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Air transportation and the environment

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ABSTRACT

This special issue of air transportation and the environment brings together analyses carried out by the integrated aviation modeling teams at the Massachusetts Institute of Technology and the University of Cambridge over the past 5–8 years. All contributions directly or indirectly relate to the challenges of measuring and/or responding to the environmental impact of air transportation in terms of noise, air pollution, and climate change. The contributors to this special issue identify several promising mitigation opportunities. However, in light of an anticipated continued growth in global aviation demand in the order of 5–6% per year, the identified opportunities are likely to only mitigate the growth in environmental impacts, at least over the next 20–30 years.

1. Introduction

Air transportation is a vital enabler of growth in the economy and quality of life through empowering trade and tourism on a global scale. The air transportation system accounts for about 10% of all passenger-km traveled and for 35% of the value of all goods traded internationally (Schäfer et al., 2009; IATA, 2013). According to the International Air Transport Association (IATA, 2013), the air transport industry also supports more than 56 million people worldwide, including directly providing 8.4 million jobs. Because of the large and still growing scale of the air transportation system, its undesirable environmental impacts have become increasingly important. Air transportation impacts people at the local level near airports (mainly through noise and air pollution), regional level (mainly through air pollution), and at a global scale (through climate change and air pollution).

Because the factors affecting growth in air transportation (such as rising income and the growing share of higher-value goods demanded) are likely to continue to increase, the relative and absolute importance of aviation is expected to continue to grow too. Figs. 1 and 2 depict the historical growth in world passenger and freight aviation up to 2011 and projections by the airline industry and the International Civil Aviation Organization (ICAO), various years. Since 1950, global air transportation has grown at a rate of about 5% and 6% per year for passenger and freight, respectively. Most of the projections in Figs. 1 and 2 are based on assumptions that these historical trends will continue. For passenger travel, prior projections have been quite accurate at least until 2011, the most recent year recorded. In contrast, in airfreight, where the economic downturns caused more significant and lasting reductions in demand, long-run projections after 1990 cover a larger spread. The dashed lines, representing a growth rate of 6% per year at different reference years, define an envelope that includes most projections.

If these trends materialize, world air transportation demand would double every 14 years for passenger services and every 12 years for freight operations. In absence of any change in technology and operations, the local, regional, and global environmental impacts would grow at a similar rate. Because of the increasing significance of these impacts, researchers worldwide are trying to quantify them and develop strategies for their reduction. This special issue brings together analyses carried out by the integrated modeling teams at the Massachusetts Institute of Technology and the University of Cambridge over the past 5–8 years.

2. Contributions to this special issue

The rate of growth in air transportation demand of 5–6% per year is unlikely to be significantly influenced by constrained runway capacities at primary airports within industrialized countries. Using a recently developed model that predicts airline operational responses to airport capacity constraints, Evans and Schäfer (in this issue) show that airlines would adjust operations within a constrained flight network in such a way as to avoid airports with high delays. In particular, airlines would reroute their flights towards less congested secondary airports, and, in addition,

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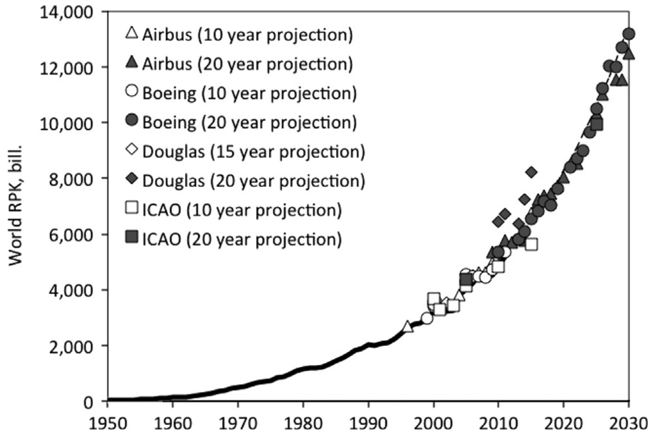

Fig. 1. World passenger revenue passenger-km, historical (1950–2011) and projections (Source: Airbus Industries, various years; Boeing Commercial Airplanes Group, various years; McDonnell Douglas, various years; International Civil Aviation Organization (ICAO), various years).

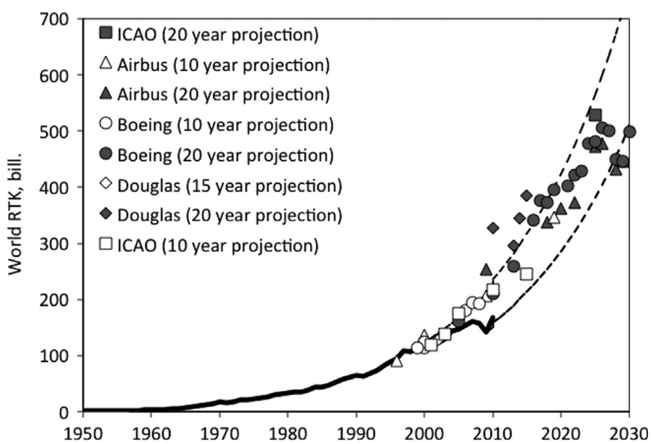

Fig. 2. World freight revenue tonne-km, historical (1950–2011) and projections (Source: Airbus Industries, various years; Boeing Commercial Airplanes Group, various years; McDonnell Douglas, various years; International Civil Aviation Organization (ICAO), various years).

increase the use of larger aircraft. However, the latter effect is small as airlines compete for market share by increasing their flight frequencies, an effect that naturally favors the use of smaller aircraft. While most system-wide implications for operations seem to be manageable, local impacts at congested hub-airports may be significant in terms of arrival delay, energy use, and emissions.

Already, aviation is responsible for about 2–4% of total energy-related greenhouse gas emissions. Due to its abundance, CO_2 is the single largest contributor to the anthropogenic greenhouse effect. Historically, aviation-induced CO_2 emissions have been responsible for about 3% of climate forcing, i.e., the energy imbalance of incoming solar irradiance and outgoing thermal energy (Dessens et al., in this issue). However CO_2 emissions are not the only aviation-related climate forcing agents. In fact, other aviation related emissions can be at least as harmful to the Earth's climate system and the question is how to account for those. As Dessens et al. (in this issue) argue, there is no simple metric that would allow inclusion of other greenhouse gases as a multiple of CO_2 emissions. For example, line-shaped contrails depend on the flight altitude and associated physical conditions rather than the amount of fuel burned and in the case of emissions of nitrogen oxides, it is the geographical location and altitude of the aircraft during flight that influence the magnitude of the climate forcing.

Importantly, the aviation environmental impact is not limited to climate change. Aircraft also emit fine particulate matter (PM2.5) and gaseous precursors of particulate matter. Because these pollutants originate from airport operations and are transported through the atmosphere, health damages may be distributed over local to global scales. As estimated with a response surface model by Brunelle-Yeung et al. (in this issue), airport take-off and landing operations were responsible for around 210 adult premature mortalities in the U.S. in 2005. Note that this is only a fraction of the total air quality health impacts that have been estimated when cruise emissions are included (see e.g., Barrett et al., 2010). These health impacts are mainly due to damages from particulate matter derived from gaseous precursors emitted by aviation, primarily consisting of nitrate and sulfate compounds. As the authors find, reducing engine NO_x emissions and the fuel sulfur content can reduce the number of adult premature mortalities: all other factors equal, a 10% reduction of NO_x emissions would lead to a decline in mortalities by 5%, whereas a 60% reduction of fuel sulfur would lead to a decline in mortalities by nearly 20%.

What measures exist to realize meaningful reductions of CO_2 emissions? We can decompose the reduction potential into two stages: (i) the benefit resulting from the implementation of the best available technology, and (ii) that associated with enhancing best available technology through modifications of the aircraft fuselage and engines. In addition, the air traffic management system can be enhanced to route aircraft more directly to the point of destination. Finally, the currently used petroleum-based jet fuels can be replaced by low-carbon alternatives, which may result in significantly reduced levels of lifecycle greenhouse gas emissions.

The CO_2 emission reduction potential associated with implementing the best available technology is estimated by Dray (in this issue). According to her analysis, if all commercial passenger and freight aircraft were replaced by the best available technology today, global aviation fuel use and CO_2 emissions would decline by almost 9%. An additional substitution of modern turboprop aircraft for their jet engine-propelled counterparts on suitable routes would increase that potential to about 10%. However, because of the long lifetime of aircraft and of models currently in production the full potential may only be exploited over several decades, mainly depending on the current age profile of the fleet and on fleet growth rates, with older current fleets and faster growth rates allowing faster technology introduction.

The potential for reducing aircraft fuel burn and thus CO_2 emissions of the best available technology is significantly larger. Already, aircraft have reduced fuel burn by 70% between 1960 and 2000. Based on a review of recent aircraft design studies, Graham et al. (in this issue) conclude that further reductions in the order of some 20–40% should be possible by 2050, corresponding to an annual average decline of 0.6–1.4%. This decline is largely in line with the last decades of aircraft development of around 1% per year. However, because the obvious measures for reducing the aircraft environmental impacts have already been exploited and because each of the three variables, fuel burn, NO_x emissions, and noise experiences diminishing returns, thus increasing the trade-offs, more drastic design changes would need to be pursued for their joint mitigation. Otherwise, challenging reductions in each of these three key benchmark measures of externalities, as projected by ACARE, are unlikely to be achieved. While tighter fuel-burn reduction targets of 75% by 2050 may be approachable with an appropriate combination of radical technologies (such as counter-rotating propeller engines, laminar flow control, automatic stability control, aeroelastic wings, double-bubble lifting fuselages, and box-wing construction), it appears that noise goals of a 65% reduction would most readily be achieved with radical,