Federal Aviation Administration
Office of Environment and Energy

Aviation & Emissions
A Primer

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Aviation plays a key role in the economic prosperity and lifestyle Americans enjoy. Our economy benefits greatly from the ability to move people and products all over the globe - quickly and safely. Aviation contributes to our quality of life - allowing us to visit friends and relatives, to travel, to experience new places, to shrink the borders of the world. The statistics are impressive. In 1903 the year of the Wright brothers' first flight, earth's population was 1.6 billion[1]; today, over 1.6 billion people use the world's airlines[2]. The air transport industry provides 28 million direct, indirect, and induced jobs worldwide[3]. And aircraft carry about 40% of the value of all world trade[4], driving the "just in time" deliveries critical to productivity improvements.

Air transport links our world and is a key tenet of continued economic development and security for the U.S. However, aviation also has environmental impacts – primarily noise and atmospheric emissions. While aircraft noise issues are better known, less focus has been placed on emissions. This paper provides a brief overview of important issues regarding aviation emissions.

What emissions come from aviation?

Aircraft produce the same types of emissions as your automobile. Aircraft jet engines, like many other vehicle engines, produce carbon dioxide (CO_2), water vapor (H_2O), nitrogen oxides (NO_x), carbon monoxide (CO), oxides of sulfur (SO_x), unburned or partially combusted hydrocarbons (also known as volatile organic compounds (VOCs)), particulates, and other trace compounds. A small subset of the VOCs and particulates are considered hazardous air pollutants (HAPs). Aircraft engine emissions are roughly composed of about 70 percent CO_2, a little less than 30 percent H_2O, and less than 1 percent each of NO_x, CO, SO_x, VOC, particulates, and other trace components including HAPs. Aircraft emissions, depending on whether they occur near the ground or at altitude, are primarily considered local air quality pollutants or greenhouse gases, respectively. Water in the aircraft exhaust at altitude may have a greenhouse effect, and occasionally this water produces contrails, which also may have a greenhouse effect. About 10 percent of aircraft emissions of all types, except hydrocarbons and CO, are produced during airport ground level operations and during landing and takeoff. The bulk of aircraft emissions (90 percent) occur at higher altitudes. For hydrocarbons and CO, the split is closer to 30 percent ground level emissions and 70 percent at higher altitudes.

Aircraft are not the only source of aviation emissions. Airport access and ground support vehicles produce similar emissions. Such vehicles include traffic to and from the airport, ground equipment that services aircraft, and shuttle buses and vans serving passengers. Other emissions sources at the airport include auxiliary power units providing electricity and air conditioning to aircraft parked at airport terminal gates, stationary airport power sources, and construction equipment operating on the airport.

What determines aviation emissions?

Aviation emissions reflect the level of overall aviation activity. The growth of air travel for the past several decades has been very rapid. Demand for travel services, both passenger travel

Emissions from Combustion Processes

CO_2 – Carbon dioxide is the product of complete combustion of hydrocarbon fuels like gasoline, jet fuel, and diesel. Carbon in fuel combines with oxygen in the air to produce CO_2.

H_2O – Water vapor is the other product of complete combustion as hydrogen in the fuel combines with oxygen in the air to produce H_2O.

NO_x – Nitrogen oxides are produced when air passes through high temperature/high pressure combustion and nitrogen and oxygen present in the air combine to form NO_x.

HC – Hydrocarbons are emitted due to incomplete fuel combustion. They are also referred to as volatile organic compounds (VOCs). Many VOCs are also hazardous air pollutants.

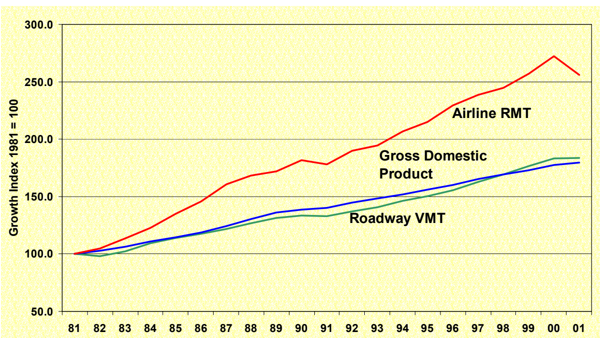
CO – Carbon monoxide is formed due to the incomplete combustion of the carbon in the fuel.

SO_x – Sulfur oxides are produced when small quantities of sulfur, present in essentially all hydrocarbon fuels, combine with oxygen from the air during combustion.

Particulates – Small particles that form as a result of incomplete combustion, and are small enough to be inhaled, are referred to as particulates. Particulates can be solid or liquid.

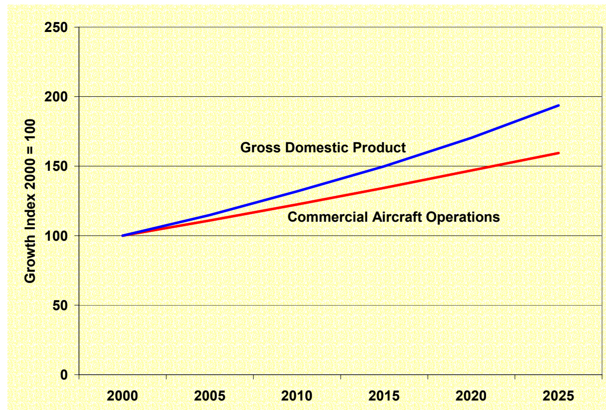
Ozone – O_3 is not emitted directly into the air but is formed by the reaction of VOCs and NO_x in the presence of heat and sunlight. Ozone forms readily in the atmosphere and is the primary constituent of smog. For this reason it is an important consideration in the environmental impact of aviation.

and freight transportation, is increasing substantially. According to the U.S. Bureau of Transportation Statistics[5] a 21.5 percent increase in population, 32 percent increase in the labor force, and 90 percent increase in GDP between 1980 and 2000 have driven this demand. The chart[6] below shows the growth of aviation and the economy. Demand for air travel grows as the economy grows and prosperity increases.



For 20 years aviation growth in the U.S. outpaced the growth of the economy although all transportation has grown significantly.

Over the long term, we expect that demand for air transportation will continue to grow rapidly to support our economic productivity, our quality of life, and our national security. More and more the worldwide transportation system is becoming an integrated transportation network. For most long-distance travel, however, aviation's speed, convenience, and cost overcome consideration of other travel modes. It only faces competition on short trips or when moving low value or high volume products. Looking to the future, the forecast is for continued strong growth as shown in the following graph[7]. This is consistent with the demand for transportation generally, which is increasing largely in response to very positive structural changes in both the domestic and global economies.



Long range forecasts of aviation activity anticipate continued growth but at a somewhat slower rate than for the U.S. economy as a whole.

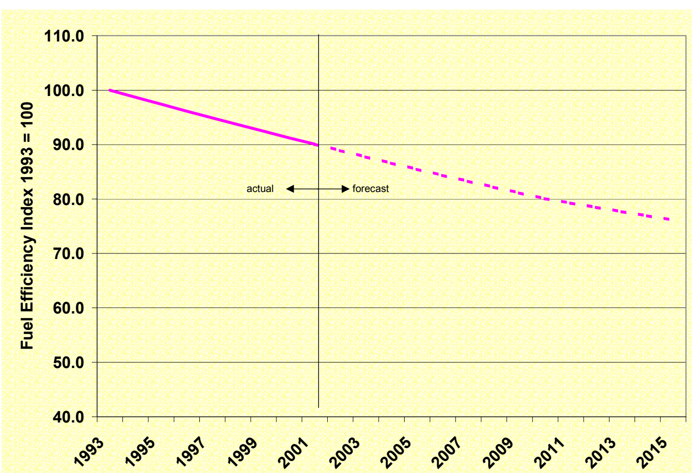
As a result, growth of the aircraft fleet and expansion and further development of existing airports are expected. This also means that emissions from aviation activity are expected to grow and concerns about aviation emissions will also grow.

What have been the trends in aviation emissions?

Technological advancement has reduced aircraft fuel consumption and emissions significantly over the last 30 years and this is expected to continue in the future.

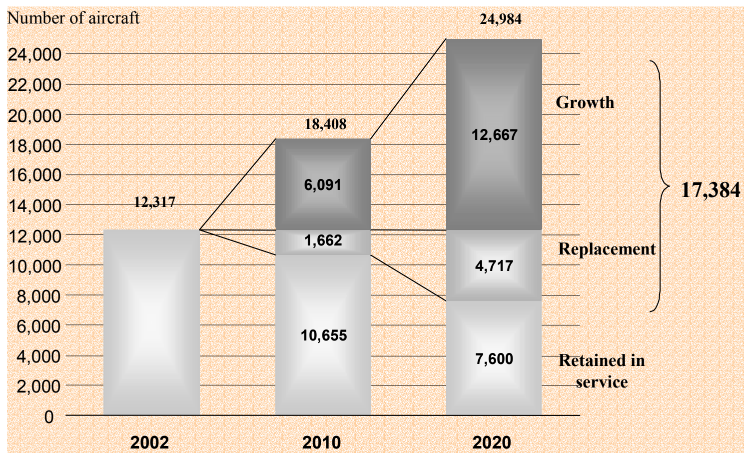
The industry's historical transition from piston engines to modern high-bypass turbofans resulted in major advancements in energy efficiency and environmental performance. During this same era, the industry developed and deployed new, lightweight, high-strength materials, automated navigational, operational, and engine control systems, and employed vast new computational capabilities to improve aerodynamic efficiency and integrate highly complex operational strategies.

Changes to fleet average fuel economy progress slowly as commercial passenger service aircraft typically remain in the fleet for 35-40 years. The next chart[8] shows the trend and projections in aircraft fuel economy over time.



Aircraft fuel efficiency has historically improved by about one percent per year. This trend is expected to continue for the foreseeable future.

As they age, existing aircraft are retired and replaced with new aircraft. New aircraft also are added to the fleet for new capacity. By 2020, 70% of the fleet will be aircraft added since 2002, which will have advanced technology and capabilities. The chart below, replicated from an International Civil Aviation Organization (ICAO) report[9], illustrates this transition of the international commercial aircraft fleet.

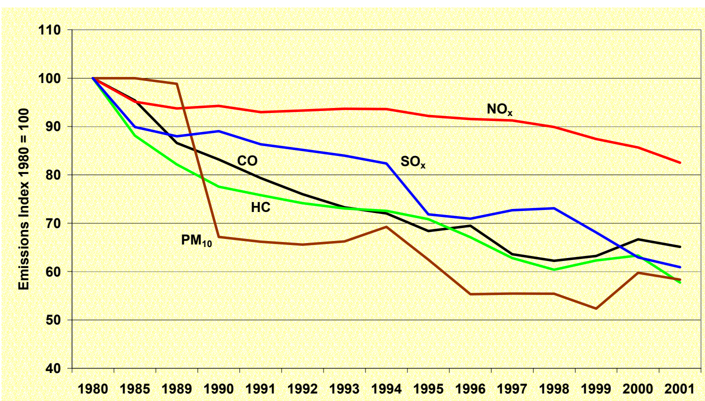


Over an 18-year period, many of today's aircraft will be retired as they reach the end of their life. These aircraft will be replaced and other aircraft will be added to accommodate the growing demand for air travel. The new fleet will be much more energy efficient and have lower emissions.

How do aviation emissions compare to general trends in local air pollutants?

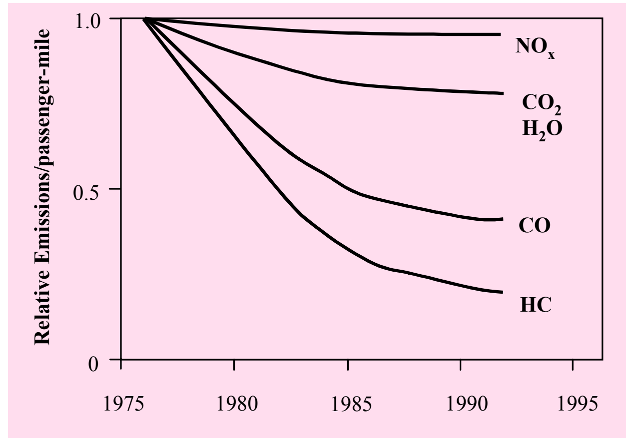
Compared to other sources, aviation emissions are a relatively small contributor to air quality concerns both with regard to local air quality and greenhouse gas emissions. While small, however, aviation emissions cannot be ignored.

In the past three decades, aggregate emissions of the air pollutants EPA regulates (nitrogen dioxide, ozone, sulfur dioxide, particulate matter, carbon monoxide, and lead) have declined by 25 percent nationally, according to their report *National Air Quality 2001 Status and Trends*[10]. As can be seen in the following chart, greater progress has been made with some individual pollutants than with others.



Local air quality pollutants have declined steadily over the past several years. NO_x has been the most challenging pollutant to constrain and progress has lagged that of other pollutants.

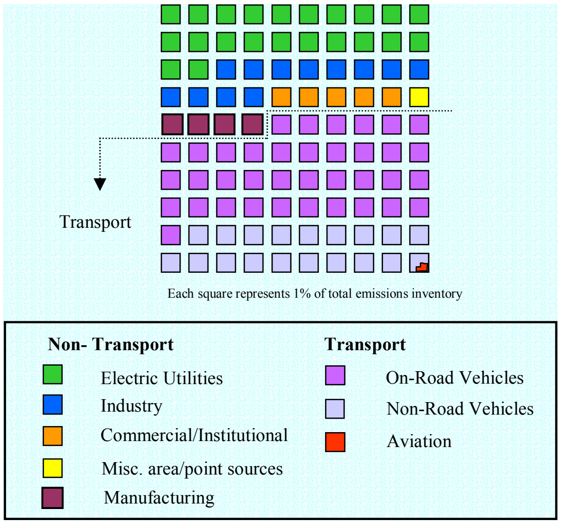
Aircraft emissions have also declined over time when you consider the emissions from transporting one passenger one mile. The following chart[11] shows that relative aircraft emissions have fallen consistently over time. Total aircraft emissions have increased, however, since aviation has grown considerably over the same period. As with emissions nationally, a great deal of progress has been made reducing emissions of HC and CO.



Aircraft emissions of all species have declined over time, however, considerably more progress has been made with HC and CO than with NO_x.

NO_x, a key constituent of ozone, has proven to be the most difficult pollutant to control both nationally and for aviation. NO_x comes from a wide variety of sources in all sectors of the economy. Since esssentially all NO_x comes from combustion processes, electric utilities, industry, and transportation are significant emitters and make up the largest share of the total inventory. Currently aviation contributes 0.4 percent of the inventory as can be seen in the illustration[12] on the following page.

Aviation's contribution to the national NO_x emissions inventory has recently declined further as air travel growth has been interrupted during the past two to three years due to the terrorist acts of 9/11, the war on terrorism in Iraq, the emergence of severe acute respiratory syndrome (SARS), and a generally difficult economic



While all transportation makes up more than 55 percent of the total national NO_x inventory, aviation represents only about 0.4 percent.

environment. These conditions have caused a more than ten- percent decline in air traffic and a similar drop in emissions. However, these factors are not likely to have a permanent effect on air transportation and growth of travel demand and emissions have recently resumed.

Total national pollutant inventory numbers do not tell the full story with regard to aviation's contribution in regions with air quality problems. The worst local air quality generally occurs in and around cities, which is also where aviation activity primarily occurs. The Clean Air Act requires EPA to identify air quality areas and to determine whether they comply with (i.e. attain) National Ambient Air Quality Standards[13]. Ozone is by far the principal air quality problem in U.S. cities today. According to EPA data[14], there are currently 474 counties, out of 3,142 counties nationally, that do not meet the new 8-hour ozone standard and are considered nonattainment areas. Comparing this list to the location of primary U.S. airports, 37 of the 50 largest airports are in ozone nonattainment areas.

To calculate aviation's contribution to regional NO_x, we can examine local emission inventories. A multitude of sources comprises air quality area emission inventories.

- *Point sources – large stationary, industrial facilities that are regulated under Federal, state, or local regulations,*
- *On-Road Mobile sources – cars, trucks, buses, and other vehicles licensed for highway travel,*
- *Non-Road Mobile sources – aircraft, ground support equipment, construction equipment, farm equipment, boats, locomotives, and lawn and garden equipment, and*
- *Area sources – small sources that individually have low emissions but that are significant when combined throughout the area like dry cleaning establishments, bakeries, painting, and vehicle fueling.*

The table on the following page summarizes aviation's contribution to NO_x emission inventories in several metropolitan areas. All of these areas have at least one airport that is among the 50 largest airports in the country. To provide a context, Atlanta, Chicago O'Hare, and Los Angeles International are the three busiest U.S. airports. In 2002, Atlanta had nearly 900,000 aircraft operations and enplaned over 37 million passengers; Chicago O'Hare had over 900,000 aircraft operations and enplaned almost 32 million passengers; and Los Angeles International had nearly 800,000 aircraft operations and enplaned almost 27 million passengers.

In the Southern California area, categorized as "severe" nonattainment, EPA's most restrictive designation, aviation's contribution was less than two percent even where the cumulative NO_x from multiple airports was included. While it is apparent from this data that aviation emissions make only a small contribution to regional emissions, even at the largest airports and even in areas with the worst air quality, it is still a contribution that needs to be dealt with effectively.

Airport	National Rank (enplanements)[15]	Ozone Attainment Area Status[16]	Airport Contribution to Area NO_x Inventory	Aircraft Contribution to Non-Road NO_x Inventory
Hartsfield Atlanta International (ATL)[17]	1	Marginal	2.8%	14.1%
Chicago Nonattainment Area (ORD, MDW)[18]	2 (ORD), 28 (MDW)	Moderate	0.8-2.0%	10.5%
South Coast California (BUR. LAX, LGB, ONT, SNA)[19]	3 (LAX), 44 (SNA), 51 (ONT), 61 (BUR), 93 (LGB)	Severe	1.5%	5.7%
Dallas/Fort Worth Air Quality Area (DFW, DAL, AFW)[20]	4 (DFW), 53 (DAL)	Moderate	6.1%	19.9%
Houston Bush Intercontinental (IAH)[21]	8	Moderate	0.7%	3.3%
New York (JFK, LGA, EWR)[22]	12 (EWR), 13 (JFK), 21 (LGA)	Moderate	4.0%	13.8%
Seattle-Tacoma International (SEA)[23]	15	Attainment	1.9%	6.7%
St. Louis Lambert International (STL)[24]	17	Moderate	1.4%	8.5%
Boston Logan International (BOS)[25]	20	Moderate	0.7%	2.3%

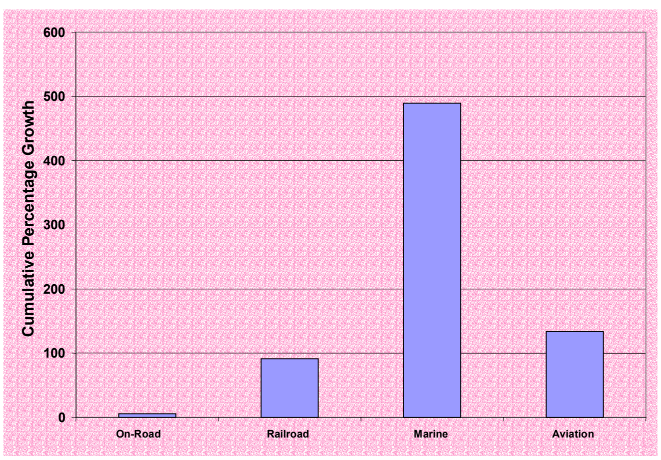
Airports, including aircraft, ground support equipment, and all other vehicles operating around the airport, contribute only a small percentage of NO_x emissions to regional inventories even in cities with the greatest concentration of aviation activity. All of the cities shown include at least one of the 20 largest airports in the country and, except for Seattle-Tacoma, are nonattainment for NO_x under the new 8-hour ground-level ozone designation.

(Inventories are computed from available data for 1996 Atlanta & Dallas/Ft. Worth, 1999 Houston, New York, Seattle & Boston, 2000 Chicago & St. Louis, 2001 South Coast)

How do aviation local emissions compare to other transportation sources?

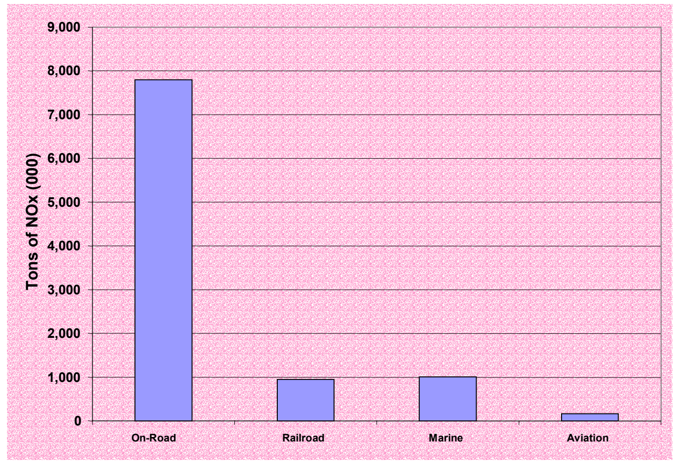
Aviation has grown faster than other modes of transportation and is expected to outpace them in the future. Despite this growth, aviation's contribution to local air quality inventories compared to other transportation sources has remained modest.

For example, as the chart below[26] shows, the *rate of growth* in aviation NO_x emissions has far outpaced on-road (i.e., cars and trucks) NO_x emissions growth.



Aviation and marine transportation grew substantially between 1970 and 1998 resulting in large percentage growth in NO_x emissions. Percentage growth in on-road emissions is small due to the large baseline emissions.

However, as the next chart shows[27], the *quantity of emissions* of other transport modes far exceeds aviation's NO_x contribution.



Total NO_x emissions from on-road transportation dwarf emissions from all other transportation modes combined (1998 data).

This is not surprising as most of an aircraft's operations take place at altitude where emissions do not affect local air quality. This is in contrast to cars and trucks that primarily operate within a single air quality region and always at ground level[28].

In the future, NO_x emissions from on-road vehicles should fall in response to the most recent environmental regulations. Aircraft, on the other hand, will be challenged to reduce their total NO_x emissions. However, even if the other sources were able to reduce their emissions by half, a highly unlikely occurrence, aviation NO_x emissions would still be less than 3 percent of the transportation NO_x inventory by 2020. Nonetheless, pressure on aviation sources will likely remain as many states and localities will face the twin challenges of meeting new ozone and particulate matter standards at the same time non-aviation source reductions become more difficult and costly.

Can a comparison be made between aviation emissions and non-transportation sources?

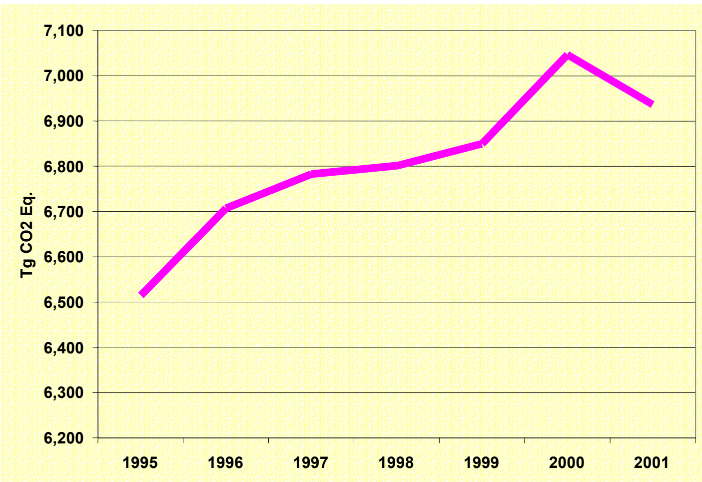
There is an understandable interest in comparing aviation emissions to other sources in local air quality areas. For example, the total mass of emissions coming from an airport may be comparable to those of a power plant or petroleum refinery in the same region.

Airports, however, are quite different from non-transportation sources. Like cities, they are comprised of a variety of different emission sources. Aircraft arrive at the airport, stay for a short period and depart, with a different aircraft taking off or landing every few minutes. Passenger cars, shuttle buses, and taxis calling on the airport do not operate there exclusively, also serving homes and retail, commercial, and governmental establishments. Power boilers and chillers at the airport are independently permitted, as is similar equipment at other locations. For these reasons it is difficult to compare the composite of sources that make up an airport to another emission source like an industrial facility or power plant even when their magnitude of emissions is similar.

What role does aviation emissions play with regard to greenhouse gas issues?

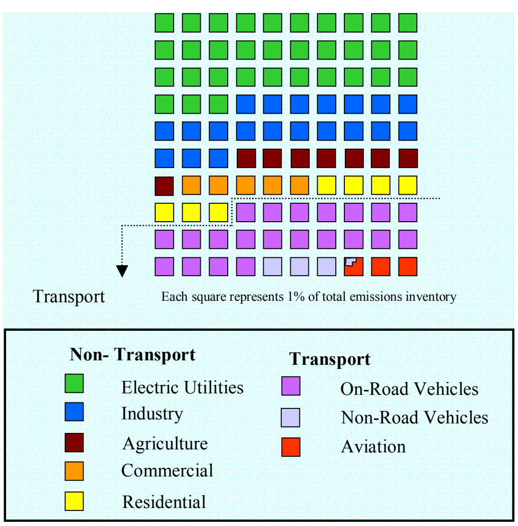
As noted earlier, the majority of aviation emissions occur at higher altitudes, thus generating greenhouse gases and potentially contributing to climate change. Also, under certain conditions, aircraft engine exhaust can produce contrails. Scientists in the U.S. and around the world are researching the potential impact of contrails to see whether they have a significant impact on the greenhouse effect.[29]

Concern regarding greenhouse gas emissions has been building worldwide. The following graph[30] shows the recent growth of total greenhouse gas emissions in the U.S. The drop in emissions in 2001 reflects the slow economic growth and reduced industrial output that year in addition to the warm winter, which reduced fuel use for heating. Growth in greenhouse gas emissions is expected to resume as the economy recovers and continues to expand in the future. While there are many different greenhouse gases, CO_2 and NO_x are generally most relevant from an aviation perspective.



U.S. greenhouse gas emissions grew steadily throughout the 1990s as the economy expanded. The recent downturn is expected to be temporary due to economic recession. With recovery and expansion the upward trend is forecast to continue.

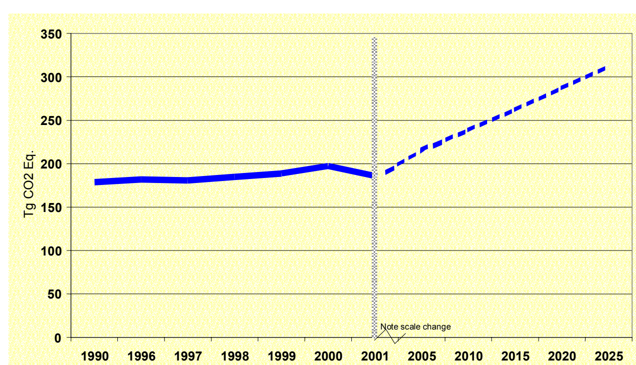
The chart below[31] breaks down national emissions of greenhouse gases. In the U.S., transportation makes up about 27 percent and aviation about 2.7 percent of the national



National greenhouse gas emissions in 2001 came from all sectors of the economy with all transportation equal to 27% of the total

greenhouse gas inventory. Global estimates[32] are similar with emissions of the world's aircraft fleet at about three percent of the total greenhouse emissions from fossil fuel, the majority of which come from commercial aviation. This compares with all transportation sources that contribute approximately 25 percent of total global fossil fuel combustion emissions.

Greenhouse gas emissions from U.S. aviation have grown over the past 10 years and are projected to increase in the future[33]. The projection shown below conservatively assumes the relationship between aircraft operations and greenhouse emissions remains constant. As such, emissions track expected growth in aviation. According to the projection, aircraft greenhouse gas emissions in the U.S. will increase 60 percent by 2025[34].

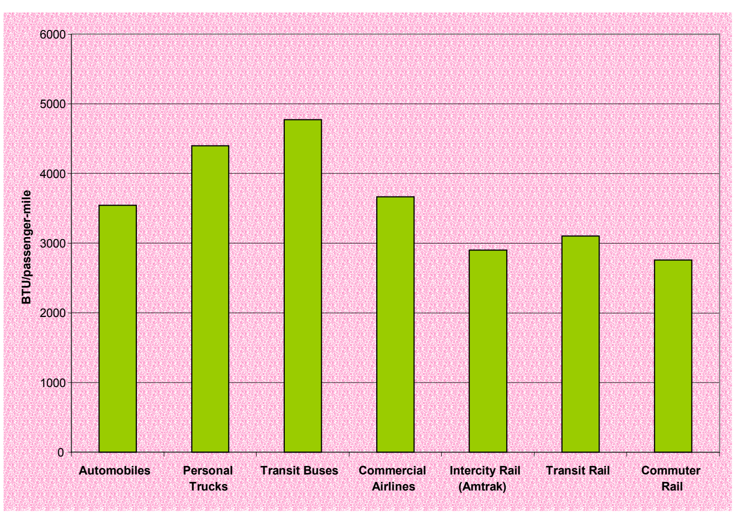


Greenhouse gas emissions from aviation have declined recently due to the fall off in air travel following the terrorist acts of 9/11, the war on terrorism in Iraq, and the worldwide recession. As air travel recovers in the coming years, greenhouse gas emissions are expected to resume their climb.

How do aviation's greenhouse gas emissions compare to other transportation sources?

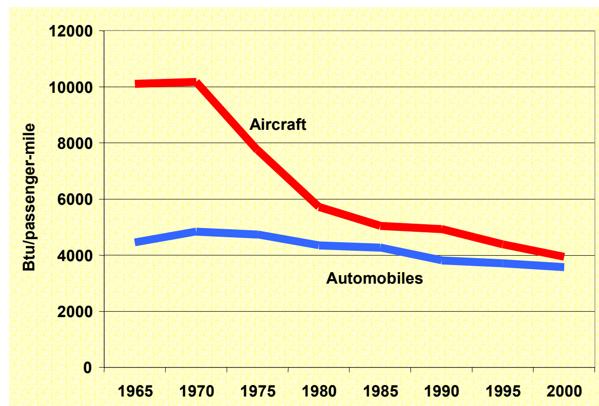
Energy intensity, that is the amount of energy consumed to transport one passenger one mile, is a useful metric for comparing greenhouse gas emissions among different transportation modes. The different modes use similar fuels and greenhouse gas emissions are directly related to fuel use.

As you can see in the following chart[35], in the U.S., aircraft and automobiles have very similar energy intensities, with automobiles at 3,543 Btu/passenger mile versus airlines at 3,666 Btu/passenger mile. Rail has the lowest energy use, and hence emissions, per passenger mile among all transport modes. Personal trucks and transit buses have the highest energy intensities.



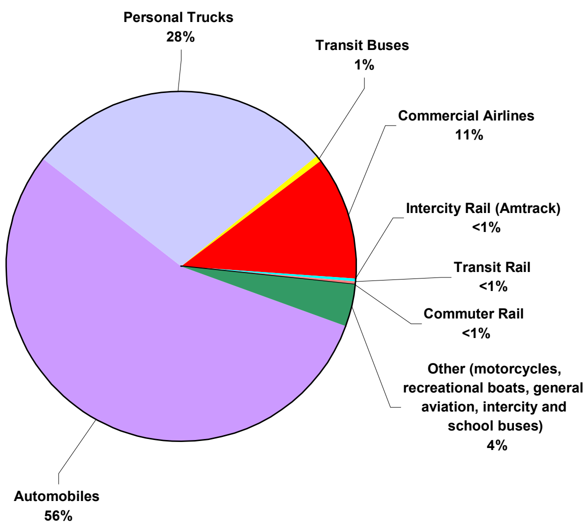
Energy intensity in terms of energy used to carry one passenger one mile is lowest for rail, followed by aircraft and automobiles, with personal trucks and transit buses as the least energy efficient.

Comparing the energy intensity of aircraft and cars shows how energy efficiency and consequently greenhouse gas emissions per passenger mile have changed over the past 35 years. The chart below[36] shows how significant this has been, especially for aircraft.



The energy intensity of aircraft and automobiles has improved substantially over the past several decades. Automobile energy intensity has fallen by almost one fifth while aircraft energy intensity has fallen by three fifths during the same period.

The pie chart[37] at the top of the following page shows the total energy consumption for each transportation mode. Since the fuels are similar, this is an indication of their total greenhouse gas emissions. Aviation is substantially less than automobiles and personal trucks though significantly more than rail and buses. However, given the greater potential to apply alternative fuel technologies to land-based transport in the next two decades, aviation greenhouse gas emissions are likely to represent a greater share of transport sources over time.



Energy consumption by the aviation industry is only a small portion of transportation energy use. Automobiles and personal trucks still account for the vast majority.

How are aviation emissions regulated?

There is some misperception that aviation in general and airlines in particular are the "only unregulated industry in the country," or "are getting a free ride on air quality," and "cars have reduced their emissions by over 98% while aircraft have done nothing." In fact, there are many, varied regulations that constrain aviation emissions. For example, both cars and aircraft have improved their energy intensity over time using new technologies, advanced materials, and improved designs for energy conservation to reduce fuel consumption.

Practically all aviation emission sources are independently regulated through equipment-specific regulations, standards and recommended practices, and operational guidelines, which are established by a variety of organizations. For example, on-road vehicles, which take passengers to and from the airport, meet stringent Federal tailpipe standards set by EPA. Stationary sources on the airport, like power boilers and refrigeration chillers, must meet independent state regulations. And FAA certification is required for essentially all aviation equipment and processes. For example there are more than 60 standards[38] that apply to aircraft engine design, materials of construction, durability, instrumentation and control, and safety, among others. These are in addition to the Fuel Venting and Exhaust Emission Requirements for Turbine Engine Powered Airplanes (FAR Part 34), which guide compliance with EPA's aircraft exhaust emission standards. This comprehensive and complex regulatory framework has enabled our safe and efficient national air transport network.

The International Civil Aviation Organization (ICAO) is a United Nations intergovernmental body responsible for worldwide planning, implementation, and coordination of civil aviation. ICAO sets emission standards for jet engines. These are the basis of FAA's aircraft engine performance certification standards, established through EPA regulations.

ICAO has long been the forum for evaluating the environmental performance of aircraft engines. ICAO has taken a "technology progressing" approach, raising standards within the capabilities of proven technologies and certified products (engines and aircraft) rather than a "technology forcing" approach, which sets standards based on technology that is not certified or may not even exist. The reason for ICAO's approach is quite simple - the very high premium placed on the safety of aircraft operation restricts the use of unproven new technologies.

Current NO_x standards were established in 1996. New standards go into effect for engines entering service beginning in 2004, which reflect a 16 percent NO_x reduction over the 1996 standards and a 33 percent reduction over the original standards agreed to in 1981. Earlier this year, ICAO's Committee on Aviation Environmental Protection recommended new certification standards that represent a further 12 percent NO_x reduction, with an effective date of 2008.

Airport air emissions from all sources also are constrained by the General Conformity regulations of the Clean Air Act Amendments of 1990. General Conformity requires Federal agencies to assure that actions that would increase emissions in nonattainment areas "conform" to the appropriate State Implementation Plan. These plans define the steps states are committed to taking to ensure their cities enjoy healthy air. Each year the environmental impacts of several hundred projects at airports throughout the country are analyzed in detail, including general conformity evaluations and analyses, using the best data and most advanced analytical models available. Emissions from the vast majority of these projects are well below the thresholds that trigger a "conformity determination." The two or three projects a year that do require further analysis essentially are able to meet the needs of state air quality plans through minor project modification.

EPA recently proposed new exhaust emission standards for non-road diesel engines. These standards, to be phased in between 2008 and 2014, will require engine manufacturers to produce new engines with advanced emission control technologies. New ground support equipment with diesel engines, which are used only on airport property, will be required to meet these standards. This new equipment will achieve emission performance comparable to today's automobiles.

While there are no national or international regulations for greenhouse gas emissions that apply to aircraft or other airport sources, the aviation industry has made significant strides here as well. Aircraft have a long history of continuously improved fuel economy, which reduces all greenhouse gas emissions. For example, according to Boeing, the B-777 is 300 percent more efficient than its early jets.[39] Fuel economy and energy conservation are also priorities at many airports. Dallas/Fort Worth International Airport for example looks at business practices at all of their facilities to minimize energy consumption. They realize that this benefits local air quality through reduced emissions as well as regional air quality as a result of reduced power purchases from electric utilities and an overall reduction in greenhouse gas emissions.

Looking to the future, FAA is working through ICAO to evaluate policy options to limit or reduce greenhouse gas emissions from aviation. Various market-based options, such as voluntary agreements, open emissions trading, and emission related levies are being analyzed. Preliminary results from analyses of market-based options show that emission related levies are not cost-beneficial, but voluntary arrangements and emissions trading may be cost effective in limiting or reducing greenhouse gas emissions. Additional analyses are underway at ICAO to evaluate further emissions trading and voluntary agreements as approaches to limit aviation emissions growth while allowing continued expansion of air travel[40].

Under this multidimensional regulatory and voluntary structure, aviation has made significant environmental progress. Given the complexity of the industry and the need for different strategies and technological approaches for different types of vehicles and equipment, a coordinated effort between the aviation industry and the many regulatory agencies that share environmental responsibility will continue.

What is being done today to reduce aviation emissions?

There are a number of initiatives underway that will achieve significant emissions reductions – both at airports and within the national aviation system – in the next few years. First, there are voluntary programs underway at airports to reduce emissions from ground support equipment and other airport vehicles. For example, FAA developed a pilot program, with EPA and DOE, to demonstrate air quality improvements with alternative fuel ground support equipment. The program is called the Inherently Low-Emissions Airport Vehicle (ILEAV) Pilot Program.

To reduce emissions from these vehicle fleets, airlines have engaged in voluntary emission reduction programs. For example, California and Texas have agreements with the major airlines to reduce emissions from their ground support equipment. These new agreements will reduce emissions by converting gasoline and diesel equipment to electricity and alternative fuels. A national stakeholders group made up of representatives of FAA, EPA, major airlines, state and local environmental regulators, airports, and environmental interest groups is currently working to establish a national agreement to reduce ground support equipment emissions at other airports in air quality nonattainment areas. This has proved challenging, and it is still unclear whether it will be successful.

In addition, many airports have independently taken action to reduce emissions from buses, trucks, taxicabs, and other on-road vehicles that operate in and around the airport. Hybrid-electric vehicles are being used for staff transportation and customer service vehicles. Airport police departments are using compressed natural gas automobiles and maintenance departments are using alternative fuel trucks. Airport shuttle buses in particular have been converted to compressed natural gas at a number of airports. Also, new clean diesel trucks are being used in heavy maintenance and construction.

Based on their experience with the ILEAV Program, FAA and EPA have expanded the initiative to reduce ground emissions at commercial service airports in all air quality nonattainment areas. The new Voluntary Airport Low Emission (VALE) program expands eligibility for airport low emission projects under the Airport Improvement Program (AIP) and the Passenger Facility Charges (PFC) program. Through the use of funding and emission credit incentives, the voluntary program includes the conversion of airport vehicles and ground support equipment to low emission technologies, modification of airport infrastructure for alternative fuels, provision of terminal gate electricity and air for parked aircraft, a pilot program to explore retrofit technology for airport ground support equipment, and other related emissions improvements.

Second, it is also worth noting that many strategies for reducing the environmental impact of aviation are inherent to the intended design and operation of the air transport infrastructure. With airports for example, access roadways are often limited access, high-speed and free flowing and parking facilities are readily available. These features minimize motor vehicle emissions and keep them contained in areas away from the public.

Third, looking at aviation more broadly, many recent changes have improved the system efficiency and reduced environmental impact. In the past few years, better meteorological information, available in the cockpit in real time, has allowed for optimized flight planning with shorter routing. Yield management tools have allowed airlines to increase load factors, which moves more people on every flight. The hub and spoke system, combined with the growth of low cost point-to-point carriers and a significant increase in the number and reach of regional airlines, has improved the efficiency of the entire aviation network.

Fourth, operating procedures can have both direct and indirect effect on aircraft emissions. Airlines generally employ standard procedures for operating their aircraft to meet company goals for safety, adherence to flight schedules, fuel conservation, complying with labor agreements, and other factors. Standard procedures vary by aircraft type, airport-specific constraints, and weather. The use of alternative procedures or best practices offers some prospect for reducing emissions.

Some procedures affect the engine-operating regime, which can directly influence the rate of pollutant emissions. NO_x emissions are higher during high power operations like takeoff when combustor temperatures are high. On the other hand, HC and CO emissions are higher during low power operations like taxiing when combustor temperatures are low and the engine is less efficient. As a result, reducing engine power for a given operation like takeoff or climb out generally increases the rate of HC and CO emissions, reduces the rate of NO_x emissions, and has little or no effect on CO_2 emissions. Other operating procedures have a more general effect on engine use and can reduce all pollutants simultaneously.

As another example of alternative operating practices at an airport, United Airlines launched a new initiative last year to reduce the average use of its auxiliary power units by using ground power whenever possible. Based on early tests of the program they expect to save approximately 12 million gallons of fuel during the year, which will result in reduced emissions of all pollutants at the airport as well[41]. Many of the strategies discussed in this section are published in ICAO Circular 303 - *Operational Opportunities to Minimize Fuel Use & Reduce Emissions*[42].

New technologies to improve air traffic management will help reduce emissions in and around airports. Commonly referred to as CNS/ATM (communication, navigation, surveillance/air traffic management), many of these technologies will improve air traffic management efficiency in the terminal area air space, reduce congestion, and consequently reduce aircraft fuel use. They will ensure more accurate approach routes to precisely keep aircraft on track. They will increase the efficiency and capability of runways, reducing arrival spacing and making ground operations more efficient. These systems are expected to be in operation throughout the U.S. over the next 10-15 years[43].

A near term example is RVSM – Reduced Vertical Separation Minimums. Reducing vertical separation between aircraft from 2000 feet to 1000 feet separation at cruise altitude (i.e., above 29,000 feet) adds flight levels and increases airspace capacity by as much as 85%. These routes are among the most fuel efficient for long flights such as oceanic or cross-country traffic and increasing their availability allows for greater flexibility in flight scheduling and routing. RVSM has been in use for transatlantic flights since 1997 and will become standard in U.S. domestic airspace starting in January 2005. Fuel savings of more than 500 million gallons each year are expected in U.S. airspace alone with full implementation of RVSM[44].

What steps are being taken to reduce aviation emissions in the longer-term?

The pace of technological change across the industry is increasing. New engine designs are improving fuel efficiency further, while simultaneously reducing NO_x emissions. New aircraft designs improve aerodynamics and reduce weight thereby improving fuel efficiency, reducing all pollutants at the same time. New air traffic control technologies, like new aircraft designs, reduce emissions by reducing fuel consumption (the effect on individual pollutants depends on the phase of flight most effected). And new management strategies like load management planning and code sharing are being used to optimize the entire system's operation.

With regard to engines, there are complex emission interrelationships that make it difficult to modify their design as a mitigation strategy since it forces a tradeoff among individual pollutants as well as between emissions and noise. For example, high-bypass turbofan engines were introduced to reduce noise and improve fuel efficiency. They require higher engine pressure ratios, which increase engine temperatures, and hence generate more NO_x. It has only been in the past 25 years that the resulting NO_x increase became a concern. FAA and other stakeholders have recently initiated an effort to better understand and quantify these interrelationships in an "environmental design space." Eventually this will lead to guidelines for setting long term goals and standards that optimize overall environmental performance and avoid unintended consequences.

Aircraft design improvements mostly fall into one of three areas: aerodynamics, weight reduction, and control systems. Continued improvement in all areas is expected in the future[45]. Some of the technologies in development for aerodynamic improvements include the design of winglets for wing tips, which reduce turbulence and vortex generation by the wings, laminar flow controls or systems for wing surfaces to reduce drag, and improved manufacturing techniques that will produce smoother surfaces. New and improved metal alloys and composite materials are being developed to reduce aircraft weight while simultaneously improving structural performance. Significant improvement of control systems has come about by replacing mechanical and hydraulic systems with electrical systems, which often reduce system weight while providing more precise control. Improvements of these systems and development of new systems for enhanced flight stability will contribute to improved overall fuel efficiency.

Aircraft technology development and capital turnover follow relatively long cycles, which limits the pace of fundamental changes in design. It takes approximately 10 to 15 years for fleet average fuel efficiency to equal the efficiency of the newest aircraft[46]. However, the ongoing evolutionary change in technology has realized substantial benefits over time. According to the Intergovernmental Panel on Climate Change, in their report *Aviation and the Global Atmosphere*[47], aircraft fuel efficiency has improved by 75 percent in the past 40 years through improvements in airframe design, engine technology, and rising load factors.

While progress in the near- and mid-terms is expected, the most significant opportunities for emission reduction lie in the future when we can derive benefits from aggressive research goals. FAA, EPA, ICAO, and many other groups have been working to elucidate and characterize the environmental issues for some time while NASA is directing a research program aimed at significantly cutting emissions from aircraft engines[48].

A comprehensive research program starts with a clear and complete understanding of the effects of aviation on air quality. FAA has developed analytical tools to quantify emissions more accurately, which are used to understand aviation's contribution to local air quality concerns and global emissions. These tools are developed on a foundation of research that FAA has conducted both independently an in conjunction with airports and other organizations. The Emissions and Dispersion Modeling System (EDMS) has been developed to quantify emissions from aircraft and other airport emission sources. It is used routinely to assess the impact of airport expansion projects and other operational changes. The System for assessing Aviation's Global Emissions (SAGE) is being developed to assess the impact of aircraft engine emissions during the whole flight regime, especially climb out and cruise emissions. The model will be able to develop aviation emission inventories, both for baseline conditions and forecasted technology, and assess operational and market-based measures and improvements. New tools are also being developed to understand and assess the environmental design space, to evaluate interrelationships among all emissions and between emissions and noise due to changes in technology and operational procedures.

NASA is the U.S. federal agency responsible for pre-commercial aerospace research, development, and demonstration. One of the key themes of their research program is to "protect local environmental quality and the global climate by reducing aircraft noise and emissions." Their strategy is to research opportunities to reduce airframe weight and drag, optimize engine systems, and optimize operations at and around airports. Through this, NASA hopes their research program results in significant or total elimination of aircraft greenhouse gas emissions, minimized impact of emissions on local air quality, and elimination of unnecessary aviation emissions due to operational procedures. The goals of this program are to reduce NO_x emissions of future aircraft by 70 percent by 2007, and by 80 percent beyond 2007 using 1996 ICAO standards as a baseline. They also intend to reduce CO_2 emissions of future aircraft by 25 percent and by 50 percent for these same milestones using 2000 state-of-the-art aircraft technology as a baseline[49].

The primary engine research project to achieve these objectives is the Ultra-Efficient Engine Technology (UEET) project, in NASA's Vehicle Systems Program. According to NASA, the UEET project will develop and transfer to U.S. industry critical turbine engine technologies that will contribute to enabling a safe, secure, and environmentally friendly air transportation system. This project is currently underway.

FAA, NASA, and Transport Canada have made a major commitment to researching aviation emissions as well as noise through the Center of Excellence for Aircraft Noise and Aviation Emissions Mitigation.[50] The Center was established in September 2003 to foster breakthrough technical, operational, and workforce capabilities enabling quieter and cleaner aircraft.

Achieving research goals will allow the aviation industry to significantly reduce its environmental impact and begin to reduce its total emissions of NO_x and CO_2. This takes time, however. As noted earlier it takes 10 to 15 years for fleet average performance to achieve current new technology performance. To go from NASA research to fleet average performance takes 20 to 40 years[51]. Also, concerns have been raised about the likelihood of these goals being met due to budget restrictions. The National Research Council recently published a report, *For Greener Skies: Reducing Environmental Impacts of*

Aviation[52], that concluded, while "the goals of the federal research program are admirable and focused on the right issues, the schedule for achieving the goals is unrealistic in view of shrinking research budgets." The report went on to call for further federal investment in engine research and technology development.

Aviation emissions are being responsibly controlled.

Aviation has progressively improved its environmental performance. Fuel economy, which is one strong indicator of environmental performance, has consistently improved. Aircraft engines have gotten more efficient and been designed with environmental performance in mind. Regulatory frameworks have developed to constrain emissions growth from many aviation sources. And improvements to the efficient operation of the complex aviation network have had a positive effect on the environment.

Looking to the future, FAA has a roadmap for continuing to mitigate the environmental impacts of aviation. This includes continuing to improve its understanding of the role of aviation emissions on the environment. FAA is working with industry and other stakeholders to advance the performance of the national and international aviation system as well as to improve individual system components. And FAA is working in the international arena to evaluate alternative strategies for market-based opportunities for reducing emissions.

FAA, together with EPA and NASA, is committed to ensuring aviation emissions do not pose health concerns for our citizens or restrain aviation's mobility and economic benefits enjoyed by society. It will take consistent, coordinated effort and continuing success in technology research and development to achieve these goals.

[1] Population Timeline, http://www.pbs.org/kqed/population_bomb/danger/time.html.
[2] http://www.atag.org/files/FAST%20FACTS-120341A.pdf
[3] *Ibid*
[4] http://www.iata.org

[5] U.S. Department of Transportation, Bureau of Transportation Statistics, *Transportation Indicators* http://www.bts.gov/publications/transportation_indicators/december_2002/ , December 2002.
[6] U.S. Department of Transportation, Federal Aviation Administration, *FAA Long-Range Aerospace Forecasts Fiscal Years 2015, 2020 and 2025*, Office of Aviation Policy and Plans, FAA-APO-00-5, http://apo.faa.gov/lng00/lng00.pdf, June 2000.
[7] GDP - U.S. Department of Commerce, Bureau of Economic Analysis, *National Accounts* Data http://www.bea.gov/bea/dn1.htm; RTM - U.S. Department of Transportation, Bureau of Transportation Statistics, *Historical Air Traffic Statistics*, http://www.bts.gov/oai/indicators/airtraffic/annual/1981-2001.html; VMT – U. S. Department of Transportation, Federal Highway Administration, *Traffic Volume Trends*, December 2002 http://www.fhwa.dot.gov/ohim/tvtw/02dectvt/tvtdec02.pdf.
[8] Ibid. Table 9-15.
[9] Wickrama, Upali, International Civil Aviation Organization, Committee on Environmental Protection, Forecasting and Economic Analysis Support Group, *Report of the FESG/CAEP/6 Traffic and Fleet Forecast*, copy of Figure 8, 2003 op. cit.
[10] U.S. Environmental Protection Agency, *National Air Quality 2001 Status and Trends*, http://www.epa.gov/airtrends/aqtrnd01/, September 2002.
[http://www.epa.gov/air/airtrends/aqtrnd03/fr_table.html]
[11] Waitz, I. A., Massachusetts Institute of Technology, private communication based on Boeing data, November 2003.
[12] U.S. Environmental Protection Agency, *Average Annual Emissions, All Criteria Pollutants; Years Including 1980, 1985, 1989-2001*, http://www.epa.gov/ttnchie1/trends/index.html, February 2003.
[13] Clean Air Act Amendments of 1990, Title I – Provisions for Attainment and Maintenance of National Ambient Air Quality Standards, Section 101(d)(1), November 15, 1990.
[14] U.S. Environmental Protection Agency, *8-Hour Ground-level Ozone Designations*, http://www.epa.gov/ozonedesignations/statedesig.htm, May 6, 2004.
[15] U.S. Department of Transportation, Federal Aviation Administration, *Enplanement Activity at Primary Airports*, http://www.faa.gov/arp/planning/stats/2002/CY02CommSerBoard.pdf , November 6, 2003.
[16] U.S. Environmental Protection Agency, *Classifications of Ozone Nonattainment Areas*, op.cit.
[17] U.S. Department of Transportation, Federal Aviation Administration, Federal Highway Administration (cooperating agency), *Final Environmental Impact Statement for 9,000-Foot Fifth Runway and Associated Projects: Hartsfield Atlanta International Airport*, August 2001.
[18]Illinois Environmental Protection Agency, *Illinois 1999 Periodic Emissions Inventory And Milestone Demonstration,* December, 2001. The higher value for in the area inventory data in the table is for a typical summer day, which is the ozone season and probably represents a worst case since it is the most active period for aviation activity. The non-road data also is based on typical summer day. The lower value, which is more representative for an annual value is from U.S. Department of Transportation, Federal Aviation Administration, *Final Environmental Assessment for the World Gateway Program and Other Capital Improvements: Chicago O'Hare International Airport, Chicago, Illinois*, June 21, 2002.
[19] South Coast Air Quality Management District, *Emissions by Category, 2001 Estimated Annual Average Emissions, South Coast Air Basin.* http://www.arb.ca.gov/app/emsinv/emssumcat_query.php?F_DIV=0&F_YR=2001&F_AREA=AB&F_AB=SC , 2001.
[20] Texas Natural Resource Conservation Commission, *Dallas/Fort Worth Ozone Nonattainment Area Emission Data*, http://www.tnrcc.state.tx.us/air/aqp/ei/rsumdfw.htm, 1996 inventory data. Data includes all airports in the nonattainment area including, DFW International Airport, Dallas Love Field, and Alliance Airport.
[21] U.S. Department of Transportation, Federal Aviation Administration, *Final Environmental Impact Statement Runway 8L-26R and Associated Near-Term Master Plan Projects; George Bush Intercontinental Airport/Houston*, July 2000.
[22] Compilation of data from the SIP inventories for New York and New Jersey provided by Mr. Raymond Forde, Region 2, U. S. Environmental Protection Agency, June 16, 2004. Additional data provided by Mr. Kevin McGarry, New York State Department of Conservation and Ms. Tonalee Key, New Jersey Department of Environmental Protection.

[23] Agyei, Kwame, Puget Sound Clean Air Agency, airport emissions calculated using EDMS 4.0; area non-road and total emissions from 1999 Air Emission Inventory Summary spreadsheet, February 11, 2003.
[24] Nonattainment area non-road and total NO_x emissions, 68 FR 25431, May 12, 2003; Airport emissions escalated from 1995 estimate by URS Greiner, Inc. (1997) based on 2000 data provided by Tony Petruska, U.S. EPA.
[25] Massachusetts Department of Environmental Protection, *Massachusetts Periodic Emissions Inventories 1999*, April 2003, for nonattainment area off-road emissions and total emissions, which are based on summer day emissions. U.S. Department of Transportation, Federal Aviation Administration, *Final Environmental Impact Statement, Logan Airside Improvements Planning Projects: Boston Logan International Airport*, June 2002 for Logan Airport emissions, which are typical for an annual value.
[26] U.S. Environmental Protection Agency, *National Air Pollutant Emission Trends, 1990-1998*, http://www.epa.gov/ttn/chief/trends/trends98/index.html, March 2000.
[27] Ibid.
[28] For NO_x, aircraft represent anywhere from 60 to 80 percent of total airport emissions with the balance coming from the other sources like ground support equipment and ground access vehicles. This is based on a review of recent Environmental Impact Statements for eleven airports (ATL, BOS, CLE, DFW, IAD, IAH, LAX, ORD, PTI, SFO, and STL).
[29] For more information about the production of contrails by aircraft, see U.S. Environmental Protection Agency, *Aircraft Contrails Factsheet*, http://www.epa.gov/otaq/regs/nonroad/aviation/contrails.pdf, September 2000.
[30] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2001*, http://yosemite.epa.gov/oar/globalwarming.nsf/UniqueKeyLookup/LHOD5MJQ6G/$File/2003-final-inventory.pdf, April 15, 2003. Estimates are presented in units of terragrams of carbon dioxide equivalents (Tg CO_2 Eq.), which weight each gas (e.g., CO2 and NOx) by its Global Warming Potential, or GWP, value.
[31] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2001*, 2003 op.cit.
[32] Intergovernmental Panel on Climate Change, *Aviation and the Global Atmosphere*, 1999.
[33] Actual Emissions 1990-2001 – U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2001*, 2003 op.cit.
[34] Forecast Emissions 2001-2025 calculated based on FAA long-range activity forecasts assuming a constant rate of emissions from aircraft. The forecast is deemed conservative since it does not account for improvements in aircraft energy efficiency over the next 20 years, which are deemed likely. Estimates are presented in units of terragrams of carbon dioxide equivalents (Tg CO_2 Eq.), which weight each gas (e.g., CO2 and NOx) by its Global Warming Potential, or GWP, value.
[35] U.S. Department of Energy, Oak Ridge National Laboratory, *Transportation Energy Data Book: Edition 22*, http://www-cta.ornl.gov/data/tedb22/Full_Doc_TEDB22.pdf, September 2002.
[36] US Department of Transportation, Bureau of Transportation Statistics, *National Transportation Statistics 2002* (BTS 02-08), Table 4-20: Energy Intensity of Passenger Modes (Btu per passenger-mile), page 281, http://www.bts.gov/publications/national_transportation_statistics/2002/pdf/entire.pdf.
[37] Ibid.
[38] See FAR Part 33 – Airworthiness Standards: Aircraft Engines http://www.airweb.faa.gov/Regulatory_and_Guidance_Library/rgFAR.nsf/CurrentFARPart?OpenView&Start=1&Count=200&Expand=10.
[39] Colpin, J. and Altman, R., *Dependable Power Reinvented*, AIAA 2003-2882, AIAA-ICAS International Air and Space Symposium and Exhibit: The Next 100 Years, July 14-17, 2003, Dayton, OH.
[40] The use of market-based options for limiting or reducing greenhouse gas emissions from aviation may also prove potentially useful applied to local air quality emissions.
[41] Air Transport World, *United says cutting APU runtime to save $12 million*, ATW Online.com, February 10, 2003.
[42] International Civil Aviation Organization, Circular 303 - *Operational Opportunities to Minimize Fuel Use & Reduce Emissions*, February 2004.

[43] U.S. Department of Transportation, Federal Aviation Administration, *National Airspace System Operational Evolution Plan*, December 2002
[44] U.S. Department of Transportation, Federal Aviation Administration, *Final Regulatory Impact Analysis, Final Regulatory Flexibility Determination, Unfunded Mandates and Trade Impact Assessment, Reduced Vertical Separation Minimum Operations in United States Domestic Airspace*, March 10, 2003
[45] Drew, P., et al., Technology Drivers for 21st Century Transportation Systems," AIAA 2003-2909, AIAA-ICAS International Air and Space Symposium and Exhibit: The Next 100 Years," 14-17 July 2003, Dayton, OH
[46] Waitz, I. A., Massachusetts Institute of Technology, *Aircraft, Gas Turbine Engines and Emissions Primer*, August 3, 2001.
[47] Intergovernmental Panel on Climate Change, 1999 op.cit.
[48] ICAO has established a Long-Term Technology Goals (LTTG) task group within Working Group 3 to monitor and track future aircraft technologies that may demonstrate better environmental performance. The LTTG will evaluate the prospects for setting emissions goals as targets for future technology performance.
[49] National Aeronautics and Space Administration, *NASA Aerospace Technology Enterprise Strategy – 2003*, http://www.aerospace.nasa.gov/strat_plan2003_low.pdf.
[50] More information on the FAA-NASA Center of Excellence for Aircraft Noise and Aviation Emissions Mitigation can be found at http://web.mit.edu/aeroastro/www/partner/.
[51] Waitz, I. A., Massachusetts Institute of Technology, 2001 op. cit., estimates "22 to 37 years total time from basic technology (e.g. NASA research) to significant fleet impact."
[52] National Research Council, Division on Engineering and Physical Sciences, Aeronautics and Space Engineering Board, Committee on Aeronautics Research and Technology for Environmental Compatibility, *For Greener Skies: Reducing Environmental Impacts of Aviation*, available at http://bob.nap.edu/html/greener_skies/notice.html, 2002.