GOING GREEN – MITIGATING AVIATION'S NEW ENVIRONMENTAL DRIVERS

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Abstract

The effect of aircraft emissions on earth's climate is a serious long-term environmental issue facing aviation. However, climate impacts are not the only environmental issues facing aviation. Any strategy to mitigate aviation climate impacts must consider noise exposure and air quality impacts, and energy availability and efficiency. This paper reviews our knowledge of aviation's climate impacts and discusses the U.S. strategy to mitigate these impacts, including enhancing scientific understanding and modeling capabilities, and development and maturation of environmental aircraft technologies, alternative fuels and operational procedures to reduce aviation environmental impacts. Market based and policy options make up the fifth pillar of a comprehensive strategy to enable aviation's growth in a sound environmental manner.

1.0 Introduction

Despite the technological advancements achieved during the last forty years [1], aircraft noise still affects people living near airports, and aircraft emissions continue to be an issue, locally, regionally and globally. Aside from their associated health and welfare impacts, aircraft noise and aviation emissions are a considerable challenge in terms of community acceptance of airport capacity expansion and this challenge is anticipated to grow.

While energy efficiency and local environmental issues have traditionally been primary drivers of aeronautics innovation, the current and projected effects of aviation emissions on our global climate is a serious long-term environmental issue facing the aviation industry [2, 3]. The climate impacts of aviation emissions include: (1) the direct climate effects from carbon dioxide (CO_2) and water vapor emissions, (2) the indirect forcing on climate resulting from changes in the distributions and concentrations of ozone and methane as a consequence of aircraft oxides of nitrogen (NOx) emissions, (3) the direct effects (and indirect effects on clouds) from emitted aerosols and aerosol precursors, and (4) the climate effects associated with contrails and cirrus cloud formation. In addition, aircraft NOx released in the upper troposphere and lower stratosphere may have a more significant impact on climate than ground level emissions of NOx [2].

The last major international coordinated effort focused solely on assessing the contribution of aviation to greenhouse gases (GHG) was published by the Intergovernmental Panel on Climate Change (IPCC) in 1999 [2]. Aircraft were estimated to contribute about 3.5 per cent of the total radiative forcing (a measure of change in climate) by all human activities and this percentage, which excludes the effects of possible changes in cirrus clouds, was projected to grow. The recently released Fourth Assessment Report (AR4) by IPCC [4] notes that aviation CO_2 emissions account for about 2 percent of global totals. More recent data referenced in the AR4 report estimates of the climate effects of contrails have been lowered and aircraft in 2005 are now estimated to contribute about 3.0 percent of the total of the anthropogenic radiative forcing by all human activities, again excluding the possible effects of cirrus clouds, The IPCC AR4 noted mitigation of CO_2 emissions from the aviation sector can come from improved fuel efficiency, which can be achieved through a variety of means, including aircraft technology, operational procedures and air traffic management (ATM). However, such improvements are expected to only partially offset the growth of aviation emissions.[1] Total mitigation potential in the sector would also need to account for non-CO_2 climate impacts of aviation emissions, In 1999, the IPCC projected that aviation may eventually (~2050) account for 5% of GHG and this projection likely remains reasonably accurate but may be lower when considering existing fuel costs and initiatives being taken by the airline industry to reduce fuel consumption.

This paper outlines U.S. aviation contribution to GHG within the context of other energy sources in the U.S. as well as within the context of international aviation markets. The paper then discusses the U.S. Next Generation Air Transportation System (NextGen) activities to advance the science and models to characterize and quantify aviation's environmental impacts. The paper also discusses goals and ongoing research, development and maturation of environmental technologies and fuels and operational procedures to address and reduce aviation environmental impacts. Finally, the paper briefly touches upon market based and policy options to reduce aviation's environmental impacts.

[1] The surge in fuel prices is producing a major restructuring in the U.S. airline fleet which will reduce emissions growth in the short-term; nonetheless grappling with aviation's growth, especially outside the U.S., will remain a significant challenge.

2.0 Aviation Greenhouse Gases

Climate change concerns have resulted in the U.S. Courts deciding in landmark rulings that GHG emissions are to be regulated by the Environmental Protection Agency (EPA) under the Clean Air Act [5], and the President has issued an Executive Order initiating that process [6]. Although the implications of this ruling on aviation are unclear, it certainly points toward the need for aviation to continue its commitment to improving fuel efficiency. Numerous state and local governments are taking action to address GHG emissions, and there have been petitions for the EPA to address aviation emissions [7, 8].

The U.S. market is not the only- nor even the primary- force in this arena. The aviation industry (at least prior to the oil price spikes of the spring of 2008) is experiencing record growth globally. It is moving the equivalent of one third of the world's population each year across the world. Airbus and Boeing have record sales, profits for airlines have recovered, and two of the fastest growing economies in the world -- China and India -- are on track to build 100 new airports in the next decade to meet demand. Pressures on the world's airlines are increasing as market-based measures and other legislative initiatives to reduce GHG emissions from the aviation sector are being considered by various countries. With the expected growth in international air transportation demand, we expect that all of these factors will lead to increasing pressure to seek environmental impact reductions from aviation-related sources.

The most recent EPA GHG emissions inventory, using input from FAA, estimates that U.S. domestic commercial aircraft contributed 156.5 million metric tons or Teragrams (Tg) of carbon dioxide in 2005 [9]. Aviation CO_2 emissions in context of other sources are shown in Figure 1.

The U.S. commercial aviation sector is contributing less, not more, to growth in GHG emissions in recent years. When you compare today to 2000, U.S. commercial aviation is moving 12% more passengers and 22% more freight while burning less fuel (Figure 2), thereby reducing carbon output. Since 2000, the restructuring of U.S. airline fleets in the aftermath of September 11th, the rise in fuel costs, use of fuel efficient operational procedures, and improvements in air traffic management technologies and operational approaches have all contributed to these savings. This compares favorably with the U.S. economy overall and aviation has clearly outperformed automobiles in improving its energy intensity in the past few decades (see Figure 3).

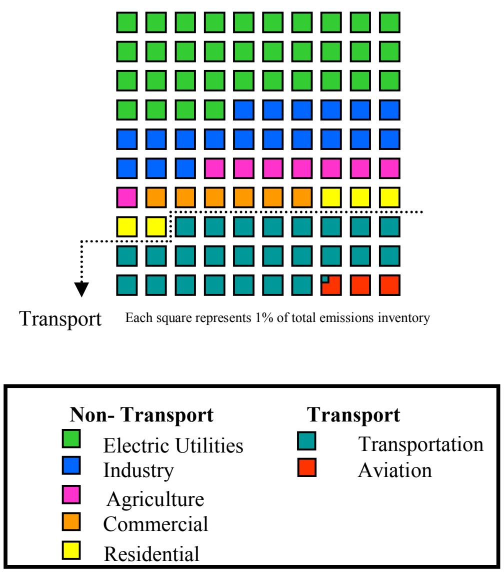

Figure 1. U.S. Aviation CO_2 emissions in context [9].

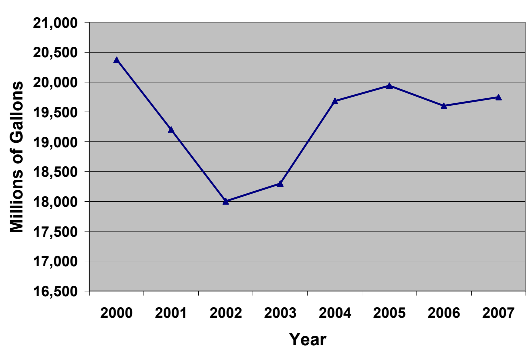

Figure 2. U.S. Commercial Aviation Fuel Consumption [10].

Another way to examine U.S. GHG emissions in context is to compare the performance of the U.S. market with other major aviation markets in the world, e.g., the European Union (EU). Between 2000 and 2006, aviation CO_2 emissions in the U.S. declined by about 4%, largely attributable to the retirement of older aircraft as a result of the restructuring brought about by the events of September 11 and the subsequent Severe Acute Respiratory Symptom (SARS) epidemic. During the same period in Europe (EU 15), emissions increased by around 30%, attributable to the effects of deregulation and the growth of low cost carriers. (See Figure 4).

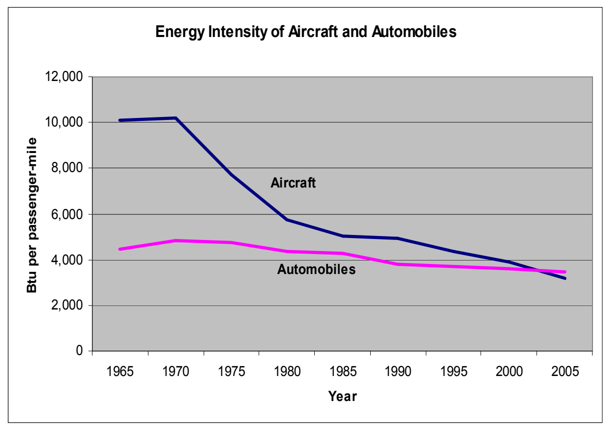

Figure 3. Energy Intensity of Aircraft and Automobiles [11].

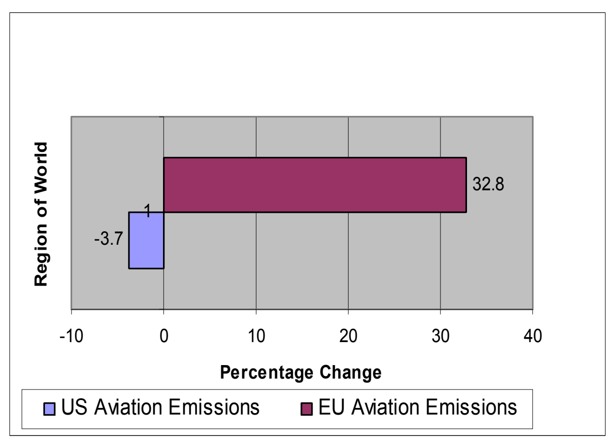

Figure 4. Percentage Change of Aviation CO_2 emissions 2000-2006, computed using the System for assessing Aviation Global Emissions (SAGE) [12, 13].

Despite the excellent performance of the U.S. system and the incentives to reduce fuel use provided by oil priced at well over $100 per barrel, as demand for passenger and cargo aviation continues to rise the aviation industry has a responsibility to reduce aviation's carbon footprint.

3.0 Next Generation Air Transportation System

The Next Generation Air Transportation System (NGATS or NextGen) refers to an initiative started in 2003 to transform the U.S. air transportation system by 2025. In contrast to today's system, the NextGen will be more flexible, resilient, scalable, adaptive, and highly automated – meeting up to two to three times current demand. The *NGATS Integrated Plan* is a plan to ensure that the NextGen meets air transportation safety, security, mobility, efficiency, and capacity needs beyond those currently included in the FAA's "Operational Evolution Plan," and was delivered to Congress in December, 2004 [14].

Protecting the environment is at the heart of the NextGen plan. Ensuring energy availability and protecting the environment will be critical elements in allowing aviation capacity to expand. The U.S. has developed a strong and compelling vision under the Joint Planning and Development Office (JPDO) NextGen plan for tackling environmental issues to ensure that aviation growth can be sustained. The environmental goals of NextGen are:

- Absolute reduction of significant *community noise* and *air quality* emissions impacts
- Reduce significant aviation impacts associated with *water quality*
- Limit or reduce the impact of aviation GHG emissions on the global *climate*
- Improve National Airspace System (NAS) *energy* efficiency and availability, including aircraft and air traffic operations and alternative fuels development

To achieve environmental protection that allows sustained aviation growth, the U.S. NextGen initiative is pursuing a systematic and comprehensive five pillar strategy to mitigate the impacts of aviation on the environment. The elements of the strategy are embedded within the approach recommended by the 2004 Report to Congress on Aviation and the Environment prepared by the Partnership for AiR Transportation Noise and Emissions Reduction (PARTNER) as pictorially depicted in Figure 5 [3]. Ultimately, the NextGen environmental goals are enabled by the research goals of the U.S. National Plan for Aeronautics Research and Development and Related Infrastructure [15].

The NextGen environmental strategy includes support of research to better understand the extent of the problem associated with aviation emissions and the development and fielding of new operational enhancements, aircraft and ATM technologies, alternative fuels, and policies to achieve near-term and long-term solutions. Although the focus of this paper is on GHG and climate impacts, these effects cannot be decoupled from other environmental impacts and the discussion below tries to touch upon these interdependencies.

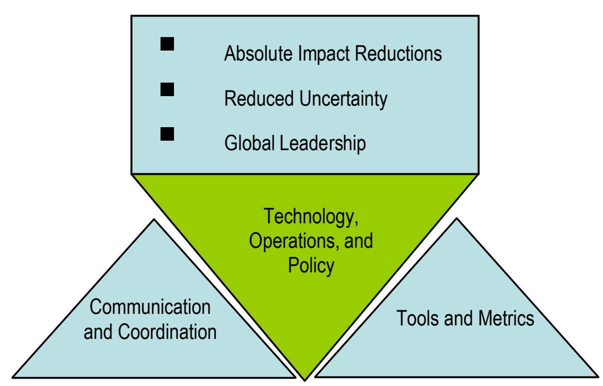

Figure 5. Framework Guiding NextGen Environmental Strategy [3]

3.1 Better Science and Models

The first pillar of the NextGen strategy to deal with aviation climate impacts entails understanding and quantifying the potential impacts of aviation emissions to help policymakers address climate and other potential environmental health and welfare impacts associated with aviation. This will ensure identifying the right issues, measuring their impact, and designing appropriate measures to mitigate their effects.

In trying to assess health and welfare impacts, optimize energy efficiency and develop environmental mitigation strategies, it has become evident that there are important interrelationships and potential trade-offs. Taking an interdisciplinary approach to enhancing energy efficiency and minimizing aviation environmental impacts by developing data, analytical tools, and models that characterize and quantify the interdependencies between energy use, aircraft noise and various air pollutant emissions is a key element of the way forward. The goal is a more complete understanding of the complex interdependencies that exist among aircraft noise, fuel burn and emissions required for designing and regulating aircraft. Efforts are underway to improve our capability to assess aircraft noise, fuel burn, and emissions impacts, using advanced technology and computer models [for further details see, for example, 16-20]. A schematic of a suite of models to enable assessing interdependencies between environmental impacts and comprehensive cost benefit analyses of various mitigation strategies is shown in Figure 6. These models will provide a leap forward in calculating how reducing one impact affects another, and how to devise the best balance of cost-beneficial solutions. If successful, this approach will better inform policy-makers, help maximize the benefits of proposed actions, guide research investment to optimize payoff, influence design practices, and inform the public about these impacts.

Embedded in these energy and environmental issues are several scientific uncertainties concerning aviation energy issues and aviation environmental impacts, particularly on climate. Today scientists have a good understanding of the effect of aircraft generated CO_2 emissions on climate.

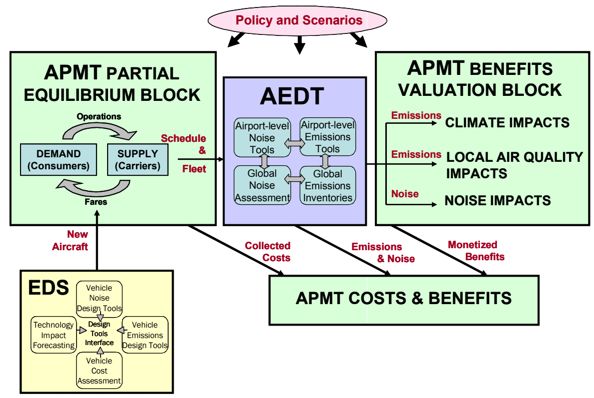

Figure 6. Environmental Impacts Model Suite being developed by the FAA, National Aeronautics and Space Administration (NASA) and Transport Canada. The Suite encompasses the Environmental Design Space (EDS), the Aviation Environmental Design Tool (AEDT), and the Aviation environmental Portfolio Management Tool (APMT).

However, there are large uncertainties in our present understanding of the magnitude of climate impacts due to other aviation emissions. Scientists still do not know the relative effect on climate of aviation NOx emissions and contrails. Scientists also do not know the impact of particulate matter (PM) and their role in enhancing cirrus cloudiness. Metrics to assess the impact of these emissions and to determine their relative impact compared to CO_2 are still being developed. Achieving the NextGen environmental goals requires enhanced scientific knowledge because often there are trade-offs associated with addressing these emissions. For example, a more efficient engine that produces less CO_2 tends to produce more NOx unless there is an associated modification in combustor technology. Understanding these trade-offs and the relative impacts of different emission is vital for optimal GHG policy making. As part of the NextGen effort to advance our understanding of aviation climate impacts, the U.S. recently launched the

Aviation Climate Change Research Initiative (ACCRI) in partnership with NASA and other agencies and stakeholders [21].

3.2 More Efficient Air Traffic Management

The second NextGen environmental strategy pillar is implementation of operational changes and improvements to air traffic management technologies to improve energy efficiency and reduce fuel burn (hence emissions). Improving energy efficiency has the dual benefit of improving both environmental and operational performance of the aviation sector.

Some efforts, like the introduction of Reduced Vertical Separation Minimum (RVSM), have been very successful, saving about 3 million tons of CO_2 annually [22]. RVSM is an International Civil Aviation Organization (ICAO) approved concept that reduces the aircraft separation standard at certain high altitudes, allowing aircraft to safely fly more optimum profiles, gain fuel savings and increase airspace capacity. The U.S. is also accelerating implementation of other enhanced ATM procedures to further improve the efficiency of the system resulting in reduced fuel burn, emissions and noise. Through the use of Required Area Navigation (RNAV) and Required Navigation Performance (RNP) technology, aircraft will be able to use descent procedures that burn less fuel and result in quieter operations. In addition, satellite-based air traffic control paired with Automatic Dependent Surveillance-Broadcast (ADS-B) technology on aircraft allow for safer but smaller separations between aircraft and more direct routing, which will improve fuel efficiency. In essence, NextGen itself will improve environmental performance.

The U.S. is already achieving early gains at a test program at Dallas-Fort Worth International Airport, where American Airlines' use of NextGen-related procedures is reducing CO_2 emissions by levels equivalent to removing 15,000 cars from the road for a year. Another good example of emissions reductions from aviation operational improvements is Continuous Descent Arrival or CDA (see Figure 7).

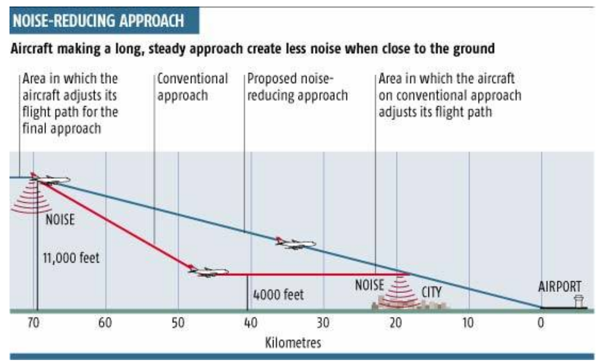

Figure 7. CDA Schematic

CDA allows an airplane to fly a continuous descent path to land at an airport, rather than the traditional "step downs" or intermediate level flight operations. The airplane initiates descent from a high altitude in a near "idle" engine (low power) condition until reaching a stabilization point prior to touch down on the runway. Flight demonstrations at Louisville International Airport in Kentucky have shown a fuel savings (and thus CO_2 emissions reduction) averaging about 12% for the arrival portion of the flight. And testing at Atlanta Hartsfield International Airport of continuous descent arrivals shows savings of about 1,300 pounds of CO_2 for each and every flight using CDA.

CDA is one of those win-win strategies, having environmental and operational benefits that can reduce noise, emissions, and fuel burn, as well as flight time. The cumulative impact of measures like this throughout the system can have a real impact. NextGen is developing other procedures and decision support tools for reducing the environmental impact of air traffic operations, and conducting simulations and field demonstrations to validate benefits and explore implementation issues. As additional advanced aircraft and air navigation procedures planned for the NextGen system are developed and deployed, we may see an even greater reduction in emissions impacts from aviation, assuming the rate of deployment outpaces growth.

Internationally, the FAA is pursuing efforts with various partners aimed at enhancing fuel efficiency and further reducing aviation's environmental impact. The Atlantic Interoperability Initiative to Reduce Emissions (AIRE), a scientific and research venture between the FAA, the European Commission (EC), and industry partners, will focus on upgrading air traffic control standards and procedures for trans-Atlantic flights. A similar initiative in the Asia-Pacific region, the Asia and South Pacific Initiative to Reduce Emissions (ASPIRE) was also recently put in place. Both will enhance fuel efficiency as well as reducing environmental impacts.

3.3 New Aircraft Technologies

The third pillar of the NextGen environmental strategy is the development and integration of promising improvements in engine and airframe technologies into the civil aviation fleets. Quick deployment of these technology improvements will allow better fuel efficiency of the aviation sector which is crucial to the NextGen concept of operations. This builds upon the fact that the vast majority of improvements in environmental performance over the last three decades have come from enhancements in engine and airframe design [1].

To help achieve the NextGen goals to increase airspace system capacity by reducing significant community noise and air quality emissions impacts in absolute terms and limit or reduce aviation GHG emissions impacts on the global climate, the FAA, in collaboration with NASA is establishing the Continuous Low Energy, Emissions and Noise (CLEEN) program [23]. The CLEEN program is focused on reducing current levels of aircraft noise, emissions that degrade air quality, GHG emissions, and energy use, and it advances alternative fuels for aviation use. The focus of the effort is to: (1) mature previously conceived noise, emissions and fuel burn reduction technologies from Technology Readiness Levels[2] (TRLs) of 3-4 to TRLs of 6-7 to enable industry to expedite introduction of these technologies into current and future aircraft and engines; and (2) assess the benefits and advance the development and introduction of alternative "drop in" fuels [24] for aviation, with particular focus on renewable options (discussed in section 3.4 below).

Elements of the CLEEN program will include developing and demonstrating:

- Certifiable aircraft technology that reduces fuel burn by 33% compared to current technology, reducing energy consumption CO_2 emissions;
- Certifiable engine technology that reduces landing and takeoff cycle (LTO) NOx emissions by 60 percent, at a pressure ratio of 30, over the ICAO standard adopted at CAEP 6, with commensurate reductions over the full pressure ratio range, while limiting or reducing other gaseous or particle emissions;
- And, Certifiable aircraft technology that reduces noise levels by 32 EPNdB[3] cumulative, relative to ICAO Chapter 4 standards.

The CLEEN program will also determine the extent to which new engine and aircraft technologies may be used to retrofit or re-engine aircraft so as to increase the level of penetration into the commercial fleet. Efforts are expected to get underway in January 2009, pending appropriation of funds by the U.S. Congress.

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[2] TRL 1: Basic principle observed and reported.
TRL 2: Technology concept and/or application formulated (candidate selected)
TRL 3: Analytical and experimental critical function, or characteristic proof of concept.
TRL 4: Component and/or breadboard validation in a relevant environment.
TRL 5: Component and/or breadboard test in a laboratory environment.
TRL 6: System/subsystem model or true dimensional test equipment validated in a relevant environment.
TRL 7: System prototype demonstrated in flight environment.
TRL 8: Actual system completed and "flight qualified" through test and demonstration.
TRL 9: Actual system "flight proven" on operational flight

[3] Effective perceived noise level in decibels.

The CLEEN program focuses on the near term (5 year) goals of the U.S. National Plan for Aeronautics Research and Development and Related Infrastructure [15], or the class of technologies referred by NASA as "next generation" (N+1). NASA is also conducting research to support the mid (N+2) and long-term (N+3) capabilities of the National R&D Plan under its Fundamental Aeronautics program.

The NASA Aeronautics Research Mission Directorate (ARMD) Fundamental Aeronautics (FA) Program performs long-term research focused on removing the environmental and performance barriers that may prevent the full realization of the projected growth in capacity of the NextGen. The Subsonic Fixed Wing project in particular seeks to develop revolutionary technologies and aircraft concepts with highly improved performance while satisfying strict noise and emission constraints. Although the primary application is intended to be transport aircraft, the project will evaluate the potential benefits of new technologies for a variety of other subsonic vehicles such as Very Light Jets and new capabilities such as Cruise-Efficient Short Takeoff and Landing (CESTOL).

The NASA FA Program also supports the growth of NextGen by enabling new classes of aircraft (including rotorcraft) that can lead to better use of the airspace system. Research on physics-based multi-disciplinary analysis and design (MDAO) techniques is being used to assess the trades between the three major objectives: (1) noise - airframe, engine, rotor noise generation and scattering, (2) emissions - propulsion systems and fuels, aircraft operations modes and emittant dispersion, and (3) performance - airframe and engine efficiency. The MDAO capability is required to understand the design compromises that will lead to very quiet airplanes with low levels of emissions and significant performance increases, as well as quieter rotorcraft with increased payload, range, and handling qualities.

3.4 Alternative Fuels

The fourth pillar of the NextGen environmental strategy is an effort to 1) assess the potential of alternative jet fuels to enable reductions in aircraft emissions and 2) enable these fuels for commercial use. Alternative fuels may have benefits for energy security, economic stability of the industry and emissions performance, depending on the fuel's lifecycle CO_2 emissions profile.

Interest in alternative aviation fuels derived from non-petroleum sources is growing. Alternative fuels may broadly be classified into two categories, "drop-in" and "non-drop-in" fuels. "Drop-in" fuels are those that can be substituted directly for conventional fuels without any changes to aircraft or engines required. The U.S. commercial aviation supply chain established the Commercial Alternative Aviation Fuel Initiative (CAAFI) in October, 2006 [24]. CAAFI is best characterized as a process to generate data and communicate among and between aviation supply chain sponsors. CAAFI coordinates the development and commercialization of "drop-in" alternative aviation fuels. CAAFI is considering the feasibility, production, and environmental footprint - "well to wake" - of aviation fuels. CAAFI is also exploring the long-term potential of other fuel options. The goal is to ensure an affordable and stable supply of environmentally progressive aviation fuels that will enable continued growth of commercial aviation.

Presently, synthetic "drop-in" jet fuels are being manufactured from coal and natural gas using a Fischer-Tropsch process. In the future, synthetic jet fuel may come from biomass or a mixture of fossil and biomass feedstocks (e.g. coal and biomass). In the Fischer-Tropsch process, the base feed stock is gasified and then recombined to form a synthetic fuel. Synthetic fuels are very similar in chemistry and performance to conventional jet fuel, but have very little sulfur and aromatics, and have a slightly higher hydrogen-to-carbon (H/C) ratio. This may result in much lower PM exhaust and secondary emissions, and slightly lower CO_2

emissions at exhaust, although significant CO_2 emissions may occur during the fuel synthesis process. In addition, synthetic fuels exhibit excellent low-temperature properties, maintaining a low viscosity at cold ambient temperatures. High temperature properties are also improved, resulting in improved heat sink capabilities with less fuel system carbon deposits. Synthetic fuels have already been in use for many years in the Johannesburg, South Africa airport; hence it is possible to supplement current jet fuel supplies with synthetic-derived fuel. Energy inputs and outputs throughout the production cycle must be considered in accordance with the CO_2 emissions produced and CO_2 mitigation strategies adopted. For example, the additional CO_2 that is produced during the fuel synthesis process could potentially be captured and permanently stored in the fuel production process. In addition, a mixed biomass feedstock has the potential to significantly reduce CO_2 emissions from the gasification process.

Additional renewable fuels provide other options that could be "drop-in" or "non-drop-in." Renewable fuels are typically made from biological oil sources, such as plants that can be grown year after year. The plant material is generally composed of oils extracted from the plant's seeds, such as soy beans, canola, or palm. In addition, animal fats are being used to produce test quantities of jet fuel from oxygenated olefins. The properties of some renewable fuels fall outside conventional jet fuel specifications, in particular energy density in terms of both volume and weight. Through additional processing these extracted materials may become more similar to diesel or jet fuels. Also, renewable fuels may be blended with other feedstocks to meet jet fuel specifications.

A challenge for renewable fuels is that, because of limited water and arable land, energy crops run the risk of competing with food crops and inducing negative land use change (e.g. deforestation). First generation biofuels are also currently not capable of supplying a large percentage of fuel [24]. However, higher-yielding next generation feedstocks, such as algae, halophytes or cellulosic biomass, may improve supply capability and avoid competition with food production. The main advantage of using renewable fuels may be their potential to reduce overall life-cycle CO_2 impact. If the performance and cost issues can be overcome, these fuels could be blended with synthetic or conventional jet fuels, which could lead to a more-sustainable aviation fuel. Renewable alternative fuels may very well be the revolutionary technology that enables carbon neutral aviation growth, and eventually moves aviation toward carbon neutral operations.

Data also indicate that low sulfur synthetic and bio-based fuels promise significant environmental benefits from reductions in PM emissions. Such benefits could also be achieved via an ultra low sulfur petroleum-derived Jet A. Efforts are underway to conduct a comprehensive assessment of the benefits and costs of ultra low sulfur jet fuels [25].

There are numerous ongoing efforts seeking to develop alternative aviation fuels [25]. The U.S. Department of Defense is pursuing an alternative fuels technology program to develop identify and enable use of a single, environmentally friendly fuel with composition and properties sufficient to serve the needs of a multi-vehicle, multi-mission battle-space environment. Of note to commercial aviation is the CLEEN program discussed in section 3.3, which is seeking to develop and demonstrate the feasibility of use of alternative fuels in aircraft, auxiliary power units (APUs) and Ground Support Equipment (GSE), including successful demonstration and quantification of benefits; and transition strategies that enable "drop in" replacement for petroleum derived turbine engine fuels with no compromise in safety.

3.5 Market Based/Policy Initiatives

The final pillar of the NextGen environmental strategy is market-based measures and policy initiatives. The price of fuel is the most fundamental market-base measure that drives innovation to reduce fuel consumption and emissions. With fuel costs now greater than labor costs for U.S. airlines for the first time in nearly four decades and the cost of fuel having quadrupled in six years, fuel price is driving significant structural changes, which further enhance fuel efficiency.

Approaches using tax incentives, emissions trading or carbon offsets may all have a role to play, though each can pose challenges in design, legality and implementation. For example, carbon offsetting is a scheme which allows airline passengers to pay for carbon reductions accomplished somewhere else to compensate for the emissions generated by the aircraft flight they took. Carbon offsetting is offered by several airlines, but questions have arisen related to calculations of carbon emissions (calculations of the same flight can produce carbon numbers that vary substantially, as discussed in [26]) and how the funds collected are spent. More recently the U.S. is looking for market-based measures to increase use of congested airspace, to simultaneously increase efficiency and drive down emissions per passenger.

With respect to emissions trading, the U.S. participated in the development of emissions trading guidance for aviation under the auspices of ICAO, the United Nations standard setting organization of international aviation. Like the overwhelming majority of countries--developed and developing, Kyoto signatories and non-Kyoto signatories—the U.S. agreed emissions trading should only be applied to another country's airlines on the basis of agreement between States. The EU however has proposed legislation that would force international airlines into their emissions trading system without the consent of non-EU governments. There are significant concerns about the EU legislation. Poorly designed and implemented emissions trading systems could actually hamper the ability of aviation to become cleaner and quieter.

The U.S. is a member the fifteen-nation Group on International Aviation and Climate Change (GIACC). This high-level group was conceived during ICAO's 2007 Assembly and is developing an international plan to address international aviation GHG emissions. The expectation is that the GIACC will ultimately develop an effective, globally devised strategy, providing goals and a framework for collaboration from which individual countries will implement measures appropriate to their circumstances and industry structure.

Market-based measures may play a role in how countries seek to reduce emissions. However, the price of fuel already provides both airlines and manufacturers strong market incentives to reduce fuel consumption. Environmental advances in the aviation sector historically have been most helped by positive economic measures that stimulate research and innovation in the industry's fleets. As the record on aircraft noise and fuel efficiency demonstrates, implementation of new technology and operational procedures have been remarkable tools for limiting and reducing aviation environmental impacts.

4.0 Summary

To grow, aviation must have a reliable, cost effective energy supply, and effectively deal with environmental issues related to energy production, noise, air quality, and climate change. Aviation's impact on climate may ultimately be the most difficult long-term issue to address, but aviation will still need to effectively address the proven environmental constraints of noise and air quality emissions.

This paper presents the U.S. NextGen strategy to enable environmentally sound aviation growth (with a focus on climate impacts) -- a balanced approach derived from the recognition that operational and technological environmental performance improvements, coupled with market measures where necessary, can form the basis to derive data-driven, challenging, goals for the international community in reducing the growth of aviation's emissions impacts.

5.0 Acknowledgements

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