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Time constants in aviation infrastructure

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ABSTRACT

If all aircraft in the global fleet were replaced with the most fuel-efficient present-day substitute technology, global aviation CO_2 emissions could be reduced by as much as 10%. However, the long lifetimes both of individual aircraft and of aircraft models in production mean that, in reality, any technology-based methods of emissions reduction will take a significant time to percolate into the fleet. The timescale over which new technology enters the fleet depends on a number of factors, most notably the demand for new aircraft, and is a potential barrier for technology-based (as opposed to economic or operational) policy measures. In this paper we evaluate aviation CO_2 emissions for the US, Europe and the world, discuss the theoretical reductions possible by substituting newer technology, assess the timescales on which these emission reductions are achievable, and discuss other timescales which may affect policy outcomes.

1. Introduction

In 2010, global aviation produced around 760 million tonnes of CO_2 (IEA, 2013) compared to a global total of 31,500 million tonnes of CO_2 from all fossil fuel usage (EIA, 2011a). Although aviation's share of total anthropogenic climate impacts depends on the pollutants, timescale and metric considered, and whether factors such as land use change are taken into account, a figure of 2–4% is typical (IPCC, 1999; Lee et al., 2009). For 2010, around 29% of these aviation emissions were from flights originating in the US and 19% from flights originating in the EU (IEA, 2013; Eurostat, 2013).

Despite the economic slowdown in recent years, global demand for aviation has already returned to growth. Airbus and Boeing forecast a roughly 5%/year increase in global revenue passenger kilometres (RPK) over the next 20 years, with more rapid growth in Asia and the Middle East, and less rapid growth in the US and EU (Schäfer and Waitz, in this issue). Unless aviation can achieve the challenging goal of reducing emissions per RPK by 5%/year, this implies an increase in total aviation emissions.

If a 5%/year rate of aviation demand growth is sustained until 2050, IPCC (1999) project that aviation would account for over 10% of global fossil fuel carbon emissions, assuming new aircraft fuel burn per RPK decreases on average by around 0.5%/year. This is due to the slower projected growth rates of emissions from other sources (IPCC, 2007). This expected future increase in the relative impact of aviation emissions has led to increased consideration of aviation by policymakers, including its (currently partial) introduction into the EU's emission trading scheme (European Union, 2009).

A variety of operational, technological and economic measures have been proposed to reduce aviation's climate impact. As discussed elsewhere in this Special Issue, each of these approaches has potential to reduce aviation emissions. The most promising solution for reducing aviation's total climate impact is likely the one in which all three approaches are utilised. However, they operate on different timescales. The timescales of economic measure introduction are determined primarily by the time required to set up the institutional infrastructures necessary for monitoring, reporting and payment. For example, the EU's directive on aviation emissions trading was issued in 2008, with trading beginning in 2012 (European Union, 2009). For operational measures, implementation timescales vary depending on the complexity of the proposed measure. New aircraft operating procedures have to go through several stages, including development, impact assessment, approval by aviation authorities, database/publication updates and crew training, before they can be implemented. Such a process can take less than a year for a minor change, or more than a decade if airspace re-design is also needed.

The introduction of new aircraft technology has played a major part in reducing per-passenger fuel use and emissions. Between 1959 and 1995, the cruise specific fuel consumption of new aircraft models declined by approximately 40%, an average of 1.5% per year (Lee et al., 2001; Greene, 1992). However, the rate of decrease has slowed over time (IPCC, 1999). Current technologies in development may lead to further reductions (Graham et al., in this issue). The long life and high capital cost of aircraft mean that this

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transition from old to new technology is associated with a significant time lag. IPCC (1999) estimate that the time between initial technology development for a successful aircraft model and the eventual retirement of that aircraft model from service is typically 45–65 years, including 5–10 years for technology development, certification and testing. For an individual jet aircraft, a total lifespan of 25–35 years is typical (Morrell and Dray, 2009), and a production run can last as long as 20 years. This implies that present-day models of aircraft will still form a significant part of the fleet in 2050.

Typically, aircraft pass through several owners before they are finally scrapped; the decision to sell or scrap depends on a number of factors, including resale value, demand growth, fuel costs, maintenance cycles and characteristics of competing models of aircraft. Because individual aircraft has long lifetimes and long-term average growth rates in aviation demand are high, the majority of new aircraft entering the fleet are purchased to serve new demand rather than as replacements for retiring aircraft. This means that the rate at which new technology enters the fleet is mainly dependent on demand growth. In particular, demand for new aircraft is low when passenger and freight demand growth is weak or negative. Under these circumstances it can be difficult to introduce new technology to the fleet even when that technology is available. However reductions in demand, such as that observed after September 11 2001, can improve fleet fuel efficiency via the storage and/or scrappage of older aircraft.

Technology development timescales are also likely to depend on fuel prices. It has been suggested (Aboulafia, 2009) that low fuel prices would delay the development of narrowbody replacement aircraft. Similarly, low fuel prices may prompt manufacturers to concentrate on designs which reduce noise or local emissions or maximise passenger comfort, rather than reducing fuel burn. These factors could influence the success of policies aimed at reducing aviation's climate impact through technological intervention.

The structure of this paper is as follows. In Section 2, recent emissions from the US, EU and global fleets are analysed and a methodology is developed to estimate what CO_2 savings would be possible if all technologies were replaced by the lowest-emission substitutable technology. In Section 3, we model the timescales over which this transition could occur. In Section 4, we discuss other important factors and policies that could be used to influence these timescales, and draw conclusions.

2. Recent fuel use and CO_2 emissions

A wide range of estimates exist for recent aviation emissions and fuel use. Estimates can be obtained either from inventories of aviation fuel used (IEA, 2013), or by starting from an inventory of known flights and modelling the fuel burn for each of these flights (Gardner et al., 1997). Inventories can differ significantly depending on the base year, the methodology used, and which emission sources and regions are included or excluded. For example, military aviation accounted for around 15% of global fuel use in 1992 (IPCC, 1999), and 11% in 2002 (AERO2k, 2004). This proportion has historically declined over time (IPCC, 1999). Non-scheduled flights in 2003 accounted for 7% of civil aviation large-body aircraft fuel use (Malwitz et al., 2007). These sources are included in some inventories but excluded in others (Lee et al., 2009). A summary of some major aircraft emission inventories is given in Table 1.

2.1. Modelling US recent fuel use and CO_2 emissions

Our approach to model the effect of introducing new technology is to first model emissions from existing technology, using schedules and flight inventories to obtain the number of flights by aircraft type, distance flown and payload carried. The same modelling is then repeated, substituting the aircraft type for one which has the lowest fuel burn or 'best-available' technology (BAT) suitable for the given range and payload.

To model emissions from present-day technology, we used the PIANO-X model (Lissys, 2009). Due to the large number of flights involved, a lookup table was constructed for each aircraft type from PIANO-X runs using a 12×24 grid of payload and distance values covering the operable limits of that aircraft type. For aircraft not represented in PIANO-X, the alternative aircraft closest in fuel burn, range and seat number was chosen based on information from the BADA database (Eurocontrol, 2004). Fuel use for a flight with a given aircraft type, payload and distance was then found by interpolating within this table.

The US Form 41 dataset (US DoT, 2013) contains detailed information about fuels issued to US carriers by aircraft type, time period and carrier. In addition, the T100 dataset (US DoT, 2013) contains information about flights within, to and from the US by carrier, aircraft type, origin and destination, including passengers, freight and mail carried. We assume great circle routes between origin and destination airports and a standard weight for a passenger plus baggage of 230 lb (US DoT, 2005) to calculate the payload carried and distance flown. Applying this methodology to the T100 data, we obtain fuel burn totals for the carriers and aircraft types included in this dataset which are around 16% lower than those observed in the Form 41 data. Despite this difference, the total time elapsed for these flights in both databases is similar. As noted by Reynolds (in this issue), modelling of routing assuming great circle trajectories will underestimate the true fuel use,

Table 1
Aviation emissions inventories from literature by date, applicable world region and part of fleet.

Source	World region	Scope	Time period	Fuel use (billion litres)	CO_2 emissions[a] (million tonnes)
AERO2k (2004)	Global	All civil and military aviation, modelled from flight track data where possible	2002 and 2025 projection	217.7 (2002) 405.0 (2025)	533 (2002) 1029 (2025)
IEA (2013)	Global	Total aviation fuel consumption	Yearly, from 1971	283.5 (2005)	725.4 (2005)
US DoT (2013)	United States	Civil aviation by US certificated air carriers, actual fuel uptake data	Monthly, from 2002	62.7 (dom) 27.2 (intl) (2005)	160.0 (dom) 69.5 (intl) (2005)
Eurostat (2013)	EU27	Total aviation fuel consumption	Monthly, from1990	67.0 (2005)	171.5 (2005)
UN (2013)	197 countries	Aviation fuel consumption in air transport	From 1990	128.0 (2005)	327.4 (2005)
EIA (2011b)	US	Supply of jet fuel	Monthly, from 1981	97.4 (2005)	249.3 (2005)
ANCAT/EC2 (Gardner et al., 1997)	Global	All civil and military aviation, mix of full ATC data and scheduled data	1991–1992	204.3 (1992)	528.0 (1992)
NASA (Baughcum et al., 1996)	Global	Civil aviation, scheduled traffic only	1992	117.6 (1992)	301.0 (1992)

[a] Where CO_2 production is not explicitly given, fuel use by kg is converted to kg CO_2 using a factor of 3.1685.

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