2nd USA/EUROPE AIR TRAFFIC MANAGEMENT R&D SEMINAR, Orlando, Fl, 1st - 4th December 1998

CNS/ATM Enhancements to Reduce Aircraft Emissions

Diana Liang
ASD-400, FAA
202.358.5236
diana.liang@awa.asd.emd

David K. Chin, Ph.D
TRW
202.651.2301
david.chin@faa.dot.gov

In support of the Free Flight paradigm, the Federal Aviation Administration (FAA) is investing billions of dollars to introduce new Communication, Surveillance, Navigation/Air Traffic Management (CNS/ATM) technologies into the National Airspace System (NAS). 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 paper summarizes our study on CNS/ATM enhancements by extending the measurement of fuel savings to NAS users to also include Free Flight's associated environmental benefits. In essence, if the Free Flight paradigm 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 analyzed the fuel and emission benefits by aircraft type and phase of flight. Calculations for aircraft emissions were made specifically for oxides of nitrogen (NOx), hydrocarbons (HC) and carbon monoxide (CO).

The key findings from this study indicate that aircraft flying in U.S. airspace could potentially reduce fuel burn by about 10 billion pounds in the year 2015, representing a 6% reduction in the amount of fuel that would have been burned without the NAS modernization. The 10 billion-pound fuel saving converts into reductions of over 209 million pounds of NOx, 211 million pounds of CO, and 59 million pounds of HC, representing reduced emission levels of 9%, 12% and 18%, respectively.

Introduction

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 at improvements in methods for measuring gaseous emissions and at considering increases in stringency of the standards. More recently, the CAEP has expanded their consideration to include operational measures that have the potential to reduce aviation emissions, including CNS/ATM implementation.

Worldwide there is a considerable amount of unnecessary fuel burn and emissions released into the atmosphere due to air traffic control delays. Significant inefficiencies in the present air traffic system can impede the ongoing efforts to meet internationally agreed environmental objectives, such as those established in the Worldwide Environmental Conference held in Kyoto, Japan in December 1997. Increased emissions levels could compromise the ability of aviation interests to meet environmental obligations.

To a significant extent, the FAA's NAS Architecture responds to this dual mantra of fuel conservation and protection of the environment. This study was undertaken to evaluate the potential fuel and emission savings that represent the benefits from the planned implementation of various capabilities in the NAS architecture. Findings from this study were presented by the FAA delegation at the ICAO Worldwide CNS/ATM Systems Implementation Conference in May 1998.

Free Flight

There is a realization shared between the government and the aviation industry that free flight will revolutionize air transportation in the 21st century in the United States, as well as internationally. In October 31, 1995, the 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 (RTCA, 1995).

"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."

In simple terms, free flight will enable aviation users to select routes, speed, altitudes and schedules in real-time. It is also anticipated that pilots will be able to make more dynamic in-flight changes to their routes, speed or altitudes in order to maximize their aircraft performance. Combining with the flexibility of visual flight rules and the safety (traffic separation capabilities) of instrument flight rules, free flight will offer substantial savings in time, fuel and emissions to users.

Concept of Operations

In September 1997, FAA Air Traffic Services (ATS) published a concept of operations, which reflects the joint efforts of the FAA and industry, through RTCA, to implement Free Flight (FAA/ATS, 1997). This document describes the evolutionary changes that are needed to meet the emerging user needs for greater flexibility in planning and predictability in flight operations. It describes the transition from a wholly ground-based system to one based on Free Flight concepts, which also embodies the International Civil Aviation Organization's CNS/ATM concept.

Before this operational concept can be implemented, technologies and procedures must be developed and validated, with an emphasis on human-factor considerations. Essentially, the concept of operations serves as the basis for procedural, investment and architectural decisions on the operational capabilities to achieve the Free Flight maxim.

NAS Architecture

With collaboration from the U.S. aviation community and international organizations, the FAA has outlined an 18-year plan to modernize the national airspace system (FAA/ASD, 1997). The NAS Architecture is the roadmap for modernizing the nation’s air traffic control system to support the free flight capabilities sought by aviation user groups. It provides a high-level description of the NAS capabilities and services, the functions to be performed, their dependencies and interactions, and the flow and integration of information among the functions.

The NAS Architecture provides a logical framework to support investment analysis and acquisition decisions by the FAA’s Joint Resources Council (JRC). It provides a starting point with initial functional requirements, costs and schedules and also highlights the interdependencies of functions and capabilities for a more systematic and comprehensive investment analysis of alternatives. It is also the intent of the NAS Architecture to be used by the aviation community to plan for avionics transitions.

The NAS Architecture is not an end-state document. It represents an evolving process that incorporates new technology into the NAS in an appropriate timeframe to satisfy the requirements of the users and service providers. Service providers refer to anyone who provides separation assurances, navigation/landing services, aviation information, search and rescue, or other assistance to NAS users. NAS users refer to anyone who uses the air traffic system, such as air carriers, general aviation and the Department of Defense

An overview of the interrelationships between the Concept of Operations, Architecture and Investment Analysis in the FAA’s acquisition process cycle is illustrated in Figure 1.

Study Scope

The scope of this evaluation covered the planned CNS/ATM improvements in the U.S. controlled oceanic, en route and terminal airspace, including airport surface operations. The analysis used concepts and technologies that are outlined in the NAS Architecture draft version 3.0 for the period between 1996 and 2015. Participants in this FAA study effort included NASA, the Air Transport Association (ATA) and three member airlines.

Approach

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 (essentially a no-modernization NAS) consists of meeting projected traffic growth with today's NAS capacity, adjusted for committed near-term funded airport capacity expansion programs.

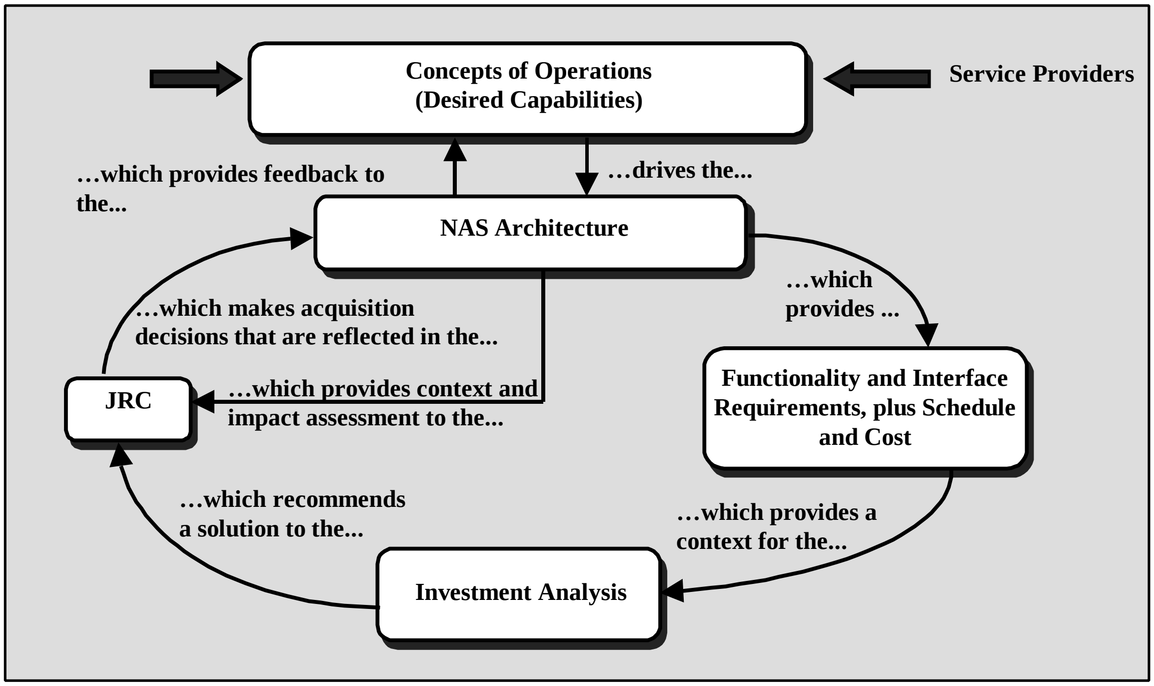

Figure 1. Interrelationships of the Concept of Operations, NAS Architecture and Investment Analysis in the FAA Acquisition Process

From this base case, three future scenarios for the time intervals 2005, 2010, and 2015 are developed. In a sense, each of these scenarios represent a time frame when key technologies and operational capabilities are introduced into the NAS to deliver new services to users, such as direct routes, optimal climb and descent and expedited taxi clearances. Simulated fuel estimates of users operating in a NAS with no modernization versus what could be achieved in a NAS with the planned CNS/ATM capabilities are then developed for each of the three scenarios. Comparison of the NAS scenarios, with and without modernization, yields incremental estimates of the fuel savings by phase of flight (below 3000', above 3000' and surface) for the years 2005, 2010, and 2015. Using ICAO and Boeing conversion algorithms, the fuel savings were then transformed into the various emission levels.

An overview of the modeling approach, based on the phased-in implementation of new operational capabilities, is illustrated below in Figure 2.

To establish the base year traffic count, standard databases like the Official Airline

Guide (OAG) and Enhance Traffic Management System (ETMS), were used to determine flights that were filed and flown, respectively. Traffic activity and fleet mix forecasts from FAA, ICAO and industry were then incorporated into the future demand generator of the National Airspace System Performance Analysis Capability (NASPAC) model to generate demand profiles for 2005, 2010 and 2015 (Millner, 1993). Airport capacity measures were incrementally augmented into NASPAC to account for planned airport and procedural improvements.

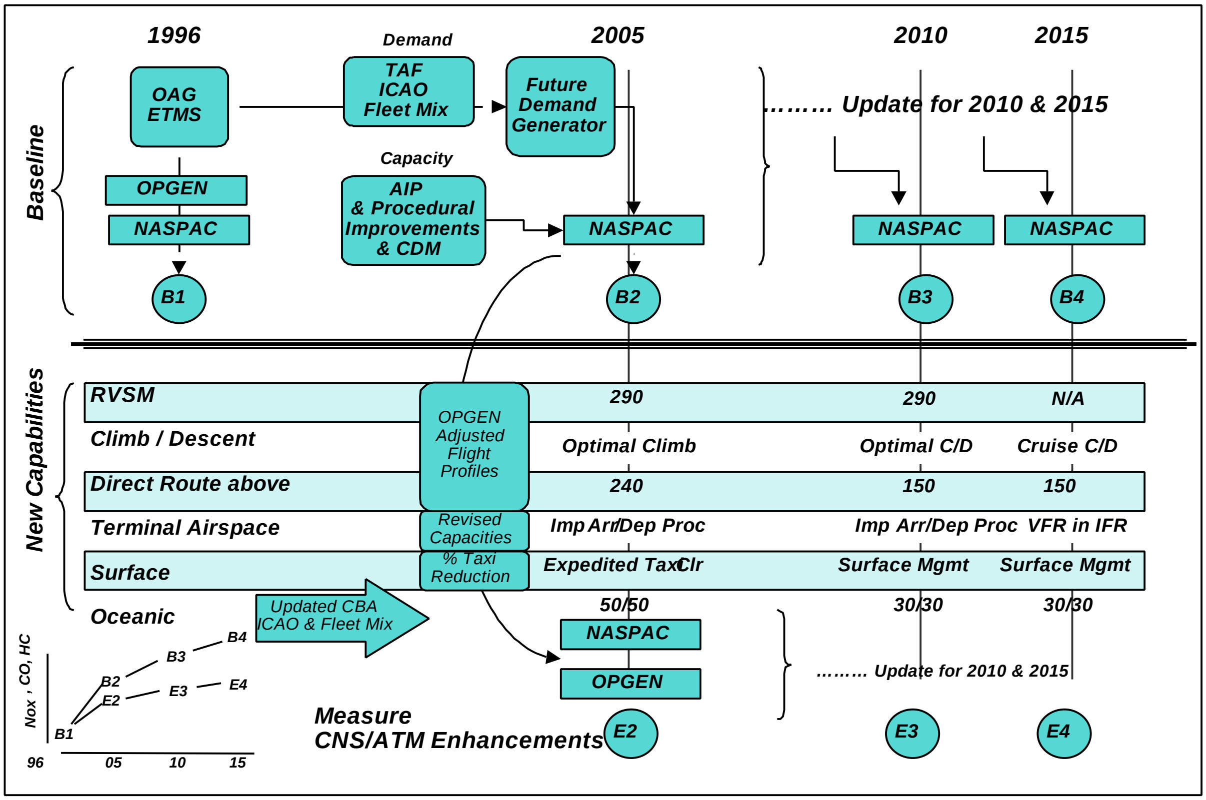

Figure 2. Overview of Modeling Scenarios

Against this baseline, new capabilities that facilitate reduced aviation fuel use and corresponding lower emission levels are analyzed. These new services are made possible by the introduction of new technologies and systems such as pilot-controller datalink, air-to-ground digital communications, automatic dependence surveillance, and satellite-based navigation and landing. In addition, a sequence of advanced automation decision support tools will improve conflict detection and resolution, facilitate more precise separation assurances and optimize traffic sequencing.

In turn, users are expected to benefit from these new capabilities. In the en route environment, new capabilities are expected to lead to reduced vertical separation minima (RVSM), optimal climb and descent profiles and more wind-optimized direct routes above flight level 240 and dropping to 15,000' by 2010. In the terminal environment, the airspace throughput will be maximized with improved arrival and departure procedures, more accurate final metering and approach spacing tools, with the eventual goal of conducting instrument flight rule operations under visual flight rule conditions. On the airport surface, more efficient traffic management practices are expected to reduce aircraft taxi times, improve gate availability and departure sequencing functions on the airport surface. In the oceanic airspace, lateral and longitudinal separations are expected to close to 50 nautical miles (nm) by 2005 and to 30 nm by 2010.

The time and fuel savings calculations were generated primarily by three FAA simulation models. The Optimal Trajectory Generator (OPGEN) and the National Airspace System Performance Analysis Capability (NASPAC) were used to derive the benefits of the modernization associated with airspace improvements while the Performance Monitoring and Analysis Capability (PMAC) was used to derive the benefits to users from surface improvements. A MITRE simulation model was used to generate the benefits attendant with the planned oceanic improvements.

Future Fleet Mix

One of the key assumptions is the future aircraft fleet composition. An accurate projection of the fleet mix is necessary in order to account for the fact that the airlines will order newer aircraft to replace their aging fleet over the next two decades irrespective of CNS/ATM enhancements. These newer high performance airplanes will be equipped with more fuel-efficient engines than their predecessors will. As a result, there is a propensity of certain aircraft types in the future fleet to consume less fuel that is not directly attributable to planned CNS/ATM enhancements.

The U.S. baseline fleet mix was developed using data obtained from ATA and NASA. The ICAO world fleet forecast was used as the primary source of information to derive the future fleet mix. Using ICAO's forecast, and the U.S. baseline fleet, the U.S. forecast for each class of aircraft was extrapolated from the world forecast (assuming that the proportion of U.S. aircraft in the world fleet would remain constant).

This forecast was validated and updated using the U.S. forecast from the FAA's Office of Aviation Policy and Planning's (APO) forecast for Stage II/III aircraft. This resulted in reduction of the future inventory for aircraft that currently are out of production (such as 727 and 737-100/200). Other aircraft in the same class were increased to compensate. The resulting U.S. forecast is shown in Figure 3.

Conversion of Fuel Burn into Emissions

In order to convert fuel burn into oxides of nitrogen (NOx), hydrocarbons (HC) and carbon monoxide (CO) emissions, the following formula was used (Anderson, 1997 and EPA, 1985).

> *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 (EPA, 1985). These indices were used in the calculations for emissions released during taxi/idle and operations below 3000'. However, because these indices are not representative of emissions above 3,000 feet Boeing developed indices for operations above 3000' by incorporating the

ICAO indices and several other factors (Baughcum, 1996). If these indices were not available for a specific engine type, the ICAO index for the approach phase was used in its place.

Claas (Generic)	Type -----------	1996 -----	2005 -----	2010 -----	2015 ----
20-40 seats					
1	DHC6	64	108	131	155
1	DHC8	144	244	296	349
1	D328	37	63	76	90
1	Embr120	237	402	488	576
1	J31	87	148	180	212
1	J32	83	141	171	202
1	J41	39	66	80	95
>40 seats					
1	ATP	12	36	48	61
1	ATR-42	100	299	400	506
1	ATR-72	51	153	204	258
1	CV-580	18	54	72	91
1	CRJ	36	108	144	182
1	DHC7	29	87	116	147
1	F27	14	42	56	71
Total (1)		**951**	**1950**	**2462**	**2994**
2	BAE146	41	47	52	57
2	BAC111				
2	A320	109	187	267	306
2	DC8	102	119	131	143
2	DC9	454	408	328	328
2	737-100	11	0	0	0
2	727/100-	680	147	0	0
2	707/720	2	2	3	3
2	737-200	312	90	5	0
2	737-500	160	459	600	658
2	737-400	94	123	135	147
2	737-300	482	561	618	673
2	MD-81/8	615	775	915	1010
2	MD-90	11	13	14	16
2	F-100	130	151	166	181
2	F-28	70	81	90	97
Total (2)		**3273**	**3163**	**3324**	**3618**

Claas (Generic)	Type -----------	1996 -----	2005 -----	2010 -----	2015 ----
3	757	660	1803	2294	2592
3	A310	41	79	99	115
Total (3)		**701**	**1882**	**2393**	**2707**
4	747-SP	4	0	0	0
4	L1011	101	49	53	53
4	DC10	176	205	175	175
4	767	224	483	611	854
4	777	12	159	218	251
4	A300	73	225	298	431
Total (4)		**591**	**1121**	**1355**	**1764**
5	MD11	55	70	93	117
5	747-400	47	91	126	161
5	747-100	59	50	50	50
5	747-200	62	60	53	52
Total (5)		**223**	**271**	**322**	**380**
6	XX		39	80	133
Total (6)		**0**	**39**	**80**	**133**
7	747-SR	0	19	92	144
Total (7)		**0**	**19**	**92**	**144**
TOTAL (class 2-7)		**4787**	**6494**	**7566**	**8745**

Class	# of Seats
1	**0-80**
2	**81-150**
3	**151-210**
4	**211-300**
5	**301-400**
6	**401-500**
7	**501-600**

Figure 3. U.S. Fleet Forecast

Because the emission indices are engine specific, it was necessary to map the aircraft types from the scenarios to specific engine types. The first step in the mapping process was to map all of the aircraft types to "default" aircraft types using the characteristics of the aircraft (i.e., size, jet vs. turboprop, number of engines, etc.). In many cases, the aircraft type was the same as the default. Once the default aircraft type was assigned, the default engine for each aircraft type was extracted from both the ICAO and Boeing documentation (Baughcum, 1996 and EPA, 1998). Where there was no default engine specified in either document, then the default engine from FAA's Office of Environment and Energy's (AEE) Emissions and Dispersion

Modeling System (EDMS) was used (Anderson, 1997). Once the default engine was determined, the appropriate emission index could be used for each aircraft type.

In addition, the phases of flight used for emission calculations are slightly 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 1000 feet and 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 out into two altitude levels (0-9 km and 9-13 km) to reflect more accurately the difference in emissions between lower cruise levels and higher cruise levels. A summary of the levels of emission calculations by phase of flight is depicted in Figure 4.

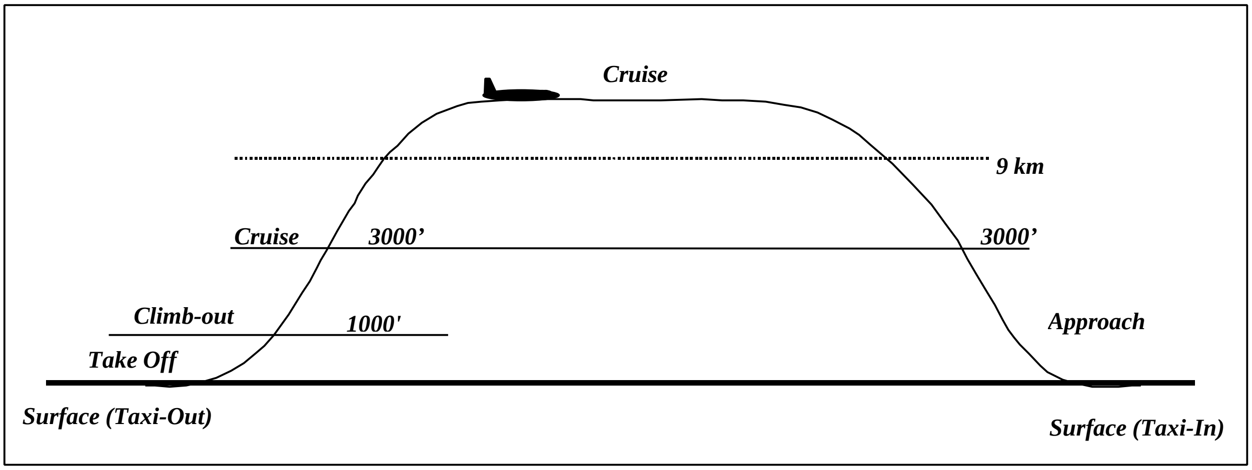

Figure 4. Calculations of Emissions by Phase of Flight

Results

A summary of the fuel and emission estimates is shown in Table 1. The numbers reported here represent fuel and emmitant levels that were simulated for a day of instrument flights in the National Airspace System for each of the respective time frames.

As a function of altitude, the phase of flight above 3,000 feet consumes the most fuel (approx. 83%) and generates the maximum levels of oxides of nitrogen (NOx), carbon dioxide (CO) and unburned hydrocarbon (HC) pollutants. Peak fuel burn and NOx emissions occur during cruise altitudes since most of the flight time occurs at these altitudes.

The next largest level of fuel use occurs for flights below 3,000 feet to the surface (the take-off and climb phases). While surface operations account for the least amount of fuel use, it has the highest proportionate output of CO and HC to fuel burn on a per pound basis. This is because carbon monoxide and unburned hydrocarbon emissions are highest at low power settings where the temperature within the engine is relatively low and combustion is less efficient.

		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	

Table 1. Fuel and Emission Results by Phase of Flight (1,000 lbs./Day)

As expected, the phased implementation of the planned CNS/ATM capabilities are estimated to produce an incremental impact on aviation fuel usage. In particular, the fuel savings are estimated to grow from 3.6 % in 2005 to 5.5 % in 2010. When all the planned CNS/ATM enhancements to the NAS are completed by 2015, the potential daily fuel savings is estimated to be 6.1% compared to the fuel that would otherwise be consumed without modernization.

Annual Benefits

Given the projected fuel and emission levels listed in Table 1, the next step in the study involved extrapolating the numbers from a daily count to an annual basis. This was accomplished by examining the pattern of traffic for the base year 1996 to adjust for operational differences between weekday and weekend traffic as well as seasonal differences. The annualized fuel and emission savings are shown in Table 2.

	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%**

Table 2. Annual Fuel and Emission Savings in 2015 (in Millions of Pounds)

The summary numbers indicate that the CNS/ATM enhancements to the NAS have a potential annual fuel savings of 10.3 billion pounds by the year 2015, which represents a savings of 6.1% from what would have been used without NAS modernization. The phase of flight above 3,000 feet accounts for 94% of the savings, with remaining savings accruing to greater efficiency in surface operations and approach and take-off phases of flight. These fuel savings translate to an annual reduction in emissions of over 200 million pounds for both oxides of nitrogen (NOx) and carbon monoxide (CO), and 60 million pounds of unburned hydrocarbon (HC), representing savings of approximately 10%, 13%, and 18%, respectively.

From an economic standpoint, these physical units of fuel savings were converted into monetary values using inputs from the Air Transportation Association and the FAA. The monetary estimates of fuel benefits for air carriers and general aviation users are summarized in Table 3. It is projected that aviation users could gain potential savings in fuel of about a billion dollars in 2015.

Almost 87% of the estimated annual fuel savings are expected to accrue to the air carriers.

	Air Carriers	GA	Total
Lbs. of Fuel Savings	9,897	362	10,259
Gallons of Fuel Savings	1,477	54	1,531
Dollars of Savings	**$886**	**$135**	**$1,021**

Table 3. 2015 Annual Fuel Cost Savings (in millions of 1998 dollars)

Summary

Fuel conservation and environmental protection have been long standing U.S. national priorities. This analysis provides evidence to suggest that the modernization of the National Airspace System can make a significant contribution to the realization of these national goals.

The key findings from this study indicate that aircraft flying in U.S. airspace could potentially reduce fuel burn by about 10 billion pounds by the year 2015, representing a 6% reduction in the amount of fuel that would have been burned without the NAS modernization.

The 10 billion-pound fuel saving converts into reductions of over 209 million pounds of NOx, 211 million pounds of CO, and 59 million pounds of HC, representing reduced emission levels of 9%, 12% and 18%, respectively. Finally, the economic value of the fuel savings on an annual basis is estimated to have a potential worth of about a billion dollars to the aviation users.

Acknowledgements

The authors gratefully acknowledge the participation, and support of several individuals and organizations. We especially like to recognize the significant contributions made by the following individuals: Fran Melone, Dan Citrenbaum and Doug Baart, FAA; Donna Middleton and Madelyn Harp, TRW; Joe Smith and Marie Pollard, SAIC; Art Tastet, JTA; and, Stephen Mondoloni, Bill Colligan and Willie Weiss, CSSI.

References

1. Anderson, Augustine, Embt, Liang, and Plante, “Emissions and Dispersion Modeling System Reference Manual,” Washington, DC: April 1997.
2. Baughcum, Steven L., Terrance G. Tritz, Stephen C. Henderson, and David C. Pickett, “Scheduled Civil Aircraft Emission Inventories for 1992: Database Development and Analysis,” Seattle, WA: Boeing Commercial Airplane Group, April 1996.
3. "A Concept of Operations for the National Airspace System in 2005". Federal Aviation Administration Air Traffic Services, September 1997.
4. “National Airspace System Architecture,” (DRAFT), Washington, D.C.: Federal Aviation Administration Office of System Architecture and Investment Analysis (ASD), December 1997.
5. Millner, David C., “Design of the NASPAC Simulation Modeling System,” McLean, VA: The MITRE Corporation, MTR 92W0000135, FAA Contract No. DTFEA01-93-C-00001.
6. RTCA "Final Report of RTCA Task Force 3 Free Flight Implementation," Washington, D.C. October 1995.
7. "Compilation of Air Pollutant Emission Factors, Volume II: Mobile Sources", AP-42, U.S. Environmental Protection Agency, Ann Arbor, Michigan: September 1985.