Chapter 1

AVIATION'S CONTRIBUTION TO CLIMATE CHANGE

Aviation's Contribution to Climate Change

Overview

By ***ICAO Secretariat***

The ICAO Environmental Report – 2007, provided detailed background information on the issues of aircraft emissions and climate change. This article provides a high-level overview as well as an update on the science of climate change as it relates to aircraft emissions.

According to the Intergovernmental Panel on Climate Change (IPCC), climate change refers to any change in climate over time, whether due to natural variability, or as a result of human activity. Global climate change is caused by the accumulation of greenhouse gases (GHG) in the lower atmosphere (see article *Aviation Greenhouse Gas Emissions – Overview*, Chapter 1 of this report). The GHG of most concern is carbon dioxide (CO_2).

Aviation is a small but important contributor to climate change. ICAO/CAEP's initial estimate is that the total volume of aviation CO_2 emissions in 2006 (both domestic and international) is in the range of 600 million tonnes. At present, aviation accounts for about 2% of total global CO_2 emissions and about 12% of the CO_2 emissions from all transportation sources.[1,2]

Aircraft engines produce emissions that are similar to other emissions produced by fossil fuel combustion (for technology advances in aircraft and aircraft engines, refer to Chapter 2 of this report). However, most of these emissions are released directly into the upper troposphere and lower stratospheres where they are believed to have a different impact on atmospheric composition, as shown in Figure 1. The specific climate impacts of these gases and particles when emitted and formed are difficult to quantify at present.

As Figure 1 illustrates, GHGs trap heat in the Earth's atmosphere, leading to the overall rise of global temperatures, which could disrupt natural climate patterns.

Estimating Climate Change Impacts

The range of estimated future impacts of aviation CO_2 emissions varies to a great degree, depending on the metric used (e.g. mass of CO_2 emissions, radiative forcing and temperature increase) and/or the methodology applied. Reducing uncertainty in estimating the total emissions and their impacts on the climate is the paramount factor in establishing sound policies.

For this reason, ICAO relies on the best technological and scientific knowledge of aviation's impact on climate change. ICAO has cooperated with IPCC, other international agencies and world-renowned scientists and technical experts on improving methodologies used when calculating aviation emissions and quantifying their impacts. The production of the IPCC 1999 special report on "Aviation and the Global Atmosphere" and a more recent IPCC assessment, the IPCC Fourth Assessment Report (AR4) are outstanding examples of such cooperation. The ICAO Workshop on Impacts in 2007 provided an opportunity for the best technical experts in aviation and climate change to come together and assess the latest scientific knowledge, uncertainties and gaps in quantifying climate change impacts[3]. The articles in this chapter will primarily focus on the state-of-the-art in measurement and modelling methods for quantifying aviation emissions and their impacts.

Impacts of Aviation GHG Emissions

Aviation climate impacts are due to both CO_2 and non-CO_2 emissions (see Figure 2). The non-CO_2 emissions include water vapor (H_2O), nitrogen oxides (NO_x), sulfur oxides (SO_x), hydrocarbons (HC), and black carbon (or soot) particles. Climate impacts of CO_2 emissions are well characterized and are independent of source location due to its relatively

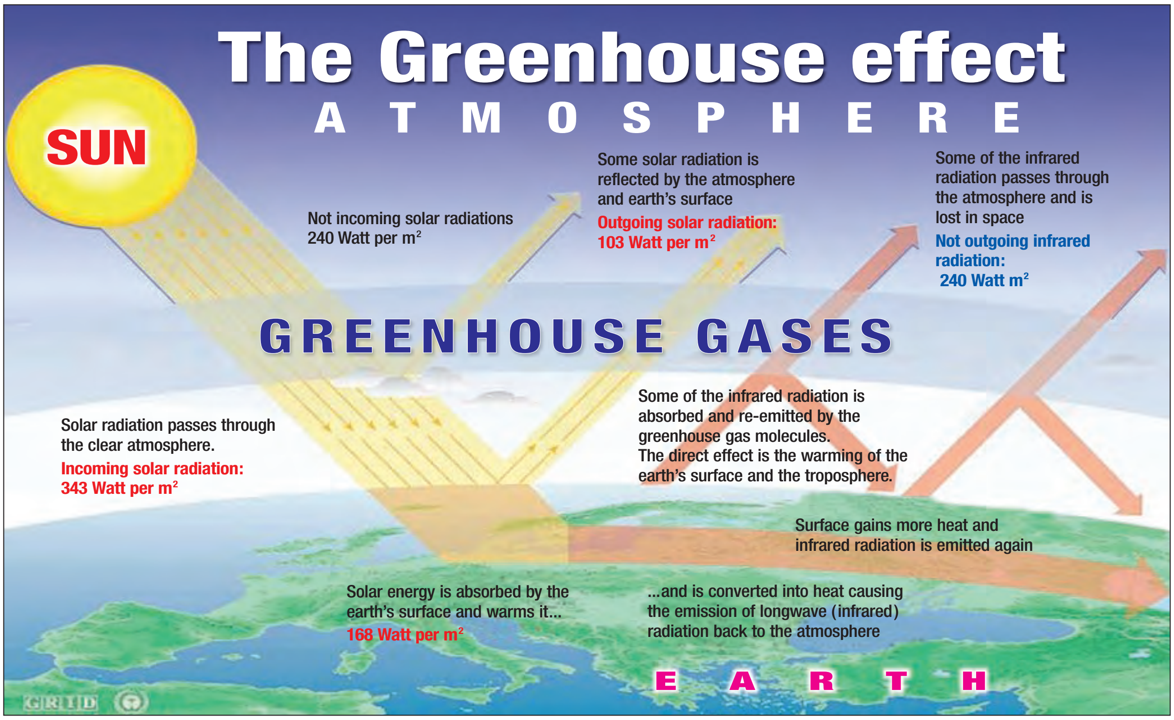


Figure 1: *The greenhouse effect on the atmosphere (IPCC Fourth Assessment Report).*

long atmospheric lifetime. On the other hand, non-CO_2 climate impacts of aviation emissions are quite variable in space and time. The primary factor for non-CO_2 emissions from aircraft is that the largest portion of these emissions are emitted in the flight corridors throughout the upper troposphere and lower stratosphere at altitudes of 8 km to 13 km (26,000-40,000 ft). The lifetime of the associated atmospheric changes ranges from minutes for contrails, to years for changes in methane.

Climate Impact Metrics:
In order to quantify the potential climate impact of changing atmospheric constituents such as GHGs, several measures can be used. Despite some of their shortcomings, these measures are convenient "metrics" that allow estimation of potential climate change in terms of such factors as global mean temperatures, from an emission of GHGs into the atmosphere.

MT (Metric ton (Mt), Million Metric Ton (MT), Giga Ton (Gt)): *Based on amounts and molecular weights of GHG compounds.*

CO_2e (Carbon Dioxide Equivalents): *"Normalizing" effects of various GHG to that of CO_2 using GWP.*

RF (Radiative Forcing): *The change in average radiation (in Watts per square metre: W/m^2) at the top of the tropopause resulting from a change in either solar or infrared radiation due to a change in atmospheric greenhouse gases concentrations; perturbance in the balance between incoming solar radiation and outgoing infrared radiation.*[4]

GWP (Global Warming Potential): *The cumulative radiative forcing effects of a gas over a specified time horizon resulting from the emission of a unit mass of gas relative to a reference gas.*[5]

Figure 2 displays a schematic of aircraft emissions and their resulting potential impacts on climate change and social welfare. Aviation CO_2, H_2O and soot emissions contribute **directly** to climate change with positive radiative forcing (net warming). Whereas, emissions of NO_x, SO_x, H_2O and black carbon aerosols contribute **indirectly** to climate change.

In general, there is a better understanding of impacts of GHG emissions that have a **direct** impact on the climate than emissions that have **indirect** impacts. For example, while the scientific understanding and modelling of NO_x effects have substantially improved over the last few years, there is still uncertainty regarding the exact extent to which NO_x emissions from air travel affect climate change through their impact on ozone formation and methane destruction. Similarly, H_2O vapor emissions can trigger formation of contrails in sufficiently cold air masses which may persist for hours and can potentially increase cirrus cloudiness. Direct emissions of black carbon and *in situ* formed aerosols can also serve as cloud condensation nuclei which, along with background aerosols, facilitate the formation of contrails and cirrus clouds. Contrails and induced cirrus clouds reflect solar short-wave radiation and trap outgoing long-wave radiation resulting in the net positive contribution to climate change.

Significant scientific advances have been made over the last decade to better characterize aviation climate impacts. However, the level of scientific understanding, particularly for quantification of the climate impacts of contrails and induced cirrus clouds remains unchanged and ranges between low and very low, respectively.[2,4] In fact, the IPCC AR4[8] did not even attempt to quantify the climate-forcing associated with aviation induced cirrus clouds. The 2007 ICAO/CAEP workshop report[3] also made similar conclusions about the understanding and uncertainties specific to non-CO_2 aviation climate impacts.

Aviation Climate Change Policies

A number of domestic and international climate-related policy actions are being presently considered that may profoundly impact the global aviation sector. A well developed suite of analysis and estimation tools, at the individual level, as well as at the national and global levels, is needed to inform optimally balanced cost-beneficial actions while accounting for system-wide environmental tradeoffs and interdependencies (see articles *Models and Databases – Review and Recommendations*, *Meeting the UK Aviation Target – Options for Reducing Emissions to 2050*, and *Greenhouse Gas Management at Airports*, in Chapter 1 of this report).

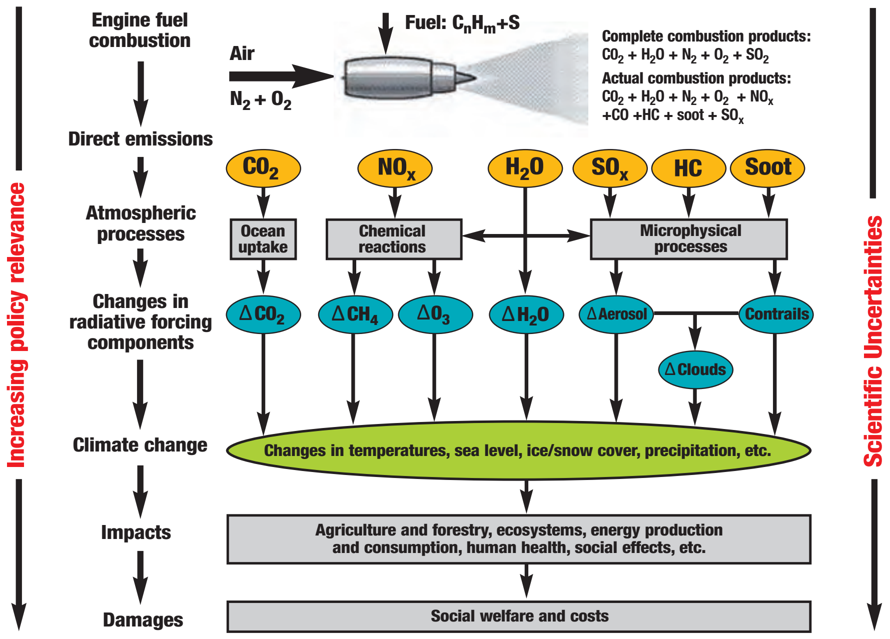
Since June 2008, the ICAO public website has included a Carbon Emissions Calculator[7], whose impartial, peer-reviewed methodology was developed through CAEP. It applies the best publicly available industry data to account for various factors such as aircraft types, route specific data, passenger load factors and cargo carried (see article *The ICAO Carbon Emissions Calculator*, in Chapter 1 of this report).

In 2006, IPCC issued its *guidelines for the national greenhouse gas inventories (2006 IPCC guidelines)*[8] in order to assist countries in compiling complete, national inventories of greenhouse gases, including those from aviation. According to the guidelines, emissions from international and domestic civil aviation include takeoffs and landings. The emissions cover civil commercial use of airplanes, including: scheduled and charter traffic for passengers and freight, air taxiing, and general aviation. The international/domestic split should be determined on the basis of departure and landing locations for each flight stage and not by the nationality of the airline. The use of fuel at airports for ground transport and stationary combustion should be excluded because they are covered under separate categories.

The *2006 IPCC guidelines* suggest collecting the fuel consumption for domestic and international aviation by surveying airline companies or estimating it from aircraft movement data and standard tables of fuel consumed, or both. As an alternative, a top down data approach could be used which involves obtaining fuel consumption data from taxation or customs authorities in cases where fuel sold for domestic use is subject to taxation and customs duties.

Next Steps

Although there is general agreement that inventories are an essential first step to quantifying impacts, there is a considerable divergence of views as to the single best approach to defining the consequent climate impacts. An "impact chain" can be defined starting from inventories, moving to regional and global indicator geophysical responses with their respective impacts on resource/ ecosystem/ energy/ health/ societal responses, and finally ending with overall social welfare/ costs responses. Although this impact chain can be described in a qualitative way, quantification of each of the steps in this chain is complex, and considerable scientific and intellectual resources are required to reach a consensus. This is a considerable challenge for society as a whole and is certainly not restricted to the debate over one sector's impacts on climate.



Sources: *Okanagan University College in Canada, Department of Geography, University of Oxford, School of Geography; United States Environmental Protection Agency (EPA), Washington; Climate Change 1995. The Science of Climate Change, contribution of Working Group 1 to the Second Assessment Report of the Intergovernmental Panel on Climate Change, UNEP and WMO, Cambridge University Press, 1996.*

Figure 2: *Schematic representation of aircraft emissions and their causal linkages with potential climate and social welfare impacts. Note that both the level of scientific uncertainties and policy relevance increase from characterization of emissions to social damage attributions. (Adapted from Wuebbles* et al.*, 2007).*[5]

Fuel Efficiency Rules of Thumb:

- On average, an aircraft will burn about 0.03kg of fuel for each kg carried per hour. This number will be slightly higher for shorter flights and for older aircraft and slightly lower for longer flights and newer aircraft.
- The total commercial fleet combined flies about 57 million hours per year; so, saving one kg on each commercial flight could save roughly 170,000 tonnes of fuel and 540,000 tonnes of CO_2 per year.
- Reducing the weight of an aircraft, for example by replacing metal components with composites, could reduce fuel burn by as much as 5%.
- Average fuel burn per minute of flight : 49 kg.
- Average of fuel burn per nautical mile (NM) of flight : 11 kg.

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http://web.mit.edu/aeroastro/partner/reports/caepimpactreport.pdf

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5 *http://www.epa.gov/climatechange/glossary.html#G*

6 *Wuebbles, D.* et al.*, Evaluating the impacts of aviation on climate change, EOS Transactions,*
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7 *http://www2.icao.int/en/carbonoffset/Pages/default.aspx*

8 *The IPCC 2006 guidelines for national greenhouse gases are available at*
http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html

Aviation Greenhouse Gas Emissions

By ***David S. Lee***

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David has been supporting the UK's activities in the CAEP arena since about 1995 and is a member of the UK delegation at CAEP meetings. He co-leads the new CAEP group, the Impacts and Science Group. David has specialized in research on aviation impacts on climate and was lead author for the recent ATTICA assessment. He has been a Lead Author for the IPCC since 1997.

Introduction

Aviation emits a number of pollutants that alter the chemical composition of the atmosphere, changing its radiative balance and hence influencing climate. The principal "greenhouse gas" pollutant emitted from aviation is CO_2 (carbon dioxide). Total emissions of aviation CO_2 represent ~2.0 to 2.5% of total annual CO_2 emissions (Lee et al., 2009a). Other emissions from aviation that affect the radiative balance include nitrogen oxides (NO_x, where NO_x=NO+NO_2), sulphate and soot particles, and water vapour. These lead to a variety of effects outlined later in this article.

Other papers have dealt extensively with non-CO_2 aviation emissions and effects (e.g. Lee et al., 2009b). In this article, the focus is upon CO_2 emissions, their contribution to global warming, and more importantly, what role future emissions may have in limiting warming to a policy target of an increase of no more than 2° C by 2100 over pre-industrial levels, as is the target of many countries, the European Union, and as mentioned in the Copenhagen Accord.

Aviation emissions of CO_2

The only 'greenhouse gas' emissions from aviation are CO_2 and water vapour: other emissions, e.g. NO_x and particles result in changes in radiative forcing (RF) but are not in themselves 'greenhouse gases'. Emissions of water vapour from current subsonic aviation are small and contribute (directly) in a negligible manner to warming.

Emissions of CO_2 are proportionally related to fuel usage (kerosene) by a factor of ~3.15. Figure 1 shows the development of aviation fuel usage since 1940, along with the

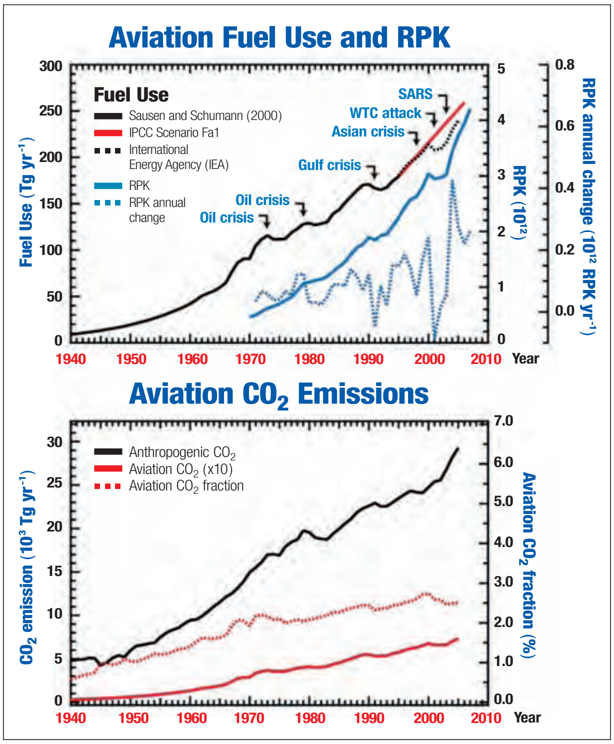

Figure 1: *Aviation fuel usage, RPK, and the annual change in RPK (Note offset zero) over time.*

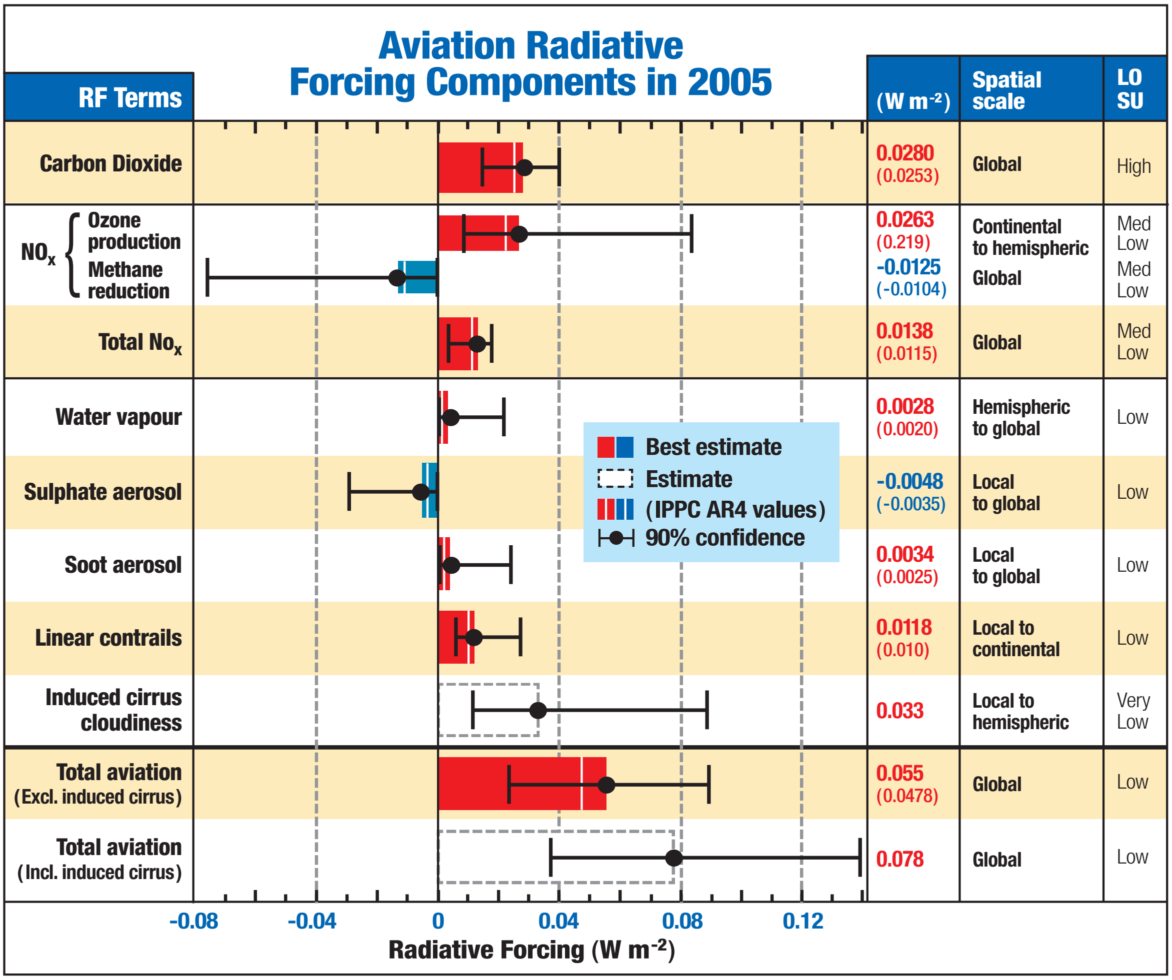

Figure 2: *Radiative forcing components for aviation in 2005 from Lee et al. (2009a) (For more details of results and calculation methodologies, see that paper).*

revenue passenger kilometres (RPK). A number of events impacting the sector (oil crises, conflicts, disease) show a response in demand and in emissions, and that the sector is remarkably resilient and adaptable to a variety of external pressures. How the current global economic crises will affect aviation remains to be seen but there are early signs of recovery. The usual pattern is a decline or downturn in demand that often recovers after 2 to 3 years, sometimes so strongly that the growth is put back 'on track'.

For example, after the early 2000s events, recovery in RPK in some subsequent years was remarkable. The lower panel of Figure 1 shows aviation CO_2 emissions in context with total historical emissions of CO_2 from fossil fuel usage. Emissions of CO_2 (total) as an annual rate increased markedly in the late 1990s and early 2000s. This was not reflected in the early 2000s by the aviation sector, because of suppression of demand in response to the events of 9-11 etc.; another reason why an annual percentage contribution of aviation emissions to total CO_2 emissions can be misleading when not placed in a longer-term perspective, as Figure 1 shows.

The lower panel of Figure 1 shows the growth in CO_2 emissions in Tg CO_2 yr^{-1} (per year) for all fossil fuel combustion and from aviation (left-hand axis), and the fraction of total anthropogenic CO_2 emissions represented by aviation CO_2 emissions (%) (right-hand axis). Note the x10 scaling of aviation CO_2 emissions. This figure was taken from Lee et al. (2009a).

Radiative Forcing

The concept of RF is used as there is an approximately linear response between a change in RF and the global mean surface temperature response. RF as a metric is inherently easier to compute than a temperature response, which adds another level of uncertainty. This is the preferred method of the IPCC in presenting impact quantification.

RF is defined as a change in the earth-atmosphere radiation balance as a global mean in units of watts per square metre, since 1750. As the earth-atmosphere system equilibrates to a new radiative balance, a change in global mean surface temperature results.

Much recent work related to climate change has considered 'metrics' (e.g. Waitz, this volume; Fuglestvedt et al., 2009). RF is a scientific metric and is fit for that purpose – other metrics for policy or emissions reductions are usually comparative, e.g. the Global Warming Potential, which compares the integrated RF of a pulse emission of a greenhouse gas over a certain time horizon to that from CO_2. Such usages and purposes of metrics should not be confused.

Aviation's RF impacts have been quantified for the year 2005 (Lee et al., 2009a) and are presented in Figure 2. It is clear, as has been the case since the IPCC assessment of aviation in 1999, that aviation's RF impacts are "more than just CO_2". However, the annual emission rates from aviation for different RF effects do not account for the accumulative nature of CO_2, when compared with shorter-term effects of NO_x, contrails, cirrus, etc. The RF for CO_2 from aviation accounts for its total emissions over time up until the present day.

Accumulation of CO_2 in the Atmosphere and the Role of Aviation

Recent policy discussions have focussed on the requirement to limit increases in global mean surface temperature (stabilization), rather than setting arbitrary emissions reductions targets that have uncertain and unpredictable outcomes. Such target-setting has already been discussed in climate science and much work has been published on this. The concept of

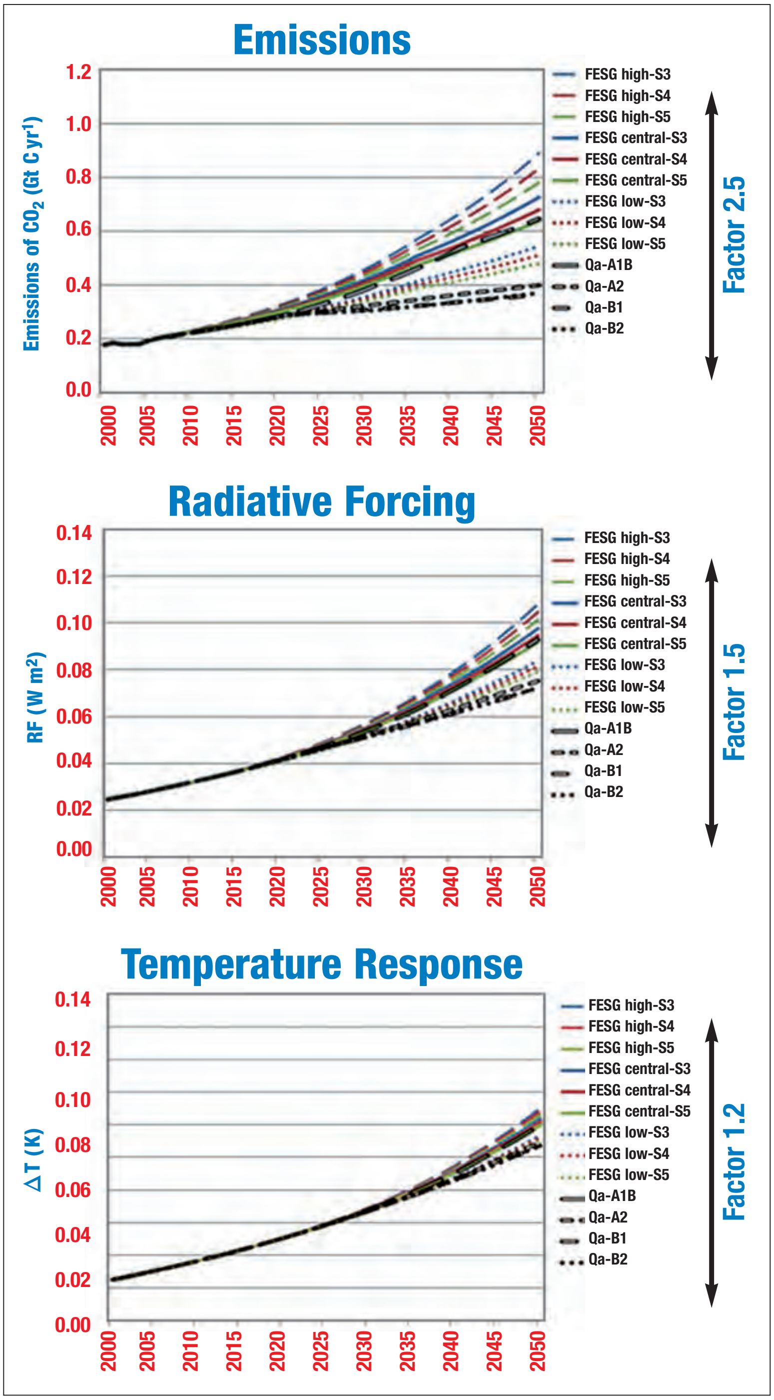

Figure 3: *Emissions of CO_2 for a range of aviation scenarios from 2000 to 2050, and their corresponding radiative forcing and temperature responses (CO_2 only).*

controlling emissions for 'stabilization' is relatively mature science, particularly for CO_2.

Total cumulative CO_2 emissions have a relationship with the temperature response of the earth-atmosphere system and it has been shown that (to a first order) limiting the total amount of CO_2 emitted is a reliable means of not exceeding some specified temperature target (e.g. Allen *et al* 2009, Meinshausen *et al* 2009, WBGU 2009).

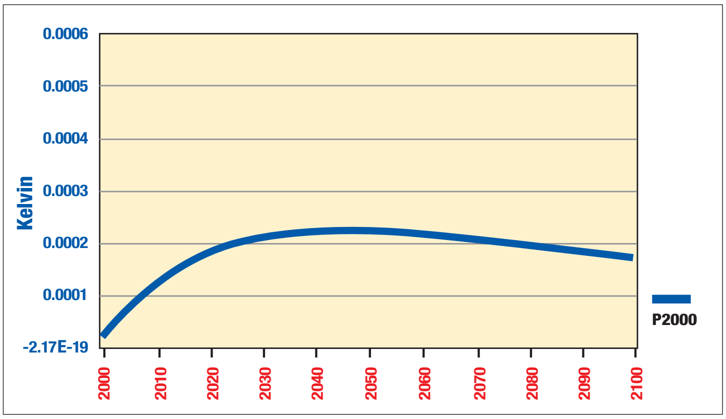

Figure 4: *Time development of the temperature response of a single year emissions from aviation in 2000.*

This makes the quantification of CO_2 emissions (past and future) a very powerful policy tool, but this must be based on total cumulative emissions, not emission rates. Currently, climate policy does not account for this, although a temperature-based target is well-suited to such a measure. Such a measure is applicable to all sectors. If a variety of future emission scenarios for aviation are selected, and their CO_2 RF and temperature response computed, it can be shown that the apparent variance between 'end-point' emissions in 2050 collapses markedly in terms of RF and temperature response.

In Figure 3, a range of currently-available aviation emissions scenarios to 2050 are utilized. The top panel shows that the 2050 end-point emissions differ by a factor of 2.5. However, when CO_2 RF response is computed, the cumulative nature of CO_2 emissions is accounted for and the end-point RF values only vary by a factor of 1.5. If the end-point temperature is then computed, this variation is reduced to a factor of 1.2 difference between these temperature responses in 2050, since another important factor, the thermal inertia of oceans is accounted for. These graphs show that differences in emissions scenarios – as an end-point – are not proportionally reflected in the temperature response and differences are much reduced.

This may be more easily understood by considering a single pulse of CO_2 emissions and observing the temperature response over subsequent decades, as shown in Figure 4. The emissions from 2000 cause this time-dependent increase and the subsequent decline in temperature. Thus, the scenario results of emissions in Figure 3 can be understood from this hypothetical case which more clearly illustrates time-dependencies of response to emissions.

In the context of CO_2 emissions and 'lifetime', it is a misconception that CO_2 has a lifetime of about '100 to 150 years'. It should be appreciated that CO_2 is more complex than other greenhouse gases and has **several** lifetimes, depending on the sink being considered. There are also biogeochemical feedbacks that affect 'lifetime'. According to IPCC (Fourth Assessment Report), 50% of an increase in concentrations will be removed within about 30 years, a further 30% being removed within a few centuries, and that the residual 20% remains in the atmosphere for many thousands of years. Thus, a simplistic concept of a simple 100 to 150 year lifetime is incorrect, and at worse dramatically underestimates impacts.

The key outcome for this methodological basis of determining how a temperature-based policy is achieved is that it is the cumulative emissions over time that matter, not the emission rate at a given future date. The science for this is mature and robust. The more contentious issue is how much CO_2 emissions (cumulative) are allocated. If a temperature-based policy is pursued, then the cumulative carbon concept is inevitable, and the science to support such a policy is mature and ready to be used. Moreover, the science can be usefully used to determine the potential impacts of sectoral reductions in emissions.

Conclusions

Aviation currently contributes around 2.0 to 2.5% of current total annual global CO_2 emissions, but discussions over such proportions are of limited value. What is important is the total of emissions over time. In the absence of policy intervention, aviation emissions of CO_2 are projected to increase over 2005 levels of 0,2 Gt C yr^{-1} by 1.9 to 4.5 fold (0.37 to 0.89 Gt C yr^{-1}) by 2050.

Emission rates are less relevant to both the effects (in terms of changes in CO_2 concentrations, RF and temperature response) and policy measures than total cumulative CO_2 emissions, since this latter measure is directly related to effects. Non-CO_2 impacts remain important and add to increases in temperature response from aviation, as long as those emissions continue but the temperature response from CO_2 persists for many thousands of years after the emission has ceased.

The amount of cumulative CO_2 emissions that will result in a 2° C temperature increase is relatively well known and quantified: one trillion tonnes of CO_2, half of which has already been emitted. The question that remains is "what proportion can aviation have of the half a trillion tonnes of CO_2 that can be emitted, before surface temperatures increase beyond 2° C?" ■

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Meeting the UK Aviation Target

Options for Reducing Emissions to 2050

*By **David Kennedy, Ben Combes** and **Owen Bellamy***

*The **UK's Committee on Climate Change** (CCC) is an independent statutory body established under the Climate Change Act to advise the UK Government on UK emissions targets, and to report to Parliament on progress made in reducing the UK's greenhouse gas emissions.*

*For more information please visit **www.theccc.org.uk***

Background

In January 2009 the previous UK Government decided to support the addition of a third runway at Heathrow Airport, committing to an expansion of allowable Aircraft Traffic Movements (ATMs) at Heathrow from 480,000 to 605,000 per annum. As part of that decision, the Government set a target that CO_2 emissions from UK aviation in 2050 should be at or below 2005 levels. It therefore asked the Committee on Climate Change, the Government's official climate advisers, to report on how this target could be met. The Committee set out its advice in a report published in December 2009 titled *Meeting the UK aviation target – options for reducing emissions to 2050*[1].

This article outlines the Committee's advice and assessment of the actions required to ensure that UK aviation CO_2 emissions in 2050 (domestic and international departing flights) do not exceed 2005 levels of 37.5 Mt CO_2[2]. In particular, it assesses the maximum increase in demand from current levels which is likely to be consistent with this target, given current best estimates of future technological progress.

If the target were to be achieved, it is estimated that UK aviation emissions would account for about 25% of the UK's total allowed emissions in 2050 under the economy-wide target – i.e. to cut all emissions by 80% in 2050 relative to 1990 levels – as included in the UK's Climate Change Act. This would require 90% reductions in other sectors of the economy.

Approach

In making its assessment, the Committee started by projecting the possible growth of demand and emissions if there were no carbon price constraining demand, and if no limits were placed on airport capacity expansion. It then considered scope for reducing emissions through carbon prices, modal shift from aviation to rail/high-speed rail, substitution of communications technologies such as video-conferencing for business travel, improvements in fleet fuel efficiency, and use of biofuels in aviation.

The work was concluded by setting out scenarios for aviation emissions to 2050, encompassing the range of options for reducing emissions, comparing emissions in 2050 with the target, and considering how any gap might be closed.

The potential implications of non-CO_2 aviation effects on global warming were also noted. The scale of such effects is still scientifically uncertain, and the effects are not covered by the Kyoto Protocol, the UK Climate Change Act, or the Government's aviation target. The report highlights the likely need to account for these effects in future global and UK policy frameworks, but does not propose a specific approach. The assessment of required policies was therefore focused on the target as currently defined – keeping 2050 UK aviation CO_2 emissions to no more than 37.5 Mt CO_2.

The Committee believes it to be the first of its kind. Although it relates specifically to achieving a UK target, the approach taken and methodology used are more widely applicable to developed countries with similar carbon constraints to the UK.

Key Findings

The key findings that came out of the study are as follows:

Projected Demand Growth

In the absence of a carbon price, and with unconstrained airport expansion, UK aviation demand could grow by more than 200% between 2005 and 2050:

- Demand for UK aviation has grown by 130% over the past 20 years in a context where UK GDP has increased by 54% and air fares have fallen significantly.
- Given forecast real UK income growth of around 150% in the period to 2050, and without a carbon price or capacity constraint, it is projected that UK aviation demand could grow by over 200% from the 2005 level of 230 million passengers annually to 695 million passengers by 2050.

A rising carbon price and capacity constraints could reduce demand growth by 2050 to 115%. Specifically, this decrease in demand would result from a carbon price rising gradually to £200/tCO_2 in 2050, together with limits to airport capacity expansion as envisaged in the 2003 UK Air Transport White Paper (i.e. expansion at Edinburgh, Heathrow, Stansted, and no further expansion).

Modal Shift and Videoconferencing

There is scope for a useful contribution to achieving the 2050 aviation emissions target through modal shift from air to rail and increased use of videoconferencing:

- There is scope for significant modal shift to rail/high-speed rail on domestic and short-haul international routes to Europe, which could reduce aviation demand by up to 8% in 2050.
- There is uncertainty over scope for substitution of videoconferencing for business travel. The report reflects this by using a conservative range, from very limited substitution, to a reduction of 30% in business demand in 2050.
- Together, modal shift and videoconferencing could result in a reduction in UK aviation emissions of up to 7 Mt CO_2 in 2050.

Improvements In Fleet Fuel Efficiency

Fleet fuel efficiency improvement of 0.8% annually in the period to 2050 is likely, given current technological trends and investment intentions:

- The Committee's expectation is that improvement in fleet fuel efficiency of 0.8% per annum in the period to 2050 is achievable through evolutionary airframe and engine technology innovation, and improved efficiency of Air Traffic Management and operations.
- This pace of improvement would reduce the carbon intensity of air travel (e.g. grams of CO_2 per seat-km) by about 30%.
- There would be scope for further improvement (i.e. up to 1.5% per annum), if funding were to be increased and technology innovation accelerated.

Use of Biofuels In Aviation

Concerns about land availability and sustainability mean that it is not prudent at this time to assume that biofuels in 2050 could account for more than 10% of global aviation fuel:

- It is likely that use of aviation biofuels will be technically feasible and economically viable.
- However, there will be other sectors which will compete with aviation for scarce biomass feedstock (e.g. road transport sector for use in HGVs, household sector biomass for cooking and heating, power generation for co-firing with CCS technology).
- It is very unclear whether sufficient land and water will be available for growth of biofuels feedstocks given the need to grow food for a global population projected to increase from the current 6.7 billion to around 9.1 billion in 2050.
- Biofuel technologies that would not require agricultural land for growth of feedstocks (e.g. biofuels from algae, or biofuels grown with water from low-carbon desalination) may develop to change this picture, but were considered speculative at this point.
- Given these concerns, it was not prudent at this time to plan for high levels of biofuels penetration. It was therefore assumed that 10% penetration is the most 'likely' scenario.

Aviation Non-CO_2 Effects

Aviation non-CO_2 effects (e.g. linear contrails, induced cirrus cloudiness and water vapour) are also likely to result in climate change and will therefore need to be accounted for in future international and UK frameworks. This may have implications for the appropriate long-term UK aviation target:

- The UK Government's aviation emission reductions target excludes these additional non-CO_2 effects, consistent with international convention and the UK Climate Change Act, as they do not derive directly from emissions of Kyoto gases.
- Aviation non-CO_2 effects are however almost certain to result in some additional warming, but with considerable scientific uncertainty over their precise magnitude.
- It will therefore be important, as scientific understanding improves, to account for aviation non-CO_2 effects in the future international policy framework and in the overall UK framework for emissions reduction.
- The implications for appropriate emissions reduction across different sectors of the economy are unclear, but some further reduction in aviation emissions may be required.

Achieving the UK Aviation Emissions Target

Given prudent assumptions on likely improvements in fleet fuel efficiency and biofuels penetration, demand growth of around 60% would be compatible with keeping CO_2 emissions in 2050 no higher than in 2005:

- The 'likely' scenario shown in Figure 1, assumes improvement in fleet fuel efficiency and biofuels penetration that would result in annual carbon intensity reduction of around 0.9%.
- The cumulative carbon intensity reduction of around 35% in 2050 provides scope for allowing an increase in demand while achieving the emissions target. This carbon intensity reduction allows for around 55% more UK ATMs with increasing load factors over the period, resulting in around 60% more UK passengers in 2050 than in 2005.
- Given the previous Government's capacity expansion plans, coupled with a demand response to the projected carbon price and to some of the opportunities for modal shift, UK demand could grow by around 115% between now and 2050 (Figure 1).
- Constraints on UK aviation demand growth in addition to the projected carbon price would therefore be required to meet the 2050 aviation target.

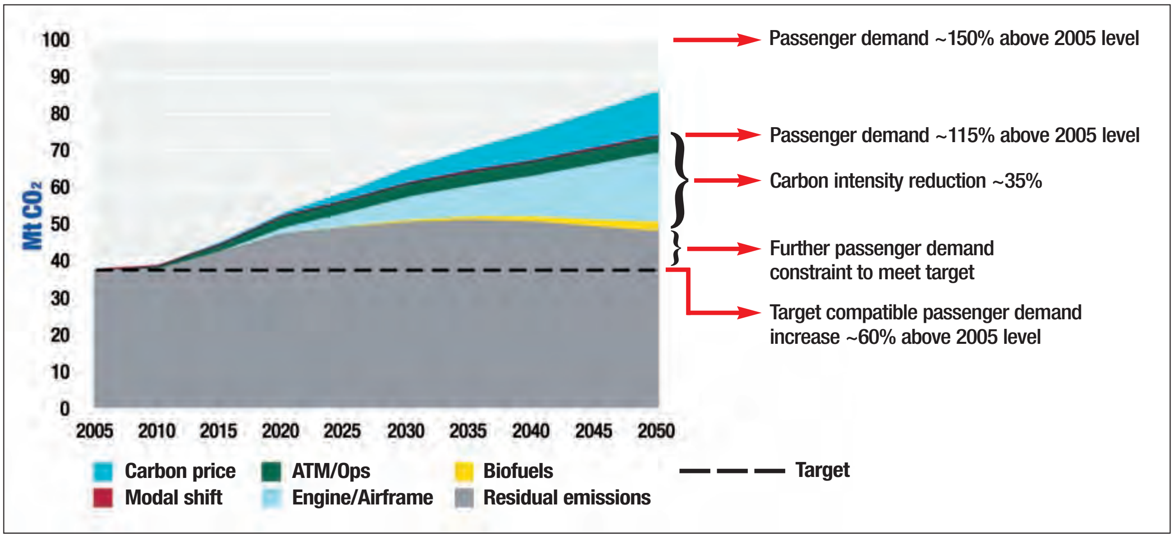

Figure 1: *UK aviation emissions to 2050 – CCC Likely scenario.*

Future technological progress may make more rapid demand growth than 60% compatible with the UK target; but it is not prudent to plan on the assumption that such progress will be achieved:

- It is possible that improvements in fleet fuel efficiency will progress more rapidly than anticipated, and/or that the prospects for sustainable biofuels will become more favourable.
- Unless and until emerging evidence clearly illustrates that this is the case, however, it is prudent to design policy around a maximum aviation demand increase of 60%.

A 60% increase in total UK aviation passenger demand could be consistent with a range of policies as regards capacity expansion at specific airports:

- The maximum increase in ATMs compatible with the emissions target is around 3.4 million per year in 2050, compared with around 2.2 million per year in 2005.
- Total current theoretical capacity at all airports in the UK is around 5.6 million ATMs per year, but demand cannot be easily switched between different geographical locations and capacity utilization differs hugely between hub and regional airports.
- Optimal capacity plans at specific airports therefore need to reflect factors other than total national demand levels, and it was not the Committee's role to assess such factors.
- The combination of different policies (e.g. tax and capacity plans) should however be designed to limit total demand increase to a maximum of around 60%, until and unless technological developments suggest that any higher figure would be compatible with the emissions target.

The UK In Context

Throughout the Committee's analysis, it was assumed that UK action would be in the context of an international agreement which limits aviation emissions in all countries:

Action at the European level is required in order to avoid leakage from UK airports to hubs in other ICAO Member States.

Action at a Global level is required in order to constrain aviation emissions in a way that is consistent with achieving broader climate change objectives, which the Committee set out in its recommendations to the previous UK Government on an international deal for aviation. Key points of that were:

- Aviation CO_2 emissions should be capped, either through a global sectoral deal or by including domestic and international aviation emissions in national or regional (e.g. EU) emissions reduction targets.
- The level of emissions reduction targets under any international agreement should be no less than that already agreed by the EU (i.e. developed country net emissions in 2020 should be no more than 95% of average annual emissions from 2004-2006).
- Emissions trading will be useful for an interim period in providing flexibility to achieve cost-effective emissions reductions, subject to the caveat that carbon prices in trading schemes provide strong signals for demand side management and supply side innovation.
- The aviation industry should also plan, however, for deep cuts in gross CO_2 emissions relative to baseline projections (e.g. for developed country aviation emissions to return to no more than 2005 levels in 2050), which will be required as a contribution to meeting the G8's agreed objective to reduce total global emission levels in 2050 by 50%.

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2 Measured on a Bunker fuels basis

Greenhouse Gas Management at Airports

By ***Xavier Oh***

__Xavier Oh__ has been the Environment Manager at ACI since September 2005 and is based in the ACI Montreal Bureau, located near ICAO Headquarters.

As an industry association, ACI is an official Observer at ICAO's Committee on Aviation Environmental Protection (CAEP). Xavier is the ACI representative.

As the Secretary of ACI's World Environment Standing Committee, one of his main tasks is developing, coordinating and implementing policy on all issues relating to the environment and airports. Noise and gaseous aircraft emissions are the main global issues, but local issues such as air and water quality, energy efficiency and land management also have global significance.

Introduction

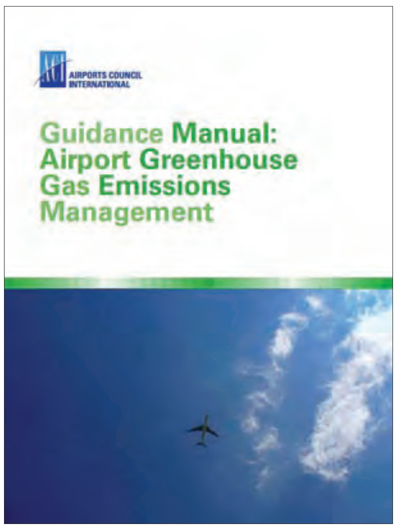
In addition to their passenger processing role, airports act as an interface between aviation and ground transportation. Because of this, there are a myriad of vehicles and activities that generate greenhouse gases (GHG) at airports, ranging from aircraft and ground support equipment (GSE) to ground transport, heavy machinery and power stations. Furthermore there are many different owners and operators of the various airport-related emission sources including the airport operator, airlines, concessionaire tenants, ground handlers, public transport providers, as well as travellers and well-wishers.

This article outlines Airports Council International's (ACI) recommended approach for an airport to address and manage its own GHG emissions and those of others associated with the airport. Additional information is available in the ACI document *Guidance Manual: Airport Greenhouse Gas Emissions Management (2009)* which is freely available at **www.aci.aero**.

Categorizing Emissions Sources

Given the complexity of the types and ownership of different emissions sources it is helpful to start by drawing a few distinctions among the various sources at an airport.

Firstly, aviation emissions need to be distinguished from airport emissions. Aviation emissions are those emissions produced by the aircraft main engines and auxiliary power units (APU) when it is in-flight or taxiing. This means that total aviation emissions are directly correlated to the total fuel loaded onto aircraft. This is a necessary distinction given that the Kyoto Protocol did not include emissions from international aviation in national inventories and targets.



Secondly, airport emissions can be divided into two categories: those produced by activities of the airport operator, and those produced by other "airport-related" activities. This helps to separate emissions that are the direct responsibility of the airport operator from other activities such as airlines (including some aircraft activity), ground handlers, concessionaires, private vehicles, etc.

The World Resources Institute (WRI) document *Greenhouse Gas Protocol, a Corporate Accounting and Reporting Standard" (WRI 2004)* provides a useful framework by dividing emissions into three scopes based on the ownership and control of airport sources that are defined as follows.

Scope 1 - GHG emissions from sources that are owned or controlled by the airport operator.

Scope 2 - GHG emissions from the off-site generation of electricity (and heating or cooling) purchased by the airport operator.

Scope 3 - GHG emissions from airport-related activities from sources not owned or controlled by the airport operator.

The ACI Manual recommends the further division of Scope 3 sources into two subcategories - Scopes 3A and 3B.

Scope 3A - Scope 3 emissions which an airport operator can influence, even though it does not control the sources.

Scope 3B - Scope 3 emissions which an airport operator cannot influence to any reasonable extent.

This Scope 3A-3B distinction is made in order to identify those sources which an airport operator can choose to include in its emissions management programme. For any particular type of source, the degree of influence will vary among airports. By categorizing a source as Scope 3A, the airport operator indicates that it believes it can work with the owner of the source to achieve emissions reductions.

Airport Emissions Inventory

Examples of the main airport and airport-related sources in each scope category are given in Table 1. At some airports, certain sources may be placed in different categories.

Calculation Methods

There are several key documents available that provide guidance on the calculations of airport and airport-related GHG emissions.

- The Airport Cooperative Research Program (ACRP) Report 11 *Guidebook on Preparing Greenhouse Gas Emissions Inventories (2009)*, provides detailed information on how to calculate the emissions from each source at an airport including aircraft, APU, GSE, ground access vehicles, stationary sources, waste management activities, training fires, construction activities, and others. Factors to use for converting non-CO_2 emissions to a CO_2-equivalent mass are also provided.
- Emissions conversion factors that are used in many countries for converting the volume of various fuels used into CO_2 mass, as well as for calculating the mass of CO_2 emitted for each kWh of electricity, are available at **www.airportcarbonaccreditation.org**
- Airport Air quality guidance manual ICAO Doc 9889, which was developed mainly for the calculation of local air quality emissions, provides detailed methodologies for calculating emissions from a variety of airport sources including aircraft engine start-up. It is also recommended that airports refer to any national reporting guidelines, such as UK DEFRA Greenhouse Gas Protocol **(http://www.defra.gov.uk/environment/business/reporting/carbon-report.htm)**.

Emissions from the combustion of renewable or biomass fuels, such as wood pellets or bio-derived fuels, will need careful consideration. In general, the contribution of GHG emissions from these non-fossil fuels will have a near zero net effect on the CO_2 levels in the atmosphere, because the equivalent CO_2 was removed from the atmosphere during their production.

Reduction of Airport Operator Emissions

Some examples of measures that can be implemented for **Scope 1 and 2** emissions reductions include the following:

- Modernization of the power, heating and cooling plants.
- Generation or purchase of electricity, for heating and cooling systems, from renewable energy sources including wind, solar, hydroelectric, geothermal and biomass sources.
- Retrofitting of "smart" and energy efficient buildings and component technologies, including double glazing, window tinting, variable shading, natural lighting, light emitting diode (LED) lighting, absorption-cycle refrigeration, heat recovery power generation and the like. LEED and BREEAM building certification programmes can provide guidance.

- Modernization of fleet vehicles and ground support equipment, and the use of alternative fuels for buses, cars and other air and land-side vehicles. Alternative fuel sources could include compressed natural gas (CNG), hydrogen, electricity, compressed air and hybrid technologies.
- Driver education about fuel conservation driving techniques and implementation and enforcement of a no-idling policy.
- Solid waste management that includes recycling and composting, and reduces volume of waste going to landfills. Reusing excavation and demolition materials on-site also reduces transportation emissions.

Source	Description
Scope 1: Airport Owned or Controlled Sources	
Power plant	Airport-owned heat, cooling and electricity production
Fleet vehicles	Airport-owned (or leased) vehicles for passenger transport, maintenance vehicles and machinery operating both airside and landside
Airport maintenance	Activities for the maintenance of the airport infrastructure: cleaning, repairs, green spaces, farming, and other vehicles
Ground Support Equipment (GSE)	Airport-owned equipment for handling and servicing of aircraft on the ground
Emergency power	Diesel generators for emergency power
Fire practice	Fire training equipment and materials
Waste disposed on-site	Airport-owned waste incineration or treatment from airport sources
Scope 2: Off-site Electricity Generation	
Electricity (and heating or cooling) generation	Emissions made off-site from the generation of electricity (and heating or cooling) purchased by the airport operator
Scope 3: Other Airport-Related Activities and Sources	
Scope 3A: Scope 3 Sources an Airport Operator Can Influence	
Aircraft main engines	Aircraft main engines during taxiing and queuing Some airports may include the LTO (Landing Take-off) cycle
APU	Aircraft Auxiliary Power Units (APU)
Landside road traffic/ground access vehicles (GAV)	All landside vehicles not owned by airport operator, operating on airport property
Airside vehicle traffic	All vehicles operated by third parties (tenants, airlines, etc) on airport airside premises
Corporate Travel	Flights taken on airport company business
Ground support equipment (GSE)	Tenant or contractor owned GSE for the handling and servicing of aircraft on the ground, if airport could provide alternative fuels or otherwise influence operation
Construction	All construction activities, usually conducted by contractors
Scope 3B: Scope 3 Sources an Airport Operator Cannot Influence	
Aircraft main engines	Aircraft main engines in the LTO cycle, excluding taxiing
	Aircraft emissions during cruise on flights to or from airport
Landside road traffic/gound Access vehicles (GAV)	All landside vehicles related to the airport, operating off-site and not owned by airport operator, including private cars, hotel and car rental shuttles, buses, goods delivery trucks, freight trucks
Electricity and other external energy	Emissions from generation of electricity, heating and cooling purchased by tenants including airlines
Aircraft and engine maintenance	Airline or other tenant activities and infrastructure for aircraft maintenance: washing, cleaning, painting, engine run-ups
Rail traffic	Rail traffic and other ground transport related to the airport
Waste disposed off-site	Off-site waste incineration or treatment from airport sources

Table 1: *Examples of Scope 1, 2, 3A and 3B emissions sources.*

Reduction of Other Airport-Related Emissions

Non-aviation emissions are dominated by ground transportation in **Scope 3A**. GHG mitigation measures can also include the following:

- Provision of energy efficient public transport and rapid transit to and from the airport including buses, coaches, light rail and trains.
- Implementation of educational campaigns (or using by-laws) to reduce vehicle idling, taxi dead-heading (one way trips), and individual passenger drop-off and pick-up.
- Consolidating hotel and rental car agency shuttle bus services.
- Encouraging the use of alternative fuel or hybrid taxis, rental and other cars; using incentives such as priority queuing, parking cost reduction, and priority parking areas.
- Providing infrastructure to fuel and power low emission vehicles, including recharging stations.

Reduction of Aviation Emissions at Airports

Airport operators can contribute to improvements in the aircraft activities of taxiing and APU usage with various mitigation measures including:

- Providing (and enforcing the use of) fixed electrical ground power (FEGP) and pre-conditioned air (PCA) supply to aircraft at terminal gates, that allow APU switch-off.
- Improving aircraft taxiways, terminal and runway configurations to reduce taxiing distance and ground and terminal area congestion.
- Implementation of departure management techniques, including holding aircraft at the gate (with APU switched off) until departure slot is ready. Such practices can also encompass virtual queuing and collaborative decision-making.
- Use of arrival management techniques that provide gates for aircraft that are located to minimize taxiing distance after landing.

Certification Programme

In June 2009, ACI launched its Airport Carbon Accreditation programme which provides a framework for airport operators to address their carbon dioxide emissions and obtain certification for reduction milestones reached. The scheme is voluntary, and for each of the four (4) levels attainable an airport operator must submit proof of certain actions, which are then audited and verified.

There are four levels of certification, whose requirements are briefly summarized as follows:

Level 1 – Mapping: An inventory of sources and annual quantities of CO_2 emissions under an airport operator's direct control (**Scope 1** and **2** sources) with options to include some **Scope 3** sources and non-CO_2 GHGs. A list of other emissions sources (**Scope 3**) is also required.

Level 2 – Reduction: As well as the Level 1 inventory, a Carbon Management Plan for **Scope 1** and **2** sources should be developed and implemented, and evidence of measurement, reporting and ongoing emissions reductions must be provided.

Level 3 – Optimization: The inventory must be extended to include some **Scope 3** sources including (at least) aircraft Landing and take-off (LTO), APU, surface access and corporate travel. The Carbon Management Plan must be extended to include further stakeholder engagement, and ongoing emissions reductions must be demonstrated.

Level 3+ - Neutrality: In addition to the Level 3 requirements, the airport operator must demonstrate that it has offset its residual **Scope 1** and **2** emissions and has thus achieved true "Carbon Neutrality."

More information on the programme is available at **www.airportcarbonaccreditation.org**

Example Inventories

In closing, the summaries of 3 airport inventories are presented in **Table 2**. The Zurich and Stansted inventories were conducted according to regulatory requirements, while Seattle-Tacoma's was made on a voluntary basis. The format allows for some comparisons between airports and, importantly, the avoidance of inappropriate comparisons. One example benefit of the Sea-Tac inventory was the identification of the high emissions of hotel shuttle buses which resulted in the airport operator initiating a project to encourage the consolidation of services.

Airport	**Zurich Airport, Switzerland**	
Study Year	2008	
Movements	274,991	
Passengers	22.1 million	
Cargo (t)	419,843	
Scopes	**Mass / Species**	**Comments**
Scope 1	30,788 t CO_2	Includes own power plant, furnaces, emergency power and own vehicles and machinery
Scope 2	2,639 t CO_2	
Scope 3A	112,260 t CO_2	Includes aircraft taxiing, APU, GPU for handling, 3rd party construction and access road traffic in airport perimeter: - Aircraft taxi: 89,149 t
Scope 3B	2,899,331 t CO_2	Landing and whole of departing flights to destination (performance based), GSE, other furnaces, aircraft maintenance, fuel farm, access train traffic - Performance based LTO (excl taxi): 159,555 t - Performance based whole flight (excl LTO): 2,720,002 t
Total Airport	3,045,018 t CO_2	

Airport	**Stansted, UK**	
Study Year	2008	
Movements	166,493	
Passengers	22.3 million	
Cargo (t)	198,054	
Scopes	**Mass / Species**	**Comments**
Scope 1	3,511 t CO_2	Gas, wood pellets, Refrigerants, Company vehicles and airside fuel use
Scope 2	51,314 t CO_2	Electricity
Scope 3A	248,626 t CO_2	Aircraft Taxi, Hold, APU, Staff vehicles, waste, business travel
Scope 3B	134,876 t CO_2	LTO (excl. taxi, hold, whole of flight), Passenger GAV, Third party airside fuel
Total Airport	438,327 t CO_2	

Airport	**Seattle Tacoma, USA**	
Study Year	2006	
Movements	340,058	
Passengers	30 million	
Cargo (t)	341,981	
Scopes	**Mass / Species**	**Comments**
Scope 1	40,000 t CO_2	Stationary sources, GSE, GAV (including employee vehicles, shuttle buses) on airport land
Scope 2	26,000 t CO_2	Electricity
Scope 3A	592,000 t CO_2	Aircraft taxi and delay, Employee vehicles off site, Shuttle buses off site
Scope 3B	3,996,000 t CO_2	Landing and whole of departure flights to destination (based of fuel dispensed), Passenger vehicles off site
Total Airport	4,654,000 t CO_2	

Table 2: *Examples of Airport Greenhouse Gas Inventories.*

Models and Databases
Review and Recommendations

By ***ICAO Secretariat***

One main task of ICAO's Committee on Aviation Environmental Protection (CAEP) is to identify and carry out analyses of the future trends and various options available to limit or reduce the current and future impact of international civil aviation noise and emissions. The aim of these studies is to assess the technical feasibility, the economic reasonableness, and the environmental benefits, as well as the trade-offs of the options considered. In doing so, CAEP has relied on the use of a variety of computer-based simulation models and databases offered by Member States and international organizations that participate in CAEP.

Over the years, CAEP's analytical role has progressively expanded from basic assessment of standard-setting options to include analyses of policy measures such as the balanced approach to limit or reduce the impact of aircraft noise and market-based options (i.e. noise and emissions charges and emissions trading). As the need for a better informed policy-making process grows, CAEP's modelling requirements in terms of coverage (i.e. noise, emissions, costs and benefits, etc.) and accuracy increase.

To support the analyses for the eighth meeting of CAEP/8 in February 2010, a thorough evaluation of the proposed models and databases was carried out. The goal of this evaluation was to advise CAEP as to which tools are sufficiently robust, rigorous, transparent, and appropriate for which analyses (e.g. stringency, CNS/ATM, market-based measures), and to understand any potential differences in modelling results. Evaluation teams were established for each of the modelling areas: noise, local air quality, greenhouse gas emissions, and economics. A common methodology was developed to ensure consistency in the model evaluation process across the four modelling areas, which included a review of the key characteristics of a robust model or database, as shown in Table 1.

The models were then used to assess two sample problems: the effects of reduced thrust takeoff, and the effects of a hypothetical NO_x stringency. One of the goals of the sample problems was to advance candidate model evaluation and development by practicing on a set of problems that are similar to those that were considered as part of the CAEP/8 work programme. The practice analyses were accompanied by a rigorous assessment process, so that the strengths and deficiencies in the models could be identified, and appropriate refinements and improvements implemented. This ensured that the models were sufficiently robust and well understood to support a broad range of CAEP/8 analyses.

The models that were approved for use by CAEP/8 are shown in Table 2. Each model and database has its strengths and weaknesses, and the use of multiple models provided CAEP insight into sensitivities of the results. Going forward, the model evaluation process developed for CAEP/8 has established a framework for the future evaluation of new models and updates to the existing tools.

Of key importance is the fact that the input databases were common to all of the models. This allowed, for the first time, exploration of the interrelationships between noise, local air quality, and greenhouse gas emissions. As experience is gained investigating these interdependencies, and as the models mature further, more advanced decision making on aviation environmental protection will become possible.

Capabilities	• Does the model do what is needed to answer the potential questions posed by CAEP?
	• What are the limitations of the model?
	• What new capability does the model bring to policy assessment? Does this capability bring added value?
	• How well can the model frame quantitative estimates of uncertainty as part of the output?
	• Conduct sensitivity tests to understand the tool structure, as well as the main sources and degree of uncertainty.
Data requirements to support interaction with forecasting activities	• Does the tool produce the noise, emissions, and fuel flow data required by FESG for the economic analyses of the CAEP/8 policy studies?
	• Does the tool generate the data in the format required by FESG?
Methodologies	• How does the model work, and does it comply with applicable standards?
	• What data are required?
	• Where do these data come from?
	• How easy is it to change assumptions, baseline data, scenarios, etc.?
Readiness	• What is the likelihood that a tool under evaluation will be ready in time for application to the CAEP/8 policy studies?
	• Assess the labour and funding commitment to the development.
	• Assess the state of software development.
	• Assess the maturity of the methodologies.
	• Assess the maturity of the models V&V activities.
	• Assess the number of innovations that have yet to be incorporated and tested.
Transparency	• Are system architecture, functional requirements, algorithm description, data description, and other software design related documents available to CAEP?
	• Are there technical reports, which describe research and V&V supporting the algorithms and methodologies, available to CAEP?
Fidelity	• Are the methods and algorithms to generate the noise, emissions, and fuel use data reasonable?
	• Where the requirement is to assess interdependencies, does the tool reasonably represent trends and relationships among environmental factors?
Usability	• Who is to use the model, and what training is required?
	• What is the level of accessibility and availability?
	• What role is CAEP to have during input processing and running?
	• How will MODTF interface with FESG during processing and running?
Validation and verification (V&V)	• Is there a "gold standard" and how does the tool compare?

Table 1: *Characteristics of a robust model or database.*

Modelling Area	Model / Database Name	Release	Sponsoring Organization
Noise	AEDT/MAGENTA	**1.4**	US FAA
	ANCON2	**2.3**	UK DfT
	STAPES	**1.1**	EUROCONTROL
Local air quality	ADMS	**3.0**	UK DfT
	AEDT/EDMS	**1.4**	US FAA
	ALAQS	**NOV08**	EUROCONTROL
	LASPORT	**2.0**	Swiss Federal Office for Civil Aviation (FOCA) German Ministry of Transport (BMVBS)
Greenhouse Gas	AEDT/SAGE	**1.4**	US FAA
	AEM III	**2.0**	EUROCONTROL
	Aero2k	**2.0**	UK DfT
	FAST	**-**	UK DfT
Economics	APMT/Economics	**4.0.3**	US FAA
	NOx Cost	**4.0**	CAEP
All	Airports Database	**1.5.4**	US FAA, EUROCONTROL
All	Common Operations Database	**2.0**	US FAA, EUROCONTROL
All	2006 Campbell-Hill Fleet Database	**CAEP/8**	CAEP
All	2006 Campbell-Hill Fleet Database Extension	**CAEP/8**	US FAA
All	Population Database	**1.0**	US FAA, EASA
LAQ, GHG	ICAO aircraft engine emissions databank (EDB)	**16A**	UK DfT, CAEP **www.caa.co.uk/EDB**
Noise	ICAO Noise database (NoisedB)		France DGAC **http://noisedb.stac.aviation-civile.gouv.fr/**
All	ANP - Aircraft Noise and Performance	**1.0**	EUROCONTROL
All	Base of Aircraft Data (BADA)	**3.6**	EUROCONTROL
All	Forecasting and Operations Module (FOM)	**2.3.2**	US FAA
All	FESG Traffic Forecast (pax. + cargo)	**CAEP/8**	ICAO Secretariat, CAEP, ICCAIA
All	FESG Retirement Curves	**CAEP/8**	ICCAIA, CAEP
All	Growth & Replacement Database	**7**	ICCAIA, CAEP

Table 2: *Summary of models and databases approved for CAEP/8 use.*

The ICAO Carbon Emissions Calculator

By **Tim Johnson**

Tim Johnson *has been working in the national and international aviation environmental policy field for over twenty years, as Director of the UK-based Aviation Environment Federation and as a consultant. He is the CAEP Observer on behalf of the International Coalition for Sustainable Aviation (ICSA) and is co-rapporteur of the Aviation Carbon Calculator Support group (ACCS). ICSA is a structured network of environmental non-governmental organizations working in the field of aviation and environmental protection.*

In 2006, members of the public and organizations interested in understanding the size of their air travel carbon footprint were faced with hundreds of websites offering calculators that delivered estimates that could vary widely for a given flight. With the users unable to find detailed documentation regarding the data and methodologies used by those calculators, it was impossible to know which estimates to trust. Recognizing the need for a fully transparent and internationally approved calculator, ICAO began work on a methodology through its Committee on Aviation Environmental Protection (CAEP).

ICAO launched its Carbon Emissions Calculator in June 2008. Positioned prominently on the Organization's home page, the Calculator uses the best publicly available data to provide the public with an easy-to-use tool to deliver consistent estimates of CO_2 emissions associated with air travel, that is suitable for

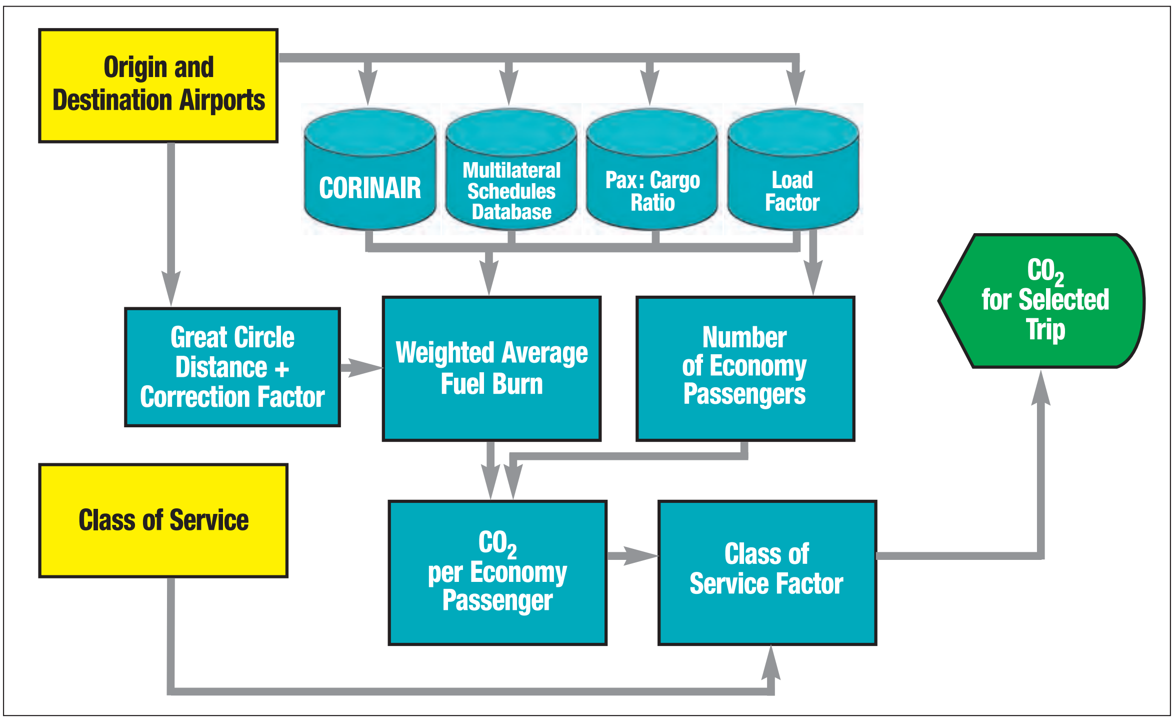


Figure 1: *ICAO Carbon Emissions Calculator methodology.*

use with offset programs. Furthermore, in the interest of maintaining transparency, the Calculator is accompanied by full documentation of the methodology that explains the variables behind every calculation (such as load factors and cabin class) as well as the data sources used. Unlike the many calculators available to compute aviation CO_2 emissions, the transparent ICAO Carbon Emissions Calculator, which exclusively uses publicly available data, is not a black box.

Methodology

The Calculator methodology, which is illustrated in Figure 1, was developed through CAEP by a team of experts from the ICAO Secretariat, Member States, universities, air carriers, aircraft manufacturers, and NGOs. It underwent significant review prior to publication, which resulted in it being internationally recognized and accepted.

While the diagram in Figure 1 appears complex, the Calculator is in fact easy to use with the user only having to provide the origin and destination airport along with the class of service flown. The user friendly web interface, shown in Figure 2, along with its transparency and positive international reviews, have brought the Calculator widespread recognition and acceptance (see *Building on the ICAO Carbon Calculator to Generate Aviation Network Carbon Footprint Reports*, in Chapter 1 of this report and *IATA's Carbon Offset Programme*, in Chapter 4 of this report).

Figure 2: *ICAO Carbon Emissions Calculator Web interface (www.icao.int).*

Early Adopters

In April 2009, the UN Environment Management Group (EMG), a body overseeing the "greening of the UN" with the ultimate objective of moving toward climate neutrality across all its organizations and agencies, adopted the ICAO Calculator as the official tool for all UN bodies to quantify their air travel CO_2 footprint. The Calculator is currently being used throughout the UN system to prepare annual air travel greenhouse gas (GHG) inventories. But the tool is not only of interest for the compilation of inventories; some UN travel offices have integrated the Calculator directly into their travel reservation and approval systems, providing real-time information to assist travel planning decisions (see *Accounting for the UN System's Greenhouse Gas Emissions article*, Chapter 8 of this report).

With similar applications in mind, and with the goal of facilitating the use of the Calculator as the source of emissions information for offsetting initiatives, ICAO and Amadeus, a global technology and distribution solutions provider for the travel and tourism industry, have signed an agreement for ICAO to supply Amadeus with an interface to the Calculator for their reservation system.

Gathering User Feedback

Since its launch, the Calculator has continued to evolve. In response to public feedback, something that is invited through a user feedback facility on the website, several user interface improvements have been made. This includes the ability to enter airport codes or city names for the origin and destination of the trip, and the ability to compute both return trips and multi-city flights. The reaction from users also highlighted two issues that were referred to the CAEP Aviation Carbon Calculator Support group (ACCS) for its consideration. Both of these issues were frequently cited by respondents; the first relating to why the Calculator did not provide information regarding the non-CO_2 effects of flights, and the second regarding the absence of any information about the potential to offset emissions.

To help explain these issues to the public, a *Frequently Asked Questions* section was added to the website. While the accuracy of the Calculator makes it very relevant as a tool to calculate offsetting requirements, ICAO cannot recommend specific services offered by commercial entities. However, the user is still aided by information that will help in choosing an offset provider, including how the carbon credit is generated, whether it conforms to a recognized standard and has been audited or verified, and whether it provides transparency. In relation to accounting for the effects of greenhouse gases other than CO_2, the scientific community has not yet reached consensus on an appropriate metric for this purpose. ICAO is working in collaboration with Intergovernmental Panel on Climate Change (IPCC) on this subject and will adopt a "multiplier" methodology in due course.

Future Enhancements

Clearly, the best source of aviation CO_2 emissions data is based on the actual fuel consumption of aircraft along a given route. ICAO is actively working to move the Calculator toward the use of measured fuel consumption data, with the requirement that it be verified in an open manner and made publicly available in order to maintain the Calculator's full transparency.

While efforts to allow the public disclosure of fuel consumption data by aircraft operators continues, further improvements and refinements are planned for the Calculator over the next couple of years. The eighth meeting of CAEP in February 2010 agreed to assess and develop several different approaches to further enhance the accuracy of the methodology. The three approaches agreed to, which will be developed in parallel, will utilize the latest information available to ICAO.

For the first approach, ACCS will focus on updating the current database. Some aircraft types are not currently in the database and have no substitute type available (a substitute uses an existing aircraft type supported in the database with similar performance characteristics, or data from a previous generation). ACCS plans to work with aircraft manufacturers to address this issue, prioritizing those new aircraft types that have entered the market and which are used extensively on some routes. Other database goals include incorporating city-pair level load factor data collected by ICAO, and with industry assistance, air carrier level seating configuration data, where available. When using the Calculator, the user is asked to input his or her class of travel. The Calculator currently distinguishes between classes on the basis of the relative space occupied, but ACCS will consider refining whether weight offers improved accuracy.

The second approach takes advantage of the wealth of models available to CAEP and used by its Modelling and Databases Group. These models have already been evaluated and used to generate greenhouse gas forecasts to support ICAO's work. The results from these models can be merged into a single ICAO database of modelled, flight-level fuel consumption (or CO_2 emissions), that could enhance the Calculator's performance.

With the third approach, the Calculator ultimately aims to rely on measured fuel consumption data at the city pair level, differentiating where possible between the types of fuel used as alternative fuels for aircraft become more common.

Obtaining this data will require close co-operation with industry partners covering scheduled, low cost and business aviation operations, subject to their willingness to disclose the information. This disclosure will be crucial, as the full transparency of the calculator cannot be compromised. Another source of information may come from a new data collection form being developed by ICAO.

Through these initiatives, ICAO hopes to provide continuous assurance that the Calculator remains an accurate, transparent and tested means of estimating the CO_2 generated by air travel.

REFERENCES

ICAO Carbon Emissions Calculator Methodology
http://www2.icao.int/en/carbonoffset/Documents/ICAO%20methodologyV2.pdf

Building on the ICAO Carbon Emissions Calculator to Generate Aviation Network Carbon Footprint Reports

*By **Dave Southgate** and **Donna Perera***

***David Southgate** is Head of the Aviation Environment Policy Section in the Australian Government Department of Transport and Regional Services. His group focuses on improving communications and building trust between airports and their communities on aircraft noise issues.*

In 2000 David's department published a well-received discussion paper entitled Expanding Ways to Describe and Assess Aircraft Noise. As a result of the positive feedback, the group developed a software-package called Transparent Noise Information Package (TNIP) which reveals information on aircraft noise, previously not accessible to the non expert. David Southgate has worked as an environmental noise specialist in the Australian Government for over 25 years and has a science / engineering background, with degrees from the Universities of Liverpool, London and Tasmania.

***Donna Perera** works in the Aviation Environment Policy Section in the Australian Government Department of Infrastructure, Transport, Regional Development and Local Government. She helped develop the Transparent Noise Information Package (TNIP) for producing rapid analyses of aircraft noise. She is now engaged in examining policy options for managing aviation carbon emissions and is developing concepts for monitoring and reporting of Australia's aviation carbon footprint. Donna has a postgraduate science degree from the University of Sydney.*

In recent years the aviation industry has received a significant amount of public pressure arising from a perception that the industry is taking inadequate steps to address its growing carbon footprint. It has become very evident that robust quantitative carbon footprinting tools for aviation are needed to facilitate policy development by ensuring that discussions and negotiations are based on facts rather than perceptions.

The importance of transparency and public confidence in carbon footprinting was recognized by ICAO in 2007 when it initiated work on the ICAO Carbon Emission Calculator. The calculator was publicly released on the ICAO website in June 2008. In Australia the Department of Infrastructure, Transport, Regional Development and Local Government has developed a software tool, built on the algorithms within the ICAO Carbon Emission Calculator, to compute and report carbon footprints across aviation networks.

Computing the Carbon Footprint

The aviation carbon footprinting tool that has been developed in Australia – *TNIP Carbon Counter* – is a Microsoft Access software application based on flight-by-flight carbon aggregation concepts. It is a generic tool that can be used to compute carbon footprints across any aviation network.

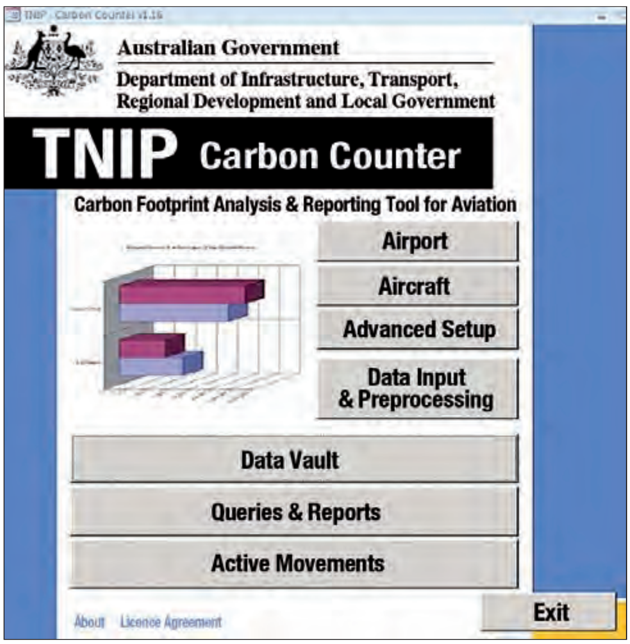


***Figure 1:** TNIP Carbon Counter main user interface.*

When data is loaded into the application it generates an archive which contains a separate folder of movements for each of the airports in the input data set. During the data import process the program computes the CO_2 for each entry in the aircraft operations file. Each flight is identified as being domestic or international through the ICAO codes of the origin and destination airports. The fuel used, and hence CO_2 generated, for each flight is computed using the CORINAIR dataset[1].

This computation is the same as that carried out by the ICAO Carbon Calculator to compute carbon footprints. *TNIP Carbon Counter* applies the ICAO Carbon Emission Calculator great circle distance adjustment in its computations.[1]

Once the archive of movements is set up, the user is able to rapidly generate filtered subsets of the datasets using simple interfaces. This enables the user to rapidly generate a wide range of reports, both numerical and graphical, involving detailed subsets or high level generic divisions of the whole database. Examples of possible outputs are shown later in this article.

Input Data

Network carbon footprint reporting for Australia is based on the operational dataset for Australian airspace provided by Airservices Australia, the air navigation service provider for Australia. An extract of the input data for the Financial Year (FY) 2008-09 is shown in Figure 2.

The application also requires the input of specific set up data: latitude and longitude of each airport to compute (adjusted) great circle distances; information on the number of seats in each aircraft type; and the load factor on particular routes, to report total CO_2 loads on a per person basis.

The dataset for FY 2008-09 contains approximately 1.1 million aircraft departures and about 1,700 Australian airports and landing areas.

Validation

Validation of the computations for the Australian network footprint (i.e. fuel uplifted in Australia) has been carried out through comparing published fuel sales data from official government statistics with the TNIP computed footprint.

In many areas of the world, it is not feasible to use national fuel sales data for validation purposes because aircraft carry out operations in one country using fuel picked up in another country. However, given that Australia is a geographically isolated island continent there is little likelihood of a significant amount of this 'tankering' of fuel taking place between Australia and other countries. Accordingly, it is believed that validation based on comparison between computed and actual fuel sales is valid in the case of Australia. Figure 3 shows that over the FY 2008-09 the cumulative difference between actual and computed fuel use is minimal (just over 2%).

While recognizing that further validation studies are required, the level of agreement shown in Figure 3 would appear to indicate that robust carbon footprinting across networks can be achieved using great circle computations (incorporating adjustment algorithms such as those used by ICAO). This obviates the need for gathering and manipulating large amounts of complex input data (e.g. radar, aircraft thrust settings, etc.) in order to carry out system carbon footprinting. It is important to point out that great circle computations, which involve the aggregation of average carbon footprints, cannot be used for computing/optimizing the carbon footprints of individual flights.

	A	B	C	D	E	F	G
1	DATE	TIME LOCAL	ORIGIN AIRPORT	DESTINATION AIRPORT	AIRCRAFT TYPE	MTOW	AVTUR
2	1/06/2009	00:08	YPPH	FAJS	A346	365000	Y
3	1/06/2009	00:14	YMML	WSSS	B772	294835	Y
4	1/06/2009	00:17	YMML	VHHH	A333	233000	Y
5	1/06/2009	00:19	YBBN	VTBS	B773	286897	Y
6	1/06/2009	00:22	YPPH	WSSS	A320	71500	Y
7	1/06/2009	00:27	YPPH	VHHH	A333	233000	Y
8	1/06/2009	00:34	YMML	WMKK	B772	286897	Y
9	1/06/2009	00:50	YMML	VHHH	B744	397210	Y
10	1/06/2009	01:03	YBBN	VHHH	A343	276500	Y

Figure 2: *Extract of a TNIP input data file.*

Month	Avtur (megalitres)			Cumulative monthly avtur totals (megalitres)		
	Sales (less 8% military)	TNIP (computed)	Difference (%)	Sales (less 8% military)	TNIP (computed)	Difference (%)
Jul 2008	494.841	476.825	-3.6	494.841	476.825	-3.6
Aug 2008	481.928	467.576	-3.0	976.770	944.402	-3.3
Sep 2008	475.186	452.660	-4.7	1,451.955	1,397.062	-3.8
Oct 2008	481.288	474.593	-1.4	1,933.243	1,871.655	-3.2
Nov 2008	470.908	461.396	-2.0	2,404.151	2,333.050	-3.0
Dec 2008	497.564	481.897	-3.1	2,901.715	2,814.948	-3.0
Jan 2009	478.787	474.407	-0.9	3,380.502	3,289.355	-2.7
Feb 2009	424.707	426.307	0.4	3,805.209	3,715.661	-2.4
Mar 2009	441.433	473.422	7.2	4,246.642	4,189.083	-1.4
Apr 2009	483.608	465.098	-3.8	4,730.250	4,654.181	-1.6
May 2009	469.916	452.957	-3.6	5,200.166	5,107.138	-1.8
Jun 2009	478.899	445.086	-7.1	5,679.064	5,552.225	-2.2

Figure 3: *Comparison of computed jet fuel usage with actual jet fuel sales for Australia, 2008-09.*

Reporting Concepts

At present, concepts are being trialled to best present comprehensive and comprehensible pictures of system-wide carbon footprints. This is a challenge given the very significant amount of disaggregated carbon footprint data that can be generated for an aviation system and the wide range in information needs of different audiences. Clearly, some form of layered approach to carbon footprint reporting is required. An example of a layered approach to carbon footprinting is shown in Figures 4 and 5.

Figure 4 gives an overview of the carbon footprint of aircraft departing from Australia to international ports shown in regional groupings. In Figure 5 this footprint is broken down on a route by route basis to the same regionally grouped international destinations.

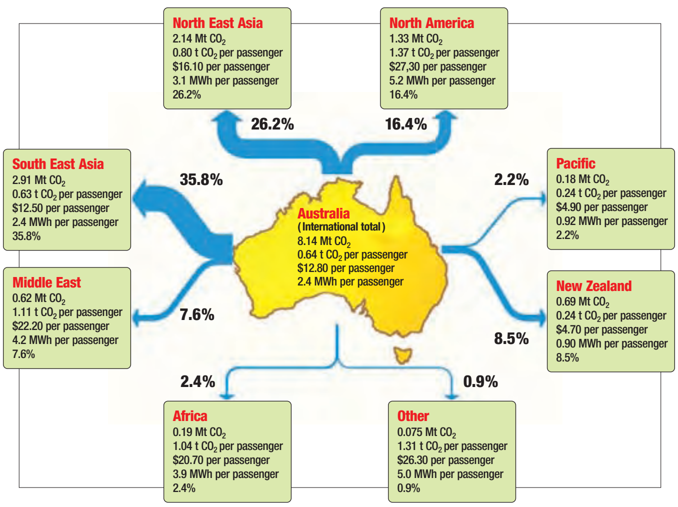


Figure 4: *CO_2 arising from international aircraft departures from Australia, 2008-09.*

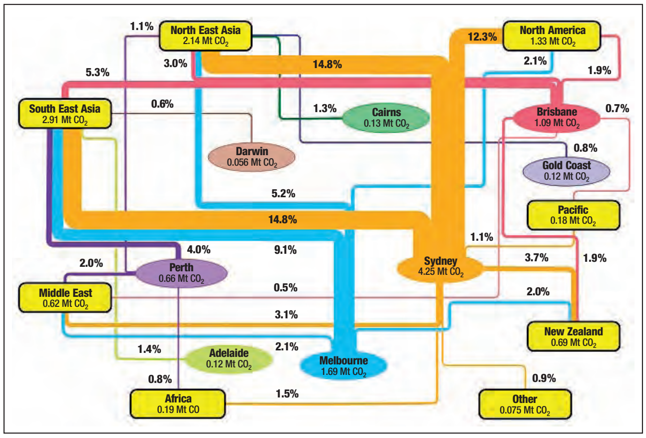


Figure 5: *Distribution of CO_2 emissions from international aircraft departures from Australia's international airports, 2008-09.*

Note: *To reduce the complexity of the diagram, only routes with greater than 40 kilotonnes CO_2 are shown. These routes comprised 98% of CO_2 emissions arising from total fuel uplifted in Australia for international departures.*

Interrelationship Between Movements and CO_2

It is commonly noted that gauging the magnitude of the carbon footprint for a particular route, or a particular sub-group of operations is not intuitive – there is an extremely poor correlation between the number of operations and the size of the footprint for a given set of movements. For example, it can be seen from Figure 6 that across aircraft operations within the Australian network, about 7.5% of the movements (international operations) generate about 57% of the carbon footprint. Conversely, about 58% of the movements only contribute about 11% of the footprint.

Understanding this relationship is important when examining options for managing carbon footprints. For example, a commonly promoted strategy for minimizing the carbon footprint of aviation is to reduce the amount of 'inefficient' short-haul aviation travel by diverting passengers away from aviation to other modes of transport. However, preliminary analysis for Australia indicates that while short-haul operations make up a significant proportion of the flights they constitute a very small contribution to the total carbon footprint.

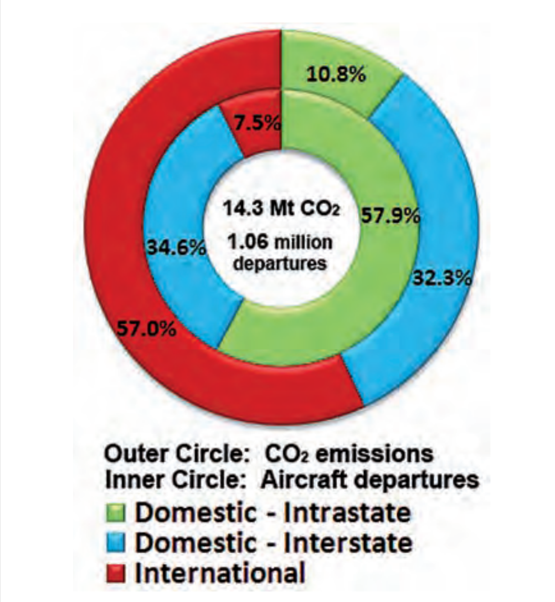


Figure 6: *Breakdown of Australia's carbon footprint and aircraft departures into intrastate, interstate and international contributions, 2008-09.*

Moving Forward – CO_2 Goals

Much of the debate within ICAO on establishing goals to reduce international aviation impact on climate change has focussed on improving fuel efficiency. At the present time ICAO has endorsed a goal of an annual 2% improvement in fuel efficiency up to the year 2050. Such a commitment requires that fuel efficiency be quantified and reported over time in order to transparently show the progress that is being made toward achieving this fuel efficiency goal.

The trend in fuel efficiency over a ten year period for international aircraft departing from Sydney Airport is shown in Figure 7. This illustrates the case that, despite the improvement in fuel efficiency over time, the total fuel consumed continues to grow. The fact that the footprint is continuing to grow underpins the discussion that is now ongoing within ICAO about the need for goals which go beyond simple fuel efficiency.

Various goals ranging from efficiency improvement, through carbon neutral growth, to emissions reductions are being considered within ICAO. If any of these goals are going to be adopted, there needs to be very clear and robust reporting on the actual (gross) carbon emissions and the extent to which any carbon credits are purchased in order to reach the agreed target. That is, there is a need to compute and report both *gross* and *net* carbon footprints. Developing these reporting concepts is a key area of future work.

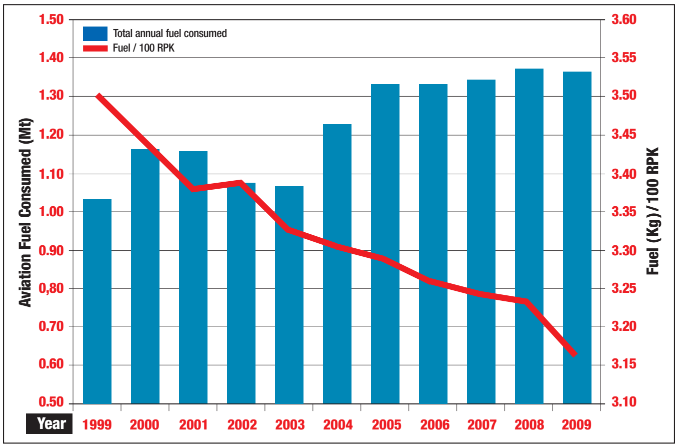


Figure 7: *Sydney Airport – Annual Fuel Consumption and Efficiency for International Aircraft Departures, 1999-2009.*

Conclusions

The development of the ICAO Carbon Emission Calculator has been a very important step in facilitating transparent and readily accessible carbon footprinting. Experience to date indicates that carbon footprint computations based on great circle methods can deliver very robust results.

Application of the concepts and algorithms underlying the ICAO Carbon Emission Calculator can provide a great deal of useful carbon footprint information using simple, transparent, and readily available, input data. These concepts facilitate rapid footprint reporting using common spreadsheet, database and graphics tools.

REFERENCES

CAEP/8-IP/41: Carbon Footprinting: Tools and Reporting Concepts Being Trialled In Australia,
presented by the Member of Australia at CAEP/8.

1 ***ICAO Carbon Emissions Calculator, Version 2, May 2009, (http://www2.icao.int/en/carbonoffset/Documents/ICAO%20MethodologyV2.pdf).***
The modified CORINAIR dataset is shown in Appendix C, *while the Great Circle Distance adjustment is on page 8 of the ICAO Carbon Emission Calculator Methodology.*