THE IMPACT OF NATIONAL AIRSPACE SYSTEMS (NAS) MODERNIZATION ON AIRCRAFT EMISSIONS

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Executive Summary

Any change in the National Airspace System (NAS) operational concept or architecture has a potential effect on the global environment. The environmental impacts have significant global implications and are of interest to the International Civil Aviation Organization (ICAO) community. The ICAO Committee on Aviation Environmental Protection (CAEP) is charged with the development of international standards and recommended practices for measuring and controlling aircraft noise and engine emissions. Historically, CAEP activities have been directed toward improving methods for measuring gaseous emissions and considering increases in stringency of the standards. More recently, the CAEP has expanded its consideration to include operational measures that have the potential to reduce aviation emissions, including Communication, Navigation, and Surveillance/Air Traffic Management (CNS/ATM) implementation. The concept that the U.S. community is focusing on for modernization, including CNS/ATM, is Free Flight.

Government and industry agree that a reduction in air traffic control restriction has an enormous potential for time and resource savings. This consensus is well documented in RTCA task force reports and in the National Civil Aviation Review Commission Report. They note that any activity that removes such ATC restrictions represents a move toward Free Flight.

In support of Free Flight, the Federal Aviation Administration (FAA) is investing billions of dollars to provide new/enhanced capabilities through the introduction of CNS/ATM technologies into the NAS. These new capabilities and services are embodied in the government/industry concept of operations. This concept forms the basis for introduction and integration of these technologies in the NAS Architecture, the aviation community's roadmap to modernization. It is expected that with the deployment of these new capabilities, users will get better services, such as more wind-optimized cruise trajectories and altitudes and more efficient surface traffic operations.

This report provides further evidence to support the pursuit of Free Flight initiatives by extending the analysis to include associated environmental benefits. In essence, if Free Flight results in lower fuel burn by users, a corollary benefit is less pollution—a clear environmental benefit that is often overlooked.

In particular, the study evaluated the fuel and emission benefits of Free Flight by aircraft type and phase of flight. Calculations for aircraft emissions were made for pollutants directly produced within the engine combuster and emitted at a rate depending on the temperature and thrust of the engine—in this instance, specifically for nitrogen oxides (NOx), hydrocarbons (HC) and carbon monoxide (CO). These calculations used emission indices in terms of unit of pollutant per 1,000 units of fuel burned for each phase of flight. The emissions for other gases such as carbon dioxide and sulfur dioxide were not included as part of this study.

Two scenarios were developed for use throughout the study, a baseline scenario representing the future airspace system without modernization and an enhanced scenario representing key technologies and operational capabilities that are planned for introduction into the NAS. Comparison of these two scenarios indicates that the CNS/ATM enhancements to the NAS have a

potential annual fuel savings of over 10 billion pounds in the year 2015, which represents a savings of 6% over what would have been expended without NAS modernization. The phase of flight above 3,000 feet, which offers capability for more fuel efficient flight operations, accounts for 94% of the savings, with remaining savings occurring on the surface and below 3,000 ft. This combined fuel savings translates to an annual reduction in emissions of over 209 million pounds of NOx, 211 million pounds of CO, and 59 million pounds of HC, representing savings of over 9%, 12%, and 18%, respectively.

Findings from this study were reported at the International Civil Aviation Organization (ICAO) Worldwide CNS/ATM Systems Implementation Conference in May 1998 and are highlighted below.

Annual Savings in Millions of Pounds

Phase of Flight	Fuel	NOx	CO	HC
Above 3,000	9,683	204.3	197.1	56.7
Below 3,000	219	4.0	1.1	0.1
Surface	358	1.2	13.2	3.1
Total	10,259	209.5	211.4	59.9
% Savings	6.1%	9.9%	12.7%	18.0%

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Section

1

INTRODUCTION

1.1 Organization

This report compiles the sources, tools, methodologies, and results of the impact study and is organized as follows. Section 1 provides a discussion of Free Flight, the Air Traffic Services Concept of Operations, and the National Airspace System (NAS) Architecture, all of which formed the technological base for the study. The scope of the study is also found in this section. Section 2 contains the broad assumptions applied to the analysis.

Section 3 introduces the modeling scenarios and discusses their development. Data preparation necessary to begin the analysis is presented in Section 4. The analysis of the baseline and enhanced scenarios is contained in Section 5 and is organized under four major headings: Airborne, Surface, Oceanic, and Emissions. Section 6 summarizes the results of the analysis and includes a discussion on extending the results to annual savings and converting the fuel savings to dollars. Section 7 covers the study's conclusions. The appendices provide additional detail used in the analysis, a description of the tools and models, and a list of the study's participants.

1.2 Background

The NAS Architecture is the U.S. aviation community's roadmap for modernization. It provides a high-level description of NAS capabilities and services, the functions to be performed, their dependencies and interactions, and the flow of information among the functions. It also describes the schedule and costs necessary to implement the capabilities and services defined in the Air Traffic Services Concept of Operations.

Any change in concept or architecture has a potential effect on the global environment. The environmental benefits to be gained from a more efficient airspace system have significant global implications and are of interest to the International Civil Aviation Organization (ICAO) community. The ICAO Committee on Aviation Environmental Protection (CAEP) is charged with the development of international standards and recommended practices for measuring and controlling aircraft noise and engine emissions. Historically, CAEP activities have been directed toward improving methods for measuring gaseous emissions and considering increases in stringency of the standards. More recently, the CAEP has expanded its consideration to include operational measures that have the potential to reduce aviation emissions, including Communication, Navigation, and Surveillance/Air Traffic Management (CNS/ATM) implementation. The concept that the U.S. community is focusing on for modernization, including CNS/ATM, is Free Flight.

"Free Flight is defined as the safe and efficient flight operating capability under instrument flight rules in which the operators have the freedom to select their path and speed in real-time. Air traffic restrictions are imposed only to ensure separation, to preclude exceeding airport capability, to prevent unauthorized flights through special use airspace, and to ensure safety of flight. Restrictions are limited in extent and duration to correct the identified problem. Any activity that removes restrictions represents a move towards Free Flight."

On October 31, 1995, RTCA Task Force 3 on Free Flight Implementation published a final report that defined the Free Flight operational concept, evaluated the Free Flight Architecture and technology needs, and identified an incremental transition to Free Flight. Task Force 3 expanded on the definition of Free Flight to include: "... user is granted both maximum flexibility and guaranteed safe separation. The goal is not only to 'optimize' the system but also to open the system for each user to 'self-optimize'." Self-optimization is the key to understanding the extent of Free Flight's reach, as well as Free Flight challenges.

"Free Flight is not limited to airspace--its spatial constraints are gate to gate, but Free Flight reaches into a flight's prehistory by providing increased flexibility in flight planning. In the broadest sense, Free Flight is the unrestricted opportunity for all to use the limited airspace in a manner that is efficient, effective, and equitable."[1]

Free Flight's influence on NAS modernization promotes the easing of ATC restrictions. As a result, there is a general consensus between government and industry that this easing of ATC restrictions has an enormous potential for time and resource savings for future flights. This consensus is well documented in RTCA task force reports and in the National Civil Aviation Review Commission Report. In response, the FAA is developing a concept for investing in planning and new technologies for CNS/ATM in the NAS.

In September 1997, FAA Air Traffic Services (ATS) published *A Concept of Operations for the National Airspace System in 2005* reflecting the joint efforts of the FAA and Industry, through RTCA, to implement Free Flight. That document describes the evolutionary changes needed to meet the user needs for greater flexibility in planning and conducting flight operations. Specifically, the air traffic system will evolve in the areas of airspace and procedures, roles and responsibilities, equipment, and automation. Once fully implemented the Concept of Operations will provide the following:

- Prior to flight, *sharing of real-time information* between the users and the service provider that ensures greater system flexibility—including departure time and traffic load

[1] Free Flight Action Plan Update, April 2, 1998, pp. 2-3

prediction and flight plans that optimize around weather, outages and traffic density constraints.

- Prior to taxiing, surface automation that facilitates the *coordination of all surface activities*, including runway and taxiway assignments based on projected runway loading and surface congestion (user preference and environmental considerations such as noise abatement will be considered).

- Arrival runway and taxiway assignments based on gate assignment and surface congestion, providing the *most efficient arrival and taxi execution.*

- Departure assignments made when the flight profile is filed, and updated accordingly until the time of pushback providing the best sequence to departure threshold, *maximizing runway throughput and minimizing queue delay.*

- During departure and arrival operations, decision support systems that *assist the service provider in providing runway assignments and in merging and sequencing traffic,* based on accurate traffic projections and user preferences.

- During en route/cruise operations, improved decision support tools for conflict detection, resolution, and flow management that allow *increased accommodation of user-preferred trajectories, schedules, and flight sequences.*

- For oceanic flights, global satellite navigation and a communication system using satellite-based communications and electronic message routing—enabling the oceanic system to be more interactive and dynamic and supporting cooperative activities among flight crews, Airline Operations Centers (AOCs), and service providers. This will result in *reduced separation between aircraft, and more flexible and preferred routes.*

These new capabilities and services are embodied in the government/industry concept of operations, which forms the basis for the introduction and integration of these technologies in the NAS Architecture.

This report describes the collaborative effort involving industry and government in supporting a study of these CNS/ATM enhancements and their benefits to users and the environment. Included are the analysis and findings of the study, along with participants from the FAA, National Aeronautics and Space Administration (NASA), Air Transportation Association (ATA), and three airlines. (For a list of study team participants and advisors, see Appendix A.) The study also contributes to the ICAO CAEP activities, Free Flight and validation of concept of operations and provides supporting information to issues that were discussed at the Worldwide Environmental Conference held in Kyoto, Japan in December 1997.

Findings from this study were presented at the ICAO Worldwide CNS/ATM Systems Implementation Conference in May 1998 and are expected to continue to receive environmental interest in the future.

1.3 Objective

The objective of the study was to examine benefits of the planned CNS/ATM enhancements in accordance with the Concept of Operations and the NAS Architecture V3.0 Draft, dated December 1997, to support Free Flight and NAS Modernization.

In particular, the study evaluated the fuel and emission benefits of the planned CNS/ATM enhancements by aircraft type and phase of flight, i.e., taxi-out, climb, cruise, approach, and taxi-in. Calculations for aircraft emissions were made for nitrogen oxides (NOx), hydrocarbons (HC), and carbon monoxide (CO). These were chosen because they were the principal emissions included in previous studies of this nature. Other pollutants, such as carbon dioxide and sulfur dioxide, are also emitted but were not included as part of this study.

1.4 Scope

This analysis covers the planned CNS/ATM concepts and technologies that are outlined in the NAS Architecture V3.0 Draft for the U.S. controlled oceanic airspace, en route and terminal airspace, and airport surface operations. The time frame for the study is from 1996 to 2015.

Section 2

ASSUMPTIONS

The study began with the development of key assumptions regarding baseline and future operations.

- Fuel and emission calculations cover only Instrument Flight Rule (IFR) flight plan traffic.
- The airspace structure and procedures will be modified in the future years of the study to incorporate CNS/ATM enhancements. These enhancements are described in paragraph 3.3.
- Systems will be deployed and users will equip according to the schedules in the NAS Architecture V3.0 Draft. These systems will reach full capability as planned currently.
- All airport improvements that are planned currently and any near-term procedural improvements were used in both scenarios.
- The 1996 Terminal Area Forecast (TAF) was used to forecast future traffic.
- A fleet mix forecast, derived from ICAO, NASA, and FAA Office of Aviation Policy and Plans (APO) forecasts, was used as the current and future domestic fleet mix.

More detailed assumptions, applicable to specific analysis areas, were developed during the analytical process. For the report, they are listed in the section to which they apply and also in Appendix B.

Section

3

MODELING SCENARIOS

3.1 Baseline and Enhanced Scenarios

Once the assumptions were agreed upon, an analytical framework was used to create two scenarios that reflect the current operations (baseline scenario) and the future concept of operations (enhanced scenario) in the NAS.

Using 1996 as the base year, the baseline scenario was developed to represent today's NAS operational procedures, enhanced only for committed and projected near-term Airport Improvement Plan (AIP) and procedural improvements. Flight data was collected for aircraft operating in the existing air traffic control (ATC) system of route structures and sector configuration. November 12, 1996, was selected to be a representative day for the baseline scenario, from which all future measurement points were derived.

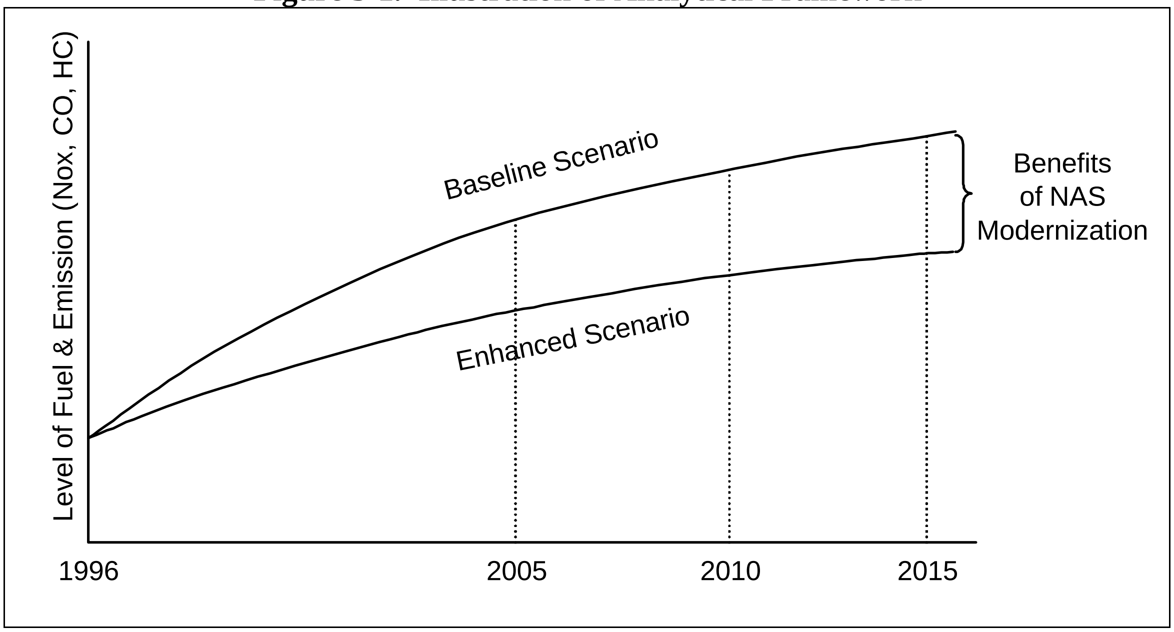
From this base year, the baseline scenario was estimated for three future time intervals of 2005, 2010, and 2015 by applying forecast traffic growth and fleet mix changes. Flights for future years were constructed by increasing the number of flights commensurate with the traffic growth forecasts. The types of aircraft in future inventories were adjusted based on fleet mix forecasts. This set of flights was "flown" in the baseline scenario to estimate fuel consumption and corresponding emissions for 1996, 2005, 2010, and 2015 in an ATC system with only planned AIP and procedural improvements.

The enhanced scenario was derived from the baseline scenario by phasing in key technologies and capabilities to the NAS as outlined in the NAS Architecture V3.0 Draft. These capabilities will provide new services to users, such as direct routes, optimal climb and descent, and expedited taxi clearances. The enhanced scenario reflects capabilities at each of the time intervals noted above.

The flight plans developed for the baseline scenario were used to create wind-optimized flight trajectories for the enhanced scenario. These wind-optimized trajectories were then "flown" in a modernized ATC system with planned AIP and procedural improvements *and* CNS/ATM enhancements to estimate fuel consumption and corresponding emissions in an ATC system reflecting the ATS Services Concept of Operations.

Simulated fuel/emission estimates of users operating in the future NAS with no modernization, (baseline scenario) versus what could be achieved in a NAS with the planned CNS/ATM capabilities and optimal routings, (enhanced scenario) were compared at each of the three time intervals. Comparison of these scenarios, with and without modernization, thus yields incremental estimates of the fuel savings and emissions' reductions for the years 2005, 2010, and 2015. An illustration of the analytical framework, based on the phased-in implementation of new operational capabilities, is shown in Figure 3-1. Further description of the scenario development follows.

Figure 3-1. Illustration of Analytical Framework



3.2 Development Steps Common to Both Scenarios

The following paragraphs discuss how the baseline set of flights was determined, how traffic growth was incorporated, how the planned physical airport improvements and procedural improvements will impact airport capacity, and how the adjustments were made to the fleet mix. These activities are common to both scenarios.

3.2.1 Enhanced Traffic Management System

The Enhanced Traffic Management System (ETMS) was used to develop the study's baseline set of flights, and the ETMS Flight Plan messages were used to construct each aircraft's flight plan database (see Appendix C for additional information on ETMS). ETMS data is derived from several primary sources. The two relevant sources for this study were the Official Airline Guide (OAG) and the NAS computers at the 20 Air Route Traffic Control Centers (ARTCCs). The OAG provided ETMS with the planned schedules of all flights arriving in and/or departing from the U.S. or Canada. The NAS computers provided the filed flight plans and the current state of all Instrument Flight Rules (IFR) air traffic in the CONUS.

3.2.2 Future Demand Generator Tool

The Future Demand Generator (FDG) Tool of the NAS Performance Analysis Capability (NASPAC) Simulation Modeling System (SMS) was used to project traffic growth to 2005, 2010, and 2015. The sources for projected traffic operations were the FAA, APO, which publishes the TAF from present to 2010, and ICAO. The ICAO's world projection was used to complement the FAA/APO projection for the CONUS and forecast oceanic traffic growth. (Additional information on the FDG is found in Appendix C.)

An algorithm was applied to increase the traffic found in the present schedule for each of the 80 airports modeled in NASPAC by applying annual growth factors recorded in the 1996 TAF. The current FDG contains 300 airports that serve air carrier operations predominately and 404 general aviation airports from which growth is adjusted. Traffic growth was projected for both air carrier and general aviation traffic.

3.2.3 Airport Improvement Plan (AIP) and Procedural Improvements

Planned physical airport and ATC procedural improvements that were modeled in both scenarios are discussed in the next two sub-sections. (Additional detail is found in Appendix D.)

3.2.3.1 AIP Physical Airport Improvements

Physical changes to an airport can have a substantial impact on airport capacity. The effect can range from opening a new airport to adding new taxiways that streamline air traffic operations. Runways can be extended to air-carrier length, allowing the airport to accommodate larger aircraft. Airport capacity can be increased by adding to the number of gates or adding room for aircraft to maneuver in the ramp area. However, the change that generally has the greatest impact on capacity is adding a new runway.

Arrival capacity generally is more restrictive than departure capacity. Therefore, the increase in maximum arrival capacity is cited as a measure of the capacity increase. (See Appendix D for a discussion of the physical airport improvements that are expected to increase airport capacity during the 1996-2015 time frame.)

Key input for both scenarios due to physical airport improvements was based on the 1997 Airport Capacity Enhancement Plan and input from the Office of Airport Planning and Programming (APP). The information used as part of the study is as follows:

- Maximum hourly arrival capacity will increase at 16 of the 80 modeled airports during the 1996 to 2005 time frame.

- Maximum hourly arrival capacity will increase at 7 additional airports by 2010.

3.2.3.2 ATC Procedural Improvements

Airport capacity can be impacted significantly by changes in ATC procedures. New procedures can increase the use of existing runways, or they can work in concert with new runways and with CNS/ATM improvements. The following procedural improvements are reflected in the increased airport capacities for both scenarios.

- Converging IFR approaches will be added to independent IFR parallel approaches. This procedure will increase airport capacity greatly at airports with the appropriate configurations, such as Chicago O'Hare (ORD) and Washington Dulles (IAD).

- Independent converging IFR approaches can be flown to converging runways with sufficient separation between runway thresholds, or to airports without sufficient separation, but at higher approach minimums. This procedure substantially increases IFR capacity at airports without parallel runways.

- Dependent Converging Instrument Approaches (DCIA) allows controllers to direct two dependent streams of arriving aircraft to converging and even intersecting runways. Consecutive arrivals in each stream are staggered to separate the aircraft. A modification to the ARTS, called the Converging Runway Display Aid (CRDA), enables controllers to maintain the correct separations.

- In some cases, the addition of a navigation aid (NAVAID) can increase airport capacity by allowing a new procedure such as dependent (staggered) parallel approaches. For example, at Portland (PDX), a recently added Instrument Landing System (ILS) allows controllers to use these approaches.

(Appendix D provides an overview of the procedural improvements predicted for airports modeled in detail in NASPAC for the 1996 - 2010 time period.) Beyond the 2010 time frame, there are no known, new procedures that could be included in this analysis; therefore, all improvements implemented by 2010 are considered to be in effect at 2015.

Table 3-1 summarizes the projected increase in the maximum hourly arrival capacities due to both the airport (physical) and procedural improvements for the 1996-2010 time frame.

Table 3-1. Summary of Airport and Procedural Improvements for 1996-2010

Improvement	**Number of Affected Airports**	**Average Estimated Increase in Maximum Hourly IFR Arrival Capacity**	
		(Percent)	**Add'l Hourly Ops**
Physical Improvements: 1996-2005 (excluding close parallels and runways designed for use with Precision Runway Monitor	12	53%	22

Improvement	Number of Affected Airports	Average Estimated Increase in Maximum Hourly IFR Arrival Capacity	
		(Percent)	Add'l Hourly Ops
(PRM)			
Physical Improvements: 2006-2010 (excluding close parallel at Los Angeles International Airport (LAX))	6	40%	16
Procedural Improvements: 1996-2010	8	41%	17

3.2.4 Fleet Mix

The fleet mix used for this study was developed using data from NASA/LMI, ATA, ICAO, and APO. The current fleet mix was compiled using data from NASA/LMI's Aviation System Analysis Capability (ASAC) database and ATA input. Since the ASAC database has information on passenger aircraft only, this data was augmented with information from ATA to account for cargo aircraft. Using both of these sources, the baseline fleet for 1995 was obtained and then extrapolated to 1996, 2005, 2010, and 2015. The future fleet mix does not assume incorporation of advanced engine technologies resulting from ongoing research activities. Additional information on fleet mix calculations is shown on Appendix E.

ICAO forecasts the world fleet out to 2015 separating aircraft by class (number of seats). Using ICAO's forecast for each class, and the U.S. fleet for 1995 developed above, the U.S. forecast for each class was extrapolated from the world forecast based on the assumption the proportion of U.S. aircraft in the world fleet would remain constant.

The U.S. forecast for each class was then used as a basis for estimating the future inventory for each type of aircraft by assuming that the percentage of each aircraft type in each class of aircraft will remain the same in the future.

The resulting U.S. forecast was then validated and updated using APO's forecast for Stage 2/3 aircraft. The term Stage 2/3 aircraft refers to aircraft that meet Stage 2/3 noise levels as prescribed in Title 14 of the Code of Federal Regulations (14 CFR), part 36. Stage 2 aircraft are being removed from the fleet inventory under section 91.853 of 14 CFR, part 91. Adjustments to the future aircraft inventory were made to account for the phasing out of these aircraft. Aircraft that currently are out of production (such as the 727 and 737-100/200) were reduced in the future fleet, and other aircraft in the same class were increased to compensate. 1996 fleet totals were obtained by interpolating between the 1995 total and 2005 total assuming a constant increasing or decreasing rate between those years. The resulting U.S. forecast is shown in Figure 3-2.

Figure 3-2. U.S. Fleet Forecast

Class	Type	1996	2005	2010	2015
20-40	DHC6	64	108	131	155
	DHC8	144	244	296	349
	D328	37	63	76	90
	Embr120	237	402	488	576
	J31	87	148	180	212
	J32	83	141	171	202
	J41	39	66	80	95
>40 seats	ATP	12	36	48	61
	ATR-42	100	299	400	506
	ATR-72	51	153	204	258
	CV-580	18	54	72	91
	CRJ	36	108	144	182
	DHC7	29	87	116	147
	F27	14	42	56	71
Total (Class 1)		951	1950	2462	2994
	BAE146	41	47	52	57
	A320	109	187	267	306
	DC8	102	119	131	143
	DC9	454	408	328	328
	707/720	2	2	3	3
	727/100-200	680	147	0	0
	737-100	11	0	0	0
	737-200	312	90	5	0
	737-300	482	561	618	673
	737-400	94	123	135	147
	MD-81/82/83/87/88	615	775	915	1010
	MD-90	11	13	14	16
	F-100	130	151	166	181
	F-28	70	81	90	97
Total Class 2 (81-150 Seats)		3273	3163	3324	3618
	757	660	1803	2294	2592
	A310	41	79	99	115
Total Class 3 (151-210 Seats)		701	1882	2393	2707
	L1011	101	49	53	53
	DC10	176	205	175	175
	747-SP	4	0	0	0
	767	224	483	611	854
	777	12	159	218	251
	A300	73	225	298	431
Total Class 4 (211-300 Seats)		591	1121	1355	1764
	MD11	55	70	93	117
	747-100	59	50	50	50
	747-200	62	60	53	52
	747-400	47	91	126	161
Total Class 5 (301-400 Seats)		223	271	322	380
	XX (future design)	0	39	80	133
Total Class 6 (401-500 Seats)		0	39	80	133
	747-SR	0	19	92	144
Total Class 7 (501-600 Seats)		0	19	92	144
TOTAL (Class 2-7)		**4787**	**6494**	**7566**	**8745**

The preceding paragraphs have described the steps taken and resources used that were common to the development of both scenarios. The remainder of Section 3 is devoted to enhanced-scenario development.

3.3 Development of the CNS/ATM Enhanced Scenario

The enhanced scenario was developed from the baseline by adding planned CNS/ATM enhancements to the NAS as outlined in the NAS Architecture and summarized in Figure 3-3. The combination of key technologies provides users with improved capabilities eventually leading to implementation of the ATS Concept of Operations and Free Flight. This study made no attempt to assess the relative contribution of each technology, but concentrated on what the capabilities would bring to users. The principal capabilities assessed during this study were extracted from the ATS Concept of Operations, which when fully implemented will provide a more efficient airspace system through increased information sharing, automated decision support tools, and relaxation of air traffic control restrictions.

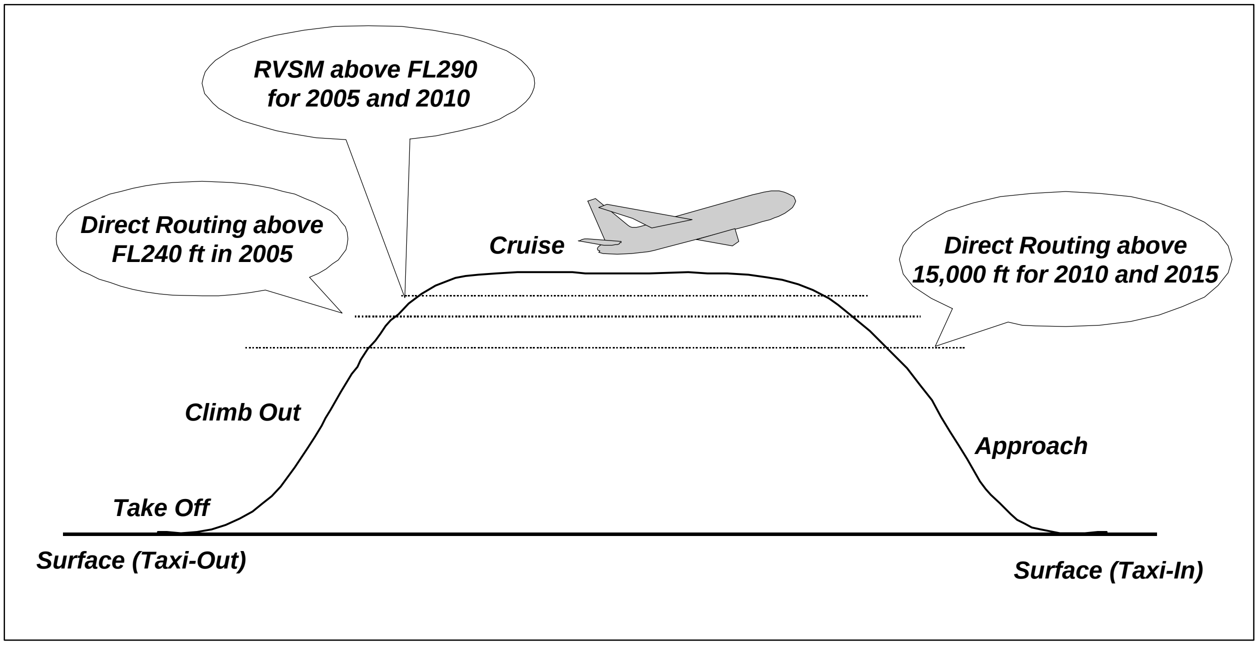
Figure 3-3. Overview of CNS/ATM Enhancements

Year	Key Technologies	New Capabilities
2005	• Controller-Pilot Data Link Communication • Automatic Dependent Surveillance – Broadcast (ADS-B) (Air to Air) • Passive Final Approach Spacing Tool • Traffic Management Advisor, Single Center • Initial Conflict Probe • Integrated Terminal Weather System • Surface Movement Advisor	• Reduced Vertical Separation (RVSM) above FL290 • Optimal climb • Wind-optimized Direct Routes above FL240 • Improved arrival/departure procedures • Expedited taxi clearance • 50/50 Oceanic Separation
2010	• Limited Digital Air/Ground Comm. • GPS Wide Area/Local Area Augmentation • Active Final Approach Spacing Tool w/Wake Vortex • Terminal Automation Enhancements • ADS-B ground stations • Surface Management System	• RVSM above FL290 • Optimal climb and descent • Wind-optimized Direct Routes above 15,000 feet • Improved arrival/departure procedures • Enhanced surface management • 30/30 Oceanic Separation
2015	• Digital Air/Ground communications • Full Conflict Probe • New Traffic Management Decision Support System	• Cruise climb/descent • Wind-optimized Direct Routes above 15,000 feet • Acceptance rates for instrument conditions equal to visual conditions • Enhanced surface management • 30/30 Oceanic Separation

3.3.1 CNS/ATM Enhanced Scenario - En Route Capabilities

For the en route environment, improved capabilities are most evident in reduction in separation, more efficient climb and descent, and wind-optimized direct routing. By 2005, improved aircraft position accuracy and communication will lead to optimal climb procedures, wind-optimized flight trajectories above FL240, and a reduction in vertical separation above FL290. By 2010, further enhancements are expected to provide for optimal climb and descent, and allow wind-optimized trajectories as low as 15,000 feet. By 2015, vertical separation standards will no longer apply and aircraft will be allowed to select their optimal cruise climb and descent and fly wind-optimized trajectories above 15,000 feet. The evolution of the en route capabilities is shown in Figure 3-4.

Figure 3-4. Evolution of En Route Capabilities



The capabilities described above were incorporated into the study by using simulation and analysis tools to modify flight trajectories accordingly at each point in the future, and by calculating the resulting flight times and fuel consumption by phase of flight.

3.3.2 CNS/ATM Enhanced Scenario - Terminal Area Capabilities

Improvements in arrival and departure procedures in terminal airspace are expected to improve airport capacities, eventually leading to acceptance rates for instrument conditions equal to that which is obtained under visual conditions. Enhanced surface management is expected to reduce taxi delay.

CNS/ATM terminal area improvements were modeled in the enhanced scenario. (See Appendix D, Section II for a detailed summary of each system.) Improvements were modeled by adjusting airport arrival and departure capacities, and taxi times based on performance metrics, investment analyses, and cost-benefit studies.

Table 3-2 lists the estimated increase in maximum IFR arrival capacity expected from the CNS/ATM improvements. The Integrated Terminal Weather System (ITWS), Weather Systems Processor (WSP), and Center-TRACON Automation System (CTAS), although applicable at several airports, provide a lesser increase in capacity than other CNS/ATM improvements. The Precision Runway Monitor (PRM), Automatic Dependent Surveillance-Broadcast/Cockpit Display of Traffic Information (ADS-B/CDTI) parallel approaches, and Wide Area Augmentation System (WAAS)/Local Area Augmentation System (LAAS) parallel approaches provide the greatest increase in arrival capacity. Each allows an airport to operate another independent stream of IFR arrivals. In addition, ADS-B/CDTI may increase airport throughput by increasing the amount of time aircraft can fly in visual meteorological conditions (VMC) by up to 13%.

Table 3-2. CNS/ATM Enhanced Scenario Improvements

CNS/ATM Improvements	No. of Affected Airports	Average Estimated Increase in Maximum Hourly IFR Arrival Capacity	
		Percent	Add'l Ops
WAAS or LAAS Parallel Approaches	5	52%	15
PRM	5	30%	16
ADS-B/CDTI Parallel Approaches	5	33%	19
ITWS	45	8%	5
CTAS	41	4%	3
WSP	1	7%	5

Section

4

DATA PREPARATION

This section describes the data preparation required to build the baseline and enhanced scenarios. A detailed discussion of data preparation is located in Appendix F.

As the data preparation process began, the following assumptions were applied to the scenarios:

- The baseline scenario assumes growth in traffic, changes in fleet mix, and continuous support of airport and procedural improvements.

- The enhanced CNS/ATM scenario includes the same assumptions used for the baseline scenario and the addition of new technologies and capabilities.

Data preparation for the scenarios began with the determination of a base day (see Paragraph 3.1). Once this was completed, the data preparation activities moved to incorporating the forecasted traffic growth, assigning aircraft types, assigning tracks, and developing flight profiles.

4.1 Traffic Growth

Traffic growth refers to projecting the base day aircraft operations to the out years (2005, 2010, and 2015), while accounting for projected demand, fleet modernization, and the acquisition of new aircraft.

To build an extension to the base day, two sets of flight data were generated for each of the future years (2005, 2010, and 2015). The first set consisted of flight data for all scheduled commercial and air taxi/commuter flights. The second set consisted of all general aviation and military flights.

The initial base year was constructed from the scheduled commercial and air taxi/commuter flights in the OAG for November 12, 1996. The origin airport, destination airport, scheduled times, flight identifier, and aircraft type were obtained for each scheduled flight in the NAS.

Along with the scheduled flights, the general aviation and military flights were obtained from the November 12, 1996, ETMS data. Flights were identified as general aviation or military based upon their flight identifiers. A set of flight data was obtained for these flights consisting of the origin airports, destination airports, actual times of flight, and aircraft type.

The scheduled flights and the general aviation and military flights combined to capture a majority of the activities in the NAS. The next step was to increase the traffic to reflect the projected demand as annotated in the TAF.

The above data sets were input into the FDG (see Paragraph 3.2.2) to increase the traffic demand to the levels expected for 2005, 2010, and 2015. The FDG provided the future flights. Once the new flights were obtained for each scenario, the aircraft types were modified in each year to account for fleet modernization and acquisition of new aircraft (see Paragraph 4.2). Trajectories were then assigned to each flight (see Paragraph 4.4 and 4.5), first in the baseline scenario and subsequently in the enhanced scenario. The enhanced scenario was optimized for the future Concept of operations.

4.2 Assignment of Aircraft Types

After the new flight was determined, an aircraft type was assigned to the flight. A database of fleet mix for the specific future year was used. For each future year, the fleet mix, consisting of the number of each aircraft type (e.g., B737) projected to be in service for the respective year (see Figure 3-2), was obtained. The following assumptions were made:

- New aircraft were added to the list by assuming that they would fly the same distribution of stage lengths as an aircraft in the same category.

- New aircraft would fly the same number of legs per aircraft per day as similar aircraft.

Each new flight generated by the FDG (see FDG in Paragraph 3.2.2) was assigned an aircraft type based on the aircraft equipment of jet or turboprop and its stage length. (See Appendix F for the methodology used in this activity.)

4.3 Assignment of Tracks

Once the flight origin and destination were identified and the aircraft type was assigned to the flight, a track was assigned. A track consists of a series of points between the flight's origin and its destination. The assignment of a track to a flight is explained in the following steps.

- A set of all filed tracks between city pairs (origin and destination) is built from the ETMS data set.

- A track is selected randomly from the set of filed tracks, based on its origin and destination.

For example, using the ETMS data set, a query is built to extract all flights flying between ORD and Los Angeles International Airport (LAX). The next step is to filter the reduced data set only for flights with a specific aircraft type (e.g., B737). From this data set, randomly select a track and assign it to the new flight.

Once the track has been assigned, the next step is to complete the flight trajectory by assigning altitude and speed.

4.4 Assignment of Trajectories - Baseline Scenario

A flight trajectory is made up of three segments: climb, cruise, and descent. In the baseline scenario, speed and altitude trajectories were assigned to each flight as a function of the track, aircraft type, desired cruise altitude, and airspeed en route. For each aircraft type,

- The climb and descent trajectory indicated the sequence of altitudes and airspeeds, and

- The cruise trajectory indicated the flight moving along a route at the specified airspeed and altitude.

For the general aviation, or unscheduled aircraft, trajectories were assigned based on their actual observed trajectories reported in the ETMS. The trajectories of new General Aviation (GA)/military flights, added by the FDG, were obtained by copying the trajectory of an existing flight between the origin and destination for that same equipment category.

4.5 Assignment of Trajectories - Enhanced Scenario

A trajectory generator called Optimized Trajectory Generator (OPGEN) (see Appendix C for a description of OPGEN) was used to create flight trajectories for the enhanced scenario. Basic assumptions were made. Aircraft performance constraints such as maximum thrust, speed, and others were considered constraint variables in creating flight trajectories. For example, an aircraft cannot fly at a speed greater than its specified performance. The special use airspace (SUA) availability and the activities around SUA were held constant. For example, the direction of flight around the SUA was held constant. Therefore, if a flight goes left around a SUA in 1996, future flights will also go around the SUA in the same direction. Finally, preserving airline schedules is an important factor in future operation of the NAS. If the airlines knew they could leave later (and possibly fill more seats) and still arrive on time, they would rather do that than get to the destination early. Other assumptions are listed below for different, future time frames.

<u>2005:</u>

- Flights flying less than 1,000 nautical miles had their distances reduced (direct routing) when operating at FL240 and above.

- Flights flying greater than 1,000 nautical miles were optimized for minimum fuel when operating at FL240 and above.

2010 and 2015:

- Flights flying less than 1,000 nautical miles had their distances reduced (direct routing) when operating at 15,000 feet and above.

- Flights flying greater than 1,000 nautical miles were optimized for minimum fuel when operating at 15,000 feet and above.

(See Appendix F for additional information on the assignment of trajectories.)

Section

5

ANALYSIS OF THE BASELINE AND ENHANCED SCENARIOS

The following paragraphs describe a) the methodologies and analysis of flights generated in each scenario for in-flight (CONUS), surface, and oceanic; b) the calculation of fuel burned; and c) the subsequent emissions of NOx, HC, and CO. (See Appendices G, H, and I for additional information supporting the analyses described in this section.)

5.1 Airborne (CONUS)

5.1.1 Fuel Burn Calculation and Analysis

Aircraft performance was used to calculate fuel burned for each IFR flight operating in the en route and terminal environments. Aircraft performance data was not available for all aircraft used in this analysis, therefore, two set of algorithms were used to calculate fuel burned. A force balance equation was applied to aircraft for which detailed aircraft performance data was available from LINKMOD[2] data (see Appendix G for fuel burn calculations). For those aircraft without performance data, fuel burn was computed in a manner similar to that used in deriving the Breguet[3] range equation.

5.1.1.1 Aircraft with Performance Data

For many flights, the aircraft model was available only in a general manner (e.g., B727) and did not contain the specific version model (e.g., –100 versus –200). In order to assign a specific (aircraft type and version number) model to each flight, the airline ID (e.g., UAL, AAL, etc.) in the flight identifier was used. Assignment of specific model type was based on the airline's fleet and the relative number of different aircraft models. When no airline model was available, the version number selected was the most popular for that aircraft type.

A second factor in aircraft fuel burn is the weight of the aircraft. In order to compute the fuel consumed by a flight, the weight of the aircraft at landing was estimated by assuming a passenger load factor of 70% and landing with 45 minutes of reserve fuel. The maximum number of passengers on board was an average across the industry.

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[2] LINKMOD is a FAA model for calculating fuel burn based on the energy balance equation.
[3] Kerrebrock, J.L., "Aircraft Engines and Gas Turbines, " 1984

Given the aircraft type (performance data), aircraft weight and trajectory, the total fuel consumed by the flight was calculated using an ordinary differential equation.

5.1.1.2 Aircraft without Performance Data

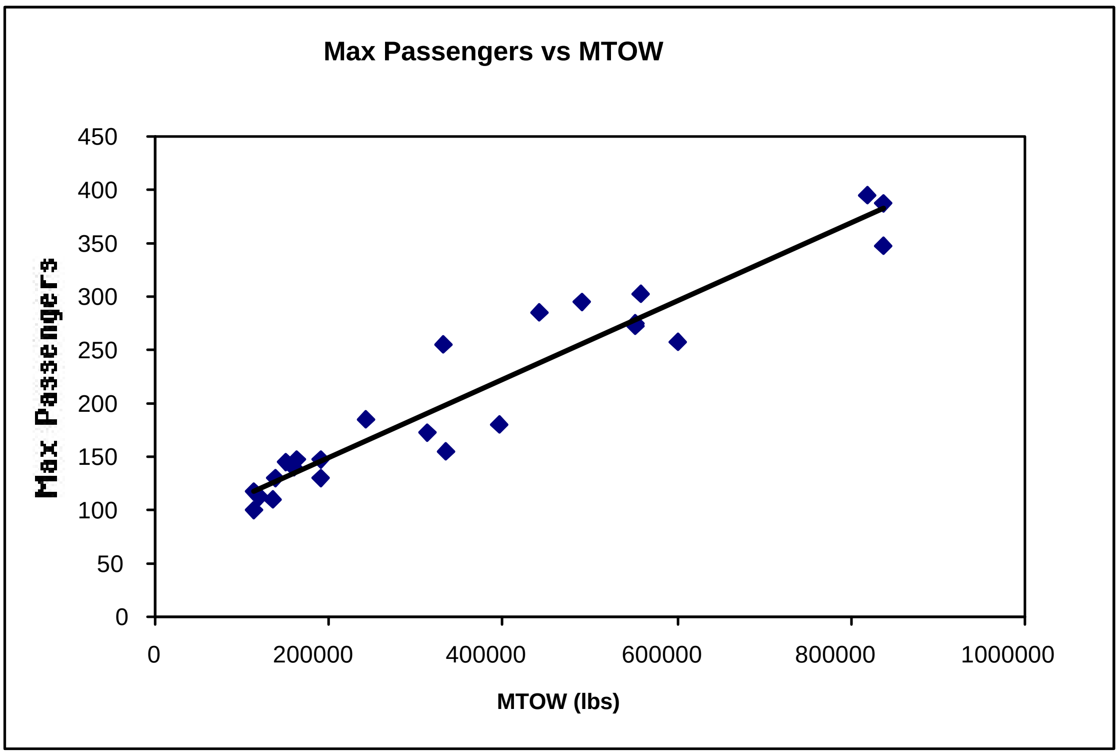
For aircraft without performance data, the weight at landing was estimated from the maximum allowable takeoff weight for the aircraft. It was assumed there would be a constant specific impulse and the aircraft operated at a roughly constant lift-to-drag (L/D), therefore a simplified equation was applied.

Similar to the previous section, the aircraft fuel burned was a function of the aircraft weight, assumed aircraft performance, and its trajectory.

5.1.1.3 New Aircraft

Finally, when a new aircraft type was projected to enter the fleet, the maximum weight of the aircraft was derived from the number of passengers expected in this new aircraft. This was accomplished by extrapolating the best-fit line from the existing data on number of passengers versus maximum takeoff weight (MTOW) of known aircraft as shown in Figure 5-1. Once the maximum takeoff weight was obtained, the new aircraft was treated in a manner similar to aircraft with no model available.

Figure 5-1. Relationship between Maximum Number of Passengers and MTOW



5.1.2 Sample Flight Trajectories

After all data preparation was completed, the baseline scenario contained a set of IFR flight plan trajectories for a day in 1996, 2005, 2010, and 2015 similar to the one shown in Table 5-1. The enhanced scenario contained a similar set of wind-optimized trajectories for all years except 1996. There were 46,102 such flights in 1996 and 56,900 flight trajectories for 2015. These included air carrier, air taxi/commuter, general aviation, and military.

The first line of the data in Table 5-1 below indicates that this is a Boeing 737-200 flying from Philadelphia to Cleveland. There are 25 segments for the flight with the following data in each segment: cumulative elapsed time in minutes, fuel consumption, altitude in hundreds of feet, mach speed, latitude, and longitude.

Table 5-1. Sample Flight Trajectory

46.XYZ01175.B737 PHL CLE
25

Cum. Time (Minutes)	Fuel/Seg. (Pounds)	Alt. (100 Ft.)	Mach Speed	Latitude	Longitude
0.000	169.481	0	0.529	39.870	-75.230
0.820	236.594	29	0.554	39.928	-75.305
2.033	311.750	66	0.590	40.031	-75.398
4.316	346.367	112	0.436	40.209	-75.560
6.848	156.393	152	0.542	40.400	-75.683
8.122	170.230	171	0.531	40.424	-75.821
9.485	327.505	191	0.552	40.450	-75.967
12.355	131.133	227	0.585	40.500	-76.283
13.551	74.542	240	0.607	40.522	-76.418
14.270	91.680	248	0.606	40.539	-76.499
15.127	26.551	257	0.623	40.560	-76.596
16.281	265.111	269	0.652	40.589	-76.731
19.063	314.910	290	0.666	40.659	-77.064
22.980	285.803	300	0.672	40.755	-77.535
26.885	284.919	300	0.671	40.849	-78.006
30.786	260.651	300	0.670	40.938	-78.479
34.686	264.454	290	0.664	41.026	-78.953
38.576	97.495	280	0.661	41.109	-79.429
40.817	75.121	240	0.662	41.157	-79.710
42.361	238.818	212	0.645	41.183	-79.909
46.093	48.240	159	0.619	41.244	-80.393
46.877	209.398	147	0.590	41.257	-80.493
50.159	355.112	99	0.503	41.304	-80.878
54.578	136.181	47	0.486	41.361	-81.364
58.790	0.0	0	0.486	41.400	-81.830

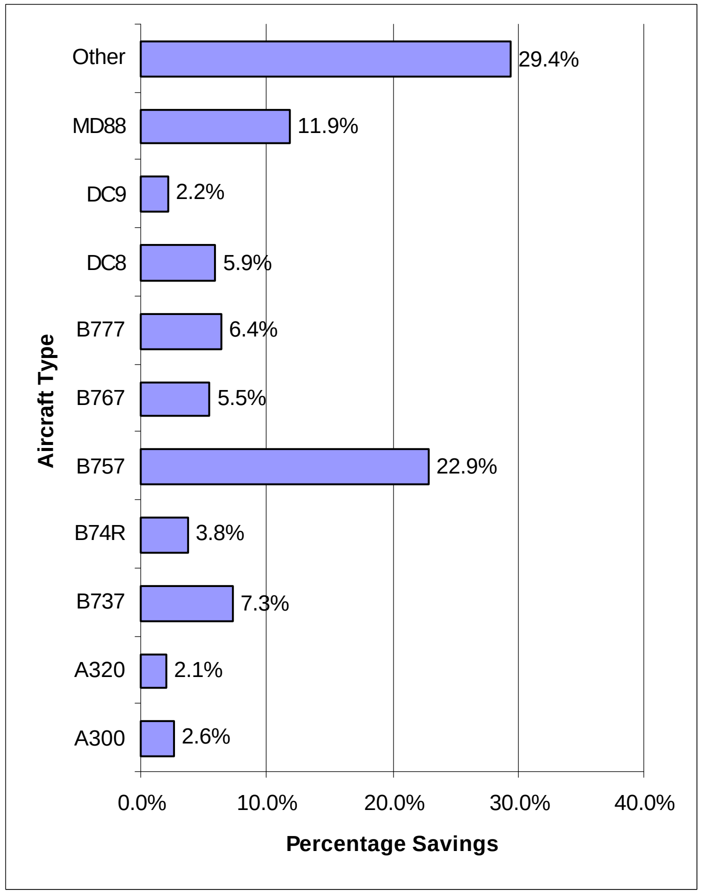
5.1.3 Analysis of Flight Trajectories

The analysis of flight trajectories was divided into two components, above and below 3000 feet. This division was made to accommodate emission calculations, which will be described in paragraph 5.4. The phase of flight above 3,000 feet offers capability for more fuel-efficient flight operations and accounts for most of the savings. A comparison of the flight trajectories and fuel consumption between the baseline and enhanced scenarios in 2015 results in a daily fuel saving of 17.4 million pounds for all flights. This saving is a direct result of more fuel-efficient trajectories and does not include savings due to reduced airborne delay, which is discussed in Section 5.1.5. Over 70% of the daily fuel savings occurred in the 10 aircraft listed in Table 5-2.

Table 5-2. Fuel Savings in 2015 by Type Aircraft (lbs.)

Aircraft Type	Name	Baseline	Enhanced	Fuel Savings	Percentage Savings
B757	Boeing 757	68,708,125	64,718,986	3,989,139	6.2%
MD88	McDonnell-Douglas 81-88	46,795,851	44,730,766	2,065,085	4.6%
B737	Boeing 737-300/400 Series	48,791,750	47,516,432	1,275,317	2.7%
B777	Boeing 777	15,741,489	14,625,496	1,115,992	7.6%
DC8	McDonnell-Douglas 8	10,915,558	9,890,987	1,024,571	10.4%
B767	Boeing 767	20,180,560	19,219,538	961,022	5.0%
B74R	Boeing 747-SR	11,728,527	11,072,394	656,134	5.9%
A300	Airbus 300	9,581,057	9,121,290	459,767	5.0%
DC9	McDonnell-Douglas 9	11,961,611	11,574,832	386,778	3.3%
A320	Airbus 320	8,991,694	8,629,766	361,928	4.2%
		253,396,221	241,100,487	12,295,734	5.1%

Figure 5-2. Percent of Total NAS Fuel Savings Above 3,000 Feet 2015



These fuel savings during the en route and cruise phases of flight result from CNS/ATM enhancements that provide improved decision support tools, improved information, and better position accuracy. The enhancements allow users to fly preferred routes that include optimum climb/descent and wind-optimized trajectories. Many of today's ATC restrictions will be removed, making structured routes the exception rather than the rule.

In the enhanced scenario, aircraft flying trajectories above 15,000 feet and distances in excess of 1,000 miles will receive the most benefit from CNS/ATM enhancements that provide capability for users to fly wind-optimized and cruise climb and descent trajectories. Of all the aircraft types included in the enhanced scenario, the Boeing 757 accounted for 22.9% of the total fuel savings for all flights modeled, as shown in Figure 5-2.

5.1.4 Arrival Airports

Efficiency savings from CNS/ATM enhancements realized during en route and cruise phases extend to the terminal area for arrivals and departures. A savings will result from increased information exchange, automated decision support tools for merging and sequencing traffic, and increased use of area navigation.

Flight trajectories above 3,000 feet were analyzed by arrival airports and indicated that the top 10 airports shown in Table 5-3 and Figure 5-3 account for 32% of daily flight trajectory fuel savings in 2015.

Table 5-3. Fuel Savings in 2015 by Arrival Airport (lbs.)

Airport ID	Airport Name	Baseline	Enhanced	Fuel Savings	Percentage Savings
ORD	Chicago O'Hare Int'l	14,029,784	13,090,414	939,370	7.2%
DFW	Dallas/Ft. Worth Int'l	16,042,454	15,004,745	1,037,709	6.9%
LAX	Los Angeles Int'l	18,889,618	17,814,106	1,075,512	6.0%
ATL	Atlanta Int'l	8,902,309	8,524,580	377,728	4.4%
DTW	Detroit Metro Wayne Co.	6,859,840	6,416,142	443,698	6.9%
MIA	Miami Int'l	5,413,989	5,169,116	244,873	4.7%
PHX	Phoenix Sky Harbor Int'l	7,804,984	7,337,076	467,909	6.4%
STL	St. Louis Int'l	6,140,680	5,867,773	272,907	4.7%
OAK	Oakland Int'l	2,459,199	2,313,867	145,332	6.3%
MSP	Minneapolis/St. Paul Int’l	7,997,762	7,432,699	565,063	7.6%
		94,540,620	88,970,518	5,570,102	6.3%

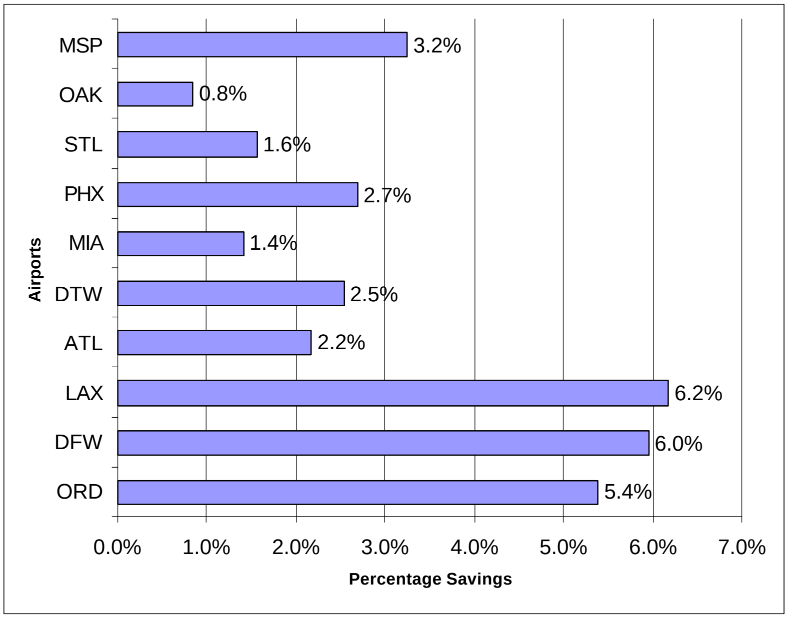


Figure 5-3. Percent of Total NAS Fuel Savings - 2015

5.1.5 Airborne Delay

Fuel burn was calculated for airborne delay by airport and aircraft type below FL240 for 1996 and 2005, and below 15,000 feet for 2010 and 2015. Airborne operational delay increases the fuel burn and accumulates when the demand exceeds the airport's capacity. There are four contributing factors in the model that account for airborne operational delay: 1) flow control restrictions, 2) arrival/departure fix limits, 3) sector capacities, and 4) arriving flights holding for occupied runways.

Flow control restrictions are defined as static or dynamic. Static flow control restrictions usually are positioned at center boundaries and are used to adjust traffic flow rates where congested Terminal Radar Approach Controls (TRACONS) are known to exist. Dynamic flow control restrictions appear during the course of the simulation when large amounts of traffic are heading toward major airports. The flow control restrictions provide additional spacing requirements on flights passing through the restriction.

Arrival and departure fixes also have minimum spacing requirements between successive flights associated with them and are located near the airport. They are spaced strategically to feed the traffic flow for the en route airspace.

Sector entry delay occurs when the instantaneous or hourly aircraft count parameters for a sector are exceeded. Sector capacities were provided by Air Traffic for all sectors modeled. The model records delay at sector boundaries when the Monitor Alert Parameter (MAP) is exceeded for any instance of time.

In addition, flights waiting to use an occupied runway incur airborne operational delay. This type of delay is caused by demand exceeding the arrival capacity of an airport. The service interval between successive arrivals is a function of the capacities currently in use at the airport and the respective arrival and departure queue lengths.

Comparison of airborne delays for the baseline and enhanced scenarios in 2015 resulted in daily fuel savings of 5.7 million lbs. for all flights in the NAS. This represents 25% of the total airborne fuel savings of 23.2 million lbs., with the other 75% due to more efficient flight trajectories as described in Section 5.1.3.

5.2 Surface Operations

Surface operations enhancements will result in improved aeronautical, departure clearance, and surface management information exchange between the service provider and users. The addition of surface automated aids will improve taxi sequencing and spacing of aircraft to departure thresholds, thus balancing taxiway usage.

The analysis evaluated taxi times and ground delays at each airport. Ground delay accumulates at airports when flights enter and hold in departure queues during the taxi-out process. Departure queues increase when the demand for departures exceeds the airport's maximum departure capacity. These capacities are dependent on the airport's runway configurations and projections of future airport improvements.

5.2.1 Fuel Burn

Surface fuel burn was calculated for each of the airports. The total ground delay time (the amount beyond the unimpeded time for all aircraft due to waiting in the departure queue) was applied to each aircraft type that was departing from an airport within the CONUS. The idle ICAO fuel flow rate was used in the following calculation:

*Fuel Burn Per Flight = Fuel Rate Lbs. Per Minute * (Total Ground Delay Time + (Unimpeded Taxi Time * Number of Aircraft)) * Number of Engines*

For all flights arriving within the CONUS, the same formula was used except that the delay time was set to zero.

5.2.2 Surface Taxi Time

The unimpeded taxi times were a key input parameter to the NASPAC simulation for measuring ground delay and calculating the amount of time on the surface for both the baseline and enhanced scenarios. Unimpeded taxi times, developed and provided by Office of Aviation Policy and Plans (APO-130), Information Systems Branch, were applied to both the taxi-out and taxi-in conditions for each of the 80 modeled airports (see Appendix J for a list of airports and their taxi-in and taxi-out times). An average taxi-out and unimpeded taxi-in time was applied to the remaining airports.

The unimpeded taxi-out condition occurs when the departure queue is equal to 1 and the arrival queue is equal to 0. Similarly, the unimpeded taxi-in condition occurs when the aircraft's wheels hit the runway and the aircraft taxis immediately to its respective gate. An unimpeded time is developed from the Airline Service Quality Performance (ASQP) data, which is reported airline data to the Department of Transportation (DOT) from the 10 largest carriers. It is computed for each airport based on airport, carrier, and season. Because gate positions of the different carriers may vary considerably depending on the airport, the average for each airport by carrier and season was used for this analysis.

Typically, an airport's unimpeded taxi-out time varies widely from its median taxi-out time, especially at the busier airports, e.g., EWR's unimpeded taxi-out time (11.7 minutes), and DFW's (9.9 minutes) are in about the 15th percentile for all of their flights. In contrast, non-busy airports, such as Dallas Love (DAL) and Indianapolis (IND) typically have unimpeded taxi times that are very close to the median. Unimpeded taxi-in times have less variability than taxi-out times and are on average about half of the taxi-out time.

In the enhanced scenario, the unimpeded taxi-out and taxi-in times were reduced by 5% for ATL in 2005 and the 12 airports that were expected to benefit from the Surface Movement Advisor (SMA). The 12 airports are Boston Logan International Airport (BOS), Dallas Fort Worth

Airport (DFW), Detroit Metropolitan Airport (DTW), Newark Airport (EWR), Los Angeles International Airport (LAX), Orlando International Airport (MCO), Miami International Airport (MIA), Minneapolis–St. Paul International Airport (MSP), O'Hare International Airport (ORD), Pittsburgh International Airport (PIT), San Francisco International Airport (SFO), and St. Louis International Airport (STL). In 2015, all other modeled airports had reduced taxi times of 5% from the 1996 baseline number.

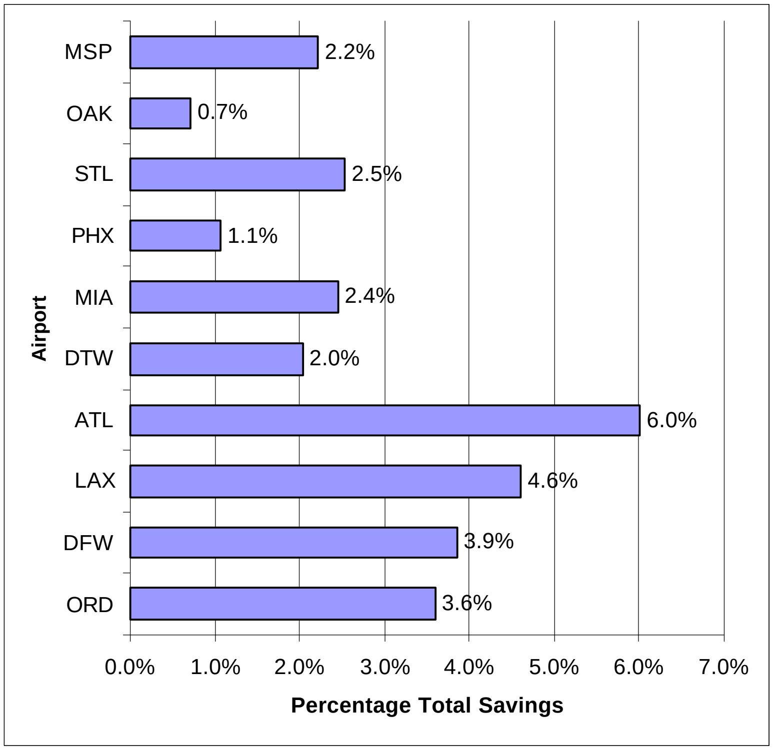
While it is difficult to extrapolate for the NAS based on observations from ATL, the NAS architecture does not address time frame reductions explicitly. The study team assumed that inferences could be made from the portrayed future improvements of the surface management system (SMS), such as cockpit moving maps and ADS-B implementation.

Ground delays, as discussed in the previous section, were computed from the NASPAC simulation by airport and aircraft type. The time spent by an aircraft in the departure queue was added to the airport's respective unimpeded taxi times. This resulted in daily fuel savings of over one million lbs. for all airports modeled. The top 10 airports for surface fuel savings are shown in Table 5-4 and Figure 5-4, and account for 29% of the total surface fuel savings.

Table 5-4. Fuel Savings in 2015 by Airport (lbs.)

Airport ID	Airport Name	Baseline	Enhanced	Fuel Savings	Percentage Saving
ORD	Chicago O'Hare Int'l	789,255	752,411	36,845	4.9%
DFW	Dallas/Ft. Worth Int'l	809,480	770,086	39,394	5.1%
LAX	Los Angeles Int'l	839,422	792,443	46,979	5.9%
ATL	Atlanta Int'l	715,231	653,910	61,321	9.4%
DTW	Detroit Metro Wayne Co.	460,250	439,423	20,826	4.7%
MIA	Miami Int'l	520,664	495,703	24,961	5.0%
PHX	Phoenix Sky Harbor Int'l	432,692	421,828	10,864	2.6%
STL	St. Louis Int'l	566,798	540,988	25,811	4.8%
OAK	Oakland Int'l	153,919	146,601	7,319	5.0%
MSP	Minneapolis/St. Paul Int’l	590,679	567,967	22,712	4.0%
		5,878,391	5,581,359	297,032	5.3%

Figure 5-4. Percent of Total NAS Surface Fuel Savings – 2015



5.3 Oceanic

The oceanic air traffic environment is different from the domestic environment in a number of aspects, rendering oceanic air traffic control much less efficient than domestic. With most oceanic routes out of range of radar and direct communications and with manual tracking of flight progress, aircraft separation standards over the ocean are very large, and there is minimal flexibility to modify flight plans.

Proposed advanced automation, direct and reliable communications, improved navigation and surveillance, and more timely and accurate weather data will greatly improve the efficiency of oceanic air traffic control and will allow for significant reduction of required separations.

5.3.1 Oceanic Fuel Savings

Calculable fuel savings were found to be available in two categories: delay and efficiency. Delay benefits are the savings obtained by reducing the amount of time spent waiting for an acceptable oceanic routing. Efficiency benefits are the fuel savings obtained by flying closer to the aircraft's optimal routes, altitudes, and speeds.

The primary source of predicted fuel savings is a simulation model developed for the Oakland oceanic airspace and run by the MITRE Corporation Center for Advanced Aviation System Development (CAASD). The model provided an analysis capability to compute fuel burn and flight time for both actual and preferred flight trajectories. The simulation model was run using a variety of input assumptions as to density and separation standards to determine the effects of each.

Current oceanic forecasts predict lower rates of growth than those used in 1996, when the original MITRE simulation model was run; therefore, the predicted annual fuel savings were adjusted for the lower growth rates and lower projected user equipage rates.

The type aircraft used for oceanic flights in the North Atlantic and Pacific airspace and their relative fuel consumption were available for the years 1996 and 2002 as shown in Table 5-5. These were coupled with hourly fuel consumption figures by type aircraft to calculate estimated savings by year in U.S. North Atlantic and Pacific airspace as shown in Table 5-6.

Table 5-5. Relative Oceanic Fuel Consumption by Aircraft Type

	Percent of 1996 Fleet			Percent of 2002 Fleet			1996	2002
Aircraft Type	Pacific	Atlantic	Total	Pacific	Atlantic	Total	Percent of Fuel	Percent of Fuel
A300	0.0%	2.1%	0.8%	0.0%	0.0%	0.0%	0.5%	0.0%
A310	0.0%	6.0%	2.4%	0.0%	4.0%	1.6%	1.4%	1.0%
A330	0.3%	1.0%	0.6%	1.7%	10.0%	5.0%	0.4%	3.7%
A340	5.1%	3.0%	4.3%	11.1%	11.0%	11.1%	3.0%	8.3%
B727	0.4%	2.0%	1.0%	0.0%	0.0%	0.0%	0.4%	0.0%
B747-200	31.7%	18.5%	26.6%	21.7%	8.2%	16.4%	35.8%	23.9%
B747-400	24.7%	14.5%	20.7%	25.7%	9.8%	19.4%	25.7%	26.0%
B757	0.3%	11.0%	4.5%	0.0%	7.0%	2.7%	1.6%	1.0%
B767	0.6%	16.0%	6.6%	2.2%	15.0%	7.2%	3.5%	4.1%
B777	0.6%	2.9%	1.5%	14.5%	19.0%	16.3%	1.0%	12.4%
DC-10	15.3%	9.0%	12.8%	10.1%	6.7%	8.8%	11.4%	8.4%
L-1011	5.9%	2.9%	4.7%	0.0%	0.0%	0.0%	3.8%	0.0%
MD-11	11.7%	5.8%	9.4%	10.5%	6.9%	9.1%	8.1%	8.5%
MD-80/ DC8	0.4%	2.0%	1.1%	0.0%	0.0%	0.0%	0.3%	0.0%
C-5	1.1%	1.1%	1.1%	1.0%	1.0%	1.0%	1.5%	1.5%
C-141	1.7%	1.7%	1.7%	1.5%	1.5%	1.5%	1.2%	1.2%
C-135	0.4%	0.4%	0.4%	0.0%	0.0%	0.0%	0.3%	0.0%

Table 5-6. Oceanic Fuel Savings by Air Traffic Control Center - 2015

	Estimated Fuel Consumed (Millions Of Gallons)					
	Oakland	New York	Anchorage	Total	Saved	Pct Saved
1996	3,429	1,468	587	5,484	0	0.0%
1997	3,627	1,627	683	5,937	0	0.0%
1998	3,707	1,670	715	6,093	4	0.1%
1999	3,870	1,735	747	6,352	15	0.2%
2000	3,945	1,791	761	6,497	34	0.5%
2001	4,115	1,873	794	6,782	54	0.8%
2002	4,087	1,853	828	6,768	69	1.0%
2003	4,264	1,930	864	7,058	83	1.2%
2004	4,448	2,008	902	7,358	106	1.4%
2005	4,641	2,086	941	7,668	126	1.6%
2006	4,859	2,166	985	8,010	135	1.7%
2007	5,088	2,237	1,031	8,356	144	1.7%
2008	5,328	2,332	1,080	8,740	154	1.8%
2009	5,579	2,418	1,131	9,128	165	1.8%
2010	5,841	2,508	1,184	9,533	178	1.9%
2011	6,116	2,600	1,240	9,957	194	1.9%
2012	6,404	2,697	1,298	10,399	211	2.0%
2013	6,706	2,796	1,359	10,862	228	2.1%
2014	7,022	2,900	1,423	11,345	246	2.2%
2015	7,352	3,007	1,490	11,850	265	2.2%

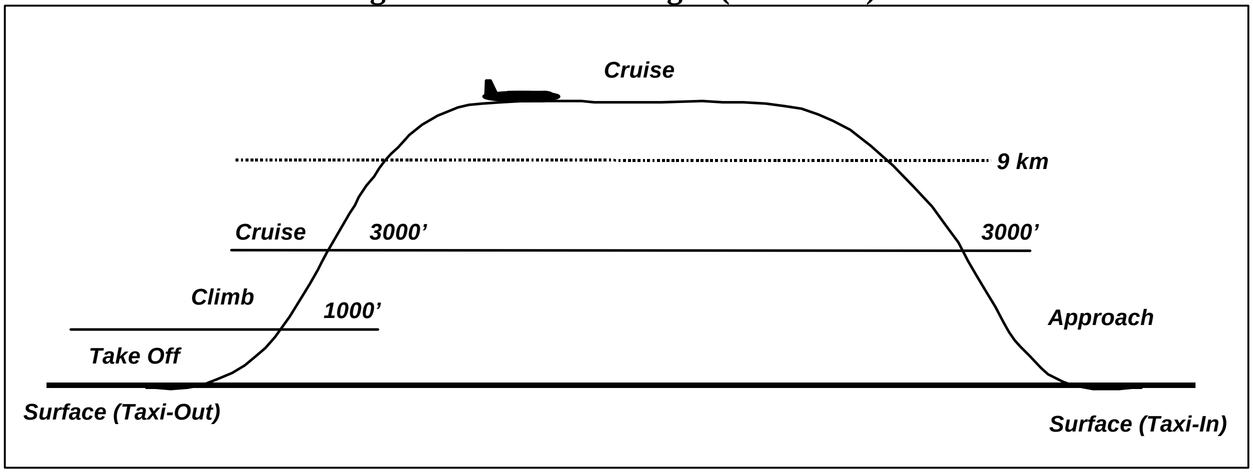
In addition to the above, better CNS and automation capabilities will provide more flexibility for controllers to grant pilot requests (e.g., for altitude changes) and will enable much faster responses by controllers. These benefits were not captured in the simulation model.

A number of factors could affect the level of benefits accrued. For example, higher levels of traffic or more rapid SATCOM/Data Link equipage would increase benefits. By contrast, lower levels of oceanic traffic, the introduction of more efficient aircraft, or delays in the reduction of aircraft separation minima would reduce benefits attributable to ATC improvements.

5.4 Emissions

The climb-out and cruise phases of flight used for emission calculations (illustrated in Figure 5-5) are different from those used for conventional phases of flight. This is due to the fact that emission dissipation acts differently closer to the ground than higher in the atmosphere. Therefore, the climb out phase is considered to be from 1,000 feet to 3,000 feet instead of continuing until the aircraft levels off. In addition to the change in climb out altitude, the cruise indices are separated into two altitude levels (0-9 km and 9-13 km) to reflect more accurately the difference in emissions (due to changes in pressure and temperature) between lower and higher cruise levels.

Figure 5-5. Phase of Flight (Emissions)



FAA-AEE and ICAO provided the algorithm for converting fuel burned to emissions of gases. The data sources and equations provide a means to calculate the emissions of gases from surface to 3,000 feet. The Landing and Take-Off (LTO) Cycle is in accordance with Environmental Protection Agency (EPA) guidance. NASA and the Boeing Aircraft Company provided data and equations for calculating emissions of gases above 3,000 feet. In order to convert fuel burn into emissions, the following emissions formula[4] was used.

> *Emissions (lbs.) = Time (min.) * Fuel Flow (1000 lbs./min.) * Emission Index (lbs. emission/1000 lbs. fuel)*

One of the main factors in the equation above is the emission index. The emission index is a function of the engine type, phase of flight (or engine thrust), and pollutant. The emission indices are based on information provided by the engine manufacturers and documented by the FAA and ICAO. These indices (which are referred to as "ICAO indices") were used in the calculations for emissions released during takeoff, climb out, approach, and taxi/idle. (See Appendix K for ICAO Indices.)

However, because the ICAO indices are available only for takeoff, climb out, approach, and taxi/idle, they do not represent emissions above 3,000 feet. Therefore, under contract with NASA, Boeing developed indices for the cruise phase of flight incorporating the ICAO indices and several other factors. These indices (referred to as the "Boeing Method #2 indices") were used to calculate emissions in the cruise phase of flight. If a Boeing Method #2 index was not available for a specific engine type, the ICAO approach index was used in its place.[5] (See Appendix K for Boeing Method #2 Indices.)

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[4] Source: Procedures for Emission Inventory Preparation, Volume IV, Mobile Sources, EPA, Ann Arbor, MI, 1992.

[5] ICAO approach indices were used for cruise indices when Boeing indices were not available, as recommended by Steve Baughcum and Steven Henderson from Boeing.

Because the emission indices are engine specific, it was necessary to map the aircraft types to specific engine types. (See Appendix H for Cross Reference to Engines.) The first step in the mapping process was to map all of the aircraft types from the scenarios to known aircraft types using the characteristics of the aircraft (i.e., size, jet vs. turboprop, number of engines, etc.). In many cases, the aircraft types were the same. In the case of an unknown aircraft type, it would be mapped to a Cessna Citation. Once the aircraft types were assigned, the default engine for each aircraft type was extracted from both the ICAO document and the Boeing Method #2 document. When there was no default engine specified in either document, the default engine from Emissions and Dispersion Modeling System (EDMS) was used. Once the default engine was determined, the appropriate emission index could be used for each aircraft type.

Section 6

SUMMARY

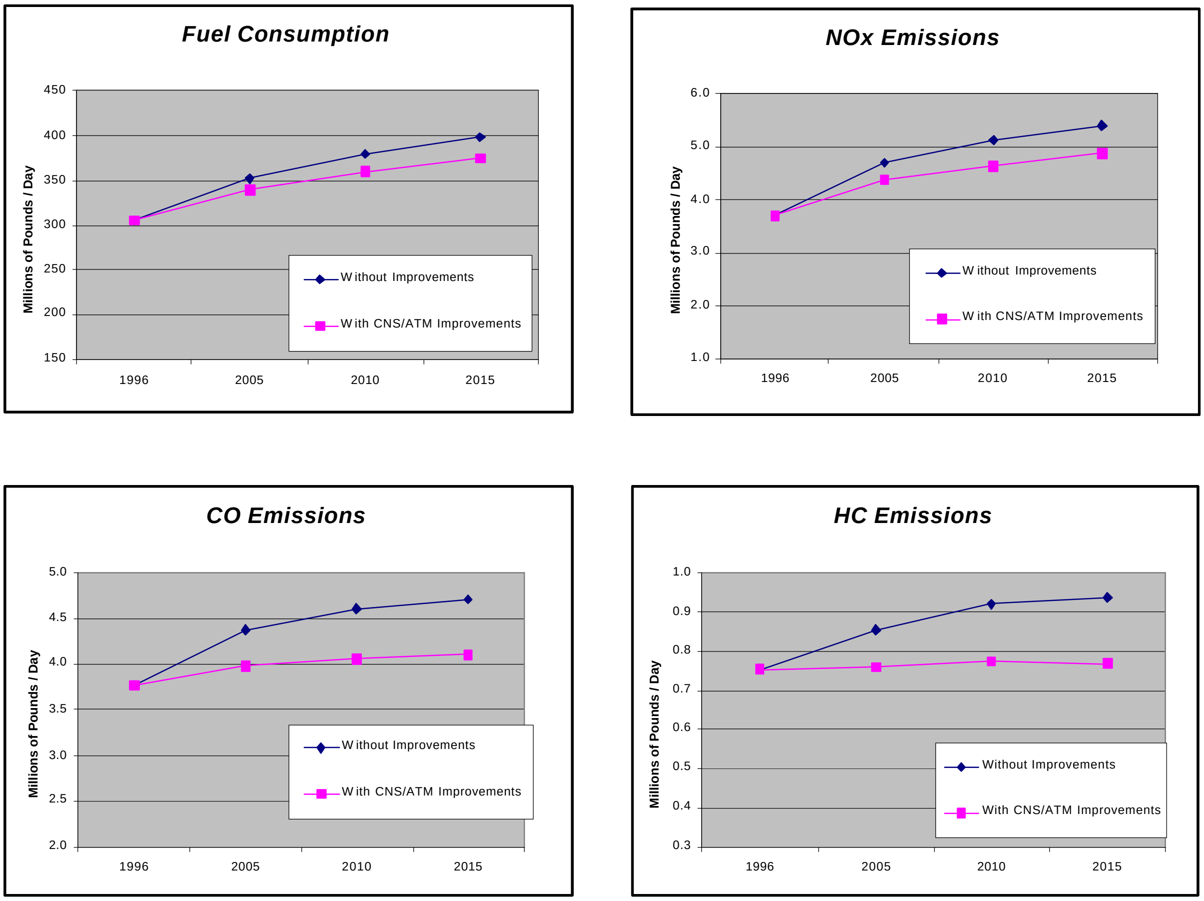
A summary of the daily fuel and emission calculations for each year of the baseline and enhanced scenarios is shown in Table 6-1, and depicted graphically in Figure 6-1.

A comparison of the baseline and enhanced scenarios in 2015 provided the daily fuel and emission savings resulting from NAS Modernization. Fuel savings exceeded 24.3 million lbs., of which 17.4 million were due to more efficient trajectories, over 5.7 million were due to reduced airborne delay, and the remaining one million lbs. derived from reduced surface delay. The emission savings resulting from reduced fuel burn in the various phases of flight were 9.9% for NOx, 12.7% for CO, and 18.0% for HC, as shown in Table 6-1 and depicted graphically in Figure 6-1.

Table 6-1. Fuel and Emission Savings (000 lbs.)

		Baseline Case				CNS/ATM Improvements							
Year	**Mode**	**Fuel**	**NOx**	**CO**	**HC**	**Fuel**		**NOx**		**CO**		**HC**	
1996	**Total**	**305,805**	**3,712**	**3,772**	**754**								
	Above 3000	253,195	3,100	2,926	569								
	Below 3000	33,380	547	200	19								
	Surface	19,231	65	647	166								
2005	**Total**	**351,964**	**4,708**	**4,373**	**854**	**339,240**	**-3.6%**	**4,377**	**-7.0%**	**3,974**	**-9.1%**	**758**	**-11.2%**
	Above 3000	292,604	3,935	3,431	657	280,656		3,609		3,041		563	
	Below 3000	38,346	702	195	19	37,824		698		191		18	
	Surface	21,013	72	747	177	20,759		71		742		176	
2010	**Total**	**380,176**	**5,126**	**4,607**	**919**	**359,263**	**-5.5%**	**4,636**	**-9.5%**	**4,059**	**-11.9%**	**773**	**-15.9%**
	Above 3000	317,224	4,292	3,595	713	297,424		3,810		3,074		572	
	Below 3000	40,414	757	194	19	40,041		752		192		18	
	Surface	22,538	77	817	188	21,797		75		793		183	
2015	**Total**	**399,157**	**5,399**	**4,706**	**937**	**374,953**	**-6.1%**	**4,867**	**-9.9%**	**4,109**	**-12.7%**	**768**	**-18.0%**
	Above 3000	333,192	4,513	3,666	727	310,633		3,996		3,110		568	
	Below 3000	42,756	806	198	19	42,132		795		195		19	
	Surface	23,209	80	842	191	22,188		76		804		182	

Figure 6-1. Fuel and Emission Savings



6.1 Annualization

The study was based on a representative day in the NAS, Tuesday, November 12, 1996. Results were then extended to annual savings. Multiplying the results by 365 would give annualized results only if traffic demand on all days in the year were comparable. However, traffic demand varies by day of the week and season. An analysis of the weekday and seasonal demand variations for 1996 resulted in a conversion factor of .96. This was primarily because the weekend traffic demand is less than that for a weekday. Daily results from the analysis were extended to annual savings in fuel and emissions by multiplying by 365 * .96. See Table 6-2 below.

Table 6-2. Annual Savings in Millions of Pounds

Phase of Flight	Fuel	NOx	CO	HC
Above 3,000	9,683	204.3	197.1	56.7
Below 3,000	219	4.0	1.1	0.1
Surface	358	1.2	13.2	3.1
Total	10,259	209.5	211.4	59.9
% Savings	6.1%	9.9%	12.7%	18.0%

6.2 Conversion of Fuel to Dollars

Economic savings were not the principle objective of this study; however, they are frequently of interest in evaluating investments such as CNS/ATM enhancements. In order to convert the fuel savings to dollars, the fuel was first converted from pounds into gallons by dividing by a factor of 6.7 for air carriers and military, and a factor of 6.0 for GA. Gallons of fuel saved were then multiplied by cost per gallon to determine the annual cost savings to users of the airspace system. ATA provided the FAA with cost of fuel and fuel consumption figures for all the major air carriers, national and large regional, over the last year. From this information, it was determined that the cost per gallon of fuel for air carriers, including air taxis/commuter, ranged from $0.51 - $0.68. An average of $0.60 was used in the analysis. Using fuel price information from AirNav and a sampling of GA pilots, it was determined that the cost per gallon of fuel for GA ranged from $1.37 - $3.95, with a national average of $2.08 used in the analysis. From this, the annual savings in 2015 were shown to be $1.0 B (in 1998 dollars). See Table 6-3 below.

Table 6-3. 2015 Annual Savings (in millions of 1998 $)

	Air Carriers/Mil	GA	Total
Lbs. of Fuel Savings	9,913	346	10,259
Gallons of Fuel Savings	1,480	58	1,537
Dollars of Savings	**$888**	**$120**	**$1,008**

Section 7

CONCLUSION

Fuel conservation and environmental protection have been long standing U.S. national priorities. The findings from this study indicate that Free Flight capabilities provided by planned CNS/ATM enhancements in the NAS Architecture clearly contribute to the realization of these national goals.

The key finding from this study indicates that aircraft flying in U.S. airspace could potentially reduce annual fuel burn by about 10 billion lbs. in the year 2015. This estimated fuel savings in effect represents a 6% reduction in the amount of fuel that would have been burned without NAS modernization. The fuel saving results in corresponding reductions of over 209 million lbs. of NOx, 211 million lbs. of CO, and 59 million lbs. of HC, representing reduced emission levels of 9%, 12% and 18%, respectively.

The fuel savings, resulting from more fuel-efficient trajectories, wind routes, and more efficient traffic handling capabilities, is estimated to provide an economic fuel benefit of about $1.0B (in 1998 dollars) in 2015 to the airspace users. On top of this economic fuel benefit potential, airlines also will experience other operating cost savings associated with reduced delays and more efficient flight paths resulting from the CNS/ATM improvements.

In general, this study has shown that there are positive environmental and economic benefits to be realized with the planned improvements in CNS/ATM capabilities by the FAA in support of Free Flight initiatives. The estimated savings in fuel to users and reduced emissions to society are considerable. Modernizing the NAS thus benefits not only the airspace users, but also the environment.

APPENDICES

A. Study Team Participants and Advisors
B. Detailed Assumptions
C. Models and Tools
D. Preliminary Report II: Airport Capacity Impacts of Airport and CNS/ATM Improvements
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APPENDICES

Appendix A: Study Team Participants and Advisors

NAME	ORGANIZATION
Fran Melone	FAA/ASD-400
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Julie Draper	FAA/AEE-120
Jim Littleton	FAA/AEE-120
Edward McQueen	FAA/AEE-110
Doug Baart	FAA/ACT-520
Christine Gerhardt	FAA/ACT-520
Joe Richie	FAA/ACT-520
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Donna Middleton	SETA
Arthur Tastet	SETA
Mark Kipperman	SETA
Marie Pollard	SETA
Madelyn Harp	SETA
Stephane Mondoloni	CSSI
Willie Weiss	CSSI
Bill Colligan	CSSI
Howard Wesoky	NASA
Mark Guynn	NASA/LaRC
Monica Hughes	NASA/LaRC
Mike White	CAASD
Howard Aylesworth	AIA
Michael Wascom	ATA
Heather Miller	ATA (Dyer Ellis & Joseph)
Julie Ellis	FEDEX
John Begin	NWA
John Buscher	UAL

Appendix B: Detailed Assumptions

(Detailed assumptions used within the study)

Paragraph 3.2.3.1 Airport Improvement Plan Physical Airport Improvements

1. Maximum arrival capacity will increase at 16 of the 80 modeled airports during the 1996 to 2005 time frame.
2. Maximum arrival capacity will increase at 7 additional airports by 2010.
3. There are no additional AIP improvements anticipated between 2010 and 2015.

Paragraph 3.2.3.2 Air Traffic Control Procedural Improvements

1. All procedural improvements implemented by 2010 were considered to be in effect at 2015.

Paragraph 3.2.4 Fleet Mix

1. When forecasting the future fleet mix, the proportion of U.S. aircraft in the world fleet will remain constant.
2. The percentage of each aircraft type in each class of aircraft in the fleet mix will remain the same in the future.
3. 1996 fleet values were obtained by interpolating between the 1995 value and 2005 value assuming a constant increasing (or decreasing) rate between those years.

Paragraph 4.0 Data Preparation

1. The baseline scenario assumes growth in traffic, changes in fleet mix, and continuous support of airport and procedural improvements.
2. The enhanced CNS/ATM scenario includes the same assumptions used for the baseline scenario and the phasing in of new technologies and capabilities.

Paragraph 4.2 Assignment of Aircraft Types

1. New aircraft were added to the list by assuming that they would fly the same distribution of stage lengths as an aircraft in the same category.
2. New aircraft would fly the same number of legs per aircraft per day as similar aircraft.

Paragraph 4.5 Assignment of Trajectories - Enhanced Scenario

1. Aircraft performance constraints such as maximum thrusts, speed, and others were considered constraint variables in creating flight trajectories.
2. The SUA availability and the activities around SUA were held constant.
3. For 2005, flights flying less than 1,000 nmi had their distances reduced (direct routing) when operating at flight level 240 and above.

4. For 2005, flights flying greater than 1,000 nmi were optimized for minimum fuel when operating at flight level 240 and above.
5. For 2010 and 2015, flights flying less than 1,000 nmi had their distances reduced (direct routing) when operating at 15,000 feet and above.
6. For 2010 and 2015, flights flying greater than 1,000 nmi were optimized for minimum fuel when operating at 15,000 feet and above.

Paragraph 5.1.1.1 Aircraft with Performance Data

1. In order to compute the fuel consumed by a flight, the weight of the aircraft at landing was estimated by assuming a passenger load factor of 70% and landing with 45 minutes of reserve fuel.
2. The maximum number of passengers on board was an average across the industry.

Paragraph 5.1.1.2 Aircraft without Performance Data

1. The weight of the aircraft at landing was estimated from the maximum allowable takeoff weight for the aircraft.
2. It was assumed that there would be a constant specific impulse and that the aircraft operated at a roughly constant lift-to-drag.

Paragraph 5.2.1 Fuel Burn

1. For all flights arriving within the CONUS, the same formula was used except that the delay time was always set to zero.

Appendix C: Models and Tools[1]

This appendix describes the various models and tools used to support the CNS/ATM Enhancement study. The tools are listed in alphabetical order.

Emissions and Dispersion Modeling System (EDMS)[2]

EDMS is a combined emissions and dispersion model for assessing air quality at civilian airports and military air bases. The FAA in cooperation with the US Air Force developed the model. The model is used to generate an inventory of emissions generated by aircraft operations at the airport and to calculate pollutant concentrations in this environment.

Today, EDMS is the FAA-preferred model for air quality assessment at the airport and air bases. It is one of the few air quality assessment tools specifically engineered for the aviation community. EDMS includes emissions and dispersion calculations, a database of emission factors for aircraft, ground support equipment, and reporting module.

ETMS Parser

The ETMS Parser is one component of the National Airspace Resource Investment Model (NARIM). The tool is used to parse raw Enhance Traffic Management System (ETMS) data and output formatted data. The ETMS data consist of messages received from different centers in the NAS. The data falls into two categories, including flown and filed flight information. The filed and flown messages are used to piece together flight information including aircraft ID, aircraft type, origin and destination, and planned and flown trajectories. The result from the parser is a clean and formatted data set that is used as input into the FDG, NASPAC, and OPGEN.

Future Demand Generator (FDG)[3]

The FDG is one component of the NASPAC model. The tool is used to grow future traffic based on today's traffic level and projected growth rate. The FDG uses the Fratar algorithm to forecast future scheduled traffic. The Frataring algorithm is a trip distribution technique that applies an iterative process to scale up the current origin/destination matrix according to the forecast year growth factor outlined in the TAF. The result of the Frataring algorithm is a scaled-up origin/destination matrix that contains the future number (the current number plus future increment) of scheduled flights from each origin to each destination.

The origin/destination matrix of current flights is subtracted from the Fratared origin/destination matrix to produce an origin/destination matrix of only the future flights. The origin/destination matrix of future flights contains the number of future

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[1] This appendix was developed by Doug Baart (Tech Center/ACT-520) and Diana Liang (FAA/ASD-400).
[2] Source – Emissions and Dispersion Modeling System Reference Manual; FAA; April 1997
[3] Source – Design of NASPAC Simulation Modeling System; David Millner; MITRE/CAAS; June 1993

scheduled flights from each origin to each destination that are to be generated by the Future Demand Generator. This matrix is an input to an algorithm that schedules these future flights and strings them together into aircraft itineraries.

The scheduling algorithm breaks the day into discrete time slots (e.g., 5 minutes) and assigns a value to each slot based on the current traffic congestion at the departure and arrival airports. The most valuable slots are those that are near current traffic peaks and that are not above capacity. Generally future flights are scheduled near existing traffic peaks. Average en route and turnaround times vary by aircraft class (i.e., jets and propeller-driven) and are used in the itinerary building logic.

The process for generating future unscheduled traffic is analogous to the scheduled traffic generation process described above. The differences are pointed out here. One difference is that the input data is produced from Host Z data. It contains records for the unscheduled IFR flights for a particular day. Another difference between the scheduled and unscheduled processes is in the airports at which traffic growth is forecast. The origin/destination airports, for which unscheduled IFR traffic growth is forecast, are approximately 400 airports that currently have the largest number of unscheduled IFR operations.

NAS Performance Analysis Capability (NASPAC)

The NASPAC SMS is a discrete-event simulation model that tracks aircraft as they progress through the NAS and compete for ATC resources. NASPAC evaluates system performance based on the demand placed on resources modeled in the NAS and records statistics at 72 of the busiest airports plus eight associated airports. NASPAC simulates system-wide performance and provides a quantitative basis for decision-making related to system improvements and management. The model supports strategic planning by identifying air traffic flow congestion problems and examining solutions.

NASPAC analyzes the interactions between many components of the ATC system and the system reaction to projected demand and operational changes. The model is designed to study nation-wide system performance rather than localized airport changes in detail; therefore, airports are modeled at an aggregate level. The model shows how improvements to a single airport can affect other airports in the NAS through the propagation of delay. An aircraft itinerary may consist of many flight legs that an aircraft will traverse during the course of a day. If an aircraft is late on any of its flight legs, successive flight legs may be affected. This is the way the model captures the rippling effect of passenger delay. The model does not reroute traffic or impose speed changes to flights because of adverse weather.

NASPAC records two different types of delay, passenger delay and operational delay. Passenger delay, which is not evaluated in this analysis, is the difference between the scheduled arrival time and the actual arrival time as simulated by NASPAC. Operational delay is the amount of time that an aircraft spends waiting to use an ATC system resource

Key output metrics recorded in the model include delay and throughput at airports, departure fixes, arrival fixes, restrictions, and sectors. This reporting is done system-wide and at all modeled airports. Operational delay consists of airborne and ground delay. Airborne operational delay is the delay that a flight experiences from competing for airborne ATC resources. Ground operational delay accumulates when an aircraft is ready to depart but has to wait for a runway to take off. It also occurs when airfield capacity limitations prohibit the aircraft from landing. Operational delay contributes to passenger delay and is assigned to the airport to which the flight is destined. Sector entry delay occurs when the instantaneous or hourly aircraft count parameters for that sector are exceeded. Sector capacities for each of the 756 sectors modeled were provided by FAA's Air Traffic organization.

Optimized Trajectory Generator (OPGEN)

OPGEN is another component of the NARIM system. The tool is used to produce 4-D flight trajectories base on the user objectives. The user objective may be to create flights that are optimized for wind and special use airspace (SUA) and use minimum fuel. The input requirement includes wind aloft information, aircraft performance, SUA activities, origin and destination and any operation procedures and cutoff level. The model uses a genetic algorithm for searching the optimized flight trajectory that meets the user requirements. The output is a formatted file with aircraft information, ID, origin and destination, interval latitude, longitude, altitude, and speed. The output from OPGEN can then be used as input to NASPAC or used to calculate fuel burned.

Appendix D: Airport Capacity Impacts of Airport and CNS/ATM Improvements[1]

This report describes how airport capacities were estimated for the study "The Impact of CNS/ATM Enhancements on Emissions" performed by and for ASD-430 in February through April 1998. The National Airspace System Performance Analysis Capability (NASPAC) Simulation Modeling System (SMS) was used to model two cases using these capacities: a baseline case and a case that included the effects of future communications, navigation, and surveillance (CNS) and Air-Traffic Management (ATM) improvements. The following scenarios were modeled:

Year Modeled	Cases Modeled	
1996	Baseline Case	-
2005	Baseline Case	CNS/ATM Improvement Case
2010	Baseline Case	CNS/ATM Improvement Case
2015	-	CNS/ATM Improvement Case

I. BASELINE-CASE AIRPORT CAPACITIES

The effects of physical airport improvements and new ATC procedures that do not require CNS/ATM improvements are reflected in the baseline capacities. Because no baseline case was analyzed for 2015, these baseline improvements were projected only to the year 2010.

A. Physical Airport Improvements

Physical changes to an airport can have a substantial impact on airport capacity. The effect can range from opening a new airport to adding new taxiways that streamline air-traffic operations. Runways can be extended to air-carrier length, allowing the airport to accommodate larger aircraft. Airport capacity can sometimes be increased by adding to the number of gates or adding room for aircraft to maneuver in the ramp area. However, the change that generally has the greatest impact on capacity is adding a new runway.

New runways are commonly built parallel to one or more existing runways so that parallel streams of traffic can be flown into and off of each runway. Separation between runways is critical; if two runways are built too close together, their operation under Instrument Flight Rules (IFR) may effectively be equivalent to a single runway. As a result, most new runways are built at least a half-mile apart (as measured from centerline to centerline). In IFR, dependent, staggered parallel approaches can be flown to parallel runways that are at least 2,500 feet apart, generating a 40-to-45 percent increase in arrival capacity over the capacity of a single runway. If parallel runways are at least 3,400 feet apart (3,000 feet apart for angled approaches) and a Precision Runway Monitor (PRM) is in use, independent parallel approaches can be flown in IFR, doubling the capacity of a single runway. (If no PRM is in use, 4,300 feet are required between runways to operate independent parallel approaches in IFR.)

[1] This appendix was developed by Dan Citrenbaum (FAA/ASD-400) and Willie Weiss (CSSI, Inc.).

There are other options that will increase airport capacity if there is insufficient space for an air-carrier length runway to be built at a separation that would allow independent parallel operations in IFR. In some cases, a shorter runway, designed for commuter and general-aviation aircraft, might be built at a separation that would allow independent operations in IFR, or an air-carrier-length runway might be built considerably closer to another runway. This runway would allow an independent stream of arrivals only under Visual Flight Rules (VFR) and is a viable alternative at generally fair-weather airports.

Table 1 shows the physical improvements that are expected to increase airport capacity during the 1996-2015 time frame among the 80 airports modeled in detail in NASPAC. Because arrival capacity is generally more restrictive than departure capacity, the increase in maximum arrival capacity is cited as a measure of the capacity increase. (Another reason for citing maximum arrival capacity is that many airports generally operate at or near maximum arrival capacity, again, because it is tends to be lower than maximum departure capacity.) Maximum arrival capacity will increase at 16 of these 80 airports during the 1996-to-2005 time frame. Capacity will increase at 7 additional airports by 2010. For the 1996-to-2005 time frame, the size of the increase is related to the number of runways in use in 1996 and is relative to the airport capacity in 1996, as well as to local ATC practices. (For the 2006-to-2010 time frame, the size of the increase relative to the airport capacity in 2005.) Also, note that the increase in capacity listed is for the effect of the new runway only; any further capacity increase due to CNS/ATM improvements or procedures that depend on CNS/ATM improvements is not included in this table. (The effects of those improvements are described later in this report.)

Table 1. Physical Airport Improvements Projected for 1996 - 2015

			Increase in Hourly Maximum Arrival Capacity		**%Weather***
Airport	**LocID**	**Improvement**	**VMC %** ***Add'l Ops***	**IMC %** ***Add'l Ops***	**< Viz Mins** ***< 1000/3***
		1996 to 2005			
Atlanta Hartsfield	ATL	Commuter runway without PRM	50% *45*	15% *13*	30.6% *12.5%*
Austin	AUS	New airport (Bergstrom AFB conversion)	0% *0*	100% *23*	28.9% *12.2%*
*The percentage of the airport's weather below visual minimums and below a 1,000-foot ceiling or 3-miles visibility (in italics) were derived from the airport's visual approach minimums and the National Climatic Data Center's International Station Meteorological Climate Summary data set. Each value in the data set are based on the average of many years of observations; values for the top 10 airports, for example, are based on an average of 40 years of observations. In the analysis, IMC operations were assumed to be flown below visual minimums. Because visual minimums vary by airport, the percent weather below 1,000/3 is included as a consistent basis of comparison of IMC weather between airports.					
Charlotte Douglas	CLT	Parallel runway (dependent in IMC)	45% *35*	21% *14*	24.2% *12.0%*
Cincinnati	CVG	New parallel	50%	50%	17.4%

			Increase in Hourly Maximum Arrival Capacity		**%Weather***
Airport	**LocID**	**Improvement**	**VMC %** ***Add'l Ops***	**IMC %** ***Add'l Ops***	**< Viz Mins** ***< 1000/3***
		(independent triple IMC approaches)	*33*	*30*	*11.9%*
Cleveland Hopkins	CLE	Close parallel runway	60% *24*	0% *0*	23.7% *11.5%*
Dallas-Fort Worth	DFW	New parallel runway will enable quadruple IMC apps.	25% *35*	33% *35*	18.1% *6.0%*
Detroit Metropolitan	DTW	New parallel runway will enable triple IMC apps.	39% *35*	33% *22*	39.6% *12.2%*
Louisville	SDF	New parallel (independent parallel approaches)	100% *35*	100% *32*	22.3% *7.6%*
Miami	MIA	Close parallel (increased VFR departure capacity)	0% *0*	0% *0*	5.2% *1.7%*
Minneapolis	MSP	New runway	15% *10*	21% *10*	27.6% *8.4%*
New Orleans	MSY	New parallel (independent approaches)	10% *6*	100% *33*	22.6% *8.7%*
Orlando	MCO	New parallel (independent triple approaches)	47% *35*	50% *29*	24.6% *5.8%*
Philadelphia	PHL	New staggered parallel (dependent approaches without PRM)	66% *37*	44% *14*	18.3% *13.0%*
Phoenix	PHX	New parallel (independent parallel approaches)	0% *0*	100% *32*	2.8% *0.3%*
Seattle	SEA	New parallel (dependent parallel approaches)	0% *0*	46% *12*	30.5% *10.5%*
St. Louis	STL	New offset parallel without PRM (dependent parallel approaches)	12% *9*	2% *1*	35.6% *9.8%*

			Increase in Hourly Maximum Arrival Capacity		**%Weather***
Airport	**LocID**	**Improvement**	**VMC %** ***Add'l Ops***	**IMC %** ***Add'l Ops***	**< Viz Mins** ***< 1000/3***
*The percentage of the airport's weather below visual minimums and below a 1,000-foot ceiling or 3-miles visibility (in italics) were derived from the airport's visual approach minimums and the National Climatic Data Center's International Station Meteorological Climate Summary data set. Each value in the data set are based on the average of many years of observations; values for the top 10 airports, for example, are based on an average of 40 years of observations. In the analysis, IMC operations were assumed to be flown below visual minimums. Because visual minimums vary by airport, the percent weather below 1,000/3 is included as a consistent basis of comparison of IMC weather between airports.					
2006 Through 2010					
Baltimore-Washington	BWI	New parallel runway	33% *17*	71% *20*	14.0% *9.0%*
Denver	DEN	New parallel runway (6th runway)	29% *35*	14% *15*	8.3% *5.3%*
Jacksonville	JAX	New parallel (independent IMC approaches)	33% *16*	100% *28*	32.3% *9.4%*
Los Angeles International	LAX	New, close parallel runway	42% *35*	0% *0*	31.1% *15.8%*
Pittsburgh	PIT	New parallel runway (triple independent IMC apps.)	40% *34*	50% *32*	25.6% *13.6%*
Tampa	TPA	New, close parallel runway	0% *0*	6% *4*	8.3% *5.4%*
Washington Dulles	IAD	New parallel runway	14% *13*	0% *0*	27.6% *11.3%*

*The percentage of the airport's weather below visual minimums and below a 1,000-foot ceiling or 3-miles visibility (in italics) were derived from the airport's visual approach minimums and the National Climatic Data Center's International Station Meteorological Climate Summary data set. Each value in the data set are based on the average of many years of observations; values for the top 10 airports, for example, are based on an average of 40 years of observations. In the analysis, IMC operations were assumed to be flown below visual minimums. Because visual minimums vary by airport, the percent weather below 1,000/3 is included as a consistent basis of comparison of IMC weather between airports.

Table 1 shows a smaller-than-expected increase in IFR capacity due to the new runways at ATL, PHL, and STL. This is because the new runways were built at a separation designed to take advantage of the Precision Runway Monitor (PRM). This is an example of the interaction between CNS/ATM improvements and physical improvements (included in the CNS/ATM Improvements cases but excluded from the baseline-case improvements described above).

B. ATC Procedural Improvements

Changes in ATC procedures can also have a significant effect on airport capacity. New procedures can increase the utilization of existing runways, or they can work in concert with new runways and with CNS/ATM improvements.

In the future, it is expected that converging IFR approaches will be added to independent parallel IFR approaches. This procedure will greatly increase capacity at airports with the appropriate configurations, such as Chicago O’Hare or Washington Dulles.

Independent converging IFR approaches can be flown to converging runways that have sufficient separation between runway thresholds, or to airports without sufficient separation, but at higher approach minimums. This procedure substantially increases IFR capacity at airports without parallel runways.

Dependent Converging Instrument Approaches (DCIA) allow controllers to direct two dependent streams of arriving aircraft to converging and even intersecting runways. Consecutive arrivals in each stream are staggered to separate the aircraft. An ARTS modification, called the Converging Runway Display Aid, enables controllers to maintain the correct separations.

In some cases, the addition of a navaid can increase airport capacity by allowing a new procedure. At Portland, a recently added Instrument Landing System (ILS) allows controllers to use dependent (staggered) parallel approaches.

Table 2 shows the procedural improvements predicted for airports modeled in detail in NASPAC for the 1996 - 2010 time period.

There were no known, new procedures beyond the 2010 time frame that could be included in this analysis.

Table 2. Procedural Airport Improvements Projected for 1996 - 2010

Airport	LocID	Improvement	Increase in Hourly Max. IMC Arrival Capacity in % and *Add'l Ops*	%Weather* < Viz Mins *< 1000/3*
Baltimore-Washington	BWI	DCIA	71% *20*	14.0% *9.0%*
Chicago O'Hare	ORD	Parallel plus converging IFR approaches	44% *30*	39.8% *10.9%*
Las Vegas	LAS	Independent converging IFR approaches	44% *16*	1.2% *0.3%*
Newark	EWR	DCIA	25% *9*	17.7% *11.8%*
Portland	PDX	Dependent parallel approaches	45% *14*	33.0% *6.7%*
San Francisco	SFO	DCIA	14% *5*	25.9% *8.7%*
Tampa	TPA	Parallel plus converging IFR approaches	38% *18*	8.3% *5.4%*
Washington Dulles	IAD	Parallel plus converging IFR approaches	43% *25*	27.6% *11.3%*

*The percentage of the airport's weather below visual minimums and below a 1,000-foot ceiling or 3-miles visibility (in italics) were derived from the airport's visual approach minimums and the National Climatic Data Center's International Station Meteorological Climate Summary data set.

II. CNS/ATM-IMPROVEMENTS CASE AIRPORT CAPACITIES

CNS/ATM improvements tend to increase capacity incrementally at the airports they affect. They may also work in concert with new runways. For example, an airport expecting a PRM can build a parallel runway at a separation of as little as 3,400 feet, rather than the standard 4,300-foot separation. This saves the airport operator land-acquisition costs and minimizes the environmental and noise impacts of the new runway.

A. Precision Runway Monitor

The PRM includes a high-update-rate, high-resolution radar and high-resolution, color display. FAA procedures allow straight-in, simultaneous Instrument Flight Rules (IFR) approaches to parallel runways with centerlines separated by as little as 3,400 feet if a PRM is in use. (The minimum distance between runway centerlines required for simultaneous IFR approaches is 4,300 feet if a PRM is *not* in use.) Simultaneous approaches to runways with centerlines separated by as little as 3,000 feet may be conducted using a PRM if 2.5-degree angled approaches are flown to one of the runways.

PRMs increase airport capacity because they enable simultaneous approaches to parallel runways where those approaches would otherwise not be possible. PRMs are being installed at five airports (Table 3) and will increase capacity over and above the capacity increase due to a new runway, where one is being built. (The capacity increases due to PRM shown in Table 3 vary because they are relative to the capacity of the best existing configuration. That is, if the best existing configuration has a high capacity, the relative increase due to the PRM will not be as large as it would be compared to a low-capacity configuration. However, even at airports that already have a high-capacity IMC configuration, a PRM may greatly increase overall airport capacity by supplying another high-capacity IMC configuration.)

New runways are being built at ATL, PHL, and STL to take advantage of the PRM. Existing runways will be used with PRMs at JFK and MSP. (Note that the capacity increases shown in Table 3 for ATL, PHL and STL do *not* include the increase due to the new runway; that increase is shown in Table 1.)

A PRM installation also implies a new procedure, in that PRM use allows an airport to operate independent, instead of dependent, parallel IFR approaches.

Table 3. Estimated Capacity Improvement Due Solely to PRM

Airport	LocID	Increase in Hourly Max. IMC Arrival Capacity in % and *Add'l Ops*	Expected Operational Date	%Weather* < Viz Mins *< 1000/3*
Atlanta Hartsfield	ATL	18% *18*	2002	30.6% *12.5%*
Minneapolis	MSP	35% *17*	September 1998	27.6% *8.4%*
New York JFK	JFK	20% *10*	August 1999	18.4% *12.1%*
Philadelphia	PHL	39% *18*	2000	18.3% *13.0%*
St. Louis	STL	40% *19*	2003	35.6% *9.8%*

B. Center-TRACON Automation System (CTAS)

CTAS is a decision-support system designed to help air traffic controllers and managers accurately predict aircraft arrival trajectories in the terminal area. CTAS also enables controllers to more accurately deliver aircraft over the runway threshold, reducing excess spacing buffers between flights and thus increasing airport capacity.

The CTAS benefits applied to those airports slated for CTAS were estimated from studies of two CTAS elements: the Passive Final Approach Spacing Tool (Passive FAST) and the Traffic Management Advisor (TMA).

In demonstrations at the terminal area surrounding Dallas-Fort Worth International Airport (DFW), Passive FAST decreased the mean separation between arriving aircraft through improved runway load balancing, more accurate aircraft sequencing, and reduced variability in longitudinal separation between aircraft. Controllers aided by Passive FAST were better able to anticipate the characteristics of the upcoming arrival stream and to direct aircraft to the best runway. This reduced delays to upstream aircraft and eliminated the need to redirect other upstream aircraft. In a comparison of 20 Passive FAST and 26 baseline-case events, the mean peak-period spacing between aircraft was 87.8 seconds for Passive FAST operations and 91.9 seconds for baseline operations, a spacing reduction of 4.1 seconds. Additionally, Passive FAST was found to decrease interarrival separation over the entire demand profile, from low demand to arrival rushes. (These results are documented in "Center/TRACON Automation System Passive Final Approach Spacing Tool (FAST) Assessment–Final Report," 5 December 1996, Crown Communications report number CTASDS-BAPRPT-002.)

TMA Time-Based Metering was also demonstrated at DFW. TMA improved metering fix accuracy and decreased threshold arrival stream gaps, thus reducing threshold separations. TMA was shown to reduce the mean interarrival threshold spacing buffer by 2.75 seconds over the baseline case. (This is documented in the briefing "CTAS Benefits Extrapolation First-Cut Analysis, given to FAA staff by Tara Weidner, George Couluris, and George Hunter of Seagull Technology, Inc. on August 20, 1997. A report is not yet available.)

Experts with the CTAS program were consulted; they determined that these spacing reductions (of 4.1 and 2.75 seconds) were both conservative and additive and applied to both Visual and Instrument Flight Rules operations. However, they also determined that the 4.1-second reduction due to Passive FAST could only be obtained at airports running 3 or more streams of arrivals. It was estimated that only 0.25 of that reduction could be obtained at airports with less than 3 arrival streams, and thus that value was added to the 2.75 seconds due to TMA at the appropriate airports.

The CTAS program reported that these benefits will be available by the year 2005, and thus the impacts they will have on airport capacity were included for the years 2005 and 2010. It is important to note that these benefits decrease interarrival separations, leaving less time to release departures. Thus, in the inputs to the NASPAC Simulation Modeling System, maximum arrival capacity was increased, but minimum departure capacity was reduced. This had a significant positive impact on airport delays despite the fact that the capacities satisfying 50/50 arrival/departure demand were generally unchanged.

To illustrate the relative improvement due to CTAS, Table 4 shows the estimated maximum IMC arrival capacity improvement due to CTAS. (Capacity also increased in VMC; however, these increases are similar to those shown in Table 4 and thus are not shown.)

Table 4. Estimated Capacity Improvement Due to CTAS

			Increase in Hourly Maximum IMC Arrival Capacity	
Airport	**LocID**	**No. of Arrival Streams**	**Percent**	**Number of Additional Ops.**
Atlanta	ATL	3	7.7%	9
Boston	BOS	2	1.9%	1

			Increase in Hourly Maximum IMC Arrival Capacity	
Airport	**LocID**	**No. of Arrival Streams**	**Percent**	**Number of Additional Ops.**
Burbank	BUR	1	2.9%	1
Charlotte	CLT	2	8.8%	7
Chicago Midway	MDW	1	3.2%	1
Chicago O'Hare	ORD	2	5.1%	5
Cincinnati	CVG	2	4.4%	4
Cleveland	CLE	2	2.0%	1
Dallas Love	DAL	2	2.2%	1
Dallas-Ft. Worth	DFW	4	7.1%	10
Denver	DEN	3	7.4%	8
Detroit	DTW	3	5.7%	5
Houston Hobby	HOU	1	3.2%	1
Houston Intercontinental	IAH	3	4.2%	3
John Wayne/ Orange Cnty.	SNA	1	3.0%	1
Las Vegas	LAS	2	1.9%	1
Long Beach	LGB	1	3.3%	1
Los Angeles	LAX	3	4.4%	3
Louisville	SDF	2	3.1%	2
Memphis	MEM	2	4.0%	3
Miami	MIA	2	3.0%	2
Minneapolis	MSP	2	3.1%	2
Nashville	BNA	2	3.6%	2
New York La Guardia	LGA	1	2.9%	1
New York JFK	JFK	2	3.3%	2
Newark	EWR	2	3.7%	2
Oakland	OAK	2	3.3%	2
Ontario	ONT	1	3.6%	1
Orlando	MCO	3	5.7%	5
Philadelphia	PHL	2	3.1%	2
Phoenix	PHX	2	3.1%	2
Pittsburgh	PIT	3	4.7%	3
Portland	PDX	2	2.2%	1
Salt Lake City	SLC	2	3.2%	2
San Diego	SAN	1	3.1%	1
San Francisco	SFO	2	2.5%	1

			Increase in Hourly Maximum IMC Arrival Capacity	
Airport	**LocID**	**No. of Arrival Streams**	**Percent**	**Number of Additional Ops.**
Seattle	SEA	2	2.6%	1
St. Louis	STL	2	3.0%	2
Washington Dulles	IAD	3	6.0%	5
Washington National	DCA	1	2.9%	1
White Plains, NY	HPN	1	3.3%	1

C. Integrated Terminal Weather System (ITWS) Terminal Winds Product

In prototype testing, controllers at Dallas-Fort Worth (DFW) used more accurate wind predictions from the Terminal Winds Product (TWP) to merge and sequence traffic more precisely. They used the improved wind projections to pass requests for wind-specific separations to upstream controllers, thus coordinating the longitudinal separations between aircraft throughout the terminal area.

One example of the benefits of the TWP is when a strong northwest wind is blowing at altitude at the northwest arrival gate ("Terminal Winds Operational Benefits for Dallas/Ft. Worth," 8 March 1996, MIT Lincoln Labs Memorandum No. 43PM-Wx-0039). Controllers are required to merge arrivals through that gate with arrivals through the southwest gate, where a crosswind exists in these conditions. The aircraft must be merged at the base leg of the final approach to runway 36L, and the large speed difference between aircraft approaching quickly through the northwest gate and aircraft flying at nominal speed through the southwest gate makes it very difficult for controllers to space and merge these aircraft in a way that produces optimal separations on final approach. Using TWP, controllers can adjust the speeds and spacing of aircraft approaching from the northwest gate, optimizing the separations on final approach for 36L and thus increasing airport capacity.

The result of these more-precise separations on final approach was an increase in airport capacity estimated by DFW controllers at 2.5 additional arrivals per runway per hour in low-ceiling and low-visibility conditions ("Integrated Terminal Weather System (ITWS) Terminal Winds Operational Benefits for New York City Airports," 24 February 1997, MIT Lincoln Labs Memorandum No. 43PM-Wx-0048). This estimate was then extrapolated to those airports slated for ITWS installations by increasing their maximum arrival capacity per arrival runway by that amount. Table 5 shows the estimated increase in hourly maximum arrival capacity due to the ITWS TWP.

Table 5. Estimated Capacity Improvement Due to ITWS

			Increase in Hourly Maximum IMC Arrival Capacity	
Airport	**LocID**	**No. of Arrival Streams**	**Percent**	**No. of Add'l Ops.**
Atlanta	ATL	3	5.6%	7
Baltimore	BWI	2	17.9%	5
Boston	BOS	2	9.4%	5
Charlotte	CLT	2	5.7%	5
Chicago Midway	MDW	1	6.3%	2
Chicago O'Hare	ORD	2	4.9%	5
Cincinnati	CVG	2	5.3%	5
Cleveland	CLE	2	9.8%	5
Columbus, OH	CMH	2	11.6%	5
Dallas Love	DAL	2	10.6%	5
Dallas-Ft. Worth	DFW	4	6.7%	10
Dayton	DAY	2	8.3%	5
Denver	DEN	3	6.0%	7
Detroit	DTW	3	7.5%	7
Ft. Lauderdale	FLL	2	8.6%	5
Houston George Bush	IAH	3	9.3%	7
Houston Hobby	HOU	1	6.3%	2
Indianapolis	IND	2	7.8%	5
Kansas City	MCI	2	7.4%	5
Louisville	SDF	2	7.6%	5
Memphis	MEM	2	6.4%	5
Miami	MIA	2	7.4%	5
Milwaukee	MKE	1	6.3%	2
Minneapolis	MSP	2	7.5%	5
Nashville	BNA	2	8.8%	5
New Orleans	MSY	2	8.1%	5
New York La Guardia	LGA	1	5.7%	2
New York JFK	JFK	2	9.7%	6
Newark	EWR	2	10.7%	6
Oklahoma City	OKC	2	8.3%	5
Orlando	MCO	3	7.6%	7
Palm Beach	PBI	1	5.4%	2
Philadelphia	PHL	2	7.6%	5
Phoenix	PHX	2	7.6%	5
Pittsburgh	PIT	3	10.4%	7
Raleigh-Durham	RDU	2	10.6%	5
Salt Lake City	SLC	2	7.8%	5

			Increase in Hourly Maximum IMC Arrival Capacity	
Airport	**LocID**	**No. of Arrival Streams**	**Percent**	**No. of Add'l Ops.**
St. Louis	STL	2	7.4%	5
Tampa	TPA	2	7.7%	5
Tulsa	TUL	2	8.3%	5
Washington Dulles	IAD	3	8.0%	7
Washington National	DCA	1	5.7%	2
Wichita	ICT	2	8.6%	5

D. Weather Systems Processor

The Airport Surveillance Radar-Weather Systems Processor (WSP) is a lower-cost system similar to ITWS that will supply some ITWS products to medium and smaller air-traffic-density airports. Of all the NASPAC airports at which it may be installed, its effects on capacity were only significant at LAX, where WSP is predicted to increase maximum arrival capacity by 7.0%.

E. Automatic Dependent Surveillance-Broadcast/Cockpit Display of Traffic Information (ADS-B/CDTI)

The combination of GPS, ADS-B, and CDTI has the potential to enhance visual approaches and thus increase airport capacity. ADS-B/CDTI may help pilots in several ways:

- Help them visually acquire traffic more quickly
- Help them positively identify traffic
- Provide a means of highlighting particular aircraft
- Provide ground speed, closure rate, and/or ground-track information

All of these elements are likely to enhance the safety of visual approaches. And, if the traffic display is reliable enough, pilots could use it to keep traffic electronically "in view" during poor-visibility conditions. All of these elements may allow a reduction in the ceiling and visibility requirements for visual approaches.

In the paper entitled "Potential ADS-B/CDTI Capabilities for Near-Term Deployment" (Mundra, et al, June 16, 1997, The MITRE Corporation, for the FAA/EUROCONTROL ATM R&D Conference), the authors discuss the potential reduction in the minimum ceiling and visibility required for visual approaches into several major airports. The ceiling and visibility reductions for those five airports (DFW, JFK, SEA, SFO, and STL) were used to modify the NASPAC scenario days for the CNS/ATM scenarios in this analysis. Because this enhancement is unlikely to be restricted to those five airports, the ceiling and visibility reductions were extrapolated to the 30 busiest airports, all of which are modeled in detail in NASPAC. The result of these modifications to the scenario days is an increase the time visual approaches can be flown into these airports.

To modify the scenario days, the average reduction in ceiling and visibility were computed for the five airports discussed in the paper described above. These average reductions (1,000 feet in ceiling and 1.5 miles in visibility) were then applied to the visual-approach ceiling and visibility minimums for the 30 busiest airports, with the exception of the five airports themselves. (The reductions listed in the paper were used for those five airports discussed in the paper.) Ceiling and visibility were *not* reduced to less than 1,000 feet and 3 miles.

To reflect the impacts in the NASPAC scenario days, the amount of time that an airport was in Visual Meteorological Conditions (VMC) was increased to reflect the lowering of the visual-approach minimums for flying. This was done by consulting a 30-to-45-year summary of airport weather conditions, called the International Station Meteorological Climate Summary, obtained from the National Climatic Data Center. The average percent of the time that the weather exceeded the current visual-approach minimums was extracted from that data set for each of the 30 busiest airports. Then, the average percent of the time that the weather exceeded the reduced visual-approach minimums was extracted from the data set and the difference in time was computed for each airport. That difference in time was used to increase the time that each airport ran visual approaches in the NASPAC simulation scenario days for the CNS/ATM case. The NASPAC SMS was then executed for the CNS/ATM case using the revised scenario days.

Table 6 shows the estimated increase in VMC due to the enabling of “electronic VFR” by ADS-B and CDTI. The effect of this increase in VMC in the NASPAC scenario days was to increase the amount of time that visual approaches were flown at airports, thus increasing airport capacity. Note that, because visual-approach minimums vary by airport, the percent increase in IMC due to ADS-B and CDTI also varies by airport.

Table 6. Estimated Increase in VMC Due to ADS-B/CDTI

LocID	Average Percent Increase in VMC	LocID	Average Percent Increase in VMC
ATL	3.4%	MCO	3.1%
BOS	11.2%	MEM	2.4%
CLT	3.9%	MIA	2.1%
CVG	3.7%	MSP	2.9%
DCA	3.6%	OAK	7.3%
DEN	1.9%	ORD	5.8%
DFW	3.9%	PDX	2.8%
DTW	8.9%	PHL	4.1%
EWR	3.5%	PHX	0.8%
IAD	13.2%	PIT	8.0%
IAH	3.5%	SEA	4.3%
JFK	2.6%	SFO	6.5%
LAS	0.8%	SLC	1.8%
LAX	2.4%	SNA	2.5%
LGA	4.2%	STL	2.7%

Because the increase in capacity due to ADS-B/CDTI manifests itself in an increase in the amount of time an airport can operate visual approaches, rather than a direct increase in airport capacity, it is impossible to cite the size of the capacity increase here. However, the impacts of that capacity increase on delays are reflected in the results of the NASPAC SMS runs. It is also important to note that the percent VMC reflects not only weather, but also the visual approach minimums for each airport. If an airport has high minimums, its percent VMC may be considerably lower than the percent VMC for another airport with lower minimums.

F. Using ADS-B/CDTI to Operate Simultaneous Parallel IFR Approaches

The combination of GPS (augmented using WAAS or LAAS), ADS-B, and CDTI may also be used in the future to provide guidance for simultaneous independent parallel IFR approaches. In effect, this combination of navaids may be used in the same way a PRM is used now for these approaches. For this effort, it was assumed that runway centerlines must be separated by 2,500 feet for straight-in parallel IFR approaches to be flown to ILS Category I minimums. (Closer separations may be possible using angled approaches, but these would most likely be to higher-than-CAT I minimums.)

Table 7 shows the airports that are likely candidates for this combination of navaids and approaches.

Table 7. Estimated Capacity Improvement Using ADS-B/CDTI for Independent Parallel Approaches

		Increase in Hourly Maximum IMC Arrival Capacity	
Airport	**LocID**	**Percent**	**No. of Add'l Ops.**
Charlotte	CLT	24%	22
Detroit	DTW	13%	13
Nashville	BNS	47%	29
Portland	PDX	35%	16
Seattle	SEA	44%	17

G. Using WAAS or LAAS for Offset Approaches

Localizer/Distance Measuring Equipment (LDA) approaches are flown to some airports today using an offset ILS localizer while aircraft fly a standard ILS approach to the parallel runway. In the offset approach, the aircraft fly an approach to a localizer offset from the runway centerline and then "sidestep" to the runway approximately 3 miles from the runway threshold. This type of approach allows aircraft on parallel approaches to maintain separation until they are only a short distance from the runway threshold. One example is the LDA approach to STL runway 12L.

Offset approaches could enable either dependent or independent IFR approaches to parallel runways. However, it should be noted that these approaches can generally *not* be flown to ILS CAT I minimums. This procedure could be duplicated by 2005, using WAAS or LAAS for guidance. Table 8 shows the estimated increase in maximum arrival capacity at airports that are candidates for this procedure.

Table 8. Estimated Capacity Improvement Using WAAS or LAAS for Independent Parallel Approaches

		Increase in Hourly Maximum IMC Arrival Capacity	
Airport	**LocID**	**Percent**	**No. of Add'l Ops.**
Boston	BOS	21%	9
Cleveland	CLE	19%	8
Colorado Springs	COS	100%	24
Newark	EWR	20%	9
Fort Lauderdale	FLL	100%	27

Note that the variability in the impact of these approaches is dependent on the existing airport configuration and its capacity. If an airport has only a single approach in IMC, then adding these approaches could double its capacity.

III. COMPARISON OF CAPACITY IMPROVEMENTS

The following two tables list the estimated increase in maximum IFR arrival capacity for each type of improvement. In Table 9, physical and procedural improvements are listed for the baseline case. The capacity increase associated with each improvement excludes any contribution by CNS/ATM systems.

Because some runways have been built with the PRM in mind, IFR capacity may increase only slightly due to those runways if the scheduled PRM is not installed (a very unlikely prospect). Also, close-parallel runways will not affect IFR capacity significantly. The effects of these two types of new runways are not included in this chart so that the results are not skewed.

Table 9. Baseline Case Physical and Procedural Improvements

Improvement	No. of Affected Airports	Average Estimated Increase in Max. Hourly IFR Arrival Cap.	
		Percent	No. of Add'l Ops.
Physical Improvements 1997-2005 (excluding close parallels and runways designed for use with PRM)	12	53%	22
Physical Improvements 2006-2010 (excluding close parallels at LAX and TPA)	6	40%	16
Procedural Improvements 1996-2010	8	41%	17

Table 10 lists the estimated increase in maximum IFR arrival capacity for CNS/ATM improvements. The PRM, ADS-B/CDTI parallel approaches, and WAAS/LAAS parallel approaches are all similar types of improvements, in that each is associated with a new procedure and a new type of surveillance. Each allows an airport to operate another independent stream of IFR arrivals. These improvements provide a significant increase in capacity. However, ITWS and CTAS, although applicable at many airports, provide only an incremental increase in capacity.

Table 10. CNS/ATM Case Improvements

CNS/ATM Improvements	No. of Affected Airports	Average Estimated Increase in Max. Hourly IFR Arrival Cap.	
		Percent	No. of Add'l Ops.
PRM	5	30%	16
CTAS	41	4%	3
ITWS	43	8%	5
ADS-B/CDTI Parallel Approaches	5	33%	19
WAAS or LAAS Parallel Approaches	5	52%	15
WSP	1	7%	6

Appendix E: Fleet Mix[1]

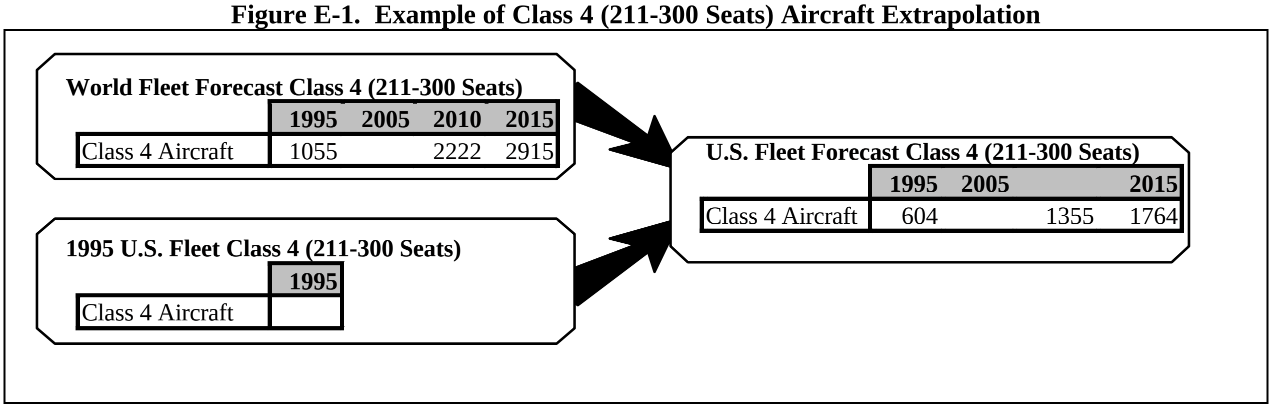
The fleet mix used for this study was developed using data from NASA/LMI, ATA, ICAO, and APO. The current fleet mix was compiled using data from NASA/LMI's Aviation System Analysis Capability (ASAC) database and ATA input. Since the ASAC database has information on passenger aircraft only, this data was augmented with information from ATA to account for cargo aircraft. Using both of these sources, the baseline fleet for 1995 was obtained and then extrapolated to 1996, 2005, 2010, and 2015. The future fleet mix does not assume incorporation of advanced engine technologies resulting from ongoing research activities.

Table E-1. Sample 1995 Data from ASAC Database

Carrier	Manufacturer	Type	Model	Yr of 1st Delivery	Seats	Country	Engine Maker	Engines	Serial #	Registration #
ALLEGHENY COMMUTER AIRLINES	BRAD	DHC8	DHC8-101	1984	37	USA	PWC	PW120A	D8007	N801MX
ALOHA AIRLINES	BOEING	737	737-200C	1985	110	USA	PW	JT8D-17A	23292	N8924E
AMERICA WEST AIRLINES	AIRBUS	A320	A320-232	1995	150	USA	IAE	V2527-A5	D0471	N901DA
AMERICA WEST EXPRESS	BEECH	1900	1900D	1991	19	USA	PWC	PT6A-67D	UE-002	N3YV
AMERICA WEST EXPRESS	BEECH	1900	1900D	1991	19	USA	PWC	PT6A-67D	UE-003	N75ZV
AMERICA WEST EXPRESS	BEECH	1900	1900D	1993	19	USA	PWC	PT6A-67D	UE-075	N78YV
AMERICA WEST EXPRESS	BEECH	1900	1900D	1993	19	USA	PWC	PT6A-67D	UE-078	N86YV
AMERICA WEST EXPRESS	BEECH	1900	1900D	1994	19	USA	PWC	PT6A-67D	UE-086	N837CA
AMERICAN AIRLINES	BOEING	727	727-200F	1977	150	USA	PW	JT8D-9A	21086	N401AL
AMERICAN AIRLINES	BOEING	767	767-200	1982	172	USA	GE	CF6-80A	22307	N302AA
AMERICAN AIRLINES	BOEING	767	767-200EREM	1984	172	USA	GE	CF6-80A	22315	N313AA
AMERICAN AIRLINES	AIRBUS	A300-600	B4-605R	1993	267	USA	GE	CF6-80C2	A0675	N962GF
AMERICAN AIRLINES	DOUGLAS	DC10	DC10-10	1970	290	USA	GE	CF6-6D	46502	N103AA
AMERICAN AIRLINES	DOUGLAS	MD11	MD11-P	1991	257	USA	GE	CF6-80C2	48419	N1752K

ICAO forecasts the world fleet out to 2015 separating aircraft by class (number of seats). Using ICAO's forecast for each class, and the U.S. fleet for 1995 developed above, the U.S. forecast for each class was extrapolated from the world forecast based on the assumption the proportion of U.S. aircraft in the world fleet would remain constant.

Figure E-1. Example of Class 4 (211-300 Seats) Aircraft Extrapolation



[1] This appendix was developed by Donna Middleton (FAA/SETA).

The U.S. forecast for each class was then used as a basis for estimating the future inventory for each type of aircraft by assuming that the percentage of each aircraft type in each class of aircraft will stay the same in the future. Figure E-2 is a continuation of the example in Figure E-1.

Figure E-2. Example of Class 4 Aircraft Interpolation (continued)

U.S. Forecast - Class 4 (211-300 Seats)

	1995	2005	2010	2015
Class 4 Aircraft	604	1121	1355	1764

U.S. 1995 Fleet - Class 4 (211-300 Seats)

	1995	%
747 SP	4	1%
L1011	98	16%
DC10	209	35%
767	214	35%
777	9	1%
A300	70	12%
Class 4 Aircraft	604	100%

U.S. Forecast by Type - Class 4 (211-300)

	1995	2005	2010	2015
747 SP	4	7	8	11
L1011	98	162	206	271
DC10	209	345	440	577
767	214	353	451	591
777	9	15	19	25
A300	70	115	147	193
Class 4 Aircraft	604	1121	1355	1764

The resulting U.S. forecast was then validated and updated using APO's forecast for Stage 2/3 aircraft. The term Stage 2/3 aircraft refers to aircraft that meet Stage 2/3 noise levels as prescribed in Title 14 of the Code of Federal Regulations (14 CFR), part 36. Stage 2 aircraft are being removed from the fleet inventory under section 91.853 of 14 CFR, part 91. Adjustments to the future aircraft inventory were made to account for the phasing out of these aircraft. Aircraft that currently are out of production (such as the 727 and 737-100/200) were reduced in the future fleet, and other aircraft in the same class were increased to compensate. 1996 fleet totals were obtained by interpolating between the 1995 total and 2005 total assuming a constant increasing or decreasing rate between those years. The resulting U.S. forecast is shown in Figure E-2.

Figure E-3. U.S. Fleet Forecast

Class	Type	1996	2005	2010	2015
20-40 seats	DHC6	64	108	131	155
	DHC8	144	244	296	349
	D328	37	63	76	90
	Embr120	237	402	488	576
	J31	87	148	180	212
	J32	83	141	171	202
	J41	39	66	80	95
>40 seats	ATP	12	36	48	61
	ATR-42	100	299	400	506
	ATR-72	51	153	204	258
	CV-580	18	54	72	91
	CRJ	36	108	144	182
	DHC7	29	87	116	147
	F27	14	42	56	71
Total (Class 1)		951	1950	2462	2994
	BAE146	41	47	52	57
	A320	109	187	267	306
	DC8	102	119	131	143
	DC9	454	408	328	328
	707/720	2	2	3	3
	727/100-200	680	147	0	0
	737-100	11	0	0	0
	737-200	312	90	5	0
	737-300	482	561	618	673
	737-400	94	123	135	147
	737-500	160	459	600	658
	MD-81/82/83/87/88	615	775	915	1010
	MD-90	11	13	14	16
	F-100	130	151	166	181
	F-28	70	81	90	97
Total Class 2 (81-150 Seats)		3273	3163	3324	3618
	757	660	1803	2294	2592
	A310	41	79	99	115
Total Class 3 (151-210 Seats)		701	1882	2393	2707
	L1011	101	49	53	53
	DC10	176	205	175	175
	747-SP	4	0	0	0
	767	224	483	611	854
	777	12	159	218	251
	A300	73	225	298	431
Total Class 4 (211-300 Seats)		591	1121	1355	1764
	MD11	55	70	93	117
	747-100	59	50	50	50
	747-200	62	60	53	52
	747-400	47	91	126	161
Total Class 5 (301-400 Seats)		223	271	322	380
	XX (future design)	0	39	80	133
Total Class 6 (401-500 Seats)		0	39	80	133
	747-SR	0	19	92	144
Total Class 7 (501-600 Seats)		0	19	92	144
TOTAL (Class 2-7)		**4787**	**6494**	**7566**	**8745**

Appendix F: Data Preparation[1]

The baseline scenario includes the following assumptions: growth in traffic, changes in fleet mix, and continuous support of improvement of airports and procedures. The enhanced CNS/ATM scenario includes the assumptions for the baseline scenario and the addition of new technologies. Data preparation for these scenarios included the process for building future flights and the assignment of aircraft type and trajectories. The following paragraphs describe the process in detail.

Developing Future Flight Data

To build an extension to the baseline scenario, two sets of flight data were generated for each of the future years (1996, 2005, 2010, and 2015). The first set consisted of flight data for all scheduled commercial flights. The second set consisted of all general aviation and military flights.

The initial base year was constructed using the scheduled or commercial flights from the OAG for November 12, 1996. The origin airport, destination airport, scheduled times, flight identifier, and aircraft type were obtained for each scheduled flight in the NAS.

Along with the scheduled flights, the general aviation and military flights were obtained from the November 12, 1996, ETMS data. Flights were identified as general aviation or military based upon their flight identifiers. A set of flight data was obtained for these flights consisting of the origin airports, destination airports, actual times of flight, and aircraft type.

The scheduled flights and the general aviation and military flights combined to capture the majority of the activities in the NAS. The next step was to grow the traffic to reflect the projected demand as described in the TAF.

The above data sets were input into the FDG to increase the traffic demand to the levels expected for 2005, 2010, and 2015. The FDG provided the future flights. Once the new flights were obtained for each scenario, the aircraft types were modified in each year to account for fleet modernization and acquisition of new aircraft. Trajectories were then assigned to each flight, first in the baseline scenario and subsequently in the enhanced scenario, which were optimized for the future concept of operations.

Assignment of Aircraft Types

To assign an aircraft type to a new flight, a database of fleet mix for the specific future year was used. For each future year, the fleet mix, consisting of the number of each aircraft type (e.g., B737) anticipated to be in service by that year), was obtained. This forecast was used to assign an aircraft model to each flight in the future. The following assumptions were included:

[1] This appendix was developed by Stephane Mondoloni (CSSI, Inc.) and Diana Liang (FAA/ASD-400).

- New aircraft are added to the list by assuming that they would fly the same distribution of stage lengths as an aircraft in the same category.

- New aircraft would fly the same number of legs per aircraft per day as similar aircraft.

An important factor in the assignment of aircraft type to a new flight is stage length. The number of legs flown by each aircraft per day is a function of stage length. A process was derived to assign the aircraft type to each flight based on the <u>travel distance</u> of each flight. (See Figure F-1 below.)

Figure F-1. Assignment Aircraft Type by Stage Length and Fleet Mix Projections

Baseline: Number of flights by stage length.

Type	Stage Length (nmi)				Total
	0 - 250	250 – 500	500– 750	…	
B737					
A300					
Total					

Multiply by growth to types

Future: Number of flights by stage length.

Type	Stage Length (nmi)				Total
	0 - 250	250 – 500	500– 750	…	
B737					
A300					
Total					

Obtain percentages by column

Future: Fraction of flights by stage length.

Type	Stage Length (nmi)			
	0 - 250	250– 500	500– 750	…
B737				
A300				
Total	100%	100%	100%	100%

The FDG assigned the jet or turboprop category to a future flight. This information was used to assist in the assignment of fleet mix to the new individual flights. A flight that was a jet or turboprop in 1996 remained so in the future years.

The 1996 OAG data was used to build a matrix that contained the number of flights by aircraft type and stage length. The projected growth in the number of aircraft of a given type was used to grow the number of flights by stage length for that aircraft type. Thus, it was assumed that aircraft of a given type would continue to operate on flights with the same distribution of stage length. Finally, the fraction of flights of a given stage length using each aircraft type was obtained. These were used to assign the aircraft type by stage length for all the flights in the future years.

As an example, if there were 120 flights with a stage length of 250-500 nautical miles (nmi) of jet aircraft X in 1996, and aircraft X was to grow 20% by 2010, there would be 144 flights of aircraft X in 2010 with a stage length of 250-500 nmi. If the total number of jet flights with a stage length of 250-500 nmi was 1000 in 1996 and 1300 in 2010, the probability of a jet flight with a stage length of 250-500 nmi being assigned aircraft X would be 11% (144/1300).

Assignment of Tracks

Once the flight origin and destination were identified and the aircraft type was assigned to the flight, a track was assigned. A track consists of a series of points between the flight's origin and its destination. The assignment is done randomly by selecting a track from the set of all filed tracks for the same origin and destination. The set of all filed tracks between city pairs was obtained through the ETMS data set. For example, if a flight flew from ORD to LAX, one track was selected from all filed tracks between ORD and LAX. Once the track was assigned, the altitude and speed trajectory was assigned to that track to establish a flight trajectory.

Assignment of Trajectories – Baseline Scenario

For the baseline scenario, speed and altitude profiles were assigned to each flight as a function of the track, aircraft type, desired cruise altitude, and airspeed en route. For each aircraft type, a climb profile was defined by a sequence of altitudes and airspeeds. When detailed aircraft information was available, it represented the fastest allowable climb to altitude as a function of stage length. The stage length was used to identify the aircraft weight. Aircraft going further are heavier and cannot climb as fast. In general the climb trajectory represented the average climb rates actually flown by analysis of ETMS data for that aircraft type. In today's operation, the aircraft climb and descend in steps. An aircraft climbs to an assigned altitude and plateaus for a time before climbing to the next assigned altitude. In this study, plateaus were removed from climb trajectories.

Once flights reached their cruise level (speed and altitude), the flights continued to fly along the track at the specified airspeed and altitude. The time at points along the track was computed by translating the airspeed to ground speed using the wind velocity field for November 12, 1996.

The descent trajectory was imposed on each flight as a function of the year being analyzed, then as a function of the aircraft type. For 1996 and 2005, the descent trajectory that was used corresponded to procedural descents obtained by looking at the descent trajectory of flights under current operations (summarized in Table F-1). For aircraft whose speed during descent was significantly below that specified in the table, the speed during descent was obtained from that observed in actual descents for that aircraft. The trajectory (distance versus altitude) was maintained as specified in Table F-1.

Table F-1. Description of Procedural Descent Trajectory

Altitude	Distance From Airport.	Speed (kts)	Descent Rate (fpm)
25,000	125	445	1000
20,000	90	400	1670
15,000	70	400	1250
10,000	50	250	830

For the years beyond 2005, the descent trajectory was obtained by averaging the descents obtained in ETMS data by aircraft type after altitude plateaus were removed. This provided a descent in which aircraft were allowed to descend uninterrupted.

The general aviation, or unscheduled aircraft, trajectories were assigned based on their actual trajectories as reported in the ETMS messages. These messages represent the position updates (at 5-minute increments) for all controlled flights in the NAS. This could be done for the 1996 baseline data since GA and military flights were obtained from the ETMS data. Thus, there was a one-to-one correspondence between the GA/military demand data and the ETMS data set. The trajectories of new GA/military flights, added by the FDG, were obtained by copying the trajectory of an existing flight between the origin and destination for that same equipment category. Note that no projection for fleet mix of general aviation or military aircraft was attempted.

Assignment of Trajectories – Enhanced Scenario

Optimized trajectories were developed for the enhanced scenario beginning with the baseline trajectories for each year using the OPGEN portion of the NARIM suite of tools. Trajectories were optimized only for the portion of the flight above 24,000 feet in 1996 and 2005. Beyond 2005, the portion of the flight above 15,000 feet was optimized for distance or fuel. Thus, the climb and descents to and from 24,000 feet and 15,000 feet were held constant in 1996-2005 and 2010-2015, respectively.

Flights that flew less than 1,000 nmi in the baseline were not optimized for minimum fuel, but had their distances reduced as much as possible so that active special use airspace (SUA) was still avoided. For these flights, the direction around SUA was held constant. (If the aircraft went left of SUA, it continued to go left around the SUA.) Only the portion of the flight above the cutoff altitude described in the preceding paragraph was modified. For flights that did not climb above the cutoff altitude, the flight trajectory was not modified. As the distance of the flights reduced, the flight speed was assumed to remain constant between the two scenarios, thus the times at each waypoint were modified to reflect the shorter flight paths. The arrival time was preserved between the baselines and the modified scenarios. The arrival time was preserved since this is what airlines prefer. If the airlines knew they could leave later (and possibly fill more seats) and still arrive on time they would rather do that than get to the destination early.

Flights that flew more than 1,000 nmi in the baseline, for which we had no aircraft performance data, were assumed to fly the minimum distance as above.

The remaining flights that flew more than 1,000 nmi in the baseline were modified above the cutoff altitude so that they would consume a minimum amount of fuel while still meeting the same time en route. If the flight could fly faster and reduce the consumed fuel further, it was assumed to do so. If the flight could not meet the desired time due to constraints, it was assumed to fly in a minimum time. Certain constraints were imposed on the allowable trajectories. These constraints are summarized below.

- Aircraft performance constraints (maximum thrust, maximum speed, etc.).

- Avoidance of active SUA.

Flights must cruise at valid altitudes for direction of flight. In 1996, current valid cruising altitudes for direction of flight were assumed. For 2005 and 2010, Reduced Vertical Separation Minima (RVSM) rules of flight were imposed. In the 2015 scenario, no altitude limits were imposed, since it was assumed that flights were allowed to cruise climb.

Appendix G: Fuel Burn Calculation[1]

This appendix describes more fully the fuel burn assumptions and methodologies used in this study. To calculate aircraft fuel burned, the following factors were considered: aircraft performance, aircraft weight, and flight trajectory. In many instances, aircraft performance data is not widely available from industry; therefore, alternative assumptions and methodologies must be considered and applied to calculate the fuel burned for the remaining aircraft that operate in the NAS.

Table G-1 is a list of all aircraft models for which detailed performance data was available for analysis. The aircraft performance data was derived from the FAA LINKMOD model. The data and its relative contribution to the total fuel consumed in the NAS were analyzed.

Table G-1. Aircraft Models for Which Detailed Performance Data was Available

Aircraft Model	Description
A300	Airbus 300
A310	Airbus 310
A320	Airbus 320
A330	Airbus 330
A340	Airbus 340
B727-100	Boeing 727-100
B727-200	Boeing 727-200
B737-200	Boeing 737-200
B73F	Boeing 737-400
B73S	Boeing 737-300
B73V	Boeing 737-500
B747-100	Boeing 747-100
B747-200	Boeing 747-200
B747F	Boeing 747-400
B757-200	Boeing 757-200
B767-200	Boeing 767-200
DC10-10	Douglas DC10-10
DC10-30	Douglas DC10-30
DC8-63	Douglas DC8
DC9-30	Douglas DC9-30
DC9-50	Douglas DC9-50
L1011	Lockheed L1011
MD11	McDonnell Douglas MD11
MD80	McDonnell Douglas MD80

An analysis of NASA CR-4700 indicated that the aircraft found in Table G-1 contributed to 87% of all fuel consumed globally. The remaining aircraft, for which fuel burn models was not

[1] This appendix was developed by Stephane Mondoloni (CSSI, Inc.) and Diana Liang (FAA/ASD-400).

available, affected only the remaining 13% of the fuel burn. It was therefore concluded that a fuel burn approximation for any aircraft not included in Table G-1 would have only a slight impact on results of the analysis.

As a secondary check on the relative contribution to total fuel burn, the total fuel consumption was computed on a day of traffic using actual flown traffic data and using the method described below. Similarly, the results indicate that 89% of all fuel consumed was attributable to those aircraft for which we had performance data.

Force balance equation

A force balance equation was used to calculate fuel burned for all aircraft listed in Table G-1. Once the trajectory and the model number were obtained for a flight, a numerical integration of the fuel weight was performed from the arrival to the departure point. This proceeded as a final value problem using an ordinary differential equation (ODE) describing the weight (W) summarized below. Note that it was assumed that the climb angle was small enough for the lift to be approximately equal to the weight.

$$C_L = \frac{W}{\frac{1}{2} r V^2 S}$$

$$Drag = C_D(C_L, M)\tfrac{1}{2} r V^2 S$$

$$T = Drag + W\sin(g) - \tfrac{W}{g}\tfrac{dU}{dt}$$

$$\tfrac{dW}{dt} = -FF(T, h, M)$$

C_L - lift co-efficient	C_D - Drag co-efficient
M - Mach number	ρ- density
S - reference area	V - airspeed
W - weight	FF - fuel flow
T = thrust	t = time
h = altitude	γ - climb angle

Once the initial weight was found, the total fuel consumed for this flight was simply the initial weight minus the final weight.

Aircraft without performance data

For the remaining aircraft where detailed performance data was not available, the equation above reduces to the following:

$$\tfrac{dW}{dt} = W\left(k_1 + k_2\sin(g) + k_3\tfrac{dU}{dt}\right)$$

The k's are constants to be determined through ordinary least squares (OLS) regression on the fuel flow obtained using the method described previously. A lower limit was imposed on the fuel flow to ensure against negative burn rates when aircraft are descending or decelerating rapidly.

In order to determine if the curve fitting approach was approximately valid for different types of general aviation aircraft, we obtained the fuel consumption (in gallons per hour) for different types of aircraft from the Aviation and Aerospace Almanac (1997). From the above equation, an average weight is implied by the average fuel consumption. Table G-2 shows that the implied weights are indeed typical for the aircraft listed.

Table G-2. Implied Weights given Fuel Consumption and Typical Aircraft

Type	**Consumption** **GPH**	**Implied Weight** **LBS**	**Example Aircraft**
Piston 1-3 seats	9.4	1178	Cessna 150 (985-1600lbs)
Piston 1-6 seats	26.6	3333	Piper PA-30 (2210-3600lbs)
Prop 1-12 seats	84.8	10626	Beech King Air (8500-14000lbs)
Jet 2 engines	263.2	32982	Dassault Falcon 2000 (19980-35000lbs)

Appendix H: Aircraft Type Cross Reference To Engines

Type	Name	Manufacturer	ICAO Default Engine	BM2 Default Engine	Engines
A10	A-10A THUNDERBOLT II	FAIRCHILD REPUBLIC	TFE731-2-2B	LRJ/	2
A300	AIRBUS-300	AIRBUS	CF6-80C2A5	A30B2-100/CF6-50C2R	2
A310	AIRBUS-310	AIRBUS	CF6-80A3	A31-200/CF6-80A3	2
A320	AIRBUS-320	AIRBUS	CFM56-5-A1	A32-200/CFM56-5A1	2
A4	A4	DOUGLAS	TFE731-2-2B	LRJ/	1
A6	A6	GRUMMAN	TFE731-2-2B	LRJ/	2
AA5	CHEETAH AA-5	GRUMMAN	IO-360-B		1
AC50	COMMANDER 500	AERO COMMANDER	IO-360-B		2
AC69	JET PROP COMMANDER	AERO COMMANDER	PT6A-65B	BE1/SMTURB	2
AJ25	ASTRA 1125-IW	ISRAEL	TFE731-2-2B	LRJ/	2
AN12	AN-12	ANTONOV	501D22A		4
ARJ	AVRO REGIONAL JET	AERO	CF34-3A		2
ATR42	AIR TRACTOR-42	AIR TRACTOR	PW120	AT4/LGTURB	2
B1	B1 LANCER	ROCKWELL	JT3D-3B		4
B52	STRATOFORTRESS	BOEING	JT3D-3B		8
B707	BOEING 707-100/200/300/400	BOEING	JT3D-3B	B3C-320CH/JT3D-3B	4
B727	BOEING 727	BOEING	JT8D-15(REC)	72S-200/JT8D-15	3
B727-100	BOEING 727-100	BOEING	JT8D-7B (R.E.C.)	727-100/JT8D-7B	3
B727-200	BOEING 727-200	BOEING	JT8D-15(REC)	72S-200/JT8D-15	3
B737	BOEING 737-100/200 SERIES	BOEING	JT8D-15(REC)	737-200/JT8D-15	2
B737-200	BOEING 737-200	BOEING	JT8D-15(REC)	737-200/JT8D-15	2
B73F	BOEING 737-400	BOEING	CFM56-3C-1	73Z-400/CFM56-3B	2
B73J	BOEING 737-500	BOEING	CFM56-3C-1	73L-500/CFM56-3C	2
B73S	BOEING 737-300/400 SERIES	BOEING	CFM56-3-B1	73Y-300/CFM56-3B	2
B747	BOEING 747	BOEING	JT9D-7Q	747-200B/JT9D-7Q	4
B747-100	BOEING 747-100	BOEING	JT9D-7A	747-100/JT9D-7A	4
B747-200	BOEING 747-200	BOEING	JT9D-7Q	747-200B/JT9D-7Q	4
B74F	BOEING 747-400	BOEING	PW4056	74I-400/PW4056	4
B74R	BOEING 747-R	BOEING	PW4056	74I-400/PW4056	4
B757	BOEING 757	BOEING	RB211-535E4	757-200/RB211-535E4	2
B757-200	BOEING 757-200	BOEING	RB211-535E4	757-200/RB211-535E4	2
B767	BOEING 767	BOEING	CF6-80A	767-200/CF6-80A	2
B767-200	BOEING 767	BOEING	CF6-80A	767-200/CF6-80A	2
B777	BOEING 777	BOEING	PW4084		2
BA11	BRITISH AIRCRAFT -111	BRITISH AIRCRAFT	SPEY MK511	BAC-500/RR_SPEY-512	2
BA14	BRITISH AIRCRAFT - 14	BRITISH AIRCRAFT	SPEY MK511	BAC-500/RR_SPEY-512	2

*Note: In the cases when the engine was not known a comparable engine was used.
*This appendix was developed by Arthur Tastet (FAA/SETA).

Appendix H: Aircraft Type Cross Reference To Engines

Type	Name	Manufacturer	ICAO Default Engine	BM2 Default Engine	Engines
BA31	BAE JETSTREAM-31	BAE	PT6A-65B	BE1/SMTURB	2
BA41	BAE JETSTREAM-41	BAE	PT6A-65B	BE1/SMTURB	2
BA46	BAE 146-200	BAE	ALF 502R-5	146-200/ALF502R-5	4
BATP	BAE ADVANCED TURBOPROP	BAE	PT6A-65B	BE1/SMTURB	2
BE02	BEECH 1900-C	BEECH	PT6A-65B	BE1/SMTURB	2
BE10	BEECH-10 KING AIR 100	BEECH	IO-360-B		2
BE18	BEECH-18 TWIN	BEECH	O-200		1
BE20	BEECH-20 SUPER KING AIR	BEECH	IO-360-B		2
BE30	BEECH-30 SUPER KING AIR	BEECH	PT6A-65B	BE1/SMTURB	2
BE33	BEECH-33 BONANZA 33	BEECH	IO-360-B		1
BE35	BEECH-35 BONANZA 35	BEECH	O-200		1
BE36	BEECH-36 BONANZA 36	BEECH	IO-360-B		1
BE3B	BEECH SUPER KING AIR 350	BEECH	PT6A-65B	BE1/SMTURB	2
BE40	BEECH JET 400	BEECH	CJ610-6	LRJ/	2
BE55	BEECH BARON 55/CHOCHISE	BEECH	IO-360-B		2
BE58	BEECH BARON 58	BEECH	IO-360-B		2
BE60	BEECH DUKE 60	BEECH	IO-360-B		2
BE76	BEECH DUCHESS 76	BEECH	IO-360-B		2
BE8T	BEECH	BEECH	IO-360-B		2
BE90	BEECH KING AIR C-90	BEECH	IO-360-B		2
BE99	BEECH AIRLINER 99	BEECH	IO-360-B		2
BN2	BN-2A/B ISLANDER	BRITTEN-NORMAN	IO-360-B		2
BN3	BN-2A MARK III TRISLANDER	BRITTEN-NORMAN	IO-360-B		3
C12	C-12 HURON	CESSNA	PT6A-45	BEK/SMTURB	2
C130	C-130 HERCULES	CESSNA	501D22A		4
C141	C-141 STARLIFTER	CESSNA	TF33-P-3		4
C152	CESSNA-152 ACROBAT	CESSNA	O-200		1
C172	CESSNA SKYHAWK CUTLASS	CESSNA	O-200		1
C177	CESSNA CARDINAL 177	CESSNA	O-200		1
C182	CESSNA SKYLANE 182/RG	CESSNA	O-200		1
C206	CESSNA STATIONAIR 6/TURBO	CESSNA	O-200		1
C208	CESSNA CARAVAN I 208-A	CESSNA	PT6A-65B	BE1/SMTURB	1
C21	CESSNA - 21	CESSNA	TFE731-2-2B	CNJ/	2
C210	CESSNA -210 CENTURION/II	CESSNA	O-200		1
C23	CESSNA - 23	CESSNA	TFE731-2-2B	CNJ/	2
C310	CESSNA - 310	CESSNA	IO-360-B		2

*Note: In the cases when the engine was not known a comparable engine was used.
*This appendix was developed by Arthur Tastet (FAA/SETA).

Appendix H: Aircraft Type Cross Reference To Engines

Type	Name	Manufacturer	ICAO Default Engine	BM2 Default Engine	Engines
C340	CESSNA - 340	CESSNA	IO-360-B		2
C401	CESSNA - 401	CESSNA	IO-360-B		2
C402	CESSNA BUSINESSLINER	CESSNA	IO-360-B		2
C414	CESSNA - 414 CANCELLOR	CESSNA	IO-360-B		2
C421	CESSNA - 421 GOLDEN EAGLE	CESSNA	IO-360-B		2
C425	CESSNA - 425	CESSNA	IO-360-B		2
C441	CESSNA - 441 CONQUEST II	CESSNA	IO-360-B		2
C5	C- 5 GALAXY	CESSNA	JT9D-7Q	747-200B/JT9D-7Q	4
C500	CESSNA - 500 CITATION I	CESSNA	CJ610-2C	CNJ/	2
C501	CESSNA - 501 CITATION I-SP	CESSNA	CJ610-2C	CNJ/	2
C550	CESSNA - 550 CITATION II/S2	CESSNA	CF34-3A		2
C560	CESSNA - 560 CITATION III/650	CESSNA	CF34-3A		2
C650	CESSNA - 650 CITATION III	CESSNA	CF34-3A		2
C9	C-9 NIGHTINGALE	CESSNA	JT8D-7 SERIES (REC)	D9S-30/JT8D-7B	2
CA21	CASA - 212 AVIOCAN	CASA	PT6A-65B	BE1/SMTURB	2
CL44	YUKON FREIGHTLINER	CANADAIR/BOMBARDIER	CT7-5	SF3/MDTURB	4
CL60	CHALLENGER 600	CANADAIR/BOMBARDIER	CF34-3A		2
CL61	CHALLENGER - 610	CANADAIR/BOMBARDIER	CF34-3A		2
CONC	CONCORDE	CONCORDE	OLYMPUS 593 MK610	Concorde	4
CRJ-200	CANADAIR REGIONAL JET	CANADAIR	CF34-3A		2
CV58	CONVAIR 580	CONVAIR	PT6A-65B	BE1/SMTURB	2
D28	DONIER 28	DONIER	PT6A-65B	BE1/SMTURB	2
D328	DONIER 328	DONIER	PW120	DH8/MDTURB	2
DA01	MERCURE 100 - C	DASSAULT	JT8D-7 SERIES (REC)	D9S-30/JT8D-7B	2
DA02	FALCON 20/C	DASSAULT	CF34-3A		2
DA05	MYSTERE FALCON 50	DASSAULT	CF34-3A		3
DA10	FALCON DA - 10	DASSAULT	TFE731-2-2B	LRJ/	2
DA20	FALCON 20	DASSAULT	CF34-3A		3
DC10	DOUGLAS - 10	MCDONNELL DOUGLAS	CF6-6D	D10-10/CF6-6D	3
DC10-10	DOUGLAS 10-10	MCDONNEL DOUGLAS	CF6-6D	D10-10/CF6-6D	3
DC10-30	DOUGLAS 10-30	MCDONNELL DOUGLAS	CF6-50C2	DLR-30/CF6-50C2	3
DC3	SKYTRAIN	MCDONNEL DOUGLAS	PT6A-65B	BE1/SMTURB	2
DC6	DOUGLAS - 6	MCDONNEL DOUGLAS	501D22A		4
DC8-63	DOUGLAS 8-63	MCDONNEL DOUGLAS	JT3D-7 (SERIES)	D8S-63H/JT3D-7	4
DC86	DOUGLAS -86	MCDONNEL DOUGLAS	JT8D-7 SERIES (REC)	D8C-33F/JT4A-11	4
DC9	DC - 9	MCDONNEL DOUGLAS	JT8D-7 SERIES (REC)	D9S-30/JT8D-7B	2

*Note: In the cases when the engine was not known a comparable engine was used.
*This appendix was developed by Arthur Tastet (FAA/SETA).

Appendix H: Aircraft Type Cross Reference To Engines

Type	Name	Manufacturer	ICAO Default Engine	BM2 Default Engine	Engines
DC9-30	DC - 9-30	MCDONNEL DOUGLAS	JT8D-7 SERIES (REC)	D9S-30/JT8D-7B	2
DC9-50	DC - 9-50	MCDONNEL DOUGLAS	JT8D-17	D9X-50/JT8D-17	2
DH2	BEAVER DHC - 2	DEHAVILLAND	IO-360-B		1
DH3	OTTER DHC - 2	DEHAVILLAND	PW120	DH3/MDTURB	1
DH6	TWIN OTTER DHC - 6	DEHAVILLAND	PT6A-45	SH6/MDTURB	2
DH8	DASH 8	DEHAVILLAND	PW120	DH8/MDTURB	2
E110	BANDEIRANTE EMB - 110	EMBRAER-EMPRESA	PT6A-45	EMB/SMTURB	2
E120	BRASILIA EMB - 120	EMBRAER-EMPRESA	PW118	EMB/SMTURB	2
E2	HAWKEYE	GRUMMAN	PW125B	F50/LGTURB	2
EA32	AIRBUS A - 320	AIRBUS	CFM56-5-A1	A32-200/CFM56-5A1	2
EA33	AIRBUS 330	AIRBUS	CF6-80E1A2		2
EA34	AIRBUS 340	AIRBUS	CFM56-5C2		4
EA6	EA6	GRUMMAN	TFE731-2-2B	LRJ/	2
F14	TOMCAT	GRUMMAN	TF30-P-412A(JFT 10A)		2
F15	EAGLE	BOEING	F100-PW-100		2
F16	FIGHTING FALCON	LOCKHEED	F100-PW-100		2
F18	HORNET	MCDONNEL DOUGLAS	F100-PW-100		2
FA27	FRIENDSHIP F-27	FAIRCHILD	CF34-3A		2
FA28	FRIENDSHIP F-28	FAIRCHILD	SPEY MK555	F28-4000/RR_SPEY-MK555	2
FK10	FOKKER 100	FOKKER	TAY MK620-15	F10-100/TAY620-15	2
FK50	FOKKER 50 TWIN-TURBOPROP	FOKKER	PW125B	F50/LGTURB	2
FK70	FOKKER 70	FOKKER	TAY MK620-15	F10-100/TAY620-15	2
G159	GAC 159-C GULFSTREAM I	GULFSTREAM	PW125B	F50/LGTURB	2
G2	GULFSTREAM II	GULFSTREAM	CF34-3A		2
G3	GULFSTREAM III	GULFSTREAM	CF34-3A		2
G4	GULFSTREAM IV	GULFSTREAM	CF34-3A		2
G73	MALLARD	GRUMMAN	PW120	DH8/MDTURB	2
HS25	HAWKER SIDDLEY	BAE	CF34-3A		2
IL62	IL - 62 CLASSIC	ILYUSHIN	CFM56-5C2	I62/SOL	4
IL76	IL - 76 CANDID	ILYUSHIN	PW4056	I72/	4
IL96	ILYUSHIN II - 96M	ILYUSHIN	PW4056	I86/KUZ	4
KC35	STRATOTANKER KC - 135	BOEING	JT9D-7Q	747-200B/JT9D-7Q	4
KE35	STRATOTANKER KC - 135E	BOEING	JT9D-7Q	747-200B/JT9D-7Q	4
KR35	STRATOTANKER KC 135 R	BOEING	JT9D-7Q	747-200B/JT9D-7Q	4
L101	TRI-STAR, ALL SERIES	LOCKHEED	RB211-22B (REV.)	L10-1/RB211-22B	3
L1011	L - 1011	LOCKHEED	RB211-22B (REV.)	L10-1/RB211-22B	3

*Note: In the cases when the engine was not known a comparable engine was used.
*This appendix was developed by Arthur Tastet (FAA/SETA).

Appendix H: Aircraft Type Cross Reference To Engines

Type	Name	Manufacturer	ICAO Default Engine	BM2 Default Engine	Engines
L188	ELECTRA 188	LOCKHEED	501D22A		4
L1F	TRI-STAR 101F	LOCKHEED	RB211-22B (REV.)	L10-1/RB211-22B	3
L329	JETSTAR	LOCKHEED	TF33-P-3		4
L382	HERCULES (130)	LOCKHEED	501D22A		4
L4T	ORION/AURORA	LOCKHEED	PT6A-65B	L4T/SMTURB	2
LR24	LEARJET - 24	LEAR	CJ610-2C	LRJ/	2
LR25	LEARJET - 25	LEAR	CJ610-6	LRJ/	2
LR31	LEARJET - 31	LEAR	TFE731-2-2B	LRJ/	2
LR35	LEARJET - 35	LEAR	TFE731-2-2B	LRJ/	2
LR55	LEARJET - 55	LEAR	TFE731-2-2B	LRJ/	2
LR60	LEARJET - 60	LEAR	TFE731-2-2B	LRJ/	2
M1F	MD - 11F	MCDONNELL DOUGLAS	PW4460	MDL-11P/PW4460	3
MD11	MD - 11	MCDONNELL DOUGLAS	CF6-80C2D1F	MDL-11P/PW4460	3
MD80	MD - 80	MCDONNELL DOUGLAS	JT8D-217	D9Z-82/JT8D-217	2
MD88	MD - 88	MCDONNELL DOUGLAS	JT8D-217	D9Z-82/JT8D-217	2
MD90	MD - 90	MCDONNELL DOUGLAS	V2525-D5		2
MO20	MOONEY MK - 20	MOONEY	IO-360-B		1
MU2	MITSUBISHI MU - 2	MITSUBISHI	PT6A-65B	MU2/SMTURB	2
MU3	MITSUBISHI DIAMOND I/300	MITSUBISHI	CJ610-6	LRJ/	2
MU30	MITSUBISHI 300 DIAMOND	MITSUBISHI	CJ610-6	LRJ/	2
N22B	N 22B - NOMAD	AEROSPACE TECHNOLOGIES	PT6A-65B	BE1/SMTURB	2
N265	SABRELINER - 65	ROCKWELL	JT8D-7 SERIES (REC)	D9S-30/JT8D-7B	2
NEWX	NEW CLASS 6 JET		PW4056	74I-400/PW4056	4
P3	ORION	LOCKHEED	501D22A		4
PA23	APACHE	PIPER	O-200		2
PA24	COMANCHE	PIPER	O-200		1
PA28	CHEROKEE ARCHER DAKOTA-	PIPER	O-200		1
PA30	TWIN COMANCHE	PIPER	IO-360-B		2
PA31	CHIEFTAN MOHAVE NAVAJO T-	PIPER	PT6A-45	SH6/MDTURB	2
PA32	CHEROKEE SIX LANCE	PIPER	IO-360-B		1
PA34	SENECA	PIPER	IO-360-B		2
PA41	CHEYENNE	PIPER	PT6A-45	SH6/MDTURB	2
PA42	CHEYENNE III/IV 400 LS	PIPER	PT6A-45	PA6/SMTURB	2
PA46	MALIBU	PIPER	IO-360-B		1
PA60	AEROSTAR 600/700	PIPER	IO-360-B		2
PARO	CHEROKEE ARROW IV	PIPER	O-200		1

*Note: In the cases when the engine was not known a comparable engine was used.

*This appendix was developed by Arthur Tastet (FAA/SETA).

Appendix H: Aircraft Type Cross Reference To Engines

Type	Name	Manufacturer	ICAO Default Engine	BM2 Default Engine	Engines
PASE	SENECA	PIPER	IO-360-B		2
PAYE	CHEYENNE II	PIPER	PT6A-45	SH6/MDTURB	2
PAZT	250 AZTEC	PIPER	IO-360-B		2
S20	S20	AEROSPATIALE	PT6A-65B	BE1/SMTURB	2
SF34	SF - 340 A	SAAB	CT7-5		2
SH7	SHORTS SC-7 SKYVAN	SHORTS BROTHERS	PW120	SH6/MDTURB	2
SHD3	SHORTS SH - 360	SHORTS BROTHERS	501D22A		2
SW3	METRO III MERLIN IVC	FAIRCHILD	TPE 331-3		2
SW4	METRO II/A	FAIRCHILD	TPE 331-3		2
T1	T1 JAYHAWK	RAYTHEON	CJ610-6	LRJ/	2
T2	BUCKEYE T-20	ROCKWELL	TFE731-2-2B	LRJ/	2
T34	MENTOR	BEECH	IO-360-B		1
T37	T-37 TWEET	CESSNA	CJ610-6	LRJ/	2
T38I	T38 TALON	GRUMMAN	TFE731-2-2B	LRJ/	2
TA4	TA4	MCDONNELL DOUGLAS	TFE731-2-2B	LRJ/	1
TU34	TU - 134	TUPOLEV	CF34-3A	T34/SOL	2
TU5	TU - 154	TUPOLEV	CF34-3A		2
U21	UTE	BEECH	PT6A-65B	BE1/SMTURB	2
UH1	IROQUOIS	BELL HELICOPTER TEXTRON	T53-L-11D		1
UH60	UH 60	BELL HELICOPTER	T53-L-11D		1
WW24	WESTWIND 2	ISRAEL	TFE731-2-2B	LRJ/	2
YK4	YAK - 42	YAKOVLEV	D-36		2
YS11	YS-11A	NIHON	CF34-3A		2

*Note: In the cases when the engine was not known a comparable engine was used.
*This appendix was developed by Arthur Tastet (FAA/SETA).

Appendix I: Data Results – Fuel and Emissions Calculations For 1996 and 2015[1]

Section 1 – Data Results Above 3,000 Feet By Aircraft Type

This section contains data relating to above 3,000 feet, by aircraft type, without including airborne delay.

Section 2 – Data Results For Air Delays By Aircraft Type

This section contains airborne delay data by aircraft type.

Section 3 – Data Results for Surface By Aircraft Type

This section contains data relating to the surface, by aircraft type, which does include ground delay.

Section 4 – Data Results for Surface By Airport

This section contains data relating to the surface, by airport, which does include ground delay. These tables only list the NASPAC 80 airports, all other airports are included in the airport named ‘Other’.

[1] This appendix was developed by Arthur Tastet (FAA/SETA).

Appendix I, Section 1: 1996 Data Results – Above 3,000 Feet By Aircraft Type

Baseline

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
A10	169,076	1,808	944	84	4,878
A300	2,272,830	38,297	12,874	5,920	12,583
A310	336,178	5,293	1,810	422	2,300
A320	8,119,414	120,895	57,539	5,671	75,248
A4	26,312	281	145	13	1,789
A6	175,512	1,875	976	87	3,873
AA5	4,444	45	3,072	43	2,760
AC50	10,756	108	7,435	104	2,463
AC69	58,427	478	233	11	8,696
AJ25	29,168	278	90	13	1,898
AN12	30,994	232	158	61	328
ARJ	62,755	430	119	8	1,166
AT42	1,206,666	15,806	5,184	0	51,608
B1	1,744,768	8,375	42,747	6,979	5,347
B52	2,051,768	9,848	50,268	8,207	5,707
B707	332,578	4,914	12,540	14,305	1,804
B727-200	29,401,404	298,525	104,646	17,516	218,144
B737-200	27,899,121	301,033	150,455	22,258	327,449
B73S	7,252,321	88,287	112,210	9,334	96,060
B747-100	8,332,907	171,425	118,931	63,348	24,855
B747-200	646,027	11,548	9,915	3,600	1,997
B74F	1,211,052	23,430	3,302	363	3,751
B757-200	29,650,257	387,344	153,741	10,816	250,555
B767-200	11,631,840	165,774	46,667	9,881	85,439
B777	2,593,579	31,123	1,037	518	6,480
BA11	14,445	164	179	23	264
BA14	352,270	4,014	4,472	561	34,331
BA31	9,067	74	36	2	902
BA41	407,154	3,336	1,626	79	25,699
BA46	439,489	3,867	3,472	351	7,021
BATP	56,274	461	225	11	1,658

Appendix I, Section 1: 1996 Data Results – Above 3,000 Feet By Aircraft Type

Baseline

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
BE02	1,079,684	8,845	4,309	207	93,923
BE10	66,536	671	45,996	645	8,561
BE18	12,713	14	15,100	0	1,981
BE20	292,302	2,949	202,068	2,832	35,481
BE30	71,282	578	314	20	7,790
BE33	13,987	141	9,669	135	7,031
BE35	13,362	15	15,871	0	7,449
BE36	30,717	309	21,235	297	12,807
BE3B	22,876	179	132	13	2,318
BE40	38,492	378	142	17	3,754
BE55	48,316	487	33,401	468	14,423
BE58	80,044	807	55,334	775	22,361
BE60	9,907	100	6,849	96	2,201
BE76	6,214	63	4,296	60	2,403
BE8T	9,145	92	6,322	89	1,596
BE90	169,018	1,705	116,842	1,637	27,712
BE99	17,379	175	12,014	168	2,364
BN2	11,639	117	8,046	113	1,980
C12	94,279	772	367	18	9,377
C130	1,761,256	13,192	8,982	3,452	14,652
C141	1,123,845	8,204	10,115	4,259	5,060
C152	146	0	174	0	134
C172	23,422	25	27,820	1	16,190
C177	5,047	6	5,994	0	2,999
C182	25,849	28	30,704	1	15,380
C206	4,079	5	4,845	0	1,652
C208	5,319	44	21	1	1,128
C21	13,731	139	54	5	7,281
C210	30,817	34	36,604	1	15,988
C23	33,426	351	197	17	2,013

Appendix I, Section 1: 1996 Data Results – Above 3,000 Feet By Aircraft Type

Baseline

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
C310	100,924	1,017	69,769	976	26,048
C340	40,483	408	27,986	392	10,225
C401	9,640	97	6,664	93	2,162
C402	18,751	189	12,962	182	4,268
C414	56,885	573	39,324	551	12,646
C421	68,584	691	47,412	664	15,280
C425	25,826	260	17,854	250	4,696
C441	53,201	537	36,778	515	8,209
C5	3,126,938	53,621	41,842	15,367	5,863
C500	13,896,816	145,324	78,301	6,821	272,589
C501	34,892	359	161	16	4,762
C550	232,515	1,593	439	28	23,563
C560	99,716	683	189	12	9,675
C650	150,779	1,033	285	19	10,485
C9	442,038	3,934	2,939	900	6,272
CA21	6,734	55	27	1	744
CL44	3,879	45	20	2	35
CL60	225,657	1,547	428	29	8,417
CL61	42,084	289	80	5	1,620
CONC	34,814	353	930	110	119
CRJ	1,512,925	10,378	2,870	193	43,505
CV58	65,513	537	262	13	1,816
D28	3,265	27	13	1	224
D328	417,624	4,927	2,128	249	20,410
DA01	53,277	466	312	94	4,468
DA02	74,533	511	141	9	3,776
DA05	102,500	703	194	13	3,858
DA10	23,987	235	89	11	2,052
DA20	87,137	597	165	11	4,619
DC10-10	3,872,918	58,002	27,041	11,633	17,266

Appendix I, Section 1: 1996 Data Results – Above 3,000 Feet By Aircraft Type

Baseline

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
DC10-30	4,976,155	78,728	39,743	16,417	19,854
DC3	32,183	264	129	6	1,841
DC6	3,804	28	19	7	64
DC8-63	105,682	744	1,849	1,398	525
DC86	11,842,836	71,729	241,152	172,697	54,051
DC9-30	9,271,793	87,151	88,078	27,797	112,604
DC9-50	4,492,136	48,012	27,245	3,574	46,369
DH2	508	5	351	5	151
DH6	13,487	166	69	8	1,808
DH8	1,677,737	19,795	8,551	1,000	74,509
E110	12,546	102	50	2	1,546
E120	1,559,568	12,623	6,240	302	91,128
E2	61,499	799	264	0	1,813
EA6	118,944	1,271	662	59	2,841
F14	137,441	973	2,089	154	2,872
F15	189,132	2,080	567	113	4,412
F16	499,140	5,490	1,496	298	22,475
F18	259,484	2,854	778	155	6,577
FA27	12,409	85	24	2	454
FA28	328,788	3,452	1,972	163	7,837
FFJ	4,081	39	13	2	189
FK10	3,226,595	36,766	49,954	6,763	52,478
FK50	86,032	1,118	370	0	1,833
FK70	113,395	1,293	1,758	238	1,788
G159	63,562	826	273	0	2,757
G2	242,580	1,664	460	31	5,998
G3	281,730	1,933	535	36	6,403
G4	198,619	1,362	377	25	4,215
G73	223	3	1	0	27
HS25	319,536	2,190	605	39	23,804

Appendix I, Section 1: 1996 Data Results – Above 3,000 Feet By Aircraft Type

Baseline

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
IL96	15,426	233	599	690	46
KC35	1,077,681	21,045	21,361	7,621	4,987
KE35	28,558	526	482	174	4,440
KR35	76,199	1,404	1,284	462	11,267
L1011	4,509,568	71,726	48,612	32,152	19,580
L188	132,090	989	674	259	1,725
L1F	9,621	175	244	181	1,279
L329	33,233	243	299	126	1,254
L382	41,345	310	211	81	391
LR24	49,890	481	166	22	6,306
LR25	63,739	628	242	29	6,645
LR31	26,226	262	108	12	2,698
LR35	241,070	2,342	841	107	20,336
LR55	65,825	648	248	30	4,877
LR60	9,130	88	31	4	607
M1F	2,500,444	49,009	18,753	1,500	5,318
MD11	1,435,608	22,661	5,788	529	6,796
MD88	32,358,468	475,189	180,982	51,694	334,573
MO20	21,747	219	15,033	210	12,745
MU2	40,226	337	148	7	6,920
MU3	18,234	188	87	9	1,846
MU30	6,248	64	28	3	649
N22B	333	3	1	0	48
N265	142,934	1,254	855	258	9,192
P3	478,237	3,582	2,439	937	4,784
PA23	7,043	8	8,366	0	2,765
PA24	5,233	6	6,216	0	3,110
PA28	33,488	37	39,776	1	16,935
PA30	4,460	45	3,083	43	1,839
PA31	90,160	1,107	458	52	19,375

Appendix I, Section 1: 1996 Data Results – Above 3,000 Feet By Aircraft Type

Baseline

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
PA32	38,514	388	26,625	372	16,333
PA34	26,213	264	18,121	254	9,523
PA41	3,406	37	17	2	561
PA42	17,260	145	62	3	2,328
PA46	10,142	102	7,011	98	3,649
PA60	36,137	364	24,981	350	9,354
PARO	7,638	8	9,072	0	4,660
PASE	6,001	60	4,149	58	2,191
PAYE	88,688	1,090	451	52	14,059
PAZT	17,165	173	11,866	166	5,100
S20	1,988	16	8	0	310
SF34	1,322,325	9,118	7,002	1,977	72,057
SH7	29,838	367	152	18	3,578
SHD3	12,227	92	62	24	802
SW3	14,353	142	100	9	1,746
SW4	122,494	1,214	856	77	18,290
T1	32,397	344	175	16	3,129
T2	43,417	452	217	21	2,424
T34	4,788	48	3,310	46	1,743
T37	26,488	283	148	13	3,011
T38I	6,654	71	37	3	978
TA4	12,352	132	68	6	1,896
TU34	10,811	102	101	31	166
U21	19,149	157	76	4	2,905
UH1	2,816	21	8	1	439
UH60	4,905	36	15	1	764
WW24	106,428	1,040	384	48	6,928
YK4	1,915	17	5	0	301
YS11	40,666	279	77	5	1,170
TOTALS:	252,249,780	3,083,700	2,956,717	567,212	3,401,663

Appendix I, Section 1: 2015 Data Results – Above 3,000 Feet By Aircraft Type

Baseline

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
A10	162,514	1,737	907	81	4,658
A300	9,581,057	179,574	104,444	43,694	50,772
A310	405,095	5,857	1,614	384	2,875
A320	8,991,694	119,095	44,647	5,498	103,320
A4	26,240	280	145	13	1,783
A6	175,512	1,875	976	87	3,873
AA5	4,430	45	3,063	43	2,751
AC50	13,792	139	9,534	133	3,174
AC69	56,922	466	227	11	8,488
AJ25	28,458	271	88	12	1,848
AT42	3,833,702	49,971	16,556	0	159,611
B1	1,744,768	8,375	42,747	6,979	5,347
B52	2,051,768	9,848	50,268	8,207	5,707
B707	352,635	4,399	10,552	11,938	1,961
B727-200	1,113,311	11,708	4,313	691	7,432
B737-200	23,861,862	237,671	115,265	18,400	277,780
B73F	5,060,617	57,186	55,772	3,980	69,342
B73S	24,929,888	284,200	291,510	23,925	308,032
B747-100	2,310,178	44,352	26,373	14,232	7,168
B747-200	49,822	922	851	307	169
B74F	3,832,159	69,329	8,179	1,148	11,814
B74R	11,728,527	233,978	35,308	3,518	20,802
B757-200	68,708,125	1,138,061	555,120	48,180	548,881
B767-200	20,180,560	323,093	103,495	22,211	144,069
B777	15,741,489	188,898	6,293	3,145	41,958
BA11	2,486	27	27	3	42
BA14	608,911	6,937	7,729	969	59,547
BA31	11,958	98	48	2	1,194
BA41	440,889	3,606	1,796	93	27,387
BA46	539,877	4,560	2,929	292	9,423

Enhanced

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
A10	143,477	1,535	803	72	4,334
A300	9,121,290	157,376	61,858	27,564	49,402
A310	400,064	5,843	1,658	393	2,857
A320	8,629,766	113,105	41,308	5,213	104,560
A4	21,820	233	120	11	1,392
A6	157,360	1,681	876	78	3,660
AA5	4,194	42	2,900	41	2,593
AC50	12,882	130	8,905	125	2,934
AC69	52,494	429	210	10	7,746
AJ25	26,780	254	80	12	1,717
AT42	3,379,525	44,003	14,605	0	140,337
B1	1,589,249	7,628	38,937	6,357	4,864
B52	2,214,007	10,627	54,243	8,856	6,016
B707	329,853	3,848	8,969	10,106	1,532
B727-200	1,110,293	11,994	4,577	710	7,368
B737-200	23,379,934	224,389	107,187	17,751	273,819
B73F	4,867,657	52,848	44,106	3,081	68,646
B73S	24,136,499	267,090	242,851	19,749	303,363
B747-100	2,276,701	43,441	25,434	13,744	7,042
B747-200	49,823	922	851	307	169
B74F	3,782,807	68,090	7,910	1,133	11,737
B74R	11,072,394	220,023	32,925	3,321	7,280
B757-200	64,718,986	959,596	429,952	34,573	531,068
B767-200	19,219,538	290,952	87,928	18,760	141,516
B777	14,625,496	175,506	5,847	2,921	29,027
BA11	2,034	23	26	3	33
BA14	488,751	5,566	6,202	776	46,239
BA31	10,715	88	43	2	1,067
BA41	358,926	2,922	1,522	87	21,692
BA46	502,289	4,183	2,309	229	8,746

Appendix I, Section 1: 2015 Data Results – Above 3,000 Feet By Aircraft Type

Baseline

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
BATP	421,235	3,454	1,684	83	12,598
BE02	705,389	5,779	2,816	136	63,367
BE10	63,523	641	43,913	615	8,187
BE18	13,014	15	15,458	0	2,028
BE20	271,166	2,736	187,457	2,627	32,969
BE30	64,631	526	272	15	7,057
BE33	15,175	153	10,491	147	7,634
BE35	13,886	15	16,494	0	7,739
BE36	32,945	332	22,775	318	13,745
BE3B	22,876	179	132	13	2,318
BE40	39,956	393	150	18	3,877
BE55	54,141	546	37,428	524	16,043
BE58	91,249	920	63,081	883	25,509
BE60	11,795	119	8,154	114	2,630
BE76	9,066	91	6,267	88	3,471
BE8T	11,671	118	8,068	113	2,030
BE90	160,533	1,619	110,976	1,555	26,308
BE99	16,636	168	11,501	161	2,288
BN2	7,274	73	5,028	70	1,039
C12	93,056	762	362	18	9,283
C130	1,756,405	13,155	8,958	3,442	14,587
C141	1,119,062	8,169	10,072	4,241	5,044
C152	116	0	138	0	105
C172	25,176	27	29,905	0	17,428
C177	5,659	6	6,721	0	3,365
C182	29,240	32	34,731	0	17,323
C206	4,563	5	5,420	0	1,857
C208	5,227	43	21	1	1,111
C21	13,731	139	54	5	7,281
C210	33,827	37	40,180	0	17,549
C23	33,426	351	197	17	2,013

Enhanced

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
BATP	330,218	2,707	1,320	65	9,481
BE02	571,188	4,676	2,287	110	50,059
BE10	59,321	598	41,008	575	7,527
BE18	12,265	14	14,568	0	1,898
BE20	251,855	2,540	174,107	2,440	30,008
BE30	59,778	487	252	14	6,418
BE33	14,578	147	10,078	141	7,282
BE35	13,248	14	15,736	0	7,344
BE36	31,731	319	21,936	307	13,163
BE3B	21,071	164	123	12	2,087
BE40	36,713	359	134	16	3,549
BE55	51,035	514	35,281	494	15,080
BE58	86,326	870	59,677	835	23,900
BE60	11,225	113	7,760	109	2,474
BE76	8,706	88	6,018	84	3,310
BE8T	11,138	112	7,700	108	1,923
BE90	150,558	1,518	104,081	1,458	24,244
BE99	15,084	152	10,428	146	2,042
BN2	8,019	81	5,543	78	1,690
C12	86,961	712	338	16	8,585
C130	1,672,604	12,528	8,530	3,278	13,720
C141	1,070,422	7,814	9,634	4,057	4,780
C152	54	0	64	0	48
C172	23,049	25	27,377	0	15,737
C177	5,410	6	6,426	0	3,186
C182	28,185	31	33,478	0	16,546
C206	4,363	5	5,183	0	1,773
C208	5,009	41	20	1	1,056
C21	12,882	130	49	5	6,777
C210	32,423	36	38,512	0	16,673
C23	32,069	337	189	16	1,911

Appendix I, Section 1: 2015 Data Results – Above 3,000 Feet By Aircraft Type

Baseline

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
C310	52,886	533	36,560	512	16,786
C340	44,589	449	30,824	432	11,286
C401	9,663	97	6,680	94	2,167
C402	21,187	214	14,647	205	4,833
C414	60,448	609	41,788	585	13,433
C421	70,263	708	48,573	680	15,671
C425	24,999	252	17,282	242	4,551
C441	51,664	521	35,716	500	7,970
C5	3,109,747	53,278	41,479	15,238	5,831
C500	5,266,722	54,440	25,676	2,478	163,687
C501	41,425	426	192	19	5,698
C550	221,369	1,516	418	27	22,389
C560	103,062	706	195	12	9,995
C650	155,164	1,063	294	19	10,815
C9	341,259	3,002	2,071	628	4,824
CA21	8,513	70	34	2	933
CL44	45,121	528	230	27	317
CL60	238,778	1,637	453	30	8,889
CL61	37,562	258	71	5	1,454
CRJ	4,802,097	32,923	9,102	602	153,273
CV58	197,062	1,616	788	39	5,439
D328	522,940	6,170	2,665	311	24,791
DA01	52,355	460	318	96	4,351
DA02	74,793	513	142	9	3,771
DA05	93,649	642	178	12	3,521
DA10	27,919	273	102	12	2,390
DA20	101,938	699	193	13	5,422
DC10-10	1,436,299	26,337	19,742	7,573	6,484
DC10-30	1,667,779	29,518	19,043	7,446	6,754
DC3	32,183	264	129	6	1,841
DC6	56,451	423	288	111	830

Enhanced

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
C310	48,815	492	33,746	472	15,438
C340	42,239	426	29,200	409	10,549
C401	9,114	92	6,301	88	2,032
C402	19,587	197	13,540	190	4,399
C414	57,436	579	39,705	556	12,626
C421	66,387	669	45,893	643	14,641
C425	23,249	234	16,072	225	4,188
C441	48,142	485	33,280	466	7,328
C5	2,957,773	50,207	38,189	14,070	5,666
C500	5,082,059	52,385	23,855	2,367	149,062
C501	37,367	384	169	17	5,069
C550	204,319	1,399	386	24	20,384
C560	94,487	647	178	11	9,026
C650	145,186	995	275	18	10,016
C9	318,298	2,788	1,861	562	4,548
CA21	8,292	68	33	2	901
CL44	43,234	506	220	26	303
CL60	221,353	1,518	420	28	8,217
CL61	34,702	238	66	4	1,313
CRJ	4,385,873	30,064	8,308	546	137,842
CV58	176,915	1,450	707	35	4,828
D328	480,274	5,658	2,449	284	23,078
DA01	48,170	422	282	85	3,962
DA02	69,887	479	132	9	3,468
DA05	86,714	595	164	11	3,224
DA10	26,151	255	93	12	2,197
DA20	92,538	634	175	11	4,907
DC10-10	1,315,023	19,567	8,926	3,864	6,074
DC10-30	1,603,480	26,882	15,572	6,229	6,558
DC3	30,734	252	123	6	1,748
DC6	53,340	400	272	104	819

Appendix I, Section 1: 2015 Data Results – Above 3,000 Feet By Aircraft Type

Baseline

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
DC8-63	105,682	744	1,849	1,398	525
DC86	10,809,875	73,330	375,193	308,160	50,452
DC9-30	2,118,981	19,624	18,457	5,788	25,749
DC9-50	9,842,629	102,256	51,096	7,152	101,385
DH3	559	7	3	0	106
DH6	52,919	627	268	29	6,517
DH8	2,933,952	34,617	14,953	1,749	132,033
E110	2,878	23	11	1	366
E120	2,834,028	22,941	11,357	550	167,029
E2	61,191	795	263	0	1,800
EA6	116,435	1,244	648	58	2,770
F14	131,857	934	2,004	148	2,743
F15	171,689	1,889	515	103	3,969
F16	467,475	5,142	1,402	279	20,638
F18	254,426	2,799	763	152	6,468
FA27	10,284	71	19	1	396
FA28	384,032	3,949	2,116	186	9,060
FK10	4,937,846	52,670	63,441	9,294	80,557
G159	55,649	723	239	0	2,408
G2	249,075	1,708	473	32	6,168
G3	279,788	1,919	531	36	6,357
G4	194,506	1,334	369	25	4,161
HS25	404,183	2,770	765	50	30,651
KC35	1,069,591	20,883	21,191	7,560	4,937
KE35	28,458	524	480	173	4,417
KR35	76,103	1,402	1,282	462	11,254
L1011	1,113,696	18,991	20,146	14,439	4,693
L188	235,933	1,767	1,203	462	2,404
L1F	65,486	1,191	1,663	1,231	3,625
L329	40,335	294	363	153	1,536
L382	47,145	353	240	92	438

Enhanced

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
DC8-63	108,677	774	2,017	1,541	524
DC86	9,782,310	63,601	285,098	226,033	44,205
DC9-30	2,040,995	18,262	14,142	4,346	24,873
DC9-50	9,523,064	97,345	44,787	6,551	99,014
DH3	136	2	1	0	22
DH6	47,928	566	243	26	6,336
DH8	2,413,372	28,465	12,298	1,434	105,393
E110	2,399	19	10	0	298
E120	2,331,574	18,867	9,360	446	133,707
E2	57,668	750	248	0	1,658
EA6	103,339	1,105	577	51	2,449
F14	123,775	876	1,881	138	2,422
F15	159,478	1,754	478	95	3,617
F16	417,923	4,597	1,253	250	18,385
F18	232,246	2,555	696	139	5,447
FA27	8,159	56	15	1	298
FA28	354,148	3,590	1,835	169	8,257
FK10	4,392,853	44,436	47,684	7,554	69,646
G159	51,987	676	223	0	2,228
G2	233,754	1,603	443	30	5,698
G3	262,276	1,799	498	33	5,888
G4	182,507	1,252	346	23	3,833
HS25	375,862	2,575	711	46	27,784
KC35	1,046,761	20,375	20,570	7,343	4,806
KE35	26,771	491	444	160	4,117
KR35	73,336	1,346	1,222	440	10,812
L1011	1,070,707	17,725	15,968	11,167	4,657
L188	216,928	1,625	1,106	425	2,719
L1F	64,996	1,182	1,651	1,221	8,721
L329	37,748	275	340	143	1,413
L382	39,401	295	201	77	361

Appendix I, Section 1: 2015 Data Results – Above 3,000 Feet By Aircraft Type

Baseline

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
LR24	50,930	491	169	22	6,446
LR25	80,108	783	289	36	8,348
LR31	36,578	366	150	17	3,772
LR35	267,381	2,597	932	118	22,687
LR55	66,691	657	252	30	4,977
LR60	7,703	74	25	3	508
M1F	884,262	16,463	5,842	478	1,910
MD11	911,172	13,805	3,148	300	4,158
MD88	46,795,851	632,464	237,092	70,651	475,301
MO20	22,891	230	15,824	221	13,427
MU2	34,735	291	128	6	6,004
MU3	20,468	211	99	10	2,087
MU30	11,826	118	48	5	1,233
N265	127,474	1,116	744	224	8,212
NEWX	4,958,348	99,503	15,203	1,487	10,844
P3	473,507	3,547	2,415	928	4,728
PA23	7,265	8	8,629	0	2,873
PA24	5,163	6	6,133	0	3,055
PA28	35,489	39	42,153	0	17,944
PA30	5,490	55	3,795	53	2,269
PA31	93,476	1,148	475	54	20,085
PA32	40,216	405	27,801	389	17,055
PA34	29,596	298	20,460	286	10,775
PA41	3,406	37	17	2	561
PA42	16,041	135	58	3	2,166
PA46	10,103	102	6,984	98	3,632
PA60	30,862	311	21,335	299	8,361
PARO	8,054	9	9,566	0	4,913
PASE	6,118	62	4,229	59	2,235
PAYE	87,853	1,079	447	51	13,924
PAZT	21,521	217	14,877	208	6,388

Enhanced

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
LR24	47,614	456	153	20	5,892
LR25	74,268	722	260	33	7,669
LR31	33,953	338	137	15	3,410
LR35	248,433	2,399	837	109	20,792
LR55	60,898	597	223	27	4,477
LR60	7,120	68	22	3	463
M1F	821,073	15,274	5,413	443	1,421
MD11	905,777	13,793	3,193	303	4,139
MD88	44,730,766	572,350	212,132	65,117	465,618
MO20	21,951	221	15,175	212	12,760
MU2	32,539	273	120	6	5,527
MU3	19,268	199	92	9	1,938
MU30	11,096	110	43	5	1,154
N265	119,049	1,037	669	200	7,582
NEWX	4,708,517	94,127	14,266	1,412	3,920
P3	442,626	3,315	2,257	867	4,297
PA23	7,017	8	8,334	0	2,759
PA24	4,914	5	5,837	0	2,885
PA28	33,213	37	39,450	1	16,710
PA30	5,260	53	3,636	51	2,166
PA31	88,030	1,081	447	51	18,707
PA32	38,591	389	26,678	373	16,232
PA34	28,388	286	19,624	275	10,246
PA41	3,204	35	16	1	516
PA42	14,979	126	54	3	1,996
PA46	9,552	96	6,604	92	3,426
PA60	28,805	290	19,913	279	7,795
PARO	7,724	8	9,174	0	4,668
PASE	5,809	58	4,016	56	2,108
PAYE	82,567	1,014	420	48	12,918
PAZT	20,521	207	14,186	199	6,045

Appendix I, Section 1: 2015 Data Results – Above 3,000 Feet By Aircraft Type

Baseline

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
SF34	734,813	5,067	3,891	1,099	40,387
SH7	14,134	174	72	8	1,659
SHD3	12,136	91	62	24	799
SW3	13,462	133	94	8	1,640
SW4	70,646	700	494	44	10,503
T1	32,367	343	175	16	3,127
T2	43,417	452	217	21	2,424
T34	4,764	48	3,293	46	1,735
T37	25,962	278	145	13	2,943
T38I	5,597	60	31	3	813
TA4	11,046	118	61	5	1,674
TU5	62,889	431	119	8	480
U21	19,079	156	76	4	2,893
UH1	2,541	19	8	1	393
UH60	4,905	36	15	1	764
WW24	124,835	1,216	443	56	8,116
TOTALS:	326,094,641	4,410,774	3,597,368	708,504	4,226,226

Enhanced

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
SF34	594,276	4,097	3,146	887	31,680
SH7	12,580	155	64	7	1,475
SHD3	9,095	68	46	18	581
SW3	12,389	123	87	8	1,482
SW4	58,051	575	405	36	8,461
T1	28,311	300	152	14	2,612
T2	39,132	407	194	19	2,144
T34	4,272	43	2,953	41	1,550
T37	24,025	257	134	12	2,674
T38I	4,498	48	25	2	622
TA4	7,820	82	40	4	1,238
TU5	53,373	366	101	7	320
U21	18,427	151	73	3	2,774
UH1	1,915	14	6	1	290
UH60	4,541	33	14	1	701
WW24	116,700	1,133	406	52	7,491
TOTALS:	308,670,234	3,968,134	3,091,147	562,930	3,917,351

Appendix I, Section 2: 1996 Data Results – Air Delays By Aircraft Type

Baseline

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
A300	28,500	604	504	202	76
AC69	349	3	1	0	19
AT42	8,827	111	39	0	408
B727	412,603	4,457	1,857	277	2,324
B737	391,337	3,894	1,884	291	3,179
B747	41,964	839	885	315	61
B757	281,235	4,384	2,165	194	1,626
B767	144,076	2,385	842	175	685
B777	7,145	88	3	1	15
BA14	2,015	23	26	3	15
BA41	3	0	0	0	0
BA46	29	0	0	0	0
BE02	4,636	38	19	1	308
BE10	43	0	30	0	23
BE20	204	2	141	2	102
BE30	511	3	10	2	45
BE33	27	0	18	0	44
BE35	12	0	15	0	21
BE36	76	1	52	1	89
BE40	3	0	0	0	0
BE55	87	1	60	1	49
BE58	53	1	37	1	37
BE60	6	0	4	0	2
BE76	6	0	4	0	4
BE90	279	3	193	3	157
BE99	1	0	1	0	1
C152	8	0	9	0	15
C172	36	0	43	0	69
C177	8	0	9	0	15
C182	35	0	41	0	78
C206	1	0	1	0	1

Appendix I, Section 2: 1996 Data Results – Air Delays By Aircraft Type

Baseline

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
C210	12	0	15	0	25
C310	101	1	70	1	56
C340	209	2	145	2	109
C401	17	0	12	0	7
C402	5	0	3	0	2
C414	81	1	56	1	39
C421	92	1	64	1	64
C425	2	0	1	0	1
C441	29	0	20	0	17
C500	33,111	343	240	18	615
C501	532	5	4	0	16
C550	4,746	33	9	1	98
C560	794	5	2	0	11
C650	3,572	25	7	0	54
CL60	576	4	1	0	14
CL61	4	0	0	0	0
CRJ	19,628	135	37	3	330
D328	117	1	1	0	5
DA01	236	2	2	1	1
DA02	14	0	0	0	0
DA10	19	0	0	0	1
DA20	16	0	0	0	0
DC10	29,283	562	483	172	106
DC3	115	1	1	0	8
DC86	7,056	52	317	271	46
DC9	86,019	768	721	224	744
DH8	1,832	22	9	1	75
E120	9,458	76	41	2	477
EA32	106,228	1,583	754	74	702
EA33	8	0	0	0	0
EA34	4	0	0	0	0

Appendix I, Section 2: 1996 Data Results – Air Delays By Aircraft Type

Baseline

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
FA28	1,488	16	9	1	10
FK10	26,266	239	285	43	329
G2	309	2	1	0	7
G4	194	1	0	0	6
G73	223	3	1	0	10
HS25	4,829	33	9	1	73
L101	60,091	747	1,362	686	221
L329	5,437	40	49	21	15
LR24	346	4	2	0	7
LR25	1,650	18	9	1	32
LR31	614	7	3	0	14
LR35	594	6	3	0	20
LR55	646	7	4	0	18
LR60	41	0	1	0	2
M1F	10,886	213	82	7	19
MD80	378,324	4,674	1,897	605	2,706
MD90	12,494	111	30	1	77
MO20	82	1	56	1	104
MU2	285	2	1	0	17
MU3	22	0	0	0	0
N265	2,640	25	25	8	20
PA23	10	0	12	0	10
PA24	1	0	2	0	3
PA28	43	0	51	0	78
PA31	612	8	3	0	48
PA32	79	1	55	1	83
PA34	67	1	47	1	43
PA42	9	0	0	0	1
PA60	7	0	5	0	3
PARO	12	0	15	0	24
PAYE	1,055	13	5	1	92

Appendix I, Section 2: 1996 Data Results – Air Delays By Aircraft Type

Baseline

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
PAZT	13	0	9	0	6
SF34	12,853	89	68	19	765
SH7	1,298	16	7	1	47
SW3	6	0	0	0	0
SW4	355	4	2	0	35
WW24	116	1	1	0	3
TOTALS:	2,152,026	26,741	16,021	3,638	18,043

Appendix I, Section 2: 2015 Data Results – Air Delays By Aircraft Type

Baseline

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
A300	73,777	1,592	1,103	442	307
AC50	11	0	8	0	5
AC69	2,450	19	10	0	183
AT42	53,699	691	232	0	2,496
B707	1,076	16	42	48	6
B727	810,110	9,391	3,923	564	4,893
B737	1,582,555	17,401	7,972	1,200	13,127
B747	359,273	7,199	7,530	2,677	510
B757	1,410,944	30,832	14,803	1,403	7,294
B767	266,321	5,308	1,652	361	1,169
B777	34,929	419	14	7	67
BA14	102,843	1,244	1,226	179	958
BA31	93	1	0	0	5
BA41	847	7	3	0	58
BA46	6,172	54	49	5	113
BE02	16,160	129	77	5	1,184
BE10	111	1	77	1	84
BE18	1	0	1	0	2
BE20	571	6	402	5	351
BE30	741	6	3	0	47
BE33	5	0	3	0	8
BE35	78	0	90	0	148
BE36	331	3	231	3	450
BE40	1,195	13	7	1	35
BE55	197	2	142	2	125
BE58	422	4	289	4	287
BE60	13	0	9	0	6
BE76	12	0	8	0	10
BE90	451	4	359	4	233
BE99	24	0	8	0	11
C152	35	0	37	0	59

Enhanced

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
A300	62,583	1,327	1,108	444	342
AC69	146	1	1	0	14
AT42	23,485	303	103	0	1,148
B727	161,730	1,882	788	113	1,082
B737	507,875	5,648	2,586	388	4,177
B747	24,675	494	521	185	69
B757	321,021	6,622	3,674	351	1,975
B767	92,249	1,802	579	126	477
B777	9,710	117	4	2	29
BA14	23,572	286	285	39	249
BA31	149	1	1	0	14
BA41	12	0	0	0	1
BE02	6,538	53	27	2	543
BE10	68	1	47	1	52
BE20	219	2	152	2	155
BE30	346	3	1	0	27
BE33	26	0	18	0	32
BE35	10	0	12	0	24
BE36	68	1	47	1	104
BE40	437	5	2	0	13
BE55	37	0	26	0	26
BE58	166	2	115	2	95
BE90	189	2	131	2	156
BE99	13	0	9	0	8
C152	11	0	13	0	14
C172	81	0	96	0	186
C177	5	0	6	0	8
C182	51	0	60	0	106
C208	4	0	0	0	1
C210	46	0	55	0	99
C310	294	3	201	3	184

Appendix I, Section 2: 2015 Data Results – Air Delays By Aircraft Type

Baseline

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
C172	263	0	310	0	477
C177	3	0	3	0	6
C182	104	0	122	0	192
C206	47	0	56	0	109
C208	47	0	0	0	5
C210	83	0	96	0	152
C310	1,169	10	868	11	606
C340	262	3	187	2	154
C401	20	0	14	0	8
C402	39	0	27	0	18
C414	83	1	58	1	41
C421	246	2	186	2	114
C425	207	2	143	2	101
C441	105	1	69	1	76
C500	421,696	4,184	3,781	225	9,009
C501	1,682	18	11	1	46
C550	9,991	75	15	1	211
C560	10,196	70	19	1	222
C650	2,216	16	4	0	41
CL60	1,991	14	4	0	63
CL61	1,166	9	2	0	13
CRJ	15,924	109	30	2	382
CV58	1,627	13	7	0	127
D328	7,346	87	37	4	387
DA01	3,064	29	29	9	14
DA02	224	2	0	0	4
DA10	1,674	18	9	1	94
DA20	61	0	0	0	0
DC10	133,141	2,743	2,436	905	427
DC3	1,734	14	7	0	158
DC86	106,003	778	4,328	3,688	544

Enhanced

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
C340	138	1	95	1	83
C401	3	0	2	0	2
C414	33	0	23	0	27
C421	18	0	12	0	11
C425	1	0	1	0	1
C441	54	1	38	1	41
C500	98,329	974	851	51	2,542
C550	4,497	34	7	1	89
C560	3,658	25	7	0	106
C650	552	4	1	0	10
CRJ	3,407	23	6	0	66
CV58	205	1	3	0	19
D328	1,144	12	6	0	61
DA02	961	7	2	0	23
DA10	10	0	0	0	1
DC10	29,514	608	540	201	115
DC3	579	5	2	0	42
DC86	27,739	202	1,245	1,065	176
DC9	56,769	529	528	166	705
DH8	325	3	2	0	17
E120	14,490	118	58	3	851
EA32	21,001	309	146	15	237
EA33	6,669	84	12	1	35
FA28	314	3	2	0	5
FK10	36,802	420	570	77	594
G2	320	2	1	0	9
G3	139	1	0	0	4
G73	195	2	1	0	11
HS25	699	5	1	0	18
L101	54,466	991	1,383	1,024	240
L329	29,332	214	264	111	80

Appendix I, Section 2: 2015 Data Results – Air Delays By Aircraft Type

Baseline

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
DC9	256,116	2,448	2,017	627	2,667
DH6	1,176	14	6	1	83
DH8	2,107	24	9	1	101
E120	83,066	699	326	15	4,567
EA32	97,318	1,457	616	63	789
EA33	7,645	151	4	0	19
EA34	16,383	191	27	1	58
FA27	189	1	0	0	6
FA28	36,283	385	211	18	390
FK10	155,458	1,775	2,342	319	1,810
G2	845	6	2	0	24
G3	824	6	2	0	26
G4	860	6	2	0	12
G73	87	1	0	0	3
HS25	13,672	99	23	2	233
L101	213,742	3,954	5,252	3,879	854
L329	22,079	161	199	84	55
LR24	1,108	12	6	1	32
LR25	12,188	107	279	5	261
LR31	223	2	1	0	6
LR35	4,140	45	22	2	148
LR55	1,169	13	6	0	26
LR60	520	6	3	0	29
M1F	8,460	166	63	5	14

Enhanced

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
LR24	192	2	1	0	3
LR25	4,480	39	106	2	131
LR31	412	4	2	0	15
LR35	3,093	33	17	2	175
LR55	209	2	1	0	7
M1F	3,397	67	25	2	12
MD80	356,700	5,236	1,996	571	3,228
MD90	6,777	60	17	0	40
MO20	22	0	15	0	21
MU2	866	7	3	0	80
N265	2,968	28	28	9	26
PA23	11	0	13	0	10
PA24	3	0	3	0	6
PA28	26	0	30	0	52
PA31	1,105	14	6	1	105
PA32	36	0	25	0	54
PA34	52	1	36	1	35
PA42	29	0	0	0	3
PA46	1	0	1	0	2
PA60	24	0	17	0	20
PARO	1	0	1	0	1
PASE	16	0	11	0	12
PAYE	2,053	25	10	1	180
PAZT	5	0	3	0	2

Appendix I, Section 2: 2015 Data Results – Air Delays By Aircraft Type

Baseline

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
MD80	1,355,950	20,259	7,096	2,060	10,849
MD90	2,502	28	5	0	18
MO20	113	1	78	1	141
MU2	3,569	30	14	1	240
MU3	790	8	4	0	10
N265	5,350	50	34	10	46
PA23	52	0	62	0	59
PA24	34	0	39	0	64
PA28	137	0	162	0	256
PA31	3,173	29	14	1	252
PA32	164	2	114	2	204
PA34	226	2	156	2	130
PA46	0	0	0	0	0
PA60	138	1	92	1	82
PARO	11	0	13	0	26
PASE	16	0	11	0	7
PAYE	2,499	29	12	1	172
PAZT	113	1	87	1	55
SF34	28,638	217	144	41	1,689
SH7	1,706	21	9	1	64
SW3	228	2	2	0	17
SW4	670	7	5	0	67
WW24	779	8	5	1	34
TOTALS:	7,790,378	114,964	72,745	18,921	74,732

Enhanced

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
SF34	18,391	127	97	28	1,373
SH7	1,709	21	9	1	68
SW3	153	2	1	0	18
SW4	39	0	0	0	5
WW24	1,203	13	7	1	68
TOTALS:	2,032,150	28,816	18,959	4,999	23,385

Appendix I, Section 3: 1996 Data Results – Surface By Aircraft Type

Baseline

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
A10	983	3	58	20	155
A300	107,351	511	2,028	159	1,980
A310	3,279	11	92	21	83
A320	59,053	236	1,039	82	2,209
A4	392	1	23	8	123
A6	827	2	48	17	130
AA5	13	0	12	1	98
AC50	203	0	182	10	767
AC69	12,007	35	792	264	2,092
AJ25	458	1	27	9	72
ARJ	495	2	21	2	38
AT42	173,535	989	2,585	0	16,403
B1	7,883	197	773	883	110
B52	47,470	1,187	4,652	5,317	332
B707	28,274	707	2,771	3,167	396
B727	1,861,568	5,957	20,477	2,718	31,770
B727-200	596,285	1,907	6,559	869	10,176
B737	3,179,795	10,175	34,978	4,643	81,400
B737-200	635,615	2,032	6,992	926	16,271
B73S	132,280	515	4,550	301	4,387
B747	673,128	2,019	35,676	8,078	5,369
B747-100	118,143	366	9,877	4,265	1,059
B747-200	13,128	39	696	158	105
B74F	17,605	85	385	34	160
B757	1,224,812	5,267	18,911	1,225	24,374
B757-200	387,108	1,664	5,977	386	7,703
B767	349,615	1,189	9,859	2,199	8,813
B767-200	101,319	344	2,857	637	2,554
B777	35,626	157	666	96	557
BA11	2,518	4	247	143	80
BA14	464,050	686	45,458	26,325	14,744

Appendix I, Section 3: 1996 Data Results – Surface By Aircraft Type

Baseline

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
BA31	2,781	8	184	61	485
BA41	36,677	106	2,421	807	6,391
BA46	57,731	218	2,363	311	2,675
BATP	1,561	5	103	34	272
BE02	200,213	580	13,214	4,404	34,885
BE10	627	1	563	31	2,371
BE18	74	0	47	2	557
BE20	2,693	3	2,417	132	10,182
BE30	12,375	36	817	272	2,156
BE33	223	0	200	11	1,687
BE35	259	0	167	7	1,957
BE36	442	0	397	22	3,344
BE3B	812	2	54	18	141
BE40	13,174	12	2,042	237	778
BE55	1,027	1	922	50	3,884
BE58	1,773	2	1,591	87	6,704
BE60	122	0	109	6	461
BE76	177	0	159	9	669
BE8T	19	0	17	1	73
BE90	2,054	2	1,844	101	7,768
BE99	206	0	185	10	778
BN2	5	0	4	0	17
C12	9,814	39	206	33	1,793
C130	109,147	384	4,759	1,922	2,683
C141	42,017	74	3,719	3,864	745
C152	45	0	29	1	337
C172	941	1	607	27	7,119
C177	87	0	56	3	656
C182	535	1	345	15	4,047
C206	62	0	40	2	468
C208	911	3	60	20	317

Appendix I, Section 3: 1996 Data Results – Surface By Aircraft Type

Baseline

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
C21	6,307	18	370	126	994
C210	501	1	323	14	3,788
C23	526	1	31	11	83
C310	2,612	3	2,344	128	9,875
C340	792	1	711	39	2,995
C401	169	0	152	8	640
C402	401	0	360	20	1,517
C414	816	1	733	40	3,087
C421	972	1	872	48	3,676
C425	316	0	283	15	1,193
C441	603	1	541	30	2,281
C5	14,426	43	765	173	115
C500	1,120,835	1,007	173,729	20,175	65,908
C501	19,650	18	3,046	354	1,155
C550	76,885	293	3,275	303	5,861
C560	35,673	136	1,520	141	2,719
C650	27,633	105	1,177	109	2,106
C9	36,068	114	516	137	1,056
CA21	104	0	7	2	18
CL44	36	0	1	0	5
CL60	19,692	75	839	78	1,501
CL61	5,090	19	217	20	388
CONC	18,873	32	1,889	630	85
CRJ	91,548	349	3,900	361	6,979
CV58	2,400	7	158	53	418
D28	204	1	13	4	36
D328	44,566	254	664	0	4,213
DA01	33,327	105	477	127	976
DA02	12,747	49	543	50	972
DA05	14,966	57	638	59	761
DA10	2,637	7	155	53	415

Appendix I, Section 3: 1996 Data Results – Surface By Aircraft Type

Baseline

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
DA20	19,293	74	822	76	980
DC10	307,495	1,384	16,666	6,457	4,485
DC10-10	38,579	174	2,091	810	563
DC10-30	57,647	208	3,563	1,257	676
DC3	2,971	9	196	65	518
DC6	148	1	6	3	4
DC8-63	1,305	3	181	160	19
DC86	408,898	1,288	5,847	1,554	5,988
DC9	1,064,638	3,354	15,224	4,046	31,181
DC9-30	249,629	785	3,570	948	7,311
DC9-50	93,516	299	982	117	2,399
DH2	3	0	2	0	21
DH3	99	1	1	0	19
DH6	6,560	26	138	22	1,198
DH8	246,432	1,404	3,671	0	23,294
E110	3,481	14	73	12	636
E120	299,862	1,648	4,887	0	28,344
E2	998	7	9	0	75
EA32	202,475	810	3,564	283	7,572
EA33	40,735	199	708	51	676
EA34	32,802	137	1,115	186	528
EA6	893	3	52	18	141
F14	4,540	11	310	175	136
F15	73,553	291	1,420	166	2,082
F16	189,994	752	3,667	429	5,377
F18	69,033	273	1,332	156	1,954
FA27	1,692	6	72	7	129
FA28	91,050	167	8,033	8,444	2,994
FFJ	134	0	21	2	8
FK10	368,262	920	8,875	1,252	12,658
FK50	363	2	3	0	27

Appendix I, Section 3: 1996 Data Results – Surface By Aircraft Type

Baseline

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
FK70	1,280	3	31	4	44
G159	7,396	51	68	0	559
G2	15,801	60	673	62	1,205
G3	15,514	59	661	61	1,183
G4	12,966	49	552	51	988
G73	1,382	8	21	0	131
HS25	64,619	247	2,753	255	4,926
KC35	41,129	123	2,180	494	328
KE35	19,746	59	1,047	237	158
KR35	29,711	89	1,575	357	237
L101	282,329	807	25,124	19,128	3,163
L1011	66,151	189	5,887	4,482	741
L188	9,298	33	405	164	229
L1F	2,943	8	262	199	33
L329	24,299	43	2,150	2,235	431
L382	568	2	25	10	14
LR24	28,480	26	4,414	513	1,675
LR25	35,352	32	5,480	636	2,089
LR31	5,939	17	348	119	936
LR35	29,866	84	1,750	598	4,705
LR55	7,483	21	438	150	1,179
LR60	1,115	3	65	22	176
M1F	37,678	185	766	63	446
MD11	21,725	105	391	30	267
MD80	1,413,181	5,229	17,382	4,706	38,945
MD88	477,037	1,763	5,868	1,587	13,146
MD90	34,122	160	424	4	1,008
MO20	446	0	400	22	3,370
MU2	10,563	31	697	232	1,840
MU3	12,941	12	2,006	233	765
MU30	506	0	78	9	30

Appendix I, Section 3: 1996 Data Results – Surface By Aircraft Type

Baseline

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
N265	68,903	217	985	262	2,018
P3	31,899	112	1,391	562	784
PA23	181	0	116	5	683
PA24	112	0	72	3	844
PA28	835	1	538	24	6,318
PA30	98	0	88	5	370
PA31	32,452	130	681	110	5,928
PA32	534	1	479	26	4,036
PA34	797	1	715	39	3,012
PA41	141	1	3	0	26
PA42	2,795	11	59	9	510
PA46	99	0	89	5	749
PA60	940	1	844	46	3,556
PARO	155	0	100	4	1,174
PASE	169	0	152	8	640
PAYE	20,104	80	422	68	3,672
PAZT	441	0	395	22	1,666
S20	59	0	4	1	10
SF34	94,289	206	3,337	376	23,767
SH7	16,116	92	240	0	1,523
SHD3	6,308	22	275	111	310
SW3	2,273	6	140	180	610
SW4	23,192	66	1,426	1,835	6,219
T1	2,368	2	367	43	140
T2	827	2	48	17	130
T34	13	0	12	1	102
T37	38,415	35	5,954	691	2,269
T38I	566	2	33	11	89
TA4	1,467	4	86	29	462
TU34	45	0	2	0	3
U21	2,757	8	182	61	480

Appendix I, Section 3: 1996 Data Results – Surface By Aircraft Type

Baseline

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
UH1	116	0	3	7	49
UH60	129	0	4	8	54
WW24	9,510	27	557	191	1,498
YS11	3,320	13	141	13	253
TOTALS:	19,275,850	65,259	650,118	166,904	767,620

Appendix I, Section 3: 2015 Data Results – Surface By Aircraft Type

Baseline

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
A10	917	3	54	18	145
A300	255,833	1,218	4,833	378	4,719
A310	4,649	16	131	29	117
A320	101,266	405	1,782	141	3,787
A4	381	1	22	8	120
A6	827	2	48	17	130
AA5	12	0	11	1	91
AC50	284	0	255	14	1,074
AC69	11,336	33	748	249	1,975
AJ25	414	1	24	8	65
AT42	357,528	2,036	5,325	0	33,795
B1	7,883	197	773	883	110
B52	47,470	1,187	4,652	5,317	332
B707	27,546	689	2,699	3,085	386
B727	1,789,387	5,726	19,683	2,613	30,538
B727-200	32,340	103	356	47	552
B737	3,247,988	10,394	35,728	4,742	83,146
B737-200	532,657	1,703	5,859	776	13,636
B73F	105,140	452	2,818	149	3,206
B73S	470,511	1,833	16,186	1,071	15,605
B747	783,048	2,349	41,502	9,397	6,246
B747-100	28,794	89	2,407	1,039	258
B747-200	1,358	4	72	16	11
B74F	54,266	260	1,186	104	493
B74R	31,778	153	695	61	289
B757	2,140,480	9,204	33,049	2,140	42,596
B757-200	1,048,115	4,505	16,183	1,045	20,858
B767	452,264	1,538	12,754	2,845	11,400
B767-200	212,446	722	5,991	1,336	5,355
B777	119,708	527	2,239	323	1,870
BA11	2,528	4	248	143	80

Enhanced

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
A10	872	2	51	17	137
A300	244,318	1,163	4,615	361	4,506
A310	4,389	15	124	28	111
A320	96,210	384	1,693	134	3,598
A4	310	1	18	6	98
A6	745	2	44	15	117
AA5	11	0	10	1	86
AC50	270	0	242	13	1,020
AC69	10,678	31	705	235	1,860
AJ25	393	1	23	8	62
AT42	332,181	1,892	4,947	0	31,399
B1	7,492	187	734	839	105
B52	45,568	1,139	4,466	5,104	319
B707	26,930	673	2,639	3,016	377
B727	1,716,404	5,492	18,880	2,506	29,292
B727-200	30,688	98	338	45	524
B737	3,142,616	10,056	34,569	4,588	80,449
B737-200	505,494	1,616	5,560	736	12,940
B73F	99,766	429	2,674	141	3,042
B73S	446,516	1,740	15,360	1,016	14,809
B747	753,177	2,260	39,918	9,038	6,008
B747-100	27,307	85	2,283	986	245
B747-200	1,290	4	68	15	10
B74F	51,558	247	1,127	99	469
B74R	30,199	145	660	58	274
B757	2,066,953	8,888	31,914	2,067	41,132
B757-200	994,199	4,273	15,350	991	19,785
B767	430,987	1,465	12,154	2,711	10,864
B767-200	201,610	685	5,685	1,268	5,082
B777	113,515	499	2,123	306	1,774
BA11	2,392	4	234	136	76

Appendix I, Section 3: 2015 Data Results – Surface By Aircraft Type

Baseline

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
BA14	674,725	998	66,096	38,277	21,438
BA31	2,927	8	193	64	510
BA41	41,037	119	2,708	903	7,150
BA46	51,819	196	2,121	279	2,401
BATP	6,427	19	424	141	1,120
BE02	196,662	570	12,980	4,326	34,266
BE10	618	1	555	30	2,337
BE18	83	0	54	2	631
BE20	2,610	3	2,342	128	9,867
BE30	12,228	35	807	269	2,131
BE33	231	0	208	11	1,749
BE35	254	0	163	7	1,918
BE36	454	1	407	22	3,432
BE3B	812	2	54	18	141
BE40	14,464	13	2,242	260	855
BE55	1,182	1	1,061	58	4,469
BE58	1,941	2	1,742	95	7,339
BE60	141	0	127	7	534
BE76	220	0	198	11	834
BE8T	23	0	20	1	86
BE90	1,966	2	1,765	96	7,435
BE99	207	0	186	10	783
BN2	5	0	4	0	17
C12	9,769	39	205	33	1,784
C130	107,947	380	4,706	1,901	2,654
C141	41,058	73	3,634	3,776	728
C152	44	0	28	1	333
C172	1,000	2	645	29	7,564
C177	96	0	62	3	727
C182	592	1	381	17	4,475
C206	59	0	38	2	449
C208	958	3	63	21	334

Enhanced

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
BA14	634,455	938	62,151	35,993	20,159
BA31	2,861	8	189	63	498
BA41	38,391	111	2,534	844	6,689
BA46	48,646	184	1,991	262	2,254
BATP	5,718	16	377	126	996
BE02	186,229	540	12,291	4,096	32,449
BE10	591	1	531	29	2,236
BE18	78	0	51	2	593
BE20	2,473	3	2,219	121	9,352
BE30	11,915	34	786	262	2,076
BE33	219	0	197	11	1,658
BE35	249	0	160	7	1,884
BE36	442	1	396	22	3,340
BE3B	772	2	51	17	134
BE40	13,823	12	2,143	249	817
BE55	1,128	1	1,012	55	4,264
BE58	1,856	2	1,665	91	7,016
BE60	125	0	112	6	473
BE76	202	0	181	10	765
BE8T	22	0	19	1	82
BE90	1,881	2	1,688	92	7,114
BE99	198	0	178	10	749
BN2	4	0	4	0	17
C12	9,271	37	195	31	1,693
C130	102,804	362	4,482	1,810	2,527
C141	39,167	69	3,466	3,602	695
C152	41	0	26	1	308
C172	944	2	608	27	7,137
C177	89	0	57	3	672
C182	568	1	366	16	4,298
C206	57	0	37	2	432
C208	846	2	56	19	295

Appendix I, Section 3: 2015 Data Results – Surface By Aircraft Type

Baseline

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
C21	6,299	18	369	126	992
C210	553	1	356	16	4,181
C23	526	1	31	11	83
C310	2,557	3	2,295	126	9,668
C340	863	1	774	42	3,262
C401	180	0	162	9	682
C402	455	1	408	22	1,720
C414	823	1	738	40	3,110
C421	1,008	1	905	49	3,811
C425	327	0	294	16	1,238
C441	534	1	479	26	2,020
C5	13,996	42	742	168	112
C500	1,874,036	1,685	290,475	33,733	110,198
C501	22,840	21	3,540	411	1,343
C550	80,131	306	3,414	316	6,108
C560	35,780	137	1,524	141	2,728
C650	28,398	108	1,210	112	2,165
C9	32,359	102	463	123	948
CA21	127	0	8	3	22
CL44	66	0	2	0	8
CL60	21,324	81	908	84	1,626
CL61	6,101	23	260	24	465
CONC	18,648	32	1,867	623	84
CRJ	171,624	655	7,311	677	13,083
CV58	6,115	18	404	134	1,065
D328	65,045	370	969	0	6,148
DA01	34,856	110	498	132	1,021
DA02	12,229	47	521	48	932
DA05	15,504	59	660	61	788
DA10	3,209	9	188	64	505
DA20	22,879	87	975	90	1,163
DC10	372,310	1,675	20,179	7,819	5,431

Enhanced

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
C21	5,959	17	349	119	939
C210	527	1	340	15	3,988
C23	500	1	29	10	79
C310	2,441	3	2,191	120	9,231
C340	810	1	727	40	3,064
C401	170	0	153	8	643
C402	439	0	394	22	1,661
C414	798	1	716	39	3,018
C421	976	1	876	48	3,690
C425	299	0	269	15	1,132
C441	532	1	477	26	2,011
C5	13,302	40	705	160	106
C500	1,793,711	1,612	278,025	32,285	105,475
C501	21,125	19	3,274	380	1,242
C550	76,351	292	3,253	301	5,820
C560	35,978	137	1,533	142	2,743
C650	27,062	103	1,153	107	2,063
C9	30,740	97	440	117	900
CA21	120	0	8	3	21
CL44	63	0	2	0	8
CL60	20,711	79	882	82	1,579
CL61	5,622	21	240	22	429
CONC	17,793	30	1,781	594	80
CRJ	160,541	612	6,839	633	12,238
CV58	5,733	17	378	126	999
D328	61,449	350	915	0	5,809
DA01	34,039	107	487	129	997
DA02	11,277	43	480	45	860
DA05	14,798	57	630	58	752
DA10	3,189	9	187	64	502
DA20	21,644	83	922	85	1,100
DC10	364,724	1,641	19,768	7,659	5,320

Appendix I, Section 3: 2015 Data Results – Surface By Aircraft Type

Baseline

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
DC10-10	12,576	57	682	264	183
DC10-30	24,576	88	1,519	536	288
DC3	2,881	8	190	63	502
DC6	1,311	5	57	23	32
DC8-63	1,305	3	181	160	19
DC86	582,502	1,835	8,330	2,213	8,530
DC9	967,302	3,047	13,832	3,676	28,330
DC9-30	49,604	156	709	188	1,453
DC9-50	216,472	692	2,273	270	5,553
DH3	99	1	1	0	19
DH6	7,222	29	152	24	1,319
DH8	291,241	1,658	4,338	0	27,530
E110	3,119	12	65	11	570
E120	434,738	2,389	7,085	0	41,094
E2	907	6	8	0	69
EA32	247,589	990	4,358	347	9,259
EA33	51,636	252	897	65	856
EA34	26,446	111	899	150	426
EA6	849	2	50	17	134
F14	3,740	9	255	144	112
F15	71,579	283	1,381	162	2,026
F16	183,263	725	3,537	414	5,187
F18	68,475	271	1,322	155	1,938
FA27	1,815	7	77	7	138
FA28	109,969	201	9,703	10,198	3,616
FK10	434,376	1,085	10,468	1,476	14,931
G159	7,576	52	70	0	573
G2	16,556	63	705	65	1,262
G3	17,283	66	736	68	1,317
G4	13,504	52	575	53	1,029
G73	1,157	7	17	0	109
HS25	71,619	273	3,051	283	5,460

Enhanced

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
DC10-10	11,950	54	648	251	174
DC10-30	23,294	84	1,440	508	273
DC3	2,983	9	197	66	520
DC6	1,256	4	55	22	31
DC8-63	1,240	3	172	152	18
DC86	552,560	1,740	7,902	2,100	8,092
DC9	919,665	2,897	13,151	3,495	26,935
DC9-30	47,298	149	676	180	1,385
DC9-50	205,293	656	2,156	256	5,266
DH3	76	0	1	0	14
DH6	6,734	27	141	23	1,230
DH8	271,514	1,546	4,044	0	25,665
E110	2,962	12	62	10	541
E120	408,261	2,244	6,654	0	38,591
E2	862	6	8	0	65
EA32	243,382	974	4,284	341	9,102
EA33	49,962	244	868	62	829
EA34	25,818	108	878	147	415
EA6	786	2	46	16	124
F14	3,446	8	235	132	103
F15	68,142	270	1,315	154	1,928
F16	173,114	685	3,341	391	4,899
F18	64,522	255	1,245	146	1,826
FA27	1,734	7	74	7	132
FA28	103,938	190	9,170	9,639	3,417
FK10	418,502	1,046	10,086	1,423	14,385
G159	7,116	49	65	0	538
G2	15,192	58	647	60	1,158
G3	16,766	64	714	66	1,278
G4	12,755	49	543	50	972
G73	1,492	9	22	0	141
HS25	68,689	262	2,926	271	5,236

Appendix I, Section 3: 2015 Data Results – Surface By Aircraft Type

Baseline

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
KC35	40,769	122	2,161	489	325
KE35	19,331	58	1,025	232	154
KR35	29,281	88	1,552	351	234
L101	216,966	621	19,308	14,699	2,431
L1011	17,083	49	1,520	1,157	191
L188	10,195	36	444	180	251
L1F	7,960	23	708	539	89
L329	25,275	45	2,237	2,324	448
L382	649	2	28	11	16
LR24	26,859	24	4,163	483	1,579
LR25	38,999	35	6,045	702	2,304
LR31	6,536	18	383	131	1,030
LR35	31,266	88	1,832	626	4,926
LR55	7,945	22	466	159	1,252
LR60	1,767	5	104	35	278
M1F	33,871	166	688	56	401
MD11	11,445	56	206	16	141
MD80	1,736,753	6,426	21,362	5,783	47,862
MD88	702,576	2,597	8,642	2,337	19,362
MD90	34,207	161	425	4	1,010
MO20	454	1	408	22	3,435
MU2	10,271	30	678	226	1,790
MU3	13,156	12	2,039	237	777
MU30	854	1	132	15	50
N265	68,757	217	983	261	2,014
NEWX	16,125	77	352	31	147
P3	31,567	111	1,376	556	776
PA23	175	0	113	5	660
PA24	117	0	75	3	883
PA28	874	1	563	25	6,612
PA30	126	0	113	6	476
PA31	33,254	133	698	113	6,074

Enhanced

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
KC35	38,734	116	2,053	465	309
KE35	18,129	54	961	218	145
KR35	27,421	82	1,453	329	219
L101	206,511	591	18,377	13,991	2,314
L1011	16,211	46	1,443	1,098	182
L188	9,636	34	420	170	237
L1F	7,566	22	673	513	85
L329	25,015	44	2,214	2,300	444
L382	617	2	27	11	15
LR24	26,607	24	4,124	479	1,565
LR25	37,354	34	5,790	672	2,207
LR31	6,237	18	366	125	983
LR35	29,476	83	1,727	591	4,644
LR55	7,546	21	442	151	1,189
LR60	2,043	6	120	41	322
M1F	31,904	156	648	53	378
MD11	10,855	53	196	15	133
MD80	1,656,099	6,128	20,370	5,515	45,639
MD88	666,968	2,465	8,204	2,219	18,381
MD90	32,102	151	399	3	948
MO20	438	1	393	21	3,314
MU2	9,743	28	643	214	1,698
MU3	12,947	12	2,007	233	765
MU30	812	1	126	15	48
N265	67,632	213	967	257	1,981
NEWX	15,268	73	334	29	139
P3	29,947	105	1,306	527	736
PA23	190	0	122	5	717
PA24	112	0	72	3	849
PA28	840	1	541	24	6,349
PA30	120	0	108	6	453
PA31	32,033	128	672	109	5,851

Appendix I, Section 3: 2015 Data Results – Surface By Aircraft Type

Baseline

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
PA32	560	1	503	27	4,238
PA34	820	1	736	40	3,100
PA41	141	1	3	0	26
PA42	3,223	13	68	11	589
PA46	101	0	90	5	762
PA60	986	1	885	48	3,729
PARO	155	0	100	4	1,170
PASE	164	0	147	8	621
PAYE	19,136	76	402	65	3,495
PAZT	491	1	441	24	1,856
SF34	87,601	192	3,101	350	22,081
SH7	13,233	75	197	0	1,251
SHD3	6,080	21	265	107	299
SW3	2,116	6	130	167	567
SW4	22,961	66	1,412	1,816	6,157
T1	2,322	2	360	42	137
T2	827	2	48	17	130
T34	13	0	12	1	98
T37	38,357	35	5,945	690	2,266
T38I	370	1	22	7	58
TA4	1,402	4	82	28	442
TU5	147	1	6	1	11
U21	2,734	8	180	60	476
UH1	100	0	3	6	42
UH60	129	0	4	8	54
WW24	10,451	29	612	209	1,646
YS11	2,319	9	99	9	177
TOTALS:	23,209,100	79,623	841,668	190,652	927,510

Enhanced

AC Type	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
PA32	539	1	483	26	4,074
PA34	769	1	690	38	2,908
PA41	134	1	3	0	24
PA42	3,001	12	63	10	548
PA46	95	0	85	5	718
PA60	957	1	859	47	3,619
PARO	146	0	94	4	1,101
PASE	156	0	140	8	591
PAYE	18,349	73	385	62	3,352
PAZT	465	1	417	23	1,757
SF34	82,305	181	2,913	329	20,746
SH7	12,435	71	185	0	1,175
SHD3	5,690	20	248	100	280
SW3	1,908	5	117	151	512
SW4	22,077	63	1,358	1,746	5,920
T1	2,152	2	334	39	127
T2	745	2	44	15	117
T34	12	0	11	1	90
T37	36,440	33	5,648	656	2,153
T38I	269	1	16	5	42
TA4	1,311	4	77	26	413
TU5	139	1	6	1	11
U21	2,599	8	172	57	453
UH1	95	0	3	6	40
UH60	122	0	4	8	52
WW24	9,949	28	583	199	1,567
YS11	2,203	8	94	9	168
TOTALS:	22,188,008	76,103	803,948	181,762	883,821

Appendix I, Section 4: 1996 Data Results – Surface By Airport

Baseline

Airport	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
ABQ	96,686	336	2,160	581	3,253
ATL	858,348	3,052	22,267	9,310	22,625
AUS	61,432	200	1,250	276	2,265
BDL	59,934	203	1,312	254	2,187
BFI	115,989	368	2,565	367	4,341
BHM	37,543	120	1,283	174	1,959
BNA	89,329	264	2,827	787	3,443
BOI	37,223	125	1,743	875	1,606
BOS	449,269	1,514	12,058	2,891	18,113
BUF	35,043	117	907	197	1,645
BUR	49,345	167	943	119	1,688
BWI	169,421	604	4,143	772	6,728
CLE	201,526	696	4,281	919	9,153
CLT	278,574	906	8,171	2,976	10,716
CMH	80,050	259	2,137	650	2,846
COS	114,100	369	2,186	434	3,482
CVG	263,266	949	5,345	1,185	9,453
DAB	22,764	74	578	97	860
DAL	57,226	181	1,237	159	2,405
DAY	87,777	276	1,911	579	2,355
DCA	225,117	770	4,247	579	7,902
DEN	394,361	1,365	9,796	1,764	12,468
DFW	575,648	2,078	10,063	2,293	19,168
DTW	377,839	1,323	7,778	1,797	12,295
ELP	36,552	112	790	112	1,176
EWR	586,170	2,122	11,658	2,323	18,314
FLL	110,893	382	2,792	921	3,983
GSO	34,669	109	1,084	284	1,632
HOU	95,338	306	1,837	242	3,540
HPN	28,868	83	1,740	336	2,146
IAD	197,223	586	10,024	3,841	8,663
IAH	318,803	1,100	4,844	931	9,660

Appendix I, Section 4: 1996 Data Results – Surface By Airport

Baseline

Airport	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
ICT	23,780	70	1,031	146	1,426
IND	81,637	251	2,865	987	3,186
ISP	17,583	56	616	218	1,082
JAX	48,105	165	1,039	175	2,024
JFK	521,885	1,794	22,814	6,848	13,226
LAS	289,103	956	7,603	1,845	8,418
LAX	780,102	2,659	28,719	9,695	21,348
LGA	391,132	1,311	7,516	1,406	12,745
LGB	49,697	131	3,951	793	2,815
MCI	126,686	410	2,319	407	4,429
MCO	289,862	1,008	7,265	2,656	8,419
MDW	116,983	375	2,866	821	3,950
MEM	242,873	824	5,980	1,583	7,703
MIA	462,316	1,912	11,755	3,719	12,836
MKE	76,018	247	2,258	571	3,544
MSP	445,092	1,493	12,526	3,574	14,889
MSY	82,653	270	1,487	314	2,676
OAK	194,949	624	6,100	1,232	5,451
OKC	42,307	134	1,069	160	1,491
OMA	44,857	146	1,218	231	1,749
ONT	82,636	274	1,892	479	2,261
ORD	874,985	3,028	21,560	4,156	25,841
OTHER	3,866,481	12,777	239,276	57,079	247,458
PBI	65,035	217	2,015	439	2,559
PDX	140,668	475	3,929	1,610	5,644
PHL	471,407	1,538	12,253	2,441	18,467
PHX	366,788	1,236	7,699	1,863	10,571
PIE	10,839	29	784	139	682
PIT	297,867	975	8,763	2,172	13,314
RDU	68,717	207	2,013	547	2,994
RIC	38,550	126	966	149	1,817
RNO	74,259	254	1,310	206	2,276

Appendix I, Section 4: 1996 Data Results – Surface By Airport

Baseline

Airport	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
ROC	40,515	128	1,312	302	1,886
SAN	141,520	492	2,969	745	4,684
SAT	62,572	201	1,478	259	2,583
SDF	134,438	469	3,325	650	3,639
SEA	306,101	1,097	8,320	3,303	10,919
SFO	414,121	1,400	14,780	3,916	11,300
SJC	104,863	358	1,891	354	3,522
SLC	215,978	745	4,457	1,071	6,379
SMF	69,689	220	1,628	568	2,149
SNA	116,128	384	4,771	726	6,243
STL	540,518	1,696	15,739	5,457	19,749
SYR	38,283	129	1,137	238	2,174
TEB	15,184	39	1,260	163	1,442
TPA	126,876	450	2,698	705	4,446
TUL	40,434	130	1,087	150	1,798
TUS	50,454	169	1,313	210	1,879
VNY	25,999	61	2,536	402	3,482
TOTALS:	19,275,850	65,259	650,118	166,904	767,633

Appendix I, Section 4: 2015 Data Results – Surface By Airport

Baseline

Airport	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
ABQ	121,710	436	3,338	853	4,048
ATL	715,231	2,551	19,734	6,241	20,817
AUS	70,867	231	2,119	386	2,781
BDL	103,366	361	3,462	629	3,909
BFI	13,196	38	892	116	1,256
BHM	43,758	144	1,630	277	2,286
BNA	131,748	416	5,049	1,167	5,352
BOI	41,083	142	1,850	769	1,826
BOS	484,939	1,674	12,723	3,070	18,936
BUF	45,517	151	1,612	361	2,116
BUR	77,729	259	1,815	254	2,537
BWI	211,365	734	6,766	1,464	8,454
CLE	167,596	586	4,195	1,030	7,019
CLT	340,176	1,140	9,806	3,052	12,638
CMH	89,986	304	2,578	587	3,283
COS	82,616	280	2,093	456	2,787
CVG	399,057	1,389	12,639	2,978	14,606
DAB	7,208	23	273	35	370
DAL	93,996	306	3,027	390	3,862
DAY	109,190	357	2,983	734	3,333
DCA	218,007	756	4,396	693	7,630
DEN	538,078	1,926	15,141	2,956	16,805
DFW	809,480	2,922	20,693	4,098	27,631
DTW	460,250	1,631	12,058	2,551	15,270
ELP	45,832	149	1,311	182	1,467
EWR	739,747	2,684	17,676	3,170	24,098
FLL	140,684	497	3,862	1,027	5,208
GSO	40,907	132	1,394	286	1,934

Enhanced

Airport	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
ABQ	117,312	419	3,207	816	3,904
ATL	653,910	2,333	18,107	5,790	19,028
AUS	67,076	219	2,004	365	2,643
BDL	98,432	344	3,308	601	3,704
BFI	12,040	34	836	107	1,158
BHM	41,644	137	1,542	263	2,168
BNA	124,409	393	4,770	1,108	5,034
BOI	39,019	134	1,759	732	1,732
BOS	466,645	1,611	12,202	2,911	18,271
BUF	42,943	142	1,507	342	1,976
BUR	75,039	249	1,751	246	2,453
BWI	195,122	683	6,199	1,375	7,711
CLE	161,477	564	4,051	995	6,763
CLT	322,102	1,079	9,244	2,835	11,954
CMH	84,878	287	2,406	546	3,093
COS	78,627	266	1,988	433	2,649
CVG	380,150	1,323	12,057	2,826	13,978
DAB	6,852	22	260	34	352
DAL	89,253	290	2,859	368	3,691
DAY	103,437	338	2,831	696	3,153
DCA	216,533	744	4,526	689	7,701
DEN	510,719	1,830	14,370	2,827	15,942
DFW	770,086	2,780	19,699	3,914	26,221
DTW	439,423	1,556	11,529	2,444	14,545
ELP	43,686	142	1,249	173	1,398
EWR	757,857	2,753	17,680	3,126	24,122
FLL	134,138	474	3,699	985	4,961
GSO	39,152	126	1,333	273	1,852

Appendix I, Section 4: 2015 Data Results – Surface By Airport

Baseline

Airport	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
HOU	130,348	425	3,816	530	4,805
HPN	51,374	161	2,811	582	3,346
IAD	251,411	820	11,270	3,442	11,085
IAH	418,728	1,483	8,334	1,539	13,015
ICT	31,042	97	1,417	204	1,819
IND	122,415	411	4,038	1,065	4,641
ISP	20,786	67	1,017	326	1,272
JAX	58,368	206	1,511	264	2,461
JFK	592,646	2,122	22,961	6,036	15,715
LAS	1,109,767	3,361	51,404	8,217	37,372
LAX	839,422	2,977	26,737	7,637	24,273
LGA	415,476	1,413	8,487	1,705	13,562
LGB	61,533	205	3,546	497	3,538
MCI	167,871	559	4,407	853	5,960
MCO	423,910	1,485	13,200	3,222	13,943
MDW	126,908	411	3,295	812	4,437
MEM	316,709	1,087	9,513	2,253	10,890
MIA	520,664	2,075	15,233	4,021	15,592
MKE	110,567	380	3,742	834	4,654
MSP	590,679	2,043	18,331	4,307	19,870
MSY	113,885	384	2,890	587	3,813
OAK	153,919	480	6,074	889	5,249
OKC	46,785	158	1,179	193	1,712
OMA	49,785	165	1,547	300	1,992
ONT	190,819	637	7,010	1,249	6,186
ORD	789,255	2,830	17,676	3,434	23,048
OTHER	4,411,405	14,744	270,840	63,709	276,653
PBI	70,487	245	2,085	442	2,693
PDX	162,219	546	5,377	1,700	6,595
PHL	365,092	1,250	10,117	2,101	13,661
PHX	432,692	1,501	10,545	1,770	14,290

Enhanced

Airport	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
HOU	125,684	411	3,671	528	4,577
HPN	48,655	152	2,703	568	3,146
IAD	245,407	793	11,510	3,525	11,059
IAH	402,636	1,426	7,958	1,470	12,549
ICT	29,573	92	1,348	194	1,729
IND	116,056	389	3,830	1,002	4,376
ISP	19,694	63	977	321	1,197
JAX	55,304	196	1,430	249	2,324
JFK	553,505	1,982	21,614	5,654	14,573
LAS	1,122,417	3,394	52,164	8,353	37,833
LAX	792,443	2,807	25,128	7,185	22,490
LGA	395,660	1,344	8,155	1,653	12,930
LGB	60,014	201	3,365	474	3,392
MCI	159,815	533	4,079	745	5,697
MCO	402,749	1,409	12,567	3,037	13,271
MDW	120,668	390	3,165	773	4,237
MEM	301,464	1,035	9,023	2,134	10,325
MIA	495,703	1,976	14,522	3,830	14,881
MKE	106,846	381	3,650	869	4,466
MSP	567,967	1,962	17,697	4,172	19,092
MSY	108,277	364	2,780	597	3,605
OAK	146,601	456	5,826	843	5,069
OKC	44,445	150	1,121	183	1,632
OMA	47,219	157	1,448	283	1,891
ONT	181,317	605	6,691	1,193	5,876
ORD	752,411	2,698	16,841	3,265	21,946
OTHER	4,172,170	13,947	256,381	60,288	261,153
PBI	67,501	234	2,012	426	2,572
PDX	155,458	523	5,112	1,604	6,323
PHL	348,617	1,193	9,664	1,990	13,034
PHX	421,828	1,461	10,240	1,708	13,913

Appendix I, Section 4: 2015 Data Results – Surface By Airport

Baseline

Airport	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
PIE	7,866	22	573	101	589
PIT	350,643	1,187	10,278	2,500	15,007
RDU	148,357	488	5,611	1,037	6,289
RIC	48,304	164	1,462	238	2,288
RNO	89,215	316	1,878	276	2,822
ROC	52,669	171	1,841	431	2,415
SAN	265,315	926	7,646	1,588	9,082
SAT	92,650	307	2,920	477	3,907
SDF	152,270	528	4,645	855	4,455
SEA	302,886	1,087	8,544	2,686	10,669
SFO	595,482	2,093	19,024	4,292	17,465
SJC	154,767	550	3,712	602	5,200
SLC	290,298	996	8,061	1,646	9,184
SMF	96,406	318	2,797	873	3,319
SNA	145,270	477	6,731	1,034	7,565
STL	566,798	1,849	17,395	4,917	20,696
SYR	61,395	210	2,260	488	3,255
TEB	19,598	51	1,594	208	2,087
TPA	169,658	592	4,944	1,113	6,195
TUL	46,426	150	1,550	222	2,029
TUS	55,601	184	1,835	305	1,980
VNY	6,942	12	841	232	612
TOTALS:	23,209,100	79,623	841,668	190,652	927,510

Enhanced

Airport	Fuel (lbs)	NOx (lbs)	CO (lbs)	HC (lbs)	Time (mins)
PIE	7,475	21	545	96	560
PIT	345,221	1,175	9,814	2,375	14,747
RDU	140,857	464	5,295	986	5,971
RIC	46,055	156	1,394	227	2,167
RNO	82,985	294	1,770	260	2,653
ROC	50,104	163	1,757	410	2,293
SAN	250,558	875	7,008	1,453	8,452
SAT	86,961	288	2,770	453	3,707
SDF	144,916	502	4,430	813	4,266
SEA	287,490	1,033	8,168	2,557	10,139
SFO	568,739	2,000	18,108	4,062	16,573
SJC	146,970	525	3,386	556	4,852
SLC	274,884	944	7,628	1,527	8,702
SMF	91,879	302	2,692	848	3,151
SNA	139,683	457	6,515	995	7,136
STL	540,988	1,767	16,626	4,760	19,745
SYR	58,053	198	2,141	463	3,030
TEB	18,682	49	1,519	198	1,990
TPA	162,077	565	4,723	1,063	5,993
TUL	44,117	143	1,472	211	1,922
TUS	52,653	174	1,739	290	1,874
VNY	6,596	11	799	221	582
TOTALS:	22,188,008	76,103	803,948	181,762	883,821

Appendix J: Unimpeded Taxi Times

	Taxi Out (mins)				Taxi In (mins)			
Airport	1996	2005	2010	2015	1996	2005	2010	2015
ABQ	9.18	9.18	9.18	8.72	4.93	4.93	4.93	4.68
ATL	10.04	9.53	9.53	9.05	4.87	4.62	4.62	4.39
AUS	8.47	8.47	8.47	8.05	3.16	3.16	3.16	3.00
BDL	8.81	8.81	8.81	8.37	3.79	3.79	3.79	3.60
BFI	7.60	7.60	7.60	7.22	3.43	3.43	3.43	3.26
BHM	7.77	7.77	7.77	7.38	2.94	2.94	2.94	2.79
BNA	8.53	8.53	8.53	8.10	4.44	4.44	4.44	4.21
BOI	9.24	9.24	9.24	8.78	3.64	3.64	3.64	3.46
BOS	11.69	11.69	11.11	11.11	5.02	5.02	4.77	4.77
BUF	8.43	8.43	8.43	8.01	2.88	2.88	2.88	2.74
BUR	9.01	9.01	9.01	8.56	1.77	1.77	1.77	1.68
BWI	9.37	9.37	9.37	8.90	3.82	3.82	3.82	3.63
CLE	9.22	9.22	9.22	8.76	3.94	3.94	3.94	3.74
CLT	9.60	9.60	9.60	9.12	3.85	3.85	3.85	3.66
CMH	8.48	8.48	8.48	8.05	3.64	3.64	3.64	3.46
COS	11.29	11.29	11.29	10.72	5.19	5.19	5.19	4.93
CVG	9.00	9.00	9.00	8.55	4.72	4.72	4.72	4.48
DAB	8.42	8.42	8.42	7.99	3.18	3.18	3.18	3.03
DAL	6.24	6.24	6.24	5.93	2.30	2.30	2.30	2.19
DAY	8.57	8.57	8.57	8.14	4.01	4.01	4.01	3.81
DCA	9.73	9.73	9.73	9.24	3.78	3.78	3.78	3.59
DEN	11.08	11.08	11.08	10.52	5.31	5.31	5.31	5.05
DFW	9.87	9.87	9.37	9.37	4.77	4.77	4.53	4.53
DTW	10.29	10.29	9.77	9.77	4.49	4.49	4.27	4.27
ELP	7.33	7.33	7.33	6.97	2.59	2.59	2.59	2.46
EWR	11.76	11.76	11.18	11.18	5.67	5.67	5.39	5.39
FLL	10.60	10.60	10.60	10.07	3.63	3.63	3.63	3.45
GSO	9.40	9.40	9.40	8.93	3.36	3.36	3.36	3.19
HOU	8.91	8.91	8.91	8.47	3.46	3.46	3.46	3.29
HPN	8.96	8.96	8.96	8.51	3.36	3.36	3.36	3.20
IAD	10.62	10.62	10.62	10.09	5.09	5.09	5.09	4.84
IAH	8.35	8.35	8.35	7.93	4.32	4.32	4.32	4.11
ICT	7.64	7.64	7.64	7.26	3.65	3.65	3.65	3.47
IND	7.88	7.88	7.88	7.48	3.96	3.96	3.96	3.76
ISP	7.91	7.91	7.91	7.52	3.98	3.98	3.98	3.78

*This appendix was developed by Dan Citrenbaum (FAA/ASD-400).

Appendix J: Unimpeded Taxi Times

	Taxi Out (mins)				Taxi In (mins)			
Airport	1996	2005	2010	2015	1996	2005	2010	2015
JAX	8.82	8.82	8.82	8.38	4.26	4.26	4.26	4.05
JFK	16.37	16.37	16.37	15.55	6.32	6.32	6.32	6.00
LAS	11.38	11.38	11.38	10.81	3.90	3.90	3.90	3.70
LAX	10.79	10.79	10.25	10.25	5.62	5.62	5.34	5.34
LGA	11.43	11.43	11.43	10.86	4.52	4.52	4.52	4.29
LGB	8.63	8.63	8.63	8.20	3.25	3.25	3.25	3.09
MCI	8.96	8.96	8.96	8.51	3.92	3.92	3.92	3.72
MCO	11.57	11.57	10.99	10.99	4.84	4.84	4.59	4.59
MDW	8.77	8.77	8.77	8.33	3.81	3.81	3.81	3.62
MEM	8.29	8.29	8.29	7.88	3.56	3.56	3.56	3.38
MIA	12.94	12.94	12.29	12.29	4.60	4.60	4.37	4.37
MKE	8.70	8.70	8.70	8.27	3.84	3.84	3.84	3.65
MSP	10.17	10.17	9.66	9.66	3.71	3.71	3.53	3.53
MSY	8.12	8.12	8.12	7.72	3.22	3.22	3.22	3.06
OAK	8.17	8.17	8.17	7.76	3.89	3.89	3.89	3.70
OKC	7.84	7.84	7.84	7.45	3.48	3.48	3.48	3.31
OMA	8.24	8.24	8.24	7.83	3.01	3.01	3.01	2.86
ONT	9.74	9.74	9.74	9.25	2.88	2.88	2.88	2.74
ORD	10.41	10.41	9.89	9.89	4.81	4.81	4.57	4.57
OTHER	7.60	7.60	7.60	7.22	3.43	3.43	3.43	3.26
PBI	9.33	9.33	9.33	8.86	3.56	3.56	3.56	3.38
PDX	9.63	9.63	9.63	9.15	3.44	3.44	3.44	3.27
PHL	10.04	10.04	10.04	9.54	4.31	4.31	4.31	4.09
PHX	10.18	10.18	10.18	9.67	3.31	3.31	3.31	3.15
PIE	7.60	7.60	7.60	7.22	3.43	3.43	3.43	3.26
PIT	10.56	10.56	10.03	10.03	5.32	5.32	5.32	5.32
RDU	8.30	8.30	8.30	7.89	3.25	3.25	3.25	3.09
RIC	8.68	8.68	8.68	8.24	4.01	4.01	4.01	3.81
RNO	10.04	10.04	10.04	9.54	4.11	4.11	4.11	3.91
ROC	7.68	7.68	7.68	7.30	4.45	4.45	4.45	4.23
SAN	10.47	10.47	10.47	9.95	2.65	2.65	2.65	2.52
SAT	8.11	8.11	8.11	7.70	2.71	2.71	2.71	2.57
SDF	7.67	7.67	7.67	7.29	3.16	3.16	3.16	3.00
SEA	10.78	10.78	10.78	10.24	3.81	3.81	3.81	3.62
SFO	11.13	11.13	10.58	10.58	4.51	4.51	4.29	4.29

*This appendix was developed by Dan Citrenbaum (FAA/ASD-400).

Appendix J: Unimpeded Taxi Times

		Taxi Out (mins)					Taxi In (mins)			
Airport		1996	2005	2010	2015		1996	2005	2010	2015
SJC		9.57	9.57	9.57	9.10		3.73	3.73	3.73	3.55
SLC		10.30	10.30	10.30	9.79		3.23	3.23	3.23	3.07
SMF		9.47	9.47	9.47	9.00		3.56	3.56	3.56	3.39
SNA		8.95	8.95	8.95	8.50		4.36	4.36	4.36	4.14
STL		10.06	10.06	9.56	9.56		3.84	3.84	3.65	3.65
SYR		9.10	9.10	9.10	8.64		3.88	3.88	3.88	3.69
TEB		7.60	7.60	7.60	7.22		3.43	3.43	3.43	3.26
TPA		9.91	9.91	9.91	9.41		3.68	3.68	3.68	3.49
TUL		8.16	8.16	8.16	7.75		3.05	3.05	3.05	2.90
TUS		8.10	8.10	8.10	7.70		3.39	3.39	3.39	3.22
VNY		7.60	7.60	7.60	7.22		3.43	3.43	3.43	3.26

*This appendix was developed by Dan Citrenbaum (FAA/ASD-400).

Appendix K: Emissions Indices[1]

Section 1 – Boeing Method Two Indices

This section contains global emission indices from "Scheduled Civil Aircraft Emission Inventories for 1992: Database Development and Analysis", Appendix M (NASA Contractor Report 4700). These were calculated by integrating the fuel burned and emissions over the 0-9 kilometer altitude band and over the 9-13 kilometer band.

Section 2 – ICAO Indices

This section contains emission indices from "ICAO Engine Exhaust Emissions Data Bank", (Doc 9646-AN/943).

[1] This appendix was developed by Donna Middleton (FAA/SETA).

Appendix K, Section 1: Boeing Method Two Indices

	0-9 km Altitude Band (lbs/1000)			9-13 km Altitude Band (lbs/1000)		
Engine	NOx	CO	HC	NOx	CO	HC
146-200/ALF502R-5	8.8	7.9	0.8	7.7	0.2	0
727-100/JT8D-7B	10.8	7.4	2.2	7.8	3.8	1.1
72S-200/JT8D-15	11.7	4.9	0.7	8.7	2.3	0.5
737-200/JT8D-15	10.8	5.4	0.8	7.7	3.3	0.7
73L-500/CFM56-3C	11.4	12.9	0.8	9.4	3.8	0.2
73Y-300/CFM56-3B	12.2	15.6	1.3	9.6	2.9	0.2
73Z-400/CFM56-3B	12.2	15	1.1	9.6	3.5	0.2
747-100/JT9D-7A	24	21.4	11.2	13.9	0.4	0.6
747-200B/JT9D-7Q	20	21.1	7.5	12.5	0.8	0.7
74I-400/PW4056	21.2	3.6	0.3	14.2	0.3	0.3
757-200/RB211-535E4	20.7	11.5	1.1	10.3	2.9	0.1
767-200/CF6-80A	18.8	6.9	1.5	12.5	2.9	0.6
A30B2-100/CF6-50C2R	21.2	17.7	7.1	15.2	1.1	0.9
A31-200/CF6-80A3	17.6	7.4	1.7	13	2.4	0.6
A32-200/CFM56-5A1	14.9	7.1	0.7	11.1	2.2	0.5
AT4/LGTURB	13.1	4.3	0			
B3C-320CH/JT3D-3B	15.1	38.8	44.3	5.9	7.7	7.7
BAC-500/RR_SPEY-512	11.4	12.7	1.6	9.3	2.6	0.5
BE1/SMTURB	8.2	4	0.2			
BEK/SMTURB	8.2	3.9	0.2			
CNJ/	10.5	5.9	0.5	9.9	2.1	0.4
Concorde	10.4	27.9	5.4	10	26	1.8
D10-10/CF6-6D	20.6	18.3	6.8	12.6	2.2	1.4
D8C-33F/JT4A-11	7.3	44.9	38.4	5.4	7.4	2
D8S-63H/JT3D-7	8.1	32.4	26.6	6.1	4.2	1.3
D9S-30/JT8D-7B	9.4	9.5	3	8.1	2.1	0.5
D9X-50/JT8D-17	10.7	6.1	0.8	9.4	2.3	0.5
D9Z-82/JT8D-217	14.7	5.6	1.6	10.7	3.8	1.3
DH3/MDTURB	11.8	5	0.6			
DH8/MDTURB	11.8	5.1	0.6			

Appendix K, Section 1: Boeing Method Two Indices

	0-9 km Altitude Band (lbs/1000)			9-13 km Altitude Band (lbs/1000)		
Engine	NOx	CO	HC	NOx	CO	HC
DLR-30/CF6-50C2	21.3	18	6.7	12.6	2.1	1.3
EMB/SMTURB	8.1	4	0.2			
F10-100/TAY620-15	11.4	15.5	2.1	8	3.2	1.1
F28-4000/RR_SPEY-MK555	10.5	6	0.5	8.5	1.5	0.4
F50/LGTURB	13	4.3	0			
I62/SOL	14.6	34.2	39.5	5.9	5.9	6
I72/	15.1	38.7	44.5	5.8	8	7.9
I86/KUZ	15.1	38.8	44.7	5.8	8.1	8
L10-1/RB211-22B	18.2	25.4	18.8	14.7	3.1	1
L4T/SMTURB	8.2	3.8	0.2			
LRJ/	10.7	5.6	0.5	8.7	1.3	0.4
MDL-11P/PW4460	19.6	7.5	0.6	13	1.5	0.2
MU2/SMTURB	8.4	3.7	0.2			
PA6/SMTURB	8.4	3.6	0.2			
SF3/MDTURB	11.7	5.1	0.6			
SH6/MDTURB	12.3	5.1	0.6			
T34/SOL	9.4	9.3	2.9	8	2.1	0.5

Appendix K, Section 2: ICAO Indices

	TAKE OFF					CLIMB OUT				
ENGINE	TIME (mins)	FUEL (kg/sec)	HC (lbs/1000)	CO (lbs/1000)	NOx (lbs/1000)	TIME (mins)	FUEL (kg/sec)	HC (lbs/1000)	CO (lbs/1000)	NOx (lbs/1000)
501D22A	0.7	0.299	0.28	2.00	8.88	2.2	0.277	0.89	2.10	9.22
ALF 502R-5	0.7	0.358	0.06	0.30	13.53	2.2	0.296	0.05	0.25	10.56
CF34-3A	0.7	0.407	0.06	0.00	11.61	2.2	0.334	0.06	0.00	10.14
CF6-50C2	0.7	2.487	0.60	0.50	36.30	2.2	1.975	0.70	0.50	29.70
CF6-6D	0.7	1.736	0.30	0.50	40.00	2.2	1.431	0.30	0.50	32.60
CF6-80A	0.7	2.145	0.29	1.00	29.80	2.2	1.795	0.29	1.10	25.60
CF6-80A3	0.7	2.254	0.30	1.00	29.60	2.2	1.885	0.37	1.10	26.60
CF6-80C2A5	0.7	2.580	0.04	0.06	28.57	2.2	2.096	0.05	0.04	21.69
CF6-80C2D1F	0.7	2.629	0.04	0.05	28.12	2.2	2.126	0.05	0.04	21.30
CF6-80E1A2	0.7	2.767	0.04	0.05	28.72	2.2	2.245	0.04	0.04	22.01
CFM56-3-B1	0.7	0.946	0.04	0.90	17.70	2.2	0.792	0.05	0.95	15.50
CFM56-3C-1	0.7	1.154	0.03	0.90	20.70	2.2	0.954	0.04	0.90	17.80
CFM56-5-A1	0.7	1.051	0.23	0.90	24.60	2.2	0.862	0.23	0.90	19.60
CFM56-5C2	0.7	1.308	0.01	0.93	32.60	2.2	1.076	0.01	0.80	25.80
CJ610-2C	0.7	0.350	0.10	27.00	4.20	2.2	0.306	0.20	27.00	3.70
CJ610-6	0.7	0.350	0.10	27.00	4.20	2.2	0.288	0.20	28.00	3.50
CT7-5	0.5	0.101	1.00	2.50	13.80	2.5	0.094	1.00	2.70	13.20
D-36	0.7	0.634	0.00	0.50	26.00	2.2	0.533	0.00	0.40	22.00
F100-PW-100	0.7	5.569	0.10	55.10	16.50	2.2	1.310	0.05	1.80	44.00
IO-360-B	0.7	0.013	10.00	199.00	1.99	2.2	0.009	8.16	983.30	4.59
JT3D-3B	0.7	1.174	4.00	1.50	12.10	2.2	0.932	2.00	2.80	9.90
JT3D-7 (SERIES)	0.7	1.254	0.50	0.89	12.69	2.2	1.032	0.40	1.90	9.59
JT8D-15(REC)	0.7	1.178	0.24	0.03	19.40	2.2	0.945	0.28	1.15	15.10
JT8D-17	0.7	1.245	0.22	0.90	20.60	2.2	0.997	0.27	1.10	15.70
JT8D-217	0.7	1.320	0.28	0.80	25.70	2.2	1.078	0.43	1.20	20.60
JT8D-7 SERIES (REC)	0.7	0.989	0.25	0.90	17.20	2.2	0.811	0.25	1.10	14.00
JT9D-7A	0.7	2.099	0.10		38.70	2.2	1.789	0.10		28.50
JT9D-7Q	0.7	2.442	0.20	0.20	31.60	2.2	2.000	0.20	0.20	25.60
O-200	0.7	0.006	20.81	974.10	4.87	2.2	0.006	20.81	974.10	4.87

Appendix K, Section 2: ICAO Indices

	TAKE OFF					CLIMB OUT				
ENGINE	TIME (mins)	FUEL (kg/sec)	HC (lbs/1000)	CO (lbs/1000)	NOx (lbs/1000)	TIME (mins)	FUEL (kg/sec)	HC (lbs/1000)	CO (lbs/1000)	NOx (lbs/1000)
OLYMPUS 593 MK610	1.2	6.365	2.90	29.00	9.50	2	2.329	1.70	19.90	9.30
PT6A-45	0.7	0.080	0.00	0.71	9.70	2.2	0.070	0.00	0.94	9.00
PT6A-65B	0.7	0.080	0.00	4.70	7.00	2.2	0.070	0.00	6.40	6.60
PW118	0.7	0.120	0.00	2.20	12.70	2.2	0.110	0.00	2.40	12.00
PW120	0.7	0.130	0.00	2.00	13.80	2.2	0.110	0.00	2.30	12.30
PW125B	0.7	0.150	0.00	2.10	18.10	2.2	0.140	0.00	2.10	16.30
PW4056	0.7	2.342	0.06	0.44	28.10	2.2	1.930	0.01	0.57	22.90
PW4084	0.7	3.411	0.10	0.10	45.00	2.2	2.689	0.10	0.10	35.50
PW4460	0.7	2.647	0.10	0.37	32.80	2.2	2.085	0.03	0.51	24.70
RB211-22B (REV.)	0.7	1.877	0.15	0.78	37.33	2.2	1.546	0.25	1.68	26.89
RB211-535E4	0.7	1.860	0.04	1.01	52.70	2.2	1.510	0.01	1.23	36.20
SPEY MK511	0.7	0.889	0.98	1.81	23.27	2.2	0.726	1.32	2.06	19.18
SPEY MK555	0.7	0.720	0.88	0.44	18.92	2.2	0.589	0.16	0.00	14.64
T53-L-11D	0.7	0.086	0.29	3.00	7.36	2.2	0.086	0.29	3.00	7.36
TAY MK620-15	0.7	0.760	0.80	0.70	21.10	2.2	0.630	0.30	0.80	16.80
TF30-P-412A(JFT 10A)	0.7	5.040	1.00	15.00	6.75	2.2	0.932	0.09	2.10	16.66
TF33-P-3	0.7	1.257	0.30	1.30	11.00	2.2	0.923	0.40	1.80	9.00
TFE731-2-2B	0.7	0.205	0.11	1.39	15.25	2.2	0.173	0.13	2.03	13.08
TPE 331-3	0.7	0.058	0.11	0.80	12.36	2.2	0.052	0.15	1.00	11.86
V2525-D5	0.7	1.053	0.04	0.53	26.50	2.2	0.880	0.04	0.62	22.30

Appendix K, Section 2: ICAO Indices

	APPROACH					IDLE				
ENGINE	TIME (mins)	FUEL (kg/sec)	HC (lbs/1000)	CO (lbs/1000)	NOx (lbs/1000)	TIME (mins)	FUEL (kg/sec)	HC (lbs/1000)	CO (lbs/1000)	NOx (lbs/1000)
501D22A	4	0.144	1.96	5.10	7.49	26	0.077	17.61	43.60	3.52
ALF 502R-5	4	0.103	0.22	7.10	6.60	26	0.041	5.39	40.93	3.78
CF34-3A	4	0.119	0.13	1.90	6.86	26	0.050	3.95	42.60	3.82
CF6-50C2	4	0.660	1.00	4.30	9.50	26	0.215	21.80	61.80	3.60
CF6-6D	4	0.484	0.70	6.50	11.40	26	0.173	21.00	54.20	4.50
CF6-80A	4	0.615	0.47	3.10	10.30	26	0.150	6.29	28.20	3.40
CF6-80A3	4	0.641	0.45	2.80	10.80	26	0.150	6.28	28.20	3.40
CF6-80C2A5	4	0.672	0.11	1.91	12.53	26	0.205	1.48	18.89	4.76
CF6-80C2D1F	4	0.688	0.11	1.90	12.66	26	0.205	1.38	18.02	4.85
CF6-80E1A2	4	0.724	0.11	1.85	12.66	26	0.228	1.25	17.37	4.88
CFM56-3-B1	4	0.290	0.08	3.80	8.30	26	0.114	2.28	34.40	3.90
CFM56-3C-1	4	0.336	0.07	3.10	9.10	26	0.124	1.42	26.80	4.30
CFM56-5-A1	4	0.291	0.40	2.50	8.00	26	0.101	1.40	17.60	4.00
CFM56-5C2	4	0.356	0.08	1.75	10.00	26	0.118	5.68	34.00	4.19
CJ610-2C	4	0.124	2.70	88.00	1.50	26	0.064	18.00	155.00	0.90
CJ610-6	4	0.129	0.00	88.00	1.50	26	0.064	18.00	155.00	0.90
CT7-5	4.5	0.045	1.50	5.30	6.90	26	0.015	4.00	35.40	2.20
D-36	4	0.211	0.00	2.70	9.00	26	0.000	5.40	20.70	5.50
F100-PW-100	4	0.378	0.60	3.00	11.00	26	0.134	2.26	19.30	3.96
IO-360-B	4	0.005	9.70	691.30	10.10	26	0.001	49.20	897.40	1.16
JT3D-3B	4	0.346	4.00	24.50	4.80	26	0.135	112.00	98.00	25.00
JT3D-7 (SERIES)	4	0.389	2.10	19.50	5.30	26	0.128	123.00	138.99	2.20
JT8D-15(REC)	4	0.340	0.55	2.77	6.90	26	0.148	1.46	11.00	3.20
JT8D-17	4	0.354	1.96	2.70	8.00	26	0.147	1.25	10.50	3.20
JT8D-217	4	0.383	1.60	4.20	9.10	26	0.137	3.33	12.30	3.70
JT8D-7 SERIES (REC)	4	0.286	0.40	2.20	6.30	6	0.129	3.80	14.30	3.15
JT9D-7A	4	0.619	1.30	7.60	7.60	26	0.211	36.10	83.60	3.10
JT9D-7Q	4	0.680	0.30	1.70	7.80	26	0.237	12.00	53.00	3.00
O-200	4	0.003	0.03	1,187.80	1.14	26	0.001	29.00	644.40	1.58

Appendix K, Section 2: ICAO Indices

	APPROACH					IDLE				
ENGINE	TIME (mins)	FUEL (kg/sec)	HC (lbs/1000)	CO (lbs/1000)	NOx (lbs/1000)	TIME (mins)	FUEL (kg/sec)	HC (lbs/1000)	CO (lbs/1000)	NOx (lbs/1000)
OLYMPUS 593 MK610	2.3	1.171	11.40	52.90	3.50	26	0.421	33.40	100.10	1.70
PT6A-45	4	0.040	0.00	4.80	6.20	26	0.021	3.40	21.00	4.00
PT6A-65B	4	0.041	3.80	21.80	4.50	26	0.022	22.00	66.00	2.90
PW118	4	0.060	0.00	6.50	7.90	26	0.040	0.00	16.30	5.50
PW120	4	0.070	0.00	6.00	8.10	26	0.040	0.00	14.90	5.70
PW125B	4	0.080	0.00	3.50	10.00	26	0.050	0.00	9.20	6.90
PW4056	4	0.658	0.13	2.00	11.60	26	0.208	1.92	21.86	4.80
PW4084	4	0.875	0.20	0.40	12.00	26	0.242	2.70	18.70	4.40
PW4460	4	0.703	0.14	1.78	12.00	26	0.213	1.66	20.32	4.90
RB211-22B (REV.)	4	0.566	5.96	20.65	8.18	26	0.225	67.75	88.99	2.86
RB211-535E4	4	0.570	0.04	1.71	7.50	26	0.190	1.00	15.44	4.30
SPEY MK511	4	0.279	7.23	20.30	7.94	26	0.119	56.73	97.96	1.48
SPEY MK555	4	0.222	6.97	22.22	5.92	26	0.115	92.74	88.23	1.83
T53-L-11D	4	0.086	0.29	3.00	7.36	26	0.018	63.38	29.60	1.41
TAY MK620-15	4	0.230	0.90	3.90	5.70	26	0.110	3.40	24.10	2.50
TF30-P-412A(JFT 10A)	4	0.327	1.12	15.20	7.08	26	0.126	38.44	68.20	2.40
TF33-P-3	4	0.478	3.79	9.00	7.30	26	0.107	91.96	88.50	1.77
TFE731-2-2B	4	0.067	4.26	22.38	5.90	26	0.024	20.04	58.60	2.82
TPE 331-3	4	0.032	0.64	7.00	9.92	26	0.014	79.11	61.50	2.86
V2525-D5	4	0.319	0.06	2.44	8.90	26	0.128	0.11	12.43	4.70

Appendix L: Glossary of Acronyms

A

ADS-B	Automatic Dependent Surveillance - Broadcast
AEE	FAA Office of Environment and Energy
AIP	Airport Improvement Plan
AOC	Airline Operation Center
APO	FAA Office of Aviation Policy & Plans
APP	FAA Office of Airport Planning and Programming
ARTCC	Air Traffic Control Center
ASAC	Aviation System Analysis Capability
ASD	FAA System Architecture and Investment Analysis Division
ASQP	Airline Service Quality Performance
ATA	Air Transportation Association
ATC	Air Traffic Control
ATS	Air Traffic Services

B

BOS	Boston Logan International Airport
BWI	Baltimore/Washington International Airport

C

CAASD	Center for Advanced Aviation System Development
CAEP	Committee on Aviation Environmental Protection
CDTI	Cockpit Display of Traffic Information
CNS/ATM	Communications, Navigation, and Surveillance/Air Traffic Management
CO	Carbon Monoxide
CONUS	Continental United States
CRDA	Converging Runway Display Aid
CTAS	Center-TRACON Automation System

D

DAL	Dallas Love Airport
DCIA	Dependent Converging Instrument Approaches
DEN	Denver International Airport
DFW	Dallas/Fort Worth Airport
DOT	Department of Transportation
DTW	Detroit Metropolitan Airport

E

EDMS	Emissions and Dispersion Modeling System
EPA	Environmental Protection Agency
ETMS	Enhanced Traffic Management System
EWR	Newark Airport

F

FAA	Federal Aviation Administration
FDG	Future Demand Generator

G

GA	General Aviation

H

HC	Hydrocarbon

I

IA	Investment Analysis
IAD	Washington Dulles Airport
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IND	Indianapolis Airport
ITWS	Integrated Terminal Weather System

J

JAX	Jacksonville Airport

K

L

L/D	lift-to-drag
LAAS	Local Area Augmentation System
LAS	Las Vegas Airport
LAX	Los Angeles International Airport
LTO	Landing and Take-Off

M

MAP	Monitor Alert Parameter
MCO	Orlando International Airport
MIA	Miami International Airport
MSP	Minneapolis–St. Paul International Airport
MTOW	Maximum Takeoff Weight

N

NARIM	National Airspace Resource Investment Model
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NASPAC	National Airspace System Performance Analysis Capability
NAVAID	navigational aid
NEXCOM	Next Generation Air/Ground Communications System
NOx	Nitrogen Oxides

O

OAG	Official Airline Guide
ODE	ordinary differential equation
OPGEN	Optimized Trajectory Generator
ORD	O’Hare International Airport

P

PDX	Portland Airport
pFAST	passive Final Approach Spacing Tool
PIT	Pittsburgh International Airport
PRM	Precision Runway Monitor

Q

R

RVSM	Reduced Vertical Separation Minima

S

SATCOM	Satellite Communications
SETA	System Engineering and Technical Assistance
SFO	San Francisco International Airport
SMA	Surface Movement Advisor
SMS	Simulation Modeling System
SMS	Surface Management System
STARS P3I	Standard Terminal Automation Replacement System, Preplanned Product Improvements
STL	St. Louis International Airport
SUA	special use airspace

T

TAF	Terminal Area Forecasts
TMA	Traffic Management Advisor
TPA	Tampa Airport
TRACON	Terminal Radar Approach Control

U

U.S.	United States

V

VFR	Visual Flight Rules
VMC	visual meteorological conditions

W

WAAS	Wide Area Augmentation System
WSP	Weather Systems Processor

X

Y

Z

ZOA	Oakland Air Traffic Control Center

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