calculating the capacity remain the same. The initial conditions must be set, arrival and departure sequences created and then the sequences iterated through using FAA procedures to determine when events can occur.

Table C-6. Average departure speed.

	Aircraft Type			
Average Speed (knots)	Small	Large	B757	Heavy
	100	150	150	170

C-3.2. Initial Conditions

In addition to the type of flight rules being applied, when calculating the capacity of an airport, the runway configuration must also be decided. The majority of airports have multiple configurations that are used depending on the winds and visibility. The capacity of an airport is calculated with respect to a specified runway configuration and will change depending on which runways are in use.

Also, the number of aircraft sequences that need to be generated will also vary depending on the runway configuration being considered. For every runway being used, at least one sequence must be generated. If a runway is being used for both arrivals and departures, a sequence for both must be created. However, if a runway is dedicated to arrivals or departures, only one sequence needs to be generated. For example, a single runway handling both arrivals and departures requires the same number of sequences as two parallel runways with one runway dedicated to arrivals and the other to departures.

C-3.3. Set Arrival Times

With multiple runways, separate arrival sequences interact with each other as arrivals on intersecting runways restrict each other. These interactions are described in JO 7110.65S 3-10-4. These procedures can be summarized to say that an arrival cannot land until an arrival or departure on an intersecting runway or flight path has already crossed the intersection or has turned to avoid crossing the path of the arrival, or is stopping and holding short of the intersection. Wake vortex restrictions also apply in this case as well. If an arrival is going to fly through an intersection where a heavy/B757 has just flown through as it departs, the arrival must be separated from the heavy/B757 crossing the intersection by 2 minutes.

In order to determine when an arrival will cross an intersection, a general landing pattern can be assumed. The arrival pattern is simplified to having the arrival cross the threshold at an elevation of 50 ft., touch down on the runway 1000 ft. beyond the threshold and then decelerate from its average arrival speed listed in Table C-4 to a stop 5000 ft. down the runway. Between crossing the threshold, the arrival can be assumed to perform a quarter g pull up.

C-3.4. Departure Spacing

If aircraft are on not on the same runway, but are on intersecting runways, the departure may not begin takeoff roll until the following conditions are met. If the preceding aircraft is another departure, the current departure cannot begin its take off roll until the preceding departure has "passed the intersection, has crossed the departure runways, or is turning to avert any conflict (JO 7110.65S 3-9-8.b.1)." If the preceding aircraft is an arrival, the departure cannot begin rolling until the "preceding arriving aircraft is clear of the landing runway, completed the landing roll and will hold short of the intersection, passed the intersection, or has crossed over the departure runway (JO 7110.65S 3-9-8.b.2)."

Other restrictions are based on wake turbulence constraints. An IFR/VFR aircraft departing behind a heavy jet/B757 must be separated by 2 minutes, when both are departing from the same runway or parallel runways separated by less than 2,500 ft. If a departure follows a heavy/B757 arrival or an arrival follows a heavy/B757 departure, these aircraft must be separated by 2 minutes if they are on a runway with a displaced landing threshold if the projected flight paths will cross. Small aircraft must be separated from "a large aircraft taking off or making a low/missed approach when utilizing opposite direction takeoffs on the same runway by 3 minutes unless a pilot has initiated a request to deviate from the 3 minute interval (JO 7110.65S 3-9-6.i)." All aircraft departing "behind a heavy jet /B757 departing or making a low/missed approach when utilizing opposite direction takeoffs or landings on the same or parallel runways separated by less than 2,500 ft. (must be separated by) 3 minutes (JO 7110.65S 3-9-6.j)."

Other wake turbulence constraints must be used when aircraft are on intersecting runways or flight paths. An IFR/VFR departure must be separated from a departing heavy/B757 by 2 minutes when the preceding departure is on an intersecting runway and the projected flight paths will cross or the two aircraft are on parallel runways separated by more than 2,500 ft. if the projected flight paths will cross. Also, in the case of an arriving heavy/B757 landing on a crossing runway in front of a departing IFR/FR aircraft, the departing aircraft must be separated by two minutes if the departure will fly through the airborne path of the preceding arrival (JO 7110.65S 3-9-8.b.3-4).

C-4. Results

The results of these calculations should be a curve similar to that shown in Figure C-1 or below in Figure C-3. The departure rate is expected to drop off with an increase in arrival rate and vice versa. The exception rule is the case of

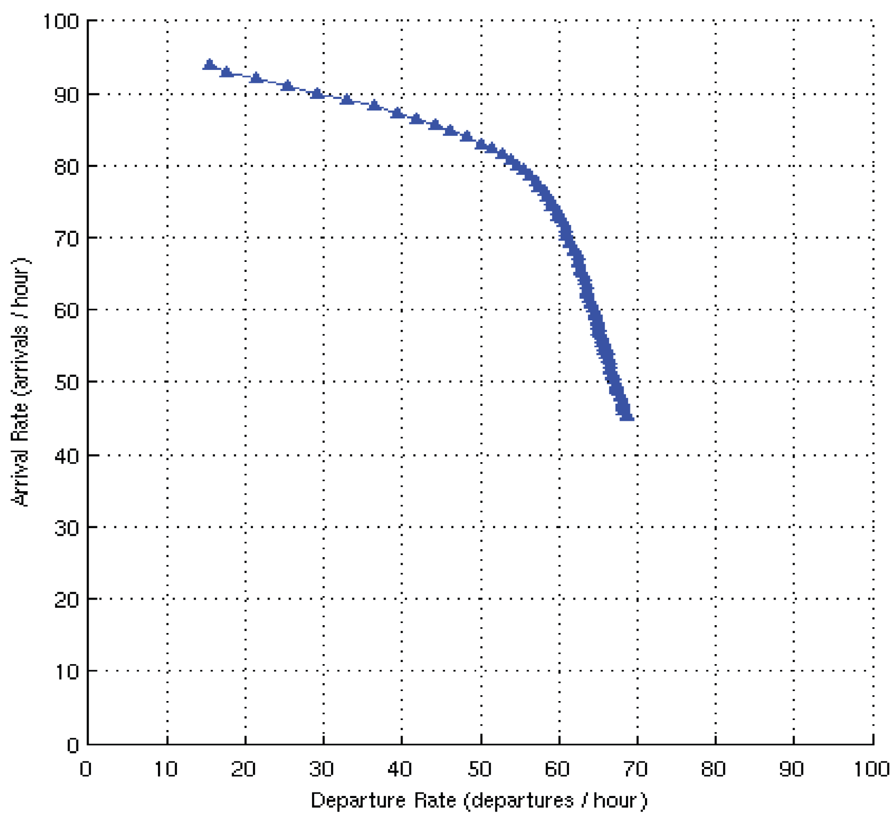


Figure C-3. Example of calculated runway capacity Pareto frontier.

independent runways independent of each other being used for arrivals and departures. In this case, the expected result is a constant departure rate for any arrival rate since the departure rate does not depend on the arrival rate.

The calculated arrival and departure rates need not go to zero as seen in Figure C-1. The end point at the maximum arrival rate is due to the fact that there is a maximum arrival rate that certain configurations can handle. So for this case, even if there were no departures, the arrival rate could not increase any more. The other end point in this case is a result of the maximum lambda describing the distribution for the spacing between arrivals. This shaping variable could be increased further so as to decrease the arrival rate and continue the curve downward.

APPENDIX D

Noise Abatement Departures and Runway Throughput Analysis

D-1. Introduction

The acronym Noise Abatement Departure Procedures (NADPs) is used to describe actions taken to minimize or reduce aircraft operational noise in the neighboring communities in the vicinity of the airport. Although typically applied to define the vertical profile (engine thrust and aircraft configuration management) during the initial climb it can also be applied to other noise mitigation measures such as curfews/restrictions and restricted ground paths or tracks when departing an airport.

At noise sensitive airports it is quite common for the airport to have negotiated with surrounding neighborhoods to achieve acceptable departure ground tracks. These agreements are enforced by the airport through departure clearances issued by the airport traffic controllers (ATC). While some of these agreements include dispersing the departures with divergent headings (fanning) others include minimal departure tracks to prevent over-flight of specific areas.

With the projected growth in air traffic, the FAA's Next Generation Air Transportation System (NextGen) is committed to capacity increases while reducing the environmental impact of operations for both noise and emissions. The presence of minimal ground paths can negatively affect runway(s) departure capacity or throughput.

One method of increasing the runway departure capacity is the implementation of divergent heading departures. A modeling analysis of this methodology is presented to support the expected capacity gains and benefits associated with this departure procedure. However, it should be noted that such studies are highly dependent on the specifics at each airport.

D-2. Overview

The ATC procedures for departures are contained in Chapter 3, Section 9 of the FAA JO 7110.65. Departing aircraft are classified in four categories: HEAVY, B757, LARGE, and SMALL (See Table D-1). All aircraft require an in-trail separation or spacing of 3 nautical miles (NM) while within the TRACON airspace with the exception of the HEAVY and B757 classes which require a separation of 5 NM and 4 NM respectively due to wake turbulence concerns. This wake turbulence distance separation translates to a 2-minute time separation before trailing aircraft can receive a departure clearance (See Table D-2). The minimum separation requirement is then stretched to the 5 NM minimum in-trail separation required in the Air Route Traffic Control Center (ARTCC) airspace which is approximately 40 NM from the airport. It is not uncommon for an ARTCC, with high-density traffic to request 7 NM separations to facilitate existing traffic while transitioning departures to the en-route phase.

D-3. Divergent Heading Departures

The FAA Joint Order 7110.65 (Chapter 3, Section 9) defines the departure separation requirements. As stated, if the minimum separation requirement can be assured, a departure clearance for Category III aircraft can be issued after the preceding aircraft has reached a point 6,000 feet down the runway and a visual confirmation of rotation (nose gear off the runway) is made. Initially, divergent heading departures required a minimum heading change of 15 degrees and ground radar confirmation of the course change. Currently, divergent heading departures are relying on the airborne capability of RNAV-equipped aircraft to execute a defined departure route containing the required heading change.

D-4. Modeling of Divergent Heading Departures

SIMMOD *PRO!* was used to produce a comparative model analysis of a straight-out in-trail departure versus a divergent heading departure. SIMMOD is an industry standard analysis tool used by airport planners and operators, airspace

Table D-1. Aircraft categories.

AIRCRAFT TYPE	CLASS
A300, A330, A340, B747, B767, B777, DC10, MD11	HEAVY
A318, A319, A320, A321, B727, B737, MD80, ERJ170, ERJ195, FOKKER F50, FOKKER F100, CRJ700	LARGE
CRJ100, CRJ200, GA-PROP	SMALL
B757	B757

designers and ATC authorities for high-fidelity simulations of both airport and airspace operations. The SIMMOD model also includes an animator which provides a detailed view of simulated aircraft operations both on the ground and airborne.

D-5. Model Design

Several factors can affect the implementation of divergent heading departures—the airport and runway configuration, ground traffic crossing the active departure runway, the aircraft fleet mix, and the departure schedule. These factors render any modeling effort only applicable to the conditions modeled. Given that the analysis was for runway departure optimization, the following design and inputs were used:

- The airport design chosen was a parallel runway configuration with the terminal/gates between the runways eliminating the need for traffic crossing the active runway.
- The fleet mix included all four separation classes; HEAVY, B757, LARGE, and SMALL.
- The departure schedule was intentionally made unrealistically high (120 departures, departing at 30-second intervals) to ensure that the departure queue was full for either scenario (divergent and non-divergent).

D-6. Model Inputs

Available aircraft performance data was used to determine the distance and altitude associated with a typical departure profile and this data was used for the SIMMOD input requirements for the aircraft model *INITIAL_DEP* and *LOW_CLIMBING* departure segments which required a speed input (Minimum, Nominal, and High). Since the initial climb-out speed (V2) varies by airport elevation, airframe type, weight, and temperature; a sea level airport elevation was assumed and the speed for a nominal takeoff weight was chosen.

Available aircraft performance data was also used to determine the input for takeoff roll distance. Since the minimum distance for Category III aircraft is 6000 feet and confirmed rotation, a 7000 foot roll was assumed for all modeled aircraft which introduces a somewhat conservative factor in the model results.

The SIMMOD model default departure separations were removed, and iterative runs of the model were made to determine the departure spacing required to result in the minimum aircraft separations given in Table D-2. It should also be noted here that the separations used were applicable to Visual Meteorological Conditions (VMC). Using the SIMMOD Animator, the actual separation for each iteration was checked by measuring the separation when the trailing aircraft was over the end of the departure runway (See Figure D-1). The divergent departure routing incorporated a heading change (turn) initiated approximately 1 nm off the end of the departure runway.

Both the non-divergent and divergent model scenario analysis was for the same 120 aircraft comprised of 50.8% Heavy, 15% B757, 19.2% Large, and 15% Small with the identical departure schedule. To assess the influence of fleet mix, an additional model scenario was run with the HEAVY aircraft replaced by B737-800s and the B757 aircraft replaced with EMB 145s, producing a schedule of 70% LARGE, and 30% SMALL. Again, for the additional model the identical departure schedule was used.

D-7. SIMMOD Results

Two metrics were used to assess the benefits of the divergent heading departure methodology; Departure Queue Time and Departure Rate. Taxi times were not considered representative

Table D-2. Wake turbulence separation.

		LEADING AIRCRAFT			
		HEAVY	B757	LARGE	SMALL
TRAILING AIRCRAFT	HEAVY	4 nm	4 nm*	2.5 nm	2.5 nm
	B757	5 nm*	4 nm*	2.5 nm	2.5 nm
	LARGE	5 nm*	4 nm*	2.5 nm	2.5 nm
	SMALL	6 nm	5 nm	4 nm	2.5 nm

* Wake Turbulence Requirement

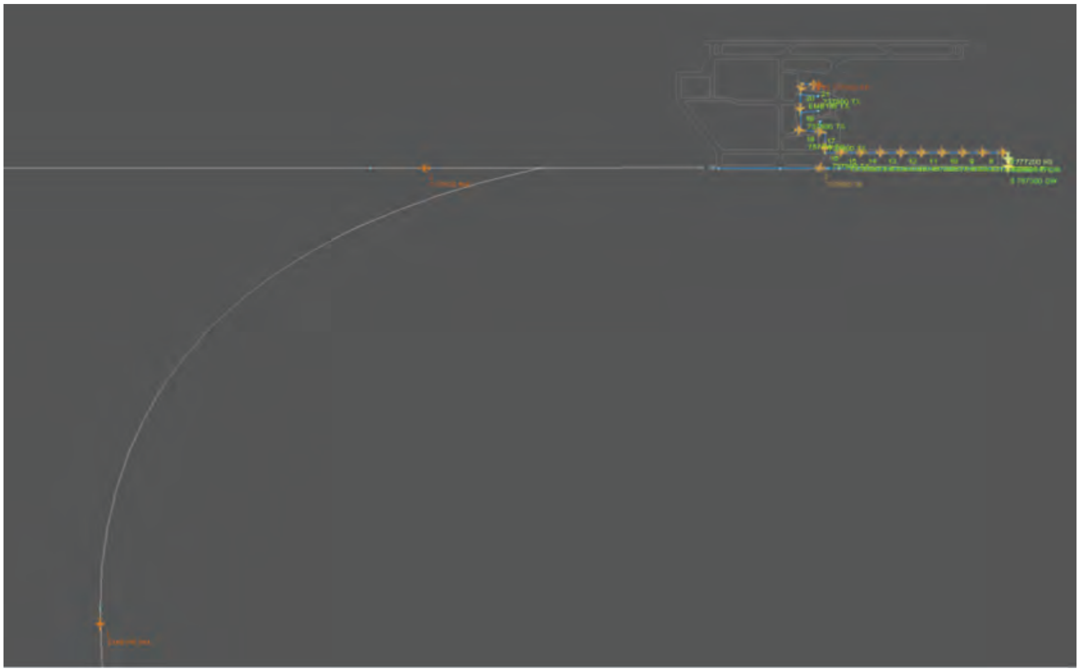


Figure D-1. SIMMOD animator.

since the departure schedule was non-realistic and inflated to produce a departure queue for each scenario.

Full Fleet Mix - Non-Divergent versus Divergent:

- Departure Queue Reduction – 13.79 minutes (9.8%) improvement.
- Runway Departure Rate – 5.59/hour (10.88%) improvement.

The additional scenario for an assessment of the influence of fleet mix compared the non-divergent departure scenario with a full fleet mix and a fleet mix of only LARGE and SMALL aircraft. This comparison produced the following results and supports the earlier statement that the fleet mix does impact runway capacity.

Non-Divergent – Full Fleet Mix versus No Mix:

- Departure Queue Reduction – 6.6 minutes (4.7%) improvement.
- Runway Departure Rate – 2.49/hour (4.8%) improvement.

D-8. Current Activities and Conclusions

RNAV departures with a divergent heading of 10 degrees are currently being demonstrated at Atlanta Hartsfield-Jackson airport. Although no published results are currently available, discussions with Atlanta TRACON report that using the divergent headings for departures off of two runways has resulted in an increase of 8 to 13 departures per hour. This report is in good agreement with the results of the SIMMOD modeling discussed above. The significance of the reduced divergent heading departure (10 degrees versus the current 15-degree minimum requirement) could enable some noise-impacted airports to apply the procedure and still avoid over-flights of existing noise sensitive areas. As such, the use of a divergent heading departure method can result in increases of runway capacity or throughput. Again, this demonstration was provided for illustration only. Airport capacity assessments are dependent on the specific operations, layout, etc. of each airport.

APPENDIX E

Optimization Tool Scenario and Examples

E-1. Scenario Development Methodology

Because this tool is meant to provide an understanding of the environmental effects of changing airport fleet and/or flight track utilization, setting up an analysis entails generating two separate scenarios: the reference and the scenario proper. Only by generating an appropriate baseline is it possible to assess the effects of any related future or alternative propositions. There are also two approaches to developing scenarios using this tool: (1) creating scenarios that look at the entire airport environment by modeling the fleet, operations, and utilizations for all runways and flight tracks; and (2) developing scenarios that only cover a specific set of tracks to address a change limited to a particular runway and departure procedure. The choice of approach depends on both the scenario to address and on the level of data comprehensiveness the user is ready to enter. Analysis addressing scenarios like preferential runway usage will probably require the user to set up the tool to model the entire airport while the analysis of direct routing for low-noise aircraft might require only part of the information. Whatever the case, users should enter the necessary information following the order in which the input tabs are organized.

The first step in creating a scenario is to review the airport layout, keeping in mind the scenario being modeled. The north parallel runway is located close to the population centers and offers a multi-turn NAP in the westerly direction, a related direct track, and a set of eight intermediate tracks between them; in addition there are also two flight tracks with west and south-west headings. On the east flow the runway provides a single-turn NAP with related direct and intermediate flight tracks which are complemented by two tracks heading east and south-east; their geometry can accommodate modeling of fanning procedures. The southern runway can only serve an east flow and provides tracks with north-east, east, and south-east headings. The runway is located further from the population centers and can support modeling of scenarios such as preferential runway use.

The next step should be to enter the scenario information. The name and description of the scenario should be filled in at this stage along with any initial notes. As the development of the scenario proceeds, the user should return to this tab to add any remarks, assumptions, and information resulting from working through the scenario input requirements. Once the scenario is completed the date should be updated to indicate when the scenario was finalized.

The technology tab is where the users can modify the available fleet to better simulate their airport reality or envisioned changes. In general the two sets of aircraft, current and future, are provided so that a mix of existing and new or future aircraft can be modeled simultaneously; however, especially for an existing condition baseline, the two can be used in parallel to extend the fleet coverage by using substitutions. As previously noted, noise adjustments for aircraft substitution can be calculated using the standard methodology that has been defined by both ICAO and ECAC. The fuel burn and emissions adjustments can be calculated by comparing the overall fuel burn and emissions over a common flight boundary (e.g., up to 10,000 feet altitude) to develop the different percentages. Ultimately, the user needs to decide how to best leverage the available aircraft to meet his/her modeling needs; the note field next to each of the aircraft provides a readily available space to document what has been done.

Once the fleet has been defined the related operations need to be provided. The day and night number of flights for each aircraft are entered in the operations sections of the table of the operations tab. The operations are entered by-aircraft type and then split between the two sets of fleet. As the split percentages are input the overall mix can be monitored at the aircraft level, aircraft category level, and airport level using the provided summary fields. These fields can assist in developing scenarios where the operations are not defined in great detail at the aircraft level and the aim is to reach a specific balance instead. Operations information can be entered to represent the entire airport movements, or only a subset of a specific scenario depending on the need.

Having the fleet and the operations volume developed the next step is to setup the airport's parameters. The user should first setup the utilization by-aircraft category starting with the runways utilization. If the operations entered in the previous step were entered for the whole airport then all runways will require a percentage assigned to them, otherwise the one of interest should be set to 100% and all the other ones to zero. The flight track utilizations are entered next; only the percentages for the runways in use are required. If the user needs to further refine the utilization on a by-aircraft basis, the appropriate aircraft's day and/or night entry fields should be activated in the utilization by-aircraft tab and the values entered. The final step in the scenario input process is to define the dispersion associated with each of the flight tracks. As with the utilizations, the user should first define the dispersion distribution by-aircraft category and then refine those by-aircraft using the dispersion by-aircraft tab.

Once all the data has been entered the user can verify that the scenario was modeled as desired by reviewing the compiled operations data in both the noise and fuel burn and emissions data summary tabs. The results can be assessed in the results tab both in terms of absolute values and, if a reference scenario was selected, in terms of the change.

The optimization process can be approached from three angles: (1) the fleet, (2) the airport utilization, or (3) both. Approaching optimization from the fleet point of view means modifying the fleet characteristics or composition until the desired result is achieved for the defined airport utilization. This is generally more of a research approach given that the fleet composition and technology are not elements that can be necessarily affected unilaterally. Addressing optimization from the airport utilization angle, on the other hand, is in line with what an airport operator has more definite control over. Using an iterative process the user can modify where and when aircraft fly so as to limit or decrease the noise exposures at the point of interest while reducing the overall fuel burn and emissions impacts. The last approach can be used to assess a future scenario when a change in the fleet composition and technology is expected. In this scenario the change will enable implementing an alternate airport utilization which leverages the new fleet capabilities to improve each flight's fuel burn and emissions performance without affecting the noise environment.

E-2. Sample Analysis Scenario

The following example illustrates how to approach the development of an analysis to address a specific scenario. The intent is to demonstrate how a problem should be framed in the context of the tool's capabilities, how the data should be set up, and how the analysis should be undertaken.

E-2.1. Analysis Background

The airport in this scenario is a smaller medium size airport with a fleet dominated by short and medium range aircraft, with a few heavy aircraft operations and some business jet and general aviation traffic. The airport was informed by two of the major carriers that they are planning to modernize their fleet, one by replacing their aging Boeing 737-300s with A319neo aircraft and the other by upgrading the avionics on the CRJ9 aircraft. The first airline expects that 90% of their 737 fleet operating at the airport will be replaced while the second expects a 70% penetration of the new avionics within the timeframe of interest. The airport has decided that given the improved acoustic and flight performance of the new equipment and their predominance in the airport's daily operations, there might be an opportunity to reassess its current departure procedures and possibly diminish the airport's environmental impacts without affecting the communities' noise exposure. The target procedure is the Multi-turn NAP currently in effect off of one of the runways.

E-2.2. Reference Scenario Setup

The goal of the reference scenario is to provide the user with a baseline condition to which different scenarios can be compared. By loading the results from the baseline scenario in the reference scenario results tab of other scenarios a user can determine the environmental benefits and/or impacts resulting from the implemented changes. Additionally, the comparison can also be used to aid the analyst in applying further changes to either maximize the benefits or minimize the impacts.

E-2.2.1. Scenario Information

The first step for performing this analysis is to setup the baseline scenario file by copying and renaming a blank copy of the tool. The initial scenario information needs to be edited by entering the date, name and description as shown in Figure E-1. The scenario was given a descriptive name and a brief description of the contents. Any assumptions will be added to the Notes field as the development progresses.

E-2.2.2. Fleet Technology Adjustments

The airport in this sample problem includes a total of 30 different aircraft types, all but six in the Large and Small aircraft categories, and none requiring modeling by substitution. For a baseline scenario a decision has to be made

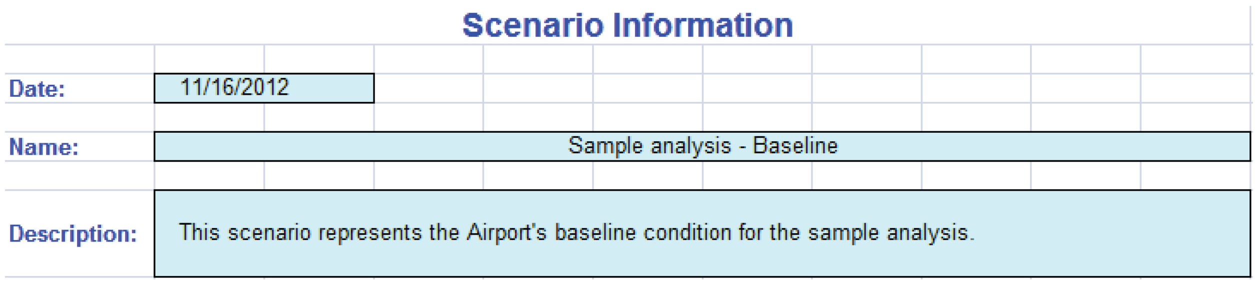


Figure E-1. Baseline scenario information.

whether to take the time necessary to research the fleet actually operating at the airport and develop adjustment values to adapt the model's aircraft to better represent the actual fleet. Such level of detail might not be required when the tool is used to provide a quick assessment of a problem or to simply investigate and learn the effects of different environmental performances and facilities utilization. However, when the intent is to evaluate a more concrete situation one has to review the type of changes that are being tested in terms of fleet, operations, and flight track utilization. If the changes affect only a subset of aircraft and all other aircraft characteristics, operations, and flight track assignments will remain unchanged, then only the affected aircraft need to be adjusted. Since all other aircraft will provide the same contribution in the baseline and all scenarios, any errors in source characterization would not affect the amount of change. However, the other aircraft should be reviewed and updated as necessary if they are moved between tracks since their contribution would not be a bias that remains constant between scenarios.

For this specific analysis only the 737-300 aircraft needs to be reviewed for the baseline. The main analysis will focus on rerouting the new and updated aircraft without affecting the remainder of the fleet. From the information in the Reference Data tab, we know the data in the model represents the version of the aircraft equipped with CFM56-3B-1 engines, has a maximum takeoff weight of 135,000 lb. (61,235 Kg), and a Departure average certification level of 88.4dB. The aircraft at the airport are the same model, but mount CFM56-3B-2 engines and has a MTOW of 130,000 lb. (58,967 Kg). Based on the certification data provided in the NoiseDB database webpage (see the Reference Data tab) the noise certification values for the lateral and flyover measurements positions are 89.6dB and 83.4dB respectively. So the decibel adjustment that needs to be applied to the aircraft is calculated as follows:

$$\left(\frac{89.6\,dB + 83.4\,dB}{2}\right) - 88.4\,dB = -1.9\,dB$$

To calculate the correction percentages for the fuel burn and emissions parameters the Takeoff data for the actual engine must be collected by searching the information provided in the ICAO Emissions Databank found at the internet address listed in the Reference Data tab. The data for the aircraft in the tool and the data reported in the databank for the CFM56-3B-2 engines are the following:

Aircraft	Engine	FF (kg/s)	EI NOx (g/kg)	EI CO (g/kg)	EI THC (g/kg)
Original	CFM56-3B-1	0.946	17.7	0.9	0.04
Substitute	CFM56-3B-2	1.056	19.4	0.9	0.036

Engine	Fuel Flow	NO_x	CO	THC
CFM56-3B-1	0.946	17.7	0.9	0.04
CFM56-3B-2	1.056	19.4	0.9	0.036

So the adjustment percentages for each parameter are calculated as follows:

$$Fuel\ Flow_{Adj} = \left(\frac{1.056 - 0.946}{0.946}\right) \times 100 = 11.6\%$$

$$NOx_{Adj} = \left(\frac{19.4 - 17.7}{17.7}\right) \times 100 = -9.6\%$$

$$CO_{Adj} = \left(\frac{0.9 - 0.9}{0.9}\right) \times 100 = 0\%$$

$$THC_{Adj} = \left(\frac{0.04 - 0.036}{0.036}\right) \times 100 = 10\%$$

As expected based on the differences between the two sets of indices, the fuel flow and NO_x corrections actually represent an increase, which is expressed in the tool as a negative percentage of Reduction. Figure E-2 shows the adjustment values entered in the baseline scenario Technology tab table and the information added to the Notes field that identifies the aircraft variant being approximated. Note that CO_2, SO_x, and H_2O would acquire the same adjustment value as that for Fuel Burn because their emissions are directly modeled based on fuel composition.

E-2.2.3. Airport Operations

When performing a whole airport analysis the operations tab should contain the annual average day (AAD) movements for

Current and Future Fleet Technology Definition

					Emissions Reduction (%)						
Tech Group	Aircraft Category	Aircraft	Noise Reduction (dB)	Fuel Burn Reduction (%)	NO_X	CO	THC	CO_2	SO_X	H_2O	Notes
Current	HEAVY	747400									
		767300									
		777200									
		777300									
		A300-622R									
		A300B4-203									
		A310-304									
		A340-211									
		A380-841									
		DC1030									
		MD11GE									
	LARGE	717200									
		727EM2									
		737300	1.9	-11.6%	-9.6%		10.0%				MTOW: 130Klb, Engine: CFM56-3B-2
		737700									
		737800									
		757RR									
		A319-131									
		A320-211									
		A320-232									
		A321-232									
		CL601									
		CRJ9-ER									
		DC95HW									
		EMB145									
		EMB14L									
		GV									
		MD82									
		MD83									
	SMALL	CL600									
		CNA55B									
		CNA750									
		FAL20									
		IA1125									
		LEAR35									
		MU3001									
	PROP	DHC6									
		DHC8									
		DHC830									
		HS748A									

Figure E-2. Existing fleet adjustment data.

the airport. The reason the operations should be set according to the requirement set for noise studies is that noise is the discriminating factor on which the feasibility of a scenario is evaluated. However, in cases when only a specific noise abatement procedure is being addressed, the operations entered can be limited to those that are expected to fly the procedure of interest. While operations on other flight tracks and runways would in general affect the results near the locations of interest, their effect would not change between scenarios and, therefore, would be cancelled out when performing change comparisons.

For this baseline scenario setup all the operations were entered since the data was readily available. While the sample airport facilities built in the tool might not match those of the actual airport, building a representative baseline operations dataset is the most efficient approach. A fully developed baseline can be edited at a later date and be adapted for use in other analyses without having to spend any additional time in finding and collecting additional information. Figure E-3 shows the completed operations table with the technology mix percentages assigning all operations to the Current fleet.

E-2.2.4. Runway and Flight Track Utilization

How the operations are assigned to the sample airport flight tracks depends on what operations were entered, all or a subset, the goal of the analysis, and on how similar or dissimilar the actual airport is. The sample airport can be used as a full airport with operations assigned to all runways and tracks, but individual runway ends and noise abatement procedures can also be used by themselves to assess the potential of new technologies and procedures even if the actual airport's layout is very different.

In this example all runways and flight tracks were assigned percentages of utilization in the "Utilization by AC Category" tab. The data was only entered for the Current technology group because those are the only aircraft that have operations assigned to them in the operations table. The aircraft level utilization input was not required for the baseline as no one particular aircraft required special attention in the Current fleet (i.e., no data additions/changes need to be made to the "Utilization by-Aircraft" tab). Figure E-4 shows the runways and flight tracks distributions defined for this baseline scenario (only track information for the Current fleet shown). The figure also shows how the input validation functionality highlighted the runways distribution total fields for the Future fleet, which were not given any value since that fleet has no operations in this scenario.

E-2.2.5. Flight Track Dispersion Utilization

The flight tracks dispersion utilization controls the width of the corridor flown by the aircraft and depends on the navi-

Fleet Operations and Technology Distribution Setup

Aircraft Category	Aircraft	Operations			Technology Mix (%)					
					Day Ops		Night Ops		Total Ops	
		Day	Night	Total	Current	Future	Current	Future	Current	Future
HEAVY	747400			0.00	100%	0%	100%	0%	-----	-----
	767300	0.33	0.00	0.33	100%	0%	100%	0%	100.0%	0.0%
	777200			0.00	100%	0%	100%	0%	-----	-----
	777300			0.00	100%	0%	100%	0%	-----	-----
	A300-622R	2.14	0.00	2.14	100%	0%	100%	0%	100.0%	0.0%
	A300B4-203	2.05	0.00	2.05	100%	0%	100%	0%	100.0%	0.0%
	A310-304	2.44	0.13	2.57	100%	0%	100%	0%	100.0%	0.0%
	A340-211			0.00	100%	0%	100%	0%	-----	-----
	A380-841			0.00	100%	0%	100%	0%	-----	-----
	DC1030			0.00	100%	0%	100%	0%	-----	-----
	MD11GE			0.00	100%	0%	100%	0%	-----	-----
	Total	6.96	0.13	7.09						
LARGE	717200	47.57	5.29	52.86	100%	0%	100%	0%	100.0%	0.0%
	727EM2	0.54	4.86	5.40	100%	0%	100%	0%	100.0%	0.0%
	737300	76.67	8.52	85.19	100%	0%	100%	0%	100.0%	0.0%
	737700	38.64	4.29	42.93	100%	0%	100%	0%	100.0%	0.0%
	737800	2.74	0.69	3.43	100%	0%	100%	0%	100.0%	0.0%
	757RR	6.41	0.71	7.12	100%	0%	100%	0%	100.0%	0.0%
	A319-131	14.19	1.58	15.77	100%	0%	100%	0%	100.0%	0.0%
	A320-211	0.36	0.04	0.40	100%	0%	100%	0%	100.0%	0.0%
	A320-232	1.14	0.13	1.27	100%	0%	100%	0%	100.0%	0.0%
	A321-232	0.04	0.00	0.04	100%	0%	100%	0%	100.0%	0.0%
	CL601	0.19	0.02	0.21	100%	0%	100%	0%	100.0%	0.0%
	CRJ9-ER	43.07	4.79	47.86	100%	0%	100%	0%	100.0%	0.0%
	DC95HW	8.81	0.98	9.79	100%	0%	100%	0%	100.0%	0.0%
	EMB145	12.73	1.41	14.14	100%	0%	100%	0%	100.0%	0.0%
	EMB14L	14.44	1.60	16.04	100%	0%	100%	0%	100.0%	0.0%
	GV			0.00	100%	0%	100%	0%	-----	-----
	MD82	28.05	3.12	31.17	100%	0%	100%	0%	100.0%	0.0%
	MD83	13.44	1.49	14.93	100%	0%	100%	0%	100.0%	0.0%
	Total	309.03	39.52	348.55						
SMALL	CL600	0.47	0.05	0.52	100%	0%	100%	0%	100.0%	0.0%
	CNA55B	8.77	0.11	8.88	100%	0%	100%	0%	100.0%	0.0%
	CNA750	1.35	0.15	1.50	100%	0%	100%	0%	100.0%	0.0%
	FAL20	3.19	0.00	3.19	100%	0%	100%	0%	100.0%	0.0%
	IA1125	0.35	0.01	0.36	100%	0%	100%	0%	100.0%	0.0%
	LEAR35	4.04	0.08	4.12	100%	0%	100%	0%	100.0%	0.0%
	MU3001	0.28	0.02	0.30	100%	0%	100%	0%	100.0%	0.0%
	Total	18.45	0.42	18.87						
PROP	DHC6	3.54	0.39	3.93	100%	0%	100%	0%	100.0%	0.0%
	DHC8			0.00	100%	0%	100%	0%	-----	-----
	DHC830			0.00	100%	0%	100%	0%	-----	-----
	HS748A	0.24	0.03	0.27	100%	0%	100%	0%	100.0%	0.0%
	Total	3.78	0.42	4.20						
	Grand Total	338.22	40.49	378.71						

Figure E-3. Airport baseline operations.

gation technology installed. The application's three settings provide a range of dispersions from no dispersion to wide dispersion. The "None" setting assumes a perfect navigation with no dispersion; the "Standard" represents the dispersion observed during regular operations, and the "SID" (for Standard Instrument Departure) dispersion estimates what can be expected with RNAV implementation.

One of the changes expected by this airport is for the CRJ9 aircraft operating there to receive an avionics upgrade. In this scenario, the basic assumption is that all of the aircraft in the Heavy category and most of those in the Large category are already equipped with RNAV navigation equipment while the remaining categories, Small and Propeller, are not. Of the Large aircraft, only the CRJ9s, the 727s, DC9s, and the MD80s do not have the more precise navigation technology. In order to model this baseline condition both the dispersion by category and by-aircraft tabs have to be used. As shown in Figure E-5, the basic category wide assumptions are set in the Dispersion by AC Category tab by assigning all operations to the SID dispersion for the Heavy and Large aircraft and to Standard dispersion for the Small and Propeller (only one runway shown). The exception

Runway and Flight Track Utilization by Aircraft Category

Runway Utilization

Tech Group	Runway	Heavy		Large		Small		Propeller	
		Day	Night	Day	Night	Day	Night	Day	Night
Current	09	45%		45%		30%	15%	15%	40%
	27	45%		45%		30%		15%	40%
	28	10%	100%	10%	100%	40%	85%	70%	20%
	Total	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*
Future	09	45%		45%		30%	15%	15%	40%
	27	45%		45%		30%		15%	40%
	28	10%	100%	10%	100%	40%	85%	70%	20%
	Total	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*

Flight Track Utilization

Tech Group	Runway	Track	Heavy		Large		Small		Propeller	
			Day	Ngt	Day	Ngt	Day	Ngt	Day	Ngt
Current	09	N09NAP	65%	65%	65%	65%	65%	65%	65%	65%
		N0902								
		N0903								
		N0904								
		N0905								
		N0906								
		N0907								
		N0908								
		N0909								
		N09DIR								
		E09	15%	15%	15%	15%	15%	15%	15%	15%
		S09	20%	20%	20%	20%	20%	20%	20%	20%
		Total	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*
	27	N27NAP	65%	65%	65%	65%	65%	65%	65%	65%
		N2702								
		N2703								
		N2704								
		N2705								
		N2706								
		N2707								
		N2708								
		N2709								
		N27DIR								
		W27	30%	30%	30%	30%	30%	30%	30%	30%
		S27	5%	5%	5%	5%	5%	5%	5%	5%
		Total	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*
	28	N28	55%	55%	55%	55%	55%	55%	55%	55%
		W28	25%	25%	25%	25%	25%	25%	25%	25%
		S28	20%	20%	20%	20%	20%	20%	20%	20%
		Total	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*

Figure E-4. Runway and flight track utilization by-aircraft group (only track information for the current fleet shown).

for the CRJ9, 727, DC9, and MD80 aircraft is instead established by modifying the information in the Dispersion by-Aircraft tab. In this tab the ad-hoc information for these aircraft is first made active by switching the Current technology Enable toggle to the on position and then by setting the dispersion utilization percentages for all tracks to the Standard dispersion. Figure E-6 exemplifies the entered settings for the CRJ9-ER and DC95HW aircraft (only one runway shown). Identical settings also need to be made for 727EM2, MD82, and MD83 aircraft.

E-2.2.6. Scenario Review and Completion

Having entered all the input information for the baseline scenario the user can review the information in terms of numbers of operations assigned to each of the flight tracks. The two data summaries, for noise ("Noise Data Summary" tab) and fuel burn/emissions ("FB & Emissions Data Summary" tab), enable the user to see both the actual operations assigned as well as the number of operations as affected by the technology input given to the model. Depending on those parameters, and the number

Flight Track Dispersion by Aircraft Category

Tech Grou	Runway	Track	Dispersion	Flight Track Dispersion							
				Heavy		Large		Small		Propeller	
				Day	Ngt	Day	Ngt	Day	Ngt	Day	Ngt
Current	09	N09NAP	Standard					100%	100%	100%	100%
			SID	100%	100%	100%	100%				
			None								
			Total	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*
		N0902	Standard					100%	100%	100%	100%
			SID	100%	100%	100%	100%				
			None								
			Total	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*
		N0903	Standard					100%	100%	100%	100%
			SID	100%	100%	100%	100%				
			None								
			Total	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*
		N0904	Standard					100%	100%	100%	100%
			SID	100%	100%	100%	100%				
			None								
			Total	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*
		N0905	Standard					100%	100%	100%	100%
			SID	100%	100%	100%	100%				
			None								
			Total	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*
		N0906	Standard					100%	100%	100%	100%
			SID	100%	100%	100%	100%				
			None								
			Total	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*
		N0907	Standard					100%	100%	100%	100%
			SID	100%	100%	100%	100%				
			None								
			Total	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*
		N0908	Standard					100%	100%	100%	100%
			SID	100%	100%	100%	100%				
			None								
			Total	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*
		N0909	Standard					100%	100%	100%	100%
			SID	100%	100%	100%	100%				
			None								
			Total	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*
		N09DIR	Standard					100%	100%	100%	100%
			SID	100%	100%	100%	100%				
			None								
			Total	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*
		E09	Standard					100%	100%	100%	100%
			SID	100%	100%	100%	100%				
			None								
			Total	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*
		S09	Standard					100%	100%	100%	100%
			SID	100%	100%	100%	100%				
			None								
			Total	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*

Figure E-5. Flight track dispersion by-aircraft category (only one runway shown).

of night operations for noise, the total number of operations actually modeled will be different compared to those initially entered by the user in the operations tab.

For this scenario a quick review of the operations totals for the noise computations shows that

- About 132 actual operations (day + night) are flown using standard dispersion and about 246 actual operations (day + night) using SID dispersion;
- The noise adjustment for the 737-300 aircraft causes the operations assigned to SID dispersion to be decreased by approximately 30 operations; and
- Accounting for the night-time penalty results in a total of approximately 277 operations flown using the standard dispersion and 409 using the SID dispersion.

A review of the fuel burn and emissions data shows that the emissions adjustment parameters entered in the technology

Tech Group	Runway / Track		Dispersion	LARGE							
				CL601		CRJ9-ER		DC95HV		EMB145	
				Day	Night	Day	Night	Day	Night	Day	Night
	Current Tech		Enable	Off	Off	On	On	On	On	Off	Off
	Future Tech		Enable	Off	Off	Off	Off	Off	Off	Off	Off
Current	09	N09NAP	Standard	100%	100%	100%	100%	100%	100%	100%	100%
			SID								
			None								
			Total	100%	100%	100%	100%	100%	100%	100%	100%
		N0902	Standard	100%	100%	100%	100%	100%	100%	100%	100%
			SID								
			None								
			Total	100%	100%	100%	100%	100%	100%	100%	100%
		N0903	Standard	100%	100%	100%	100%	100%	100%	100%	100%
			SID								
			None								
			Total	100%	100%	100%	100%	100%	100%	100%	100%
		N0904	Standard	100%	100%	100%	100%	100%	100%	100%	100%
			SID								
			None								
			Total	100%	100%	100%	100%	100%	100%	100%	100%
		N0905	Standard	100%	100%	100%	100%	100%	100%	100%	100%
			SID								
			None								
			Total	100%	100%	100%	100%	100%	100%	100%	100%
		N0906	Standard	100%	100%	100%	100%	100%	100%	100%	100%
			SID								
			None								
			Total	100%	100%	100%	100%	100%	100%	100%	100%
		N0907	Standard	100%	100%	100%	100%	100%	100%	100%	100%
			SID								
			None								
			Total	100%	100%	100%	100%	100%	100%	100%	100%
		N0908	Standard	100%	100%	100%	100%	100%	100%	100%	100%
			SID								
			None								
			Total	100%	100%	100%	100%	100%	100%	100%	100%
		N0909	Standard	100%	100%	100%	100%	100%	100%	100%	100%
			SID								
			None								
			Total	100%	100%	100%	100%	100%	100%	100%	100%
		N09DIR	Standard	100%	100%	100%	100%	100%	100%	100%	100%
			SID								
			None								
			Total	100%	100%	100%	100%	100%	100%	100%	100%
		E09	Standard	100%	100%	100%	100%	100%	100%	100%	100%
			SID								
			None								
			Total	100%	100%	100%	100%	100%	100%	100%	100%
		S09	Standard	100%	100%	100%	100%	100%	100%	100%	100%
			SID								
			None								
			Total	100%	100%	100%	100%	100%	100%	100%	100%

Figure E-6. Flight track dispersion by-aircraft type.

tab caused the operations used to model the different parameters to change as follows:

- Modeling operations for Fuel Burn increased by approximately ten operations compared to the original operations for SID dispersion;
- Operations to model NO_x increased by eight operations; and
- The THC modeling related operations decreased by eight operations.

Having verified that the modeled operations for noise and emissions changed as expected, the last task is to record all information on the assumptions implemented into the Notes field of the scenario information tab, Figure E-7, update the date, and save the scenario making sure that the file has been

Scenario Information

Date:	11/16/2012
Name:	Sample analysis - Baseline
Description:	This scenario represents the Airport's baseline condition for the sample analysis.
Notes*:	The 737300 aircraft in the current fleet was adjusted to reflect the different engine version mounted on the actual aircraft. All Heavy and Large Aircraft modeled to user RNAV dispersion with the exception of the 727EM2, CRJ9-ER, DC95HW, MD82, and MD83 which use standard flight track dispersion. All Small and Propellar aircraft also use standard dispersion.

Figure E-7. Completed baseline scenario information.

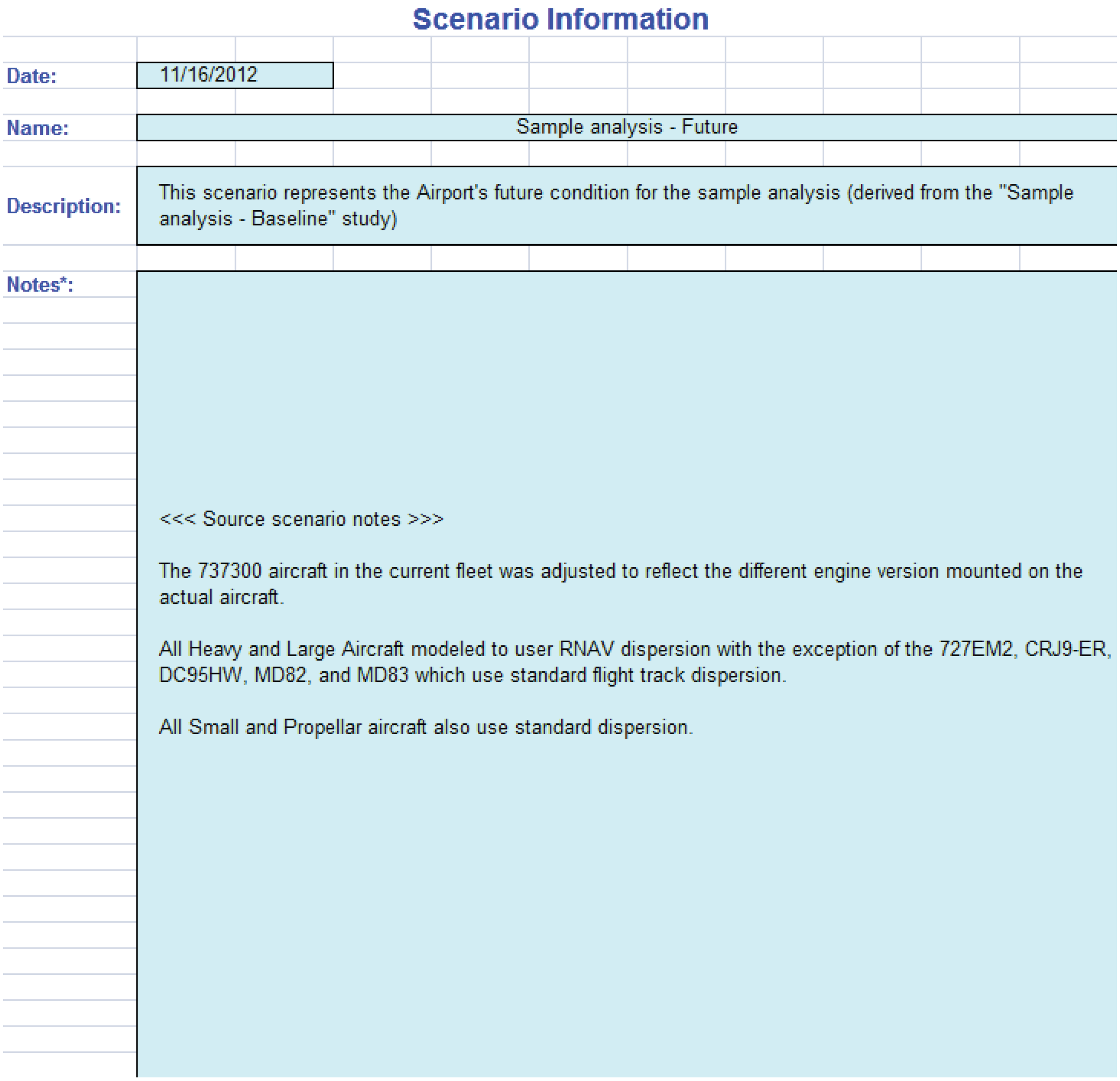
renamed to avoid overwriting the original application blank template.

E-3. Future Scenario Setup

The future scenario for this example is the alternative condition in which the previously described fleet changes are implemented. The scenario development comprises two steps: (1) the implementation of the actual fleet changes, both in terms of source characteristics and performance, and (2) the revision of the airport procedure and flight track utilization to optimize the system's environmental performance. Since the future scenario is a variation of the baseline, the initial work performed can be directly leveraged by using it as the starting point for the new scenario. The first step is therefore to create a copy of the baseline scenario file with a new name that reflects what the new scenario will represent.

E-3.1. Scenario Information

After opening the new file the first step is to update the information contained in the scenario information tab to reflect the new scenario intent. As shown in Figure E-8, the description field in this case also includes a note regarding the original source of the study. This information can be helpful in tracing the genesis of the data contained. Alternatively, this background information can be maintained by not deleting the information entered in the notes field during the development of the



Scenario Information

Date: 11/16/2012

Name: Sample analysis - Future

Description: This scenario represents the Airport's future condition for the sample analysis (derived from the "Sample analysis - Baseline" study)

Notes*:

<<< Source scenario notes >>>

The 737300 aircraft in the current fleet was adjusted to reflect the different engine version mounted on the actual aircraft.

All Heavy and Large Aircraft modeled to user RNAV dispersion with the exception of the 727EM2, CRJ9-ER, DC95HW, MD82, and MD83 which use standard flight track dispersion.

All Small and Propellar aircraft also use standard dispersion.

Figure E-8. Future scenario information.

source file and then adding notes on the changes applied to create the new analysis.

E-3.2. Fleet Technology Adjustments

This example's future scenario prescribes that the A319neo aircraft will be introduced in the airport's fleet. Since this aircraft does not appear in the set included within the application, it needs to be modeled using a replacement adjusted to reflect the new aircraft characteristics. Actual certification noise and emissions data is not available for the new aircraft, so the adjustments have to be based on the information that is available from the manufacturer. The new aircraft should be modeled using the A319 entry within the tool's future fleet aircraft set. Using the alternative set allows controlling its utilization and parameters separately without influencing the way the current fleet is setup and operated within the model.

The Airbus website does not provide specific information on the performance of the A319neo—the link points to a document that mentions the aircraft type, but provides more specific information for the A320 version. For the purposes of this example, the assumption is made that the A320 data is applicable to A319neo. Based on Airbus, the A319neo aircraft will be able to achieve the following:

- 15dB below Chapter 4 limit,
- 50% less NO_x emissions compared to the CAEP/6 limit, and
- 15% reduction in fuel burn.

The noise adjustment has to be performed based on the departure certification information for the A319 in the tool as well as the departure Chapter 4 noise limit. The Chapter 4 cumulative limit for a departure operation of an aircraft of its weight is 186.5 dB; the aircraft in the tool has an average departure certification level of 88.1, which means that the cumulative departure level was 176.2 dB (the average value times 2). Based on this information, the original A319 already achieves 10.3 dB below the Chapter 4 margin, so the A319neo will require an additional reduction of 4.7 dB.

To determine NO_x emissions reduction necessary to model the new aircraft using the one existing in the database, the information for the existing aircraft relative to the CAEP/6 standard needs to be assessed. A review of the information in the engine emissions databank shows that the original engine was slightly over the CAEP/6 limit for NO_x (101.1% of the limit). Based on this information, to reflect the 50% below CAEP/6 limit figure provided by Airbus will require the adjustment factor to be 51.1%, the predicted reduction plus the overage the original aircraft's engines exhibited.

Finally, the fuel burn adjustment needs to be applied to both the fuel burn for the future aircraft as well as to all the remaining pollutants. Since the manufacturer did not provide any information for other pollutants beyond NO_x, applying the fuel burn adjustment to the other pollutants needs to be carefully considered. In the case of CO_2, H_2O, and SO_x, the adjustment should be applied because these emissions are modeled as 100% proportional to fuel burn. For CO and THC emissions, care must be taken as they are not modeled proportional to fuel burn. Without any further data, the user may choose not to model these emissions or simply apply the fuel burn adjustment as a rough, first-order approximation to obtain some "ball-park" numbers. For example purposes, the fuel burn adjustment will be applied to CO and THC emissions. Figure E-9 shows the updated Future fleet entry for the A319 along with the comment that explains what the adjustments are meant to replicate.

E-3.3. Airport Operations

The future scenario for this example calls for 90% of the 737-300 operations to be moved to the new A319 aircraft modeled in the future fleet. For example, the 737-300 day operations decreases from 76.67 to 7.67 (69 difference) while the A319 day operations increases from 14.19 to 83.19 (69 increase). Since the A319 aircraft already has operations assigned to it in the baseline scenario, the fleet assignment percentages have to be calculated so as to preserve the appropriate fleet assignments. The percentage split between the Current and Future fleets for the A319 are therefore computed by determining the percentage the two sets of original day and night operations represent of the new totals. For example, 69 new A319 aircraft (A319neo) out of the 83.19 total A319 aircraft represent approximately 83%.

Current and Future Fleet Technology Definition

					Emissions Reduction (%)						
Tech Group	Aircraft Category	Aircraft	Noise Reduction (dB)	Fuel Burn Reduction (%)	NO_X	CO	THC	CO_2	SO_X	H_2O	Notes
Future	HEAVY	747400									
		767300									
		777200									
		777300									
		A300-622R									
		A300B4-203									
		A310-304									
		A340-211									
		A380-841									
		DC1030									
		MD11GE									
	LARGE	717200									
		727EM2									
		737300									
		737700									
		737800									
		757RR									
		A319-131	4.7	15.0%	51.1%	15.0%	15.0%	15.0%	15.0%	15.0%	A319neo - Based on A320neo info.
		A320-211									
		A320-232									
		A321-232									
		CL601									
		CRJ9-ER									
		DC95HW									
		EMB145									
		EMB14L									
		GV									
		MD82									
		MD83									
	SMALL	CL600									
		CNA55B									
		CNA750									
		FAL20									
		IA1125									
		LEAR35									
		MU3001									
	PROP	DHC6									
		DHC8									
		DHC830									
		HS748A									

Figure E-9. Future fleet adjustment data.

The future CRJ9 in this example does not receive modifications that affect its environmental performance at the source level, but instead it will be modified to fly more precise trajectories as compared to the original aircraft. This upgrade can be simply modeled within the tool by changing the percentage assignment for the dispersion utilizations while leaving all operations assigned to the Current aircraft fleet. However, as a modeling preference and to make this scenario setup more easily understandable, the operations for the upgraded aircraft are assigned to the Future fleet even if the future aircraft environmental parameters have not been modified as in the case of the A319neo (i.e., the results will make no difference whether the CRJ9 operations are assigned to the Current or Future fleet). Assuming a 30/70 split, the Current fleet is reassigned only 30% of the operations while the Future fleet is given the remaining 70%. Figure E-10 presents the results of all of the aforementioned changes to the operations.

E-3.4. Runway and Flight Track Utilization

In the future scenario that represents the do-nothing condition, no changes are necessary to the runways and flight

Fleet Operations and Technology Distribution Setup

Aircraft Category	Aircraft	Operations			Technology Mix (%)					
					Day Ops		Night Ops		Total Ops	
		Day	Night	Total	Current	Future	Current	Future	Current	Future
HEAVY	747400			0.00	100%	0%	100%	0%	-----	-----
	767300	0.33	0.00	0.33	100%	0%	100%	0%	100.0%	0.0%
	777200			0.00	100%	0%	100%	0%	-----	-----
	777300			0.00	100%	0%	100%	0%	-----	-----
	A300-622R	2.14	0.00	2.14	100%	0%	100%	0%	100.0%	0.0%
	A300B4-203	2.05	0.00	2.05	100%	0%	100%	0%	100.0%	0.0%
	A310-304	2.44	0.13	2.57	100%	0%	100%	0%	100.0%	0.0%
	A340-211			0.00	100%	0%	100%	0%	-----	-----
	A380-841			0.00	100%	0%	100%	0%	-----	-----
	DC1030			0.00	100%	0%	100%	0%	-----	-----
	MD11GE			0.00	100%	0%	100%	0%	-----	-----
	Total	6.96	0.13	7.09						
LARGE	717200	47.57	5.29	52.86	100%	0%	100%	0%	100.0%	0.0%
	727EM2	0.54	4.86	5.40	100%	0%	100%	0%	100.0%	0.0%
	737300	7.67	0.85	8.52	100%	0%	100%	0%	100.0%	0.0%
	737700	38.64	4.29	42.93	100%	0%	100%	0%	100.0%	0.0%
	737800	2.74	0.69	3.43	100%	0%	100%	0%	100.0%	0.0%
	757RR	6.41	0.71	7.12	100%	0%	100%	0%	100.0%	0.0%
	A319-131	83.19	9.25	92.44	17%	83%	17%	83%	17.0%	83.0%
	A320-211	0.36	0.04	0.40	100%	0%	100%	0%	100.0%	0.0%
	A320-232	1.14	0.13	1.27	100%	0%	100%	0%	100.0%	0.0%
	A321-232	0.04	0.00	0.04	100%	0%	100%	0%	100.0%	0.0%
	CL601	0.19	0.02	0.21	100%	0%	100%	0%	100.0%	0.0%
	CRJ9-ER	43.07	4.79	47.86	30%	70%	30%	70%	30.0%	70.0%
	DC95HW	8.81	0.98	9.79	100%	0%	100%	0%	100.0%	0.0%
	EMB145	12.73	1.41	14.14	100%	0%	100%	0%	100.0%	0.0%
	EMB14L	14.44	1.60	16.04	100%	0%	100%	0%	100.0%	0.0%
	GV			0.00	100%	0%	100%	0%	-----	-----
	MD82	28.05	3.12	31.17	100%	0%	100%	0%	100.0%	0.0%
	MD83	13.44	1.49	14.93	100%	0%	100%	0%	100.0%	0.0%
	Total	309.03	39.52	348.55						
SMALL	CL600	0.47	0.05	0.52	100%	0%	100%	0%	100.0%	0.0%
	CNA55B	8.77	0.11	8.88	100%	0%	100%	0%	100.0%	0.0%
	CNA750	1.35	0.15	1.50	100%	0%	100%	0%	100.0%	0.0%
	FAL20	3.19	0.00	3.19	100%	0%	100%	0%	100.0%	0.0%
	IA1125	0.35	0.01	0.36	100%	0%	100%	0%	100.0%	0.0%
	LEAR35	4.04	0.08	4.12	100%	0%	100%	0%	100.0%	0.0%
	MU3001	0.28	0.02	0.30	100%	0%	100%	0%	100.0%	0.0%
	Total	18.45	0.42	18.87						
PROP	DHC6	3.54	0.39	3.93	100%	0%	100%	0%	100.0%	0.0%
	DHC8			0.00	100%	0%	100%	0%	-----	-----
	DHC830			0.00	100%	0%	100%	0%	-----	-----
	HS748A	0.24	0.03	0.27	100%	0%	100%	0%	100.0%	0.0%
	Total	3.78	0.42	4.20						
	Grand Total	338.22	40.49	378.71						

Figure E-10. Future scenario operations.

track utilization tables, both by-aircraft category and by-aircraft type, for the Current fleet. However, since no information was previously entered for the Future fleet, both the runway and flight tracks information for that fleet need to be updated. In the do-nothing future scenario, these utilization values can be set to match those for the Current fleet. The values will need to be updated at a later stage during the optimization process to determine what benefits can be achieved by assigning the new aircraft to use more efficient procedures. Figure E-11 shows the initial runways and flight track utilizations for the Future fleet (only track information for the Future fleet shown).

Runway and Flight Track Utilization by Aircraft Category

Runway Utilization

Tech Group	Runway	Heavy		Large		Small		Propeller	
		Day	Night	Day	Night	Day	Night	Day	Night
Current	09	45%		45%		30%	15%	15%	40%
	27	45%		45%		30%		15%	40%
	28	10%	100%	10%	100%	40%	85%	70%	20%
	Total	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*
Future	09	45%		45%		30%	15%	15%	40%
	27	45%		45%		30%		15%	40%
	28	10%	100%	10%	100%	40%	85%	70%	20%
	Total	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*

Flight Track Utilization

Tech Group	Runway	Track	Heavy		Large		Small		Propeller	
			Day	Ngt	Day	Ngt	Day	Ngt	Day	Ngt
Future	09	N09NAP	65%	65%	65%	65%	65%	65%	65%	65%
		N0902								
		N0903								
		N0904								
		N0905								
		N0906								
		N0907								
		N0908								
		N0909								
		N09DIR								
		E09	15%	15%	15%	15%	15%	15%	15%	15%
		S09	20%	20%	20%	20%	20%	20%	20%	20%
		Total	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*
	27	N27NAP	65%	65%	65%	65%	65%	65%	65%	65%
		N2702								
		N2703								
		N2704								
		N2705								
		N2706								
		N2707								
		N2708								
		N2709								
		N27DIR								
		W27	30%	30%	30%	30%	30%	30%	30%	30%
		S27	5%	5%	5%	5%	5%	5%	5%	5%
		Total	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*
	28	N28	55%	55%	55%	55%	55%	55%	55%	55%
		W28	25%	25%	25%	25%	25%	25%	25%	25%
		S28	20%	20%	20%	20%	20%	20%	20%	20%
		Total	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*

Figure E-11. Runway and flight track utilization by-aircraft group (only track information for the Future fleet shown).

E-3.5. Flight Track Dispersion Utilization

Since the updated CRJ9 operations were assigned to the Future fleet in the operations tab and the A319neo also possess the same capability, the dispersion settings for the large aircraft category in the future fleet also need to be set to use the SID dispersion for all tracks. Figure E-12 shows the dispersion utilization by-aircraft category for the Future fleet (only one runway shown). No changes are required to the dispersion utilization by-aircraft table.

E-3.6. Operations Review

After having input the entire new scenario information, a review of the noise and emissions modeled operations and a comparison to the related actual operations should be conducted to ensure that the scenario reflects the changes that were intended. As expected, the number of both the noise and emissions modeled operations for the new A319neo aircraft reflect the reduction expected based on the adjustment values provided in the technology tab. The operations for the CRJ9

Flight Track Dispersion by Aircraft Category

				Flight Track Dispersion							
Tech Grou	Runway	Track	Dispersion	Heavy		Large		Small		Propeller	
				Day	Ngt	Day	Ngt	Day	Ngt	Day	Ngt
Future	09	N09NAP	Standard					100%	100%	100%	100%
			SID	100%	100%	100%	100%				
			None								
			Total	100%	100%	100%	100%	100%	100%	100%	100%
		N0902	Standard					100%	100%	100%	100%
			SID	100%	100%	100%	100%				
			None								
			Total	100%	100%	100%	100%	100%	100%	100%	100%
		N0903	Standard					100%	100%	100%	100%
			SID	100%	100%	100%	100%				
			None								
			Total	100%	100%	100%	100%	100%	100%	100%	100%
		N0904	Standard					100%	100%	100%	100%
			SID	100%	100%	100%	100%				
			None								
			Total	100%	100%	100%	100%	100%	100%	100%	100%
		N0905	Standard					100%	100%	100%	100%
			SID	100%	100%	100%	100%				
			None								
			Total	100%	100%	100%	100%	100%	100%	100%	100%
		N0906	Standard					100%	100%	100%	100%
			SID	100%	100%	100%	100%				
			None								
			Total	100%	100%	100%	100%	100%	100%	100%	100%
		N0907	Standard					100%	100%	100%	100%
			SID	100%	100%	100%	100%				
			None								
			Total	100%	100%	100%	100%	100%	100%	100%	100%
		N0908	Standard					100%	100%	100%	100%
			SID	100%	100%	100%	100%				
			None								
			Total	100%	100%	100%	100%	100%	100%	100%	100%
		N0909	Standard					100%	100%	100%	100%
			SID	100%	100%	100%	100%				
			None								
			Total	100%	100%	100%	100%	100%	100%	100%	100%
		N09DIR	Standard					100%	100%	100%	100%
			SID	100%	100%	100%	100%				
			None								
			Total	100%	100%	100%	100%	100%	100%	100%	100%
		E09	Standard					100%	100%	100%	100%
			SID	100%	100%	100%	100%				
			None								
			Total	100%	100%	100%	100%	100%	100%	100%	100%
		S09	Standard					100%	100%	100%	100%
			SID	100%	100%	100%	100%				
			None								
			Total	100%	100%	100%	100%	100%	100%	100%	100%

Figure E-12. Flight track dispersion by-aircraft category (only one runway shown).

also confirm that in the new scenario the aircraft is now using the RNAV dispersion tracks in the percentage intended.

E-3.7. Loading the Reference Scenario

The final preparatory step in the setup of the future scenario is the loading of the data for the reference (baseline) scenario. The reference scenario data is loaded from a previously developed file (i.e., the previously developed baseline scenario file). Figure E-13 shows the information that appears in the reference scenario results tab after the sample base information/data has been loaded (baseline scenario results only partially shown). The scenario information section allows identifying the file from which the data was retrieved, which is important since the information in this sheet is not updated if changes are made to the external file.

E-3.8. Initial Results

In the future scenario of this example, two fleet changes have been introduced: the arrival of a new aircraft and the upgrade of the navigation technology for another. Both changes affect the noise footprint of the aircraft and their fuel burn and emissions levels. The new Airbus A319neo has the largest effect as compared to the baseline condition as it affords significant reductions for all parameters. The new avionics on ERJ9, however, also afford a reduction as the narrower dispersion affects both the location of the aircraft in flight as well as the distance traveled. The narrower dispersion reduces the reach of its noise effects and also causes the aircraft to fly a different distance, which directly relates to the amount of fuel burned and pollutants produced.

A review of the noise values in the "Results" tab shows how the simple introduction of these two changes has positively affected the noise exposures around the sample airport. The SEL noise levels show reductions that range from 0.1 to 0.6 dB while the points of maximum noise change show a 0.1 dB reduction for the two POI points, a 0.6 dB reduction at the City1 point, and a 0.9 dB reduction at the City2 point. Additionally, the emissions results summary tab shows that even without changing the way the fleet utilizes the facilities, the airport will experience improvements to its environmental footprint. As shown in Figure E-14, the "Emissions Results Summary" tab shows that the fleet changes returned an overall 5.4% reduction in fuel burn, 9.2% decrease in NO_x, 11.4% reduction in CO, and 1% decrease in THC. As previously indicated, these results for CO and THC are "ballpark" estimates as only the fuel burn adjustment was applied to them (i.e., no pollutant-specific adjustments reflecting engine characteristics).

E-3.9. Multi-turn NAP Optimization

The final step in the analysis is to assess what can be achieved by allowing the new aircraft to fly more direct flight paths for the Multi-turn NAP procedure. The analysis has to be performed by reassigning the operations for the aircraft of interest to progressively more direct trajectories until the noise change results in an unacceptable increase over the populated areas of the City2 location point, which is the closest point. To

Baseline Scenario Selection and Results

Scenario Information	
Date	11/16/2012
Name	Sample analysis - Baseline
Description	This scenario represents the Airport's baseline condition for the sample analysis.
File Name	DOIT V1-BASELINE.xlsb
File Path	C:\Example\

Load Scenario　Clear

Location Point			Point Description	Scenario Results	Fuel Burn and Emissions Inventory (Kg)						
Runway	Track	Point Number		SEL (dB)	FB	NO_X	CO	THC	CO_2	SO_X	H_2O
---	---	CITY1	Point of maximum noise change	83.0	---	---	---	---	---	---	---
---	---	CITY2	Point of maximum noise change	81.7	---	---	---	---	---	---	---
---	---	POI_S27	Point of maximum noise change	93.0	---	---	---	---	---	---	---
---	---	POI_S28	Point of maximum noise change	91.3	---	---	---	---	---	---	---
09	E09	02	Point 2 miles from study center	107.9							
09	E09	03	Point 3 miles from study center	102.4							
09	E09	04	Point 4 miles from study center	99.4							
09	E09	05	Point 5 miles from study center	97.3							
09	E09	06	Point 6 miles from study center	95.7							
09	E09	07	Point 7 miles from study center	93.8	9620.5	165.1	7.1	0.5	29487.8	11561.5	12.1
09	E09	08	Point 8 miles from study center	91.2							
09	E09	09	Point 9 miles from study center	88.5							
09	E09	10	Point 10 miles from study center	86.4							
09	E09	11	Point 11 miles from study center	85.0							
09	E09	12	Point 12 miles from study center	84.2							

Figure E-13. Loaded baseline scenario data in the baseline scenario tab.

	Reduction From Baseline Scenario						
Runway	Fuel Burn and Emissions Inventory (Kg)						
	FB	NO_X	CO	THC	CO_2	SO_X	H_2O
09	3844.2	111.4	6.4	0.0	6484.6	2542.5	2.7
27	3668.4	106.5	6.1	0.0	6158.0	2414.4	2.5
28	1736.2	50.5	2.9	0.0	2913.8	1142.4	1.2
Total	9248.8	268.4	15.5	0.1	15556.3	6099.3	6.4
% of Ref	5.4%	9.2%	11.4%	1.0%	3.0%	3.0%	3.0%

Figure E-14. Fuel burn and emissions reductions resulting from the introduction of fleet changes.

facilitate the process, a new duplicate window (by selecting "New Window" under the "View" ribbon) is created for the results tab and the view of the original window is switched to show the Utilization by-aircraft tab. Placing the two windows side-by-side (by selecting "Arrange All" in the "View" ribbon and picking the "Vertical" option in the dialog box) allows the user to make changes to the scenario and observe the results at the same time without having to continuously toggle between the two different tabs.

The first change consists of reassigning the A319neo and upgraded ERJ9 operations to the more direct flight tracks by updating the Large aircraft Future fleet utilization by-aircraft percentages for the N09 tracks. Since both aircraft were modeled as Future fleet this change moves both aircraft to new tracks. By iteratively selecting the more direct flight track and monitoring the noise changes the flights in this example can be moved all the way to the direct flight track (N09DIR) without affecting the level at the City2 location point. This result means that the decrease in noise level of the new aircraft plus the effects of the narrower dispersion for the ERJ9 provide enough reduction to possibly allow the whole fleet operating on the Multi-turn NAP to be moved to a more efficient trajectory. The reassignment can be approached in two ways: (1) by moving the two aircraft and the remainder of the fleet independently, or (2) by moving them all as a whole.

To explore the first scenario the flight track utilization by category in the Current fleet for all aircraft categories has to be changed by progressively reassigning the utilization percentages to the more direct flight paths. A few iterations of this process reveal that the N0903 flight track is the most efficient track all Current fleet operations can be assigned to without negatively affecting the noise levels at the City2 point. The noise level improvement changes from 0.9 dB for the unmodified scenario to 0.2 dB once the new utilization is implemented. At the same time, the total fuel burn reduction increases almost another 2% while NOx emissions reduction increases by about 1.5%.

To review the second scenario the operations of the two aircraft in the Future fleet need to be first reassigned to the same flight track as the remainder. Since the previous scenario showed that flight track N0903 was a feasible option, the first track to attempt would be N0904 based on the assumption that the noise reduction afforded by moving the two aircraft in the new fleet farther away from the City2 point will provide enough surplus to accommodate the Current fleet as well. The resulting noise change level, however, reveals that moving the two aircraft does not provide enough and moving the whole fleet to flight track N0904 still results in an increase in noise level at the point of interest. This result means that in this situation, it is best to have the Future fleet flying the direct track and the other aircraft the N0903 flight path, which maximizes the fuel burn and emissions saving without adversely affecting the noise exposures.

In this example, the analysis treated the Future and Current fleets as single blocks and all changes were performed at that level. The results, however, highlight the possibility that changes to the way other aircraft fly could be implemented to further improve the environmental performance of the multi-turn NAP procedure off of runway 09. The maximum reductions can potentially be achieved by an analysis that assesses the benefits resulting from allowing different aircraft to fly different flight tracks.

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
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
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