항공수요증가가 지구환경에 미치는 영향 및 정책적 시사점
Air Travel Growth, Environmental Impacts and Policy Implications

이주성 (LG CNS)

I. Introduction

Air travel continues to experience the fastest growth among all modes of transport. Although the energy intensity A measure of aircraft fuel economy on a passenger-kilometer basis. It is denoted by energy used per unit of mobility provided (e.g. fuel consumption per passenger -kilometer). of the air transport system continues to decline, aviation fuel use and total emissions have steadily risen. This trend, which represents a conflict between industry growth and environmental impact, has motivated the aircraft manufacturing and airline industries, the scientific community, and governmental bodies to evaluate a variety of methods for emissions mitigation. This paper examines trends in air travel growth and aviation emissions' impacts on local air quality and global atmosphere. It also discusses policy implications for aviation emissions reduction and research efforts undertaken by international governments to assess and mitigate the environmental impacts of aviation emissions.

II. Air Travel Growth and Energy Use

The first powered passenger aircraft were developed at theturn of the twentieth century. Since then there has been growth in aviation as a form of mobility and consequently significant growth in energy use. In 2002, aviation accounted for 3 trillion revenue passenger-kilometers (RPKs), approximately 10% of world RPK's traveled on all transportation modes, and 40%of the value of world freight shipments. Demand for air travel has grown fastest among all modes of transport. Note that subsequent to the events of September 11, 2001, total RPKs fell by 8% and fuel burn by 16%, comparing 2-year averages before and after. In addition, the percentage of the commercial fleet parked increased from 6% to 13% [Waitz et al., 2004]. However, future projections estimate a resumption of the long-term growth trend within the next several years. Growth is anticipated to continue at a rate ~4% per year [FAA, 2004]. If, as expected, strong growth in air travel demand continues, aviation will become the dominant mode of transportation, perhaps surpassing the mobility provided by automobiles within a century. This evolution of transportation demand also suggests an increase in per-person energy use for transportation, which then creates increasing pressures for improvements in aircraft technology and operational efficiency [ICAO, 2002; Lee et al., 2001].

III. Environmental impacts of aviation emissions

The growth in air transportation volume has important environmental impacts associated with climate change and stratospheric ozone reduction on a global scale. On local to regional scales, noise, decreased air quality related primarily to ozone production and particulate levels, and other issues, such as roadway congestion related to airport services and local water quality, are all recognized as important impacts.

The climate impacts ofaviation are perhaps the most important of the environmental impacts mentioned, both in terms of the potential economic cost and the extent to which all aspects of the aviation system, operations and technology, determine the impact. Because the majority of aircraft emissions are injected into the upper troposphere and lower stratosphere (typically 9-13 km in altitude), resulting impacts on the global environment are unique among all industrial activities. The fraction of aircraft emissions that is relevant to atmospheric processes extends beyond the radiative forcing A measure of the change in Earth's radiative balance associated with atmospheric changes. Positive forcing indicates a net warming tendency relative to pre-industrial times. effects of CO_2. The mixture of exhaust species discharged from aircraft perturbs radiative forcing 2 to 3 times more than if the exhaust was CO_2 alone. In contrast, the overall radiative forcing from the sum of all anthropogenic activities is estimated to be a factor of 1.5 times CO_2 alone. Thus the impact of burning fossil fuels at altitude is approximately double that due to burning the same fuels at ground level. The enhanced forcing from aircraft compared with ground-based sources is due to different physical (e.g. contrails The moist, high temperature air in the jet exhaust condenses into particles in the atmosphere when it mixes with the ambient cold air and saturation occurs. The result is a condensation trail, or contrail.) and chemical(e.g.ozone formation/ destruction) effects resulting from altered concentrations of participating chemical species and changed atmospheric conditions. However, many of the chemical and physical processes associated with climate impacts are the same as those that determine air quality in the lower troposphere [Penner et al., 1999].

Estimates of the radiative forcing by various aircraft emissions for 1992 offered by the Intergovernmental Panel on Climate Change (IPCC) and projections for the year 2050 (see Penner et al. 1999) are shown in Figure 1. Theestimates translate to 3.5% of the total anthropogenic forcing that occurred in 1992 and to an estimated 5%by 2050 for an all-subsonic fleet. Associated increases in ozone levels are expected to decrease the amount of ultraviolet radiation at the surface of the earth. Future fleet composition also impacts the radiative forcing estimate. A supersonic aircraft flying at 17-20 km would have a radiative forcing 5 times greater than a subsonic equivalent in the 9-13 km range. It is important to note that these estimates are of an uncertain nature [Penner et al., 1999].

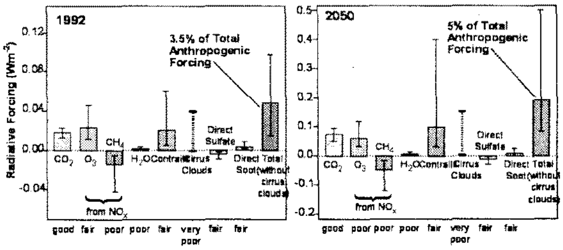

Figure 1. Radiative forcing estimated for 1992 (0.05 W/m^2 total) and projected to 2050 (0.19 W/m^{2}total) [Penner et al., 1999].

Note differences in scale. Note also that the heavier dashed bar for aviation-induced cirrus cloudiness describes the range of estimates, not the uncertainty. The level of scientific understanding of this potential impact is very poor and no estimate of uncertainty was made. Cirrus clouds are not included in the total radiative forcing estimate.

While broadly consistent with these IPCC projections, subsequent research reviewed by the Royal Commission on Environmental Protection (RCEP) in U.K. has suggested that the IPCC reference value for the climate impact of aviation is likely to be an underestimate. In particular, while the impact of contrails is probably overestimated in Figure 1, aviation-induced cirrus clouds could be a significant contributor to positive radiative forcing, NOx-related methane reduction is less than shown in Figure 1, reducing the associated cooling effect, and growth of aviation in the period 1992-2000 has continued at a rate larger than that used in the IPCC reference scenario [RECP, 2002].

IV. Trends in Aircraft Performance and Emissions

Fuel efficiency gains due to technological and operational change can mitigate the influence of growth on total emissions. Increased demand has historically outpaced these gains, resulting in an overall increase in emissions over the history of commercial aviation. The figure of merit relative to total energy use and emissions in aviation is the energy intensity(E_I). When discussing energy intensity, the most convenient unit of technology is the system represented by a complete aircraft. In this section, trends in energy use and E_I are elaborated. It also discusses the relation of E_I to the technological and operational characteristics of an aircraft.

Reviews of trends in technology and aircraft operations undertaken by Lee et al. [2001] and Babikian et al. [2002] indicate that continuation of historical precedents would result in a future decline in $E_I$for the large commercial aircraft fleet of 1.2% to 2.2% per year when averaged over the next 25 years and perhaps an increase in E_I for regional aircraft as regional jets use larger engines and replace turboprops in the regional fleet. When compared with trends in traffic growth, expected improvements in aircraft technologies and operational measures alone are not likely to offset more than one-third of total emissions growth. Therefore, effects on the global atmosphere are expected to increase in the future in the absence of additional measures. A variety of industry and government projections are in general agreement. Compared with the early 1990s, global aviation fuel consumption and subsequent CO_2 emissions are expected to increase three- to seven-fold by 2050, equivalent to a 1.8% to 3.2% annual rate of change. In addition to the different demand growth projections entailed in such forecasts, variability in projected emissions also originates from different assumptions about aircraft technology, fleet mix, and operational evolution in air traffic management and scheduling.

Figures 3 show historical trends in E_I for the U.S. large commercial and regional fleets. Year-to-year variations in E_I for each aircraft type, due to different operating conditions, such as load factor Fraction of passengers per available seats, flight speed, altitude, and routing controlled by different operators, can be ±30%, as represented by the vertical extent of the data symbols [Lee et al., 2001].

Individual aircraft EI based on 19911998 operational data with the exception of the B707 and B727, which are based on available operational data prior to 1991. Fleet averages were calculated using a RPK weighting. Data was not available for entire US fleet average during 1990 and 1991 [Lee et al., 2001].

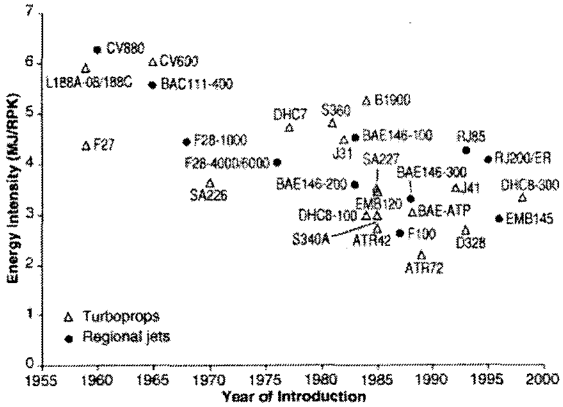

Figure 3. Historical trends in energy intensity of the US regional fleets [Lee et al., 2004]

For large commercial aircraft, a combination of technological and operational improvements has led to a reduction in $E_I$of the entire US fleet of more than 60% between 1971 and 1998, averaging about 3.3% per year. In contrast, total RPK has grown by 330%, or 5.5% per year over the same period. Long-range aircraft are ~5% more fuel efficient than short-range aircraft because they carry more passengers over a flight spent primarily at the cruise condition [Lee, 2000]. Regional aircraft are 40% to 60% less fuel efficient than their larger narrow- and wide-body counterparts, while regional jets are 10% to 60% less fuel efficient than turboprops. Importantly, fuel efficiency differences between large and regional aircraft can be explained mostly by differences in aircraft operations, not technology [Babikian et al., 2002].

V. Policy Implications for Aviation Emissions Reduction

Policy approaches to emissions reductions, as they apply to air quality concerns, have been marked by requirements for technical feasibility, cost, and safety considerations. Many options for emissions mitigation have been proposed, including higher fuel taxes, emission charges, emission caps or limits, emissions trading, increased stringency of the certification standards, retrofit mandates, voluntary actions, demand management, and the possibility of no action. In this context, understanding the pace of efficiency change and the balance of technology renewal and cost will be paramount. The diverse and sometimes contradictory effects of aircraft emissions make reconciling the local air quality focus of current regulations with the global effects of climate impacts a difficult task. The pace of improvement in energy intensity, to which reductions in smoke, CO, and HC emissions contribute, are inherently driven by fuel cost considerations within the airline industry, and run counter to efforts to control NO_x. Thus, there is a reluctance to add controls or change the focus of current emissions without adequate understanding of the magnitude and nature of the related atmospheric impacts. Manufacturers and operators are concerned that mitigating aircraft emissions may be more costly than equivalent emissions in other economic sectors, partially because of the complexity of the atmospheric effects represented in the estimates shown in Figure 1.

As a modeling tool to aid aviation policy making, several systems have been developed in the past. Three-dimensional global inventories of civil aircraft fuel burned and emissions have been developed by the U.S. National Aeronautics and Space Administration(NASA)/Boeing and European governments. All of these models compile an aircraft movement database with aircraft/engine combinations. They then calculate fuel burned and emissions along great circle paths between origin destination cities. Recently, the FAA's Office of Environment and Energy and a team comprised by Volpe National Transportation Systems Center, Massachusetts Institute of Technology(MIT) and Logistics Management Institute have begun developing the System for Assessing Aviation's Global Emissions(SAGE). SAGE is envisioned to be an internationally accepted computer model that can be used for predicting and evaluating the effects of different policy and technology scenarios on aviation-related emissions and aircraft performance. To co-consider aviation emissions, noise and costs associated with implementing environmental technologies, bigger modeling frameworks such as Aviation Environmental Design Tool (AEDT) are also under development. For policymakers, it is important to know how uncertain outcomes change with different policy options and if the outcomes can be distinguished given the uncertainties of various models used. Policy makers need to know where models disagree and the modeling assumptions that cause the differences [Lee, 2005]. They also desire as small model variability as possible in order to ensure "robustness"of their policy design. Therefore, establishing and communicating model fidelity is an important task, which must parallel model development efforts. Identifying the uncertainty associated with model assumptions as modeling goes on is important because improving assumptions can improve model performance as well [Cipra, 2000; IPCC, 2001].

Lastly, to reduce the environmental impacts of aviation, policy makers must consider not only the technological/operational solutions and economic costs but where aviation stands in relation to society. Currently, there is not a strong public demandto reduce aircraft emissions. For the cases of aircraft noise or automobile emissions, a clear demonstration of health damages followed by strong public pressure to reduce the environmental nuisances have led to dramatic improvements in both technologies and the way the engineering systems are operated. However, people's awareness about aircraft emissions is relatively low today. There are also very large scientific uncertainties about the potential effects of jet engine emissions discharged at altitude. Therefore, it will be important to continue to advance atmospheric science of jet engine emissions and raise general public awareness about aviation's impacts on local air quality and the global atmosphere.

VI. Conclusions and Suggestions

Aviation emissions are expected to increase and constitute a greater proportion of the total anthropogenic climate impact. It has been estimated that aviation emissions accounted for 3.5% of the total anthropogenic radiative forcing in 1992. While the composition of aircraft emissions is similar to other modes of transport that use fossil fuels, the influence of aircraft emissions on the atmosphere occurs through different mechanisms, resulting in a comparatively greater effect on the atmosphere per unit mass.

Historically-based projections indicate that typical in-use aircraft energy intensity can be expected to decline at a rate of 1.2-2.2% per year, a pace of change which is not sufficient to counter the projected annual 4-5% growth in demand for air transport [Lee et al, 2001]. Unless measures are taken to significantly alter the dominant historical rates of change in technology and operations, the impacts of aviation emissions on local air quality and climate will continue to grow.

International governments have developed modeling tools to predict and evaluatethe effects of different policy and technology scenarios on aviation-related emissions and aircraft performance. Such tools require integrating technological and operational characteristics of the aviation sector with today's advancement in information technology. In Korea, air transport has a unique domestic market structure competing with the high-speed rail (i.e. KTX). It does not, however, have a well-established business to provide point-to-point service between small cities with regional aircraft where no other transport modes can reach. The Korean cargo carriers rank among the major service providers in the world, and this fact also requires a focused strategy to continue its success in the profitable cargo market. These are important questions to be addressed by the Korean industry, academia and the government.

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