

USING AIRSPACE SIMULATION TO ASSESS ENVIRONMENTAL IMPROVEMENTS FROM FREE FLIGHT AND CNS/ATM ENHANCEMENTS

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ABSTRACT

There is a general consensus between the Federal Aviation Administration (FAA) and the aviation industry on the enormous potential for time and resource savings associated with future flights that are subject to less Air Traffic Control (ATC) restrictions. In support of the Free Flight paradigm, the FAA is investing billions of dollars to introduce new Communication, Surveillance, Navigation/Air Traffic Management (CNS/ATM) technologies into the National Airspace System (NAS) and has outlined an architecture plan to modernize it. It is expected that with the deployment of these new capabilities, users will benefit from better services, such as greater wind-optimized cruise trajectories and altitudes and more efficient surface traffic operations.

This paper describes the results of our Free Flight study, in which we used several simulation models and data base tools to evaluate fuel savings and aircraft emission reductions that are associated with the planned implementation of the capabilities outlined in the NAS architecture. Specifically, this paper will focus on the approach and simulation tools that were used to analyze the fuel and emission conservation metrics by aircraft type and phase of flight.

1 INTRODUCTION

The International Civil Aviation Organization (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 its purview to include operational measures that have the potential to reduce aviation

emissions resulting from planned implementation of CNS/ATM capabilities.

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. The full study, including models, tools and databases, can be found at the following FAA web-site: www.faa.gov/opsresearch/reportor.htm.

2 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 (IFR), 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 (SUA), 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 (VFR) and the safety (traffic separation capabilities) of IFR, Free Flight will offer substantial savings in time, fuel, and emissions to users.

3 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 ICAO'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.

4 NAS ARCHITECTURE

With collaboration from the U.S. aviation community and international organizations, the FAA has outlined an 18-year plan to modernize the NAS (FAA/ASD 1997). The NAS Architecture is the roadmap for modernizing the nation's ATC 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.

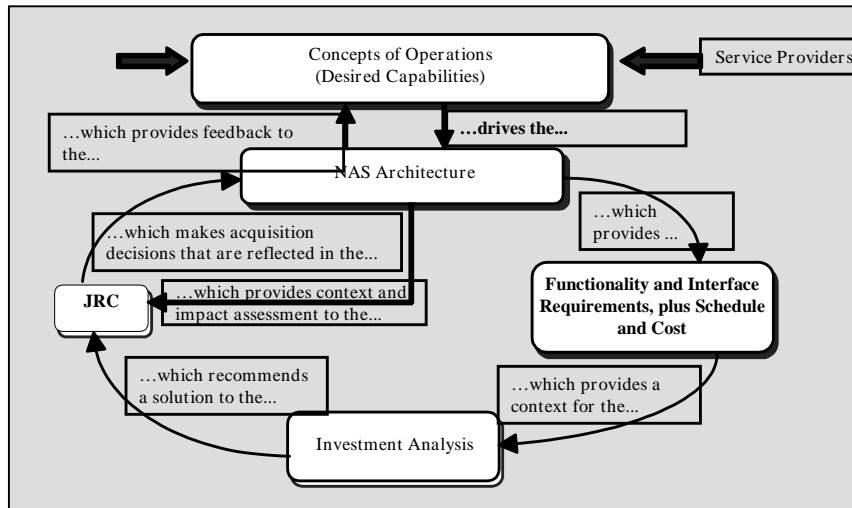


Figure 1: Interrelationships of the Concept of Ops and Investment Analysis in the FAA Acquisition Process

5 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 Version 3.0 Draft for the period between 1996 and 2015. Participants in this FAA study effort included the National Aeronautics and Space Administration (NASA), the Air Transport Association (ATA), and three member airlines.

6 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.

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 timeframe 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 3,000 feet, above 3,000 feet, 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.

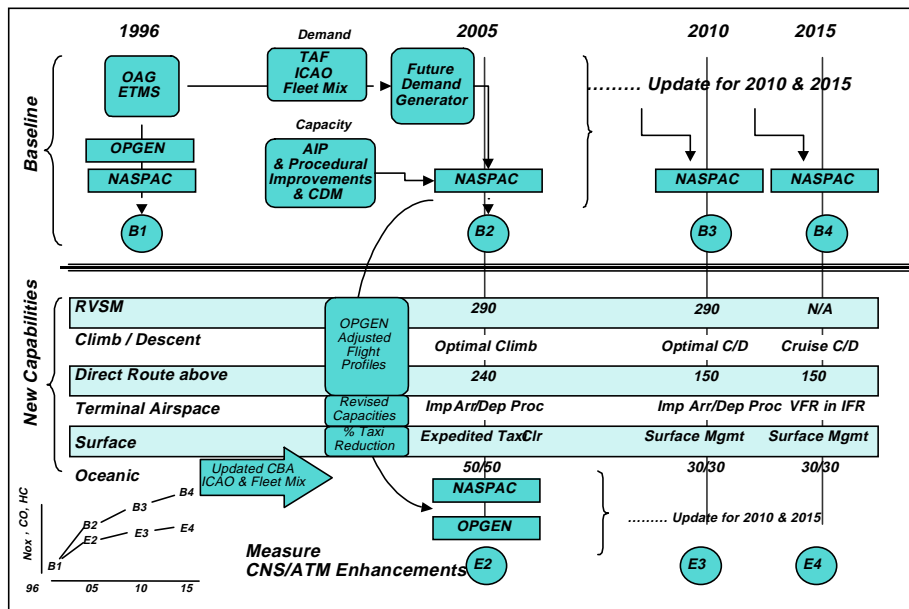


Figure 2: Overview of Modeling Scenarios

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.

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 feet 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 and 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 (nmi) by 2005 and to 30 nmi by 2010.

The time and fuel savings calculations were generated primarily by three FAA simulation models. The Optimal Trajectory Generator (OPGEN) and the 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.

7 FUTURE FLEET MIX

A key concern is the composition of future fleets. 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. Newer, high-performance aircraft will generally be equipped with more fuel-efficient engines. 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 reducing the anticipated future inventory of aircraft that are currently out of production (such as 727 and 737-100/200). Other aircraft in the same class were increased to compensate.

8 CONVERSION OF FUEL BURN INTO EMISSIONS

In order to convert fuel burn into oxides of nitrogen (NO_x), hydrocarbons (HC), and carbon monoxide (CO) emissions, the following formula was used (Anderson 1997 and U.S. Environmental Protection Agency 1985).

$$\text{Emissions (lbs.)} = \text{Time (min)} * \text{Fuel Flow (1000 lbs/min)} * \text{Emission Index (lbs emission/1000 lbs fuel)}$$

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 feet. However, because these indices are not representative of emissions above 3,000 feet, Boeing developed indices for operations above 3,000 feet 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.

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 U.S. Environmental Protection Agency 1998). Where there was no default engine specified in either document, 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 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 the difference in emissions between lower cruise levels and higher cruise levels more accurately. A summary of the levels of emission calculations by phase of flight is depicted in Figure 3.

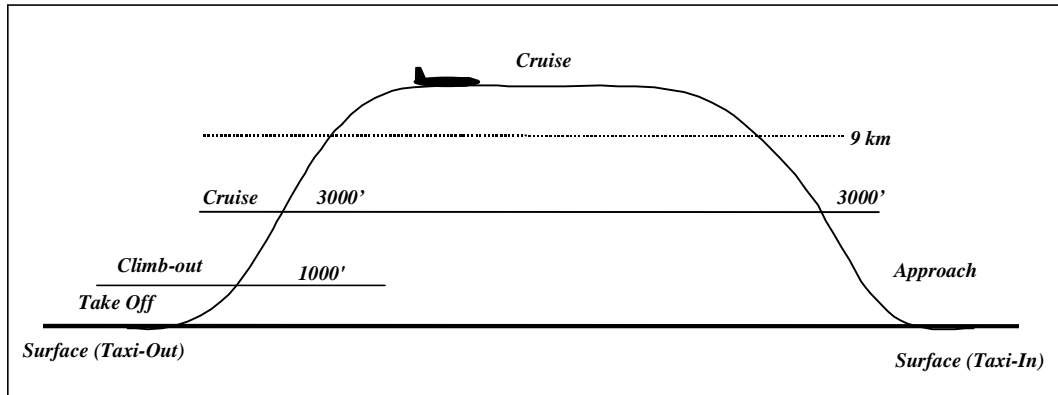


Figure 3: Calculations of Emissions by Phase of Flight

9 RESULTS

A summary of the fuel and emission estimates is shown in Table 1. The numbers reported here represent fuel and emitant levels that were simulated for a day of instrument flights in the NAS for each of the respective timeframes.

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 NOx, CO, and unburned 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 CO and unburned HC emissions are highest at low power settings where the temperature within the engine is relatively low and combustion is less efficient.

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

Year	Mode	Baseline Case				CNS/ATM Improvements			
		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

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.

10 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.

Table 2: Annual Fuel and Emission Savings in 2015

	Fuel	NO _x	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%

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 NO_x and CO, and 60 million pounds of unburned HC, representing savings of approximately 10%, 13%, and 18%, respectively.

In monetary terms, the physical units of fuel savings were converted using inputs from the ATA and the FAA. The estimates of fuel benefits for air carriers and general aviation users are summarized in Table 3.

Table 3: 2015 Annual Fuel Cost Savings (in Millions of 1998 dollars)

	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

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.

11 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 NAS 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 NO_x, 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.

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