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AVIATION AND CLIMATE CHANGE:
II – AIR TRAFFIC MANAGEMENT AND AVIATION NON-CO_2 ISSUES

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Introduction

Action on climate change is now the subject of worldwide and European legislation. The following explores some of the issues raised for air traffic management (ATM) and aviation 'Non-CO_2' Issues. A key aim is to examine some widely quoted figures about the size of aviation's emission effects.

Flight Efficiency

Aviation is a comparatively small contributor – a few per cent – to Greenhouse Gas (GHG) emissions, but its growth is rapid. Global climate science is having a variety of impacts on aviation, eg:

CO_2 emission trading schemes,

New taxes on fuel/passengers – eg UK's Airport Passenger Duty,

Increased pressure to improve engine fuel-efficiency – see Brooker (2006).

Taxes and trading schemes – discussed in Part I – mainly have the effect of choking off demand, and so reducing the number of passengers and hence flights.

What about flight efficiency? Aviation fuel savings get a great deal of industry attention. This is in the context of the huge 'real money' increases in jet kerosene prices during the last eight years. Aviation fuel closely matches the crude oil price. Figure 1 shows the oil price history: will continuing supply problems mean that the price will generally remain above ~$100? So, are aircraft travelling by direct routes and flying at fuel-efficient vertical profiles? If not, do operational improvements offer big reductions in aviation's climate effects?

When the European Commission's (EC) announced its ideas for including aviation in emissions trading (December 2006), Giovanni Bisignani, IATA's Director General, stated: "Europe has the power to reduce aviation CO_2 emissions 12% by implementing the Single European Sky." Where does this high 12% figure come from? One source is an EC (2002) document saying: "Better air traffic management would cut fuel consumption by between 6 % and 12 %, according to some estimates." Tracing this back, the actual source for the 12% figure is a report in 1997, by the USA Mitre Corporation about potential worldwide (*sic*) savings. So what are the up-to-date facts?

Table 1 (PRU 2008) compares European vertical and horizontal flight inefficiencies with other known types of inefficiencies – taxi-time and airborne delays. Horizontal flight inefficiency is much larger that the vertical component. Airspace design and its strategic utilisation drive en-route horizontal flight efficiency. So this is a major challenge for Europe’s SESAR (Single European Sky ATM Research) programme).

The en-route/terminal control (TMA) interface is important to flight efficiency, but other goals become important within the TMA. To use airport capacity efficiently, there must be a succession of aircraft on different departure routeings to maximise runway throughput. Aircraft operators must minimise noise disturbance – nearby residents are usually very unhappy if new routeings overfly them. Wind direction will necessarily affect route length, thus flights departing into an east wind may then have to manoeuvre to fly a westerly course.

Airlines and air traffic control have already developed ways of improving fuel efficiency in the TMA. An example is continuous descent approach (CDA). In traditional airport approaches, aircraft descend and level off several times before landing, with thrust applied to maintain level flight. CDA involves starting a continuous steady descent from 6,000ft, or higher. This means that engine power levels are lower, so CDAs are both more fuel-efficient and less noisy to people on the ground.

What would be good estimates of the variations of the fuel penalties with flight distance? Chesneau et al (2003) compared flight routeing data and modelled estimates for a large set of European flights ‘actual fuel burn’ and ‘direct route fuel burn’. The fuel burn estimate used both ground track and vertical components of the flight. The results as percentages relative to the direct trajectory are shown graphically here as Figure 2. This shows a reducing trend with distance in extra fuel burn. However, the authors comment:

> “…the fact that the longer the range, the higher the probability that route extension is a deliberate choice of the airline (either to avoid a congested area, or to benefit from favourable winds that decrease the flight cost). This limitation also exists for shorter ranges, but we believe that on long ranges it could be predominant.”

For example, current North Atlantic Region fuel inefficiency is probably of the order of 3 or 4 per cent. Hence, the straight line shown should flatten out for large range values.

What scope is there for improving flight-profile efficiency? Traditionally, the aircraft’s type and its weight determine a flight’s fuel-efficient profile, so for long flights pilots will usually ask controllers for step-climbs from the current flight level (FL). The FL system offers safety benefits through a structured vertical segregation of traffic. PRU (2008) examines two varieties of vertical flight inefficiency:

- Flight level capping: the flight cannot reach its optimum cruising level during the flight (mainly short flights on some city pairs)
- Interrupted climb/descent: during the climb or descent phase, the flight is kept at suboptimal flight level (ie intra-flight vertical inefficiencies)

This average increase in fuel burn for European flights is 0.6%, which equates to about 23kg per flight. This average figure conceals large variations. For example, the Heathrow average interrupted climb/descent fuel penalty was 113.3 kg/flight, but the two next highest airports (Frankfurt, Gatwick) figures were less than 50 kg/flight.

Aviation’s Non-CO_2 Effects

Atmospheric physics and chemistry is horrendously complicated because of the energy/moisture mixing and balancing in a chemically reactive environment. Estimates of GHG effects by the Intergovernmental Panel on Climate Change (IPCC) and other researchers rely on large-scale computer modelling based on physical/chemical understanding plus atmospheric measurements (eg from airborne detectors and satellite observations).

Climate-changing aircraft emissions differ from other human-related sources, eg burning fossil fuel, because most emissions occur at cruise altitudes, in the upper troposphere/lower stratosphere, and there are special non-CO_2 effects – Figure 3. How much heating do these effects produce? IPCC reports use the concept of ‘radiative forcing’ (RF) to compare the impact of the different gases and particles:

> *Radiative forcing*: instantaneous change in the energy balance of the earth-atmospheric system resulting from a perturbation in concentrations of atmospheric GHGs (measured in milliwatts per square metre, mWm^{-2})

A sustained positive RF warms, and a negative RF value cools.

GHGs such as CO_2 sit in the atmosphere for a very long time. Once emitted, the radiative forcing effect lasts for decades or centuries, even if those GHG emissions were to cease. For these long-lived and well-mixed GHGs, the steady state surface temperature change from a sustained forcing is roughly proportional to the RF, with about the same proportionality constant for all GHGs. CO_2 is generally the most important GHG because of the large quantities released and its long atmospheric residence time. But there are much larger uncertainties associated with the climate impacts from short-lived gases and particulates. Changes in concentrations will be largest near to flight routes and so tend to have a regional effect on climate.

Figure 4 summarises estimates of instantaneous RF by Sausen et al (2005), updating results in earlier IPCC documents – there is ongoing research into both the components and the total effects shown in Figure 4, eg Wuebbles et al (2006). So, can the total RF – and hence the likely temperature rise – be estimated by adding together the component RFs? Algebraically, it can – but is it a sensible calculation? There are two problems: the numbers are RFs from the changes in concentrations associated with cumulative emissions from the historical fleet, *not* annual emission rates; and the RFs are instantaneous values: they do *not* account for the different future potential forcing effects between (eg) long-lived and short-lived GHGs.

The radiative forcing index (RFI) is the ratio between the total radiative forcing from aviation at some given time to the radiative forcing from aviation emissions of CO_2 at the same time. To get the RFI, first add the RFs in Figure 4 and then divide by the CO_2 figure. This is the origin of statements that contain phrases such as ‘the environmental impacts of aircraft are thought to be 2–4 times greater than that from CO_2 alone’, and that ‘by 2030 aviation emissions could account for 31% of total UK greenhouse gas emissions’. But the RFI fails to account for the resident timescales of emissions, attributing a larger fraction of climate change emissions to aircraft than currently appears justifiable.

An international workshop on aviation and climate change has discussed this problem (Wuebbles et al, 2006): "Unfortunately, the RFI has been misapplied in some quarters…as a way of crudely accounting for the future non-CO_2 climate change impacts of aviation, by simply multiplying the CO_2 emission scenarios by the RFI."

Forster et al (2006) note:

> "CO_2 emitted by aircraft might have a much smaller initial RF than a contrail, but, crucially, it will remain in the atmosphere many times longer and continue to give a RF for the next 10–300 years, whereas the contrails and cloud RF only last for a few hours or days. Most other aircraft related climate effects have timescales of around 10 days. Aircraft methane's indirect effect on ozone is the only other aircraft related climate effect with an appreciable timescale (around 10 years)."

Forster et al (2006) made an *illustrative* calculation of an 'Emission-Weighting Factor' (EWF), which estimates the total effects of the gas emissions and other physical effects over a specified number of years. This derives from the IPCC concept of global warming potentials (GWPs): these compare the heat-absorbing ability of each gas relative to that of CO_2, as well as the decay rate of each gas – the amount removed from the atmosphere over a given number of years – relative to that of CO_2. The EWF represents the total aviation effect at the given time horizon, ie how much worse the total situation is compared with the effects of CO_2 alone. Over a (IPCC standard) 100-year period, the Forster et al EWF estimate is 1.2, rather than a figure within the 2 to 4 range.

Using an inappropriate multiplier for aviation's non-CO_2 effects could have major practical and damaging consequences. Forster et al (2007/8) comments on the European Parliament's proposal to use a factor of 2 for the EU's Emissions Trading Scheme [NB: not endorsed by the EC, which has promised to make proposals in 2009 – see http://www.euractiv.com/en/climate-change/]:

> "…emissions from international shipping are also now becoming part of international negotiations. If the European Parliament were to adopt the same methodology for calculating the uplift factor for shipping, they would obtain a negative uplift factor! This is mainly because sulphur emissions from shipping lead to the formation of short-lived particles that cause a strong cooling…on long time horizons the role of carbon dioxide becomes dominant."

Operational Solutions for Contrail/Cirrus

A contrail forms behind an aircraft if the ambient air is cold enough. Contrails form when the aircraft exhaust pushes the water content of the air past its saturation point. This produces condensation – the local increase in water vapour density condenses into tiny water droplets and/or ice crystals. In dry air, contrails dissolve quickly, but in regions of sufficiently moist air, technically described as 'super-saturated with respect to ice' (Ice Super-Saturated Regions – ISSR), contrails grow by taking up ambient water vapour, and become 'contrail cirrus'. In mid-latitudes, ISSRs generally occur just below the tropopause, typically FL290, but very rarely at altitudes below FL250.

Nobody yet knows a practical way of preventing contrails. There are several choices about how to avoid them. These depend on how well meteorological modelling can predict ISSR locations. This could be strategic, eg always flying considerably below, above or around them. It could be tactical – ie which needs real-time detection of ISSRs – by avoiding their locations through minimum necessary changes in altitude.

There have already been several studies on the best strategic approaches to reduce contrails. For example, Jelinek et al (2005), focusing on European flights, show that going around is not very hopeful, because of the large size of the ISSRs, and going above does not work well (because most flights start or end *below* an ISSR. Only a ‘fly below’ option produced potentially useful results. Other authors have found that the best reductions in contrail coverage require the aircraft to cruise about 6,000 feet lower – a considerable reduction. This would typically produce an increase in fuel burn of roughly 5%.

Tactical approaches, eg Mannstein et al (2005), would involve the aircraft carrying equipment to detect super-saturated air, and the incorporation of this data about moist atmospheric layers into ATM planning and operations. Aircraft flight management systems would need to be able to take in this tactical information. Air traffic control would need to agree changes in flight altitude.

These approaches for avoiding contrails would involve increased fuel burn, ie more CO_2 and other GHG emissions. They could also generally involve extra controller workload, because new data would need to be incorporated into a more complex ATM system (assuring at least the present levels of safety), and new kinds of decision-making would need to use this data. Note also that the FL system enables controllers safely to separate flights: an increased rate of aircraft vertical manoeuvres would tend to increase the rate of ground- and air-based conflict detection alerts, almost all of which would probably be false or unnecessary alarms.

The key environmental calculation is to compare the climate change damage caused by increased fuel burn/GHG emissions with the reduction in the contrail/cirrus warming effects. As noted earlier, contrails do not remain in the atmosphere for the decades and centuries of the GHGs, so an assumption that relative damage matches the corresponding RFs has not been substantiated. This means that it would only be worthwhile changing the ATM system specifically to reduce contrail emissions *if* the fuel burn penalty were small. Some researchers have appeared to assume that comparing RFs is sufficient to do this. The IPCC conclusion is: “Further intensive research of the impacts is required to determine whether such operational measures can be environmentally beneficial.”

Conclusions

Aviation’s contribution to greenhouse gases and the warming effect of contrails/cirrus clouds are comparatively small – but rapidly growing – proportions of total world emissions. Economic levers (Part 1) will probably do most to reduce aviation’s emissions, but operational improvements to ATM and navigation could play a significant part in reducing aviation’s effects: more research is needed. ATM redesigns must take account of the relative long-term warming effects of greenhouse gases and contrails/cirrus clouds.

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	Fuel burn
Vertical inefficiencies	0.6%
Horizontal inefficiencies	3.8%
Airborne delay	2.5%-6.0%
Taxi-in/Taxi out	0.3%-0.9%
Total	7%-11%

Table 1. Vertical, Horizontal and other flight inefficiencies (PRU, 2008).)

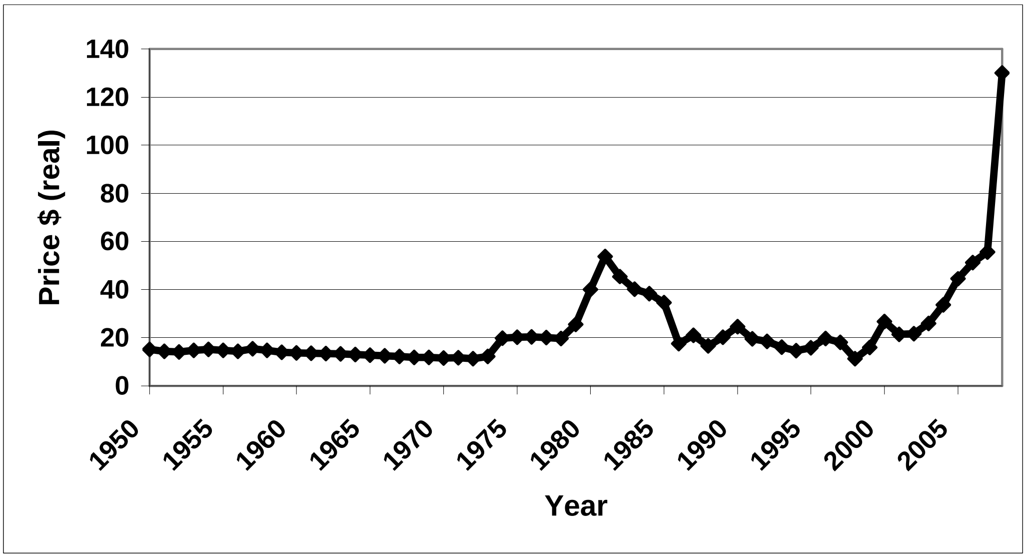

Figure 1. Oil Price ($ 2007, ie real terms) USA Energy Information Administration [http://www.eia.doe.gov/emeu/aer/txt/ptb0518.html] plus assumed $130 as 2008 mid-year value

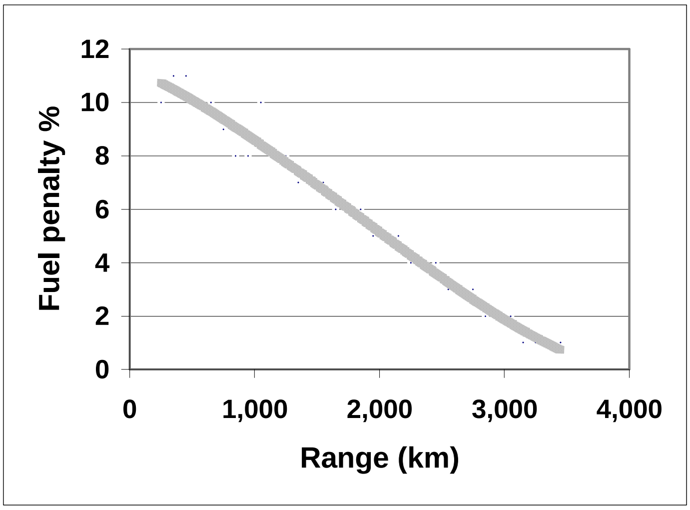

Figure 2. Estimated Fuel Burn Inefficiency by Range.

Note: This is the ‘High Bound’ estimate taken from Table 6 of Chesneau et al (2003) using mid-cell values: data/modelling to 1600 km, linear extrapolation and rounding beyond that. Calculations do not include the Landing and Take-Off cycle (LTO).

- Direct GHG effects from CO_2 etc
- NOx modifies O_3 and CH_4 concentrations
- Aerosols – liquid particles containing sulphate and organics – and soot particles can scatter/absorb solar radiation and/or trigger the formation of condensation trails (contrails)
- In right meteorological conditions, aircraft emissions of water vapour/aerosols can produce contrails and potentially cirrus clouds. These reflect incoming solar radiation (ie cool the surface) but reflect back outgoing infra-red radiation (ie warm the surface)

Figure 3. Aircraft Contributions to Climate Change

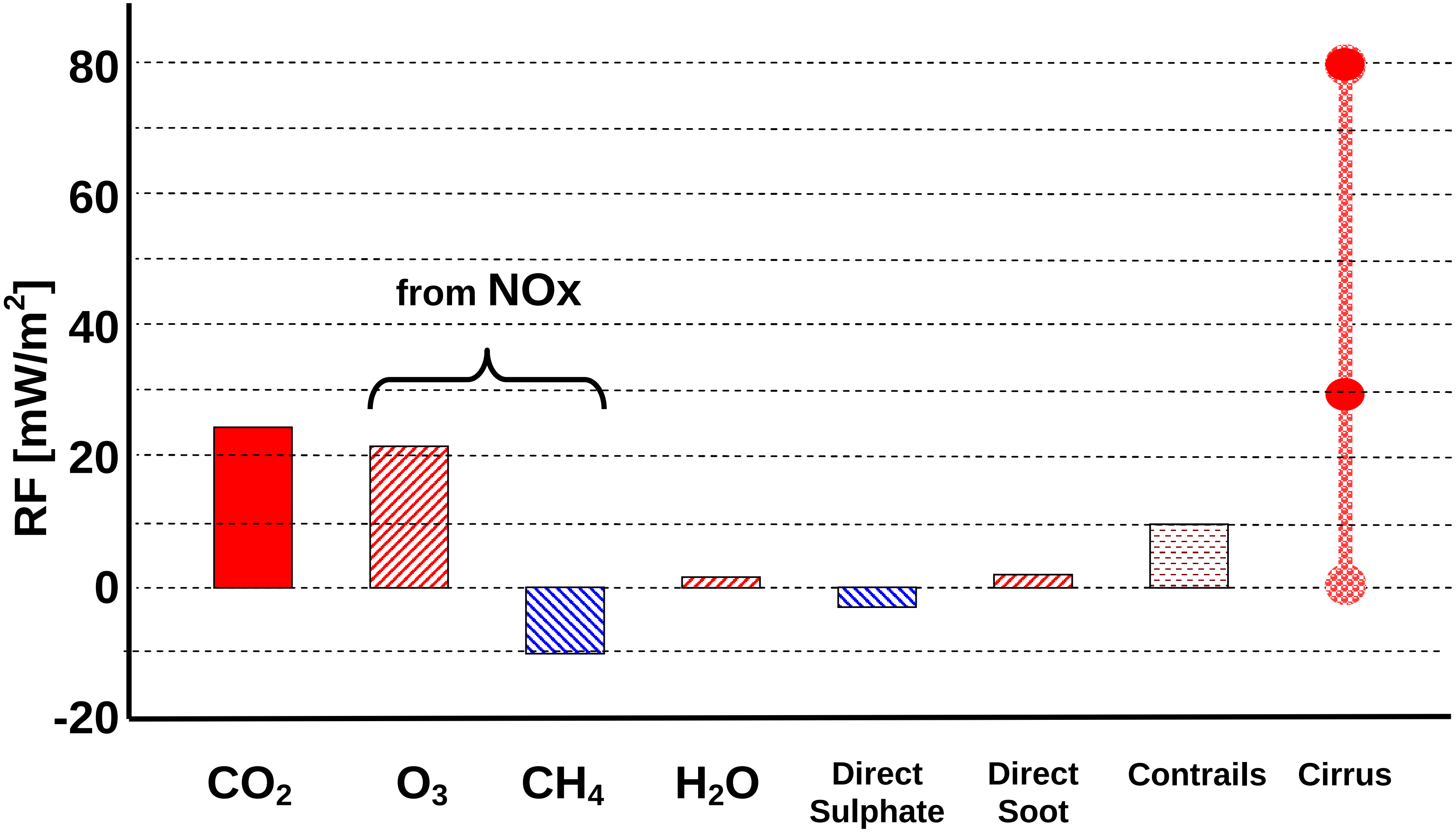

Figure 4. Aircraft Radiative Forcing: adapted from Sausen et al (2005). The shadings indicate the reduced confidence in the estimate going from left to right. The 'blobbed' cirrus values are a 'mean' and an upper bound'.