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AVIATION AND CLIMATE CHANGE:
I – UK AIRPORT CO_2 EMISSIONS

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1. Introduction

Aviation's contribution to climate change is now a topic of considerable interest. This paper summarises some key facts on airport CO_2 emissions, and highlights some policy implications.

2. Sketch of the Science

A starting point is the work of the 'Intergovernmental Panel on Climate Change' (IPCC). Figure 1 shows some key points. The bulk of the negative consequences affect poor people in low latitude countries, where agriculture is often fragile against even small temperature changes, and there are large populations living in areas susceptible to coastal damage from sea level changes.

The standard explanation for these climate changes is human activity. Figure 2 sketches the basic mechanisms. There is not unanimous agreement either that global warming exists or, if it does, that human activity causes it. Critics assert a variety of things about the scientists involved: incompetence, lack of integrity and dishonesty. It is not obvious why this particular species of scientists might be especially sloppy or 'ethically-challenged'.

Climate-changing aircraft emissions differ from other human-related sources, eg burning fossil fuel to produce CO_2, because most emissions occur at cruise altitudes, in the upper troposphere/lower stratosphere, and there are special non-CO_2 effects. The consequences of this are explored in Part II.

2. Aviation's CO_2 Emissions

What is a fair measure of aviation's CO_2 emissions? The approach here is to focus on emissions at some large UK airports, which also helps in understanding the implications of some policy initiatives. An airport's aviation emissions conventionally cover all the departures from the airport. There do not appear to be any official statistics for individual UK airports, although there are some modelled estimates.

There are potentially several ways of estimating annual CO_2 emissions. One obvious way is by starting with an estimate of fuel taken on board departing aircraft, and then do the sums using jet kerosene's chemical characteristics to estimate the corresponding CO_2 output. But this annual fuel utilisation does not appear to be published. Moreover, aircraft can 'tanker', ie carry fuel for both the outgoing and

return journey, so the fuel taken on board would not correspond exactly with that used for departures – tankering can be a substantial proportion of the fuel loaded.

Most estimates of aviation CO_2 emissions use a synthetic method. Each aircraft type generates predictable emissions on take-off and in cruise, dependent on several factors, eg the aircraft load and destination, and the two components can be estimated separately. Watterson et al's (2004) official UK methodology for UK emissions builds up the total by adding estimates of all the component parts (see also Choudrie et al, 2008). They estimate emissions from the number of aircraft movements broken down by aircraft type at each UK airport. This estimate of aviation emissions uses data on aircraft movements, broken down by airport, aircraft type, international or domestic, and great circle distances travelled.

CO_2 Emission Calculation Method

Any estimate of airport CO_2 emissions should ideally satisfy several conditions if it is to be useful and credible. These might include:

- Total airport estimates that are consistent with published official UK aviation estimates
- Method of calculation that uses published sources, is easy to reproduce, has clear assumptions, and can be upgraded if more information becomes available
- Good indication of relative changes from year to year
- Calculation providing insights into the make-up of the total emissions

The following attempts to meet the set of conditions just described. The main steps are:

1) Estimate relative CO_2 emissions for different classes of short-/long- haul flight.
2) Estimate number of flights from airports in the different short-/long- haul classes.
3) Multiply these two sets of figures, thus estimating the total relative CO_2 emissions by airport.
4) Add together the total relative CO_2 emissions for all UK airports and compare with the total UK aviation emissions. An airport's emissions are then estimated from the proportion it contributes to total emissions.

The methodology and outputs here can be compared with those of other modelled estimates, eg DfT (2007) and AEF (2008), noting that they separate out the figures for UK airport ground emissions and freight aircraft, whereas these are essentially allocated *pro rata* here.

Some UK Airport Estimates

The starting point is Figure 3. This is derived from Graichen and Gugele (2006), which in turn is based on the 'Pagoda' assessment of the departures and CO_2 emissions for all flights leaving EU (European Union) airports in 2004 (Eurocontrol 2005). Emissions estimates use a detailed model based on data gathered for route charges and air traffic management. The database does not include small aircraft,

and the estimates for 2004 are somewhat lower than the values in corresponding national inventory submissions, but the data is serviceable enough for present purposes.

Figure 3 indicates clearly the very striking differences in the CO_2 produced by different kinds of flight. This shows, for each Flight Destination Region, the ratio of emissions to departures relative to the Europe & Internal baseline – the 'Relative Emission Weighting'. The cruise phase of long-haul flights produces very large contributions to the total emissions compared with flights within Europe.

Note that the Weightings are for European flights, not UK flights. This produces some distortion when used for UK airport estimates: North America is near to the UK than Europe generally, whilst the Far East destinations are further from the UK than European countries generally. UK flights are high proportions of the total, particularly for Indian sub-continent and Australasian destinations. 'Europe & Internal' here includes domestic flights, so there is an assumption that the typical emissions for domestic and intra-European flights are the same across Europe.

The numbers in Figure 3 feed into Table 1. This table is constructed from three sources: BAA data on its 2007 airport traffic destinations; statistical data on the destination of passengers (not just UK citizens) from UK airports, published annually by the CAA (2008); and data on the total UK aviation emissions in 2006 (DEFRA, 2008) plus a growth assumption.

Table 1 presents roughly estimated ATMs (Air Transport Movements), contributing by far the bulk of aviation's CO_2 emissions. The three BAA London airports are separately identified; 'Balance' is all the other UK airports (including the Channel Islands). In 2007, Heathrow and Gatwick were the largest UK airports; Stansted was fourth largest, with plans under review to expand it substantially.

Some of the cells in the destination columns of the table can be filled immediately from published BAA data: the Europe & Internal and North Atlantic columns for the three airports. The numbers in the other cells have to be estimated. The simplest way of doing this is to assume that ATM numbers are proportional to passengers carried. This is a reasonable working assumption for comparisons where the aircraft types involved and the economics of the operations are similar. Two further complications are that ATMs also include 'all cargo' aircraft, while many passenger aircraft carry freight as belly-hold (see Nielsen (2003) for a discussion).

Thus, the calculation to fill the missing cells is a set of 'large back-of-envelope' sums. The Balance cells need particular care, because Heathrow is very atypical of the UK airports, eg it has a tiny proportion of charter operations. Hence, Balance cells are filled by assuming comparability with the data from Gatwick and Stansted combined. The estimated ATMs are then multiplied by the Emission Weightings to produce the total emissions in 'Europe & Internal equivalents' – the penultimate column. This gives the Weighted Total for each airport, ie the relative amount of emissions generated by all the ATMs. When divided into the Weighted Total for all the airports, this generates the percentage that each airport produces out of the UK total. Thus, in 2007 Heathrow produces 48.2% of the UK's emissions, and Gatwick 13.9%.

What were the total aviation emissions in 2007? DEFRA (2008) says the total for 2006 was 37.9 mtonnes CO_2. Assume that the increase from 2006 to 2007 was 2.5%, based on CAA ATM growth figures. This gives an estimated 2007 figure of 37.9 x 1.025 = 38.8 mtonnes. If the airport percentages of emissions are multiplied by the estimated 2007 figure, the result is the final column of Table 1.

Figure 4 displays the three airports' weighted figures. This illustrates *inter alia* the dominance of Heathrow for both Far East and North Atlantic traffic. Note again that a variety of stated approximations and assumptions has been made to produce these numbers – the errors *may* balance out to some degree. But the clear message is the sensitivity of the estimates to the proportion of emissions from long-haul flights.

How big the UK Aviation/Airport CO_2 Contribution?

There are many different views about how important the CO_2 emissions from UK/European aviation actually are (eg see http://www.euractiv.com/en/climate-change/eu-emissions-trading-scheme/article-133629). Some seek to stress that there are other emission sources where substantial CO_2 reductions could be made much more cost-effectively than through changes to aviation. Others note that while aviation is a relatively small percentage of (say) EU emissions, its contribution has increased considerably in recent years and is forecast to keep on increasing.

A key point here is that UK aviation generates comparable CO_2 emissions to major UK CO_2 sources. The largest 'stationary' emissions sources in the UK are mainly power stations. The largest is Drax power station, which produced 22.5 million tonnes of CO_2 in 2007 [http://uk.reuters.com/article/basicIndustries/idUKL1904070220080519]. Heathrow would probably be the second largest source if the UK list included airports, with Gatwick in the top 20.

Airport Emissions and EU Carbon Trading Schemes

International aviation is excluded from the Kyoto Protocol on climate change. The International Civil Aviation Organisation (ICAO) has endorsed the *concept* of an emissions trading system (ETS) to meet CO_2 emissions reduction objectives – but as yet no more than that. The EU decided to take unilateral action in developing an ETS.

In fact, the UK potentially has several aviation policy instruments besides ETS. These include: taxation of aviation fuel, emissions charging, VAT on air tickets, and changing Air Passenger Duty (eg see University of Oxford Environmental Change Institute, 2006). But the UK government has supported the European Commission (EC) ETS proposals made in December 2006 (EC, 2006) to incorporate aviation in the existing industrially-focused ETS. [See euractiv website above for background references.] The basic ideas are that individual airlines receive/buy tradeable allowances ('permits') to emit a certain level of CO_2 per year from their flights. If the actual emissions are lower than their allowances, the airline can sell their surplus allowances on the market or else 'bank' them to cover future emissions. If future emissions will exceed their allowances, the airline can invest in 'state of the art' efficient technologies or buy additional emission allowances on the market.

Eventually, an agreement to bring aviation into the EU ETS passed through the European Parliament in mid-2008 (EC, 2008) by a huge majority – 640 to 30. It covers both EU and non-EU airlines, flying to, from and within the EU. Emissions from aviation will be capped at 97% of their average 2004-2006 level in 2012. Airlines will have to pay for permits covering 15% of their pollution quotas, the remainder being issued free. New entrants or very fast-growing airlines will have a special reserve of free allowances.

USA officials and USA-based airlines say that the EU should wait for a global agreement on ETS, that "foreign airlines would now effectively be subsidising the EU aviation industry", and that the agreement was "not only bad policy, it is illegal". Airline criticism includes "the ETS was being used as a "punitive weapon to batter the European aviation sector", that the deal was "agreed without any serious impact assessment", and "Airlines now faced with an unacceptable deal on ETS" [samples from euractiv website].

It is puzzling why the EC focused on a comparatively complex aircraft operator-based ETSs, and did not explore more deeply an airport-based ETS. Tankering is certainly an issue here, but it is far less important for the high CO_2 emitting long-haul flights. The EC's 'Impact assessment' recognises an airport option 'would have the advantage that an airport provides a possible *point of aggregation* for the polluting activity', which is surely an extremely strong argument as regards both public and industry. The EC's reasons against an airport option are:

> "While the economic signal that emissions trading is designed to establish could conceivably be transferred to aircraft operators via airport landing charges, defining and agreeing on sufficiently accurate and harmonised mechanisms for providing correct price signals to those actually in control could be very difficult given the wide variety of approaches to airport charging that exists in the Community. If airports failed to pass on the costs or failed to pass on the costs by reference to emissions, then the scheme would not provide the right incentives and the objective of the policy would not be achieved."

Is the first objection insuperable, given the increasing openness about CO_2 emissions and the value from having consistent airport charging throughout the EU? The second seems odd: airports would surely want to pass on identified environmental costs? – if not, then EU action would be necessary.

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	ATMs (1000s)					
	Europe & Internal	**Rest Long Haul**	**North Atlantic**	**Far East**	**Weighted total (%)**	**Annual figure (mtonnes)**
Emission weighting	***1***	***8.1***	***17.4***	***28.3***		
Heathrow	317.7	42.5	64.9	50.54	3221(48.2)	18.7
Gatwick	201.5	32.4	21.9	2.96	929(13.9)	5.4
Stansted	182.5	4.0	4.9	0.08	302 (4.5)	1.7
Balance	1517.3	29.7	19.5	4.83	2234(33.4)	13.0
					6687(100.0)	38.8

Table 1. Roughly estimated ATM Breakdown and Weighted contributions for 2007.

Note: CAA/BAA/'Pagoda classes' data sources have minor differences. The significant figures used for calculation do not imply that order of precision.

- 'Summary for Policymakers', focusing on science. Very similar to 3rd Report: human activity now 'very likely' rather than 'likely' to be responsible.
- Warming accelerating? 11 of the 12 years from 1995-2006 rank in the 12 hottest years since 1850. Global increase in temperature in past century estimate is 0.74°C.
- Sea level rose on average 1.8mm a year from 1961 to 2003, but by 3.1mm a year between 1993 and 2003.
- Some scientific evidence for faster glacier melting in Greenland. Arctic summer ice deceasing by >7% a decade. But Antarctic sea ice apparently not shrinking.
- New temperature feedback mechanisms found, so predictions not yet stabilising.
- Range of temperature rise predictions for 2100 is wide: 1.1°C to 6.4°C.

Figure 1. Global climate effects bullet points: extracted from IPCC (2007)

- Solar radiation absorbed by the Earth's surface and atmosphere then re-emits as infrared radiation.
- Natural radiation-absorbing gases in the atmosphere: the main contributor carbon dioxide (CO_2), water vapour (H_2O), ozone (O_3), methane (CH_4), nitrogen oxides (NOx), etc partly trap this outgoing infrared radiation.
- This natural trapping keeps the surface and troposphere about 33°C warmer than it would be otherwise.
- But industrial activity increases the amount of these 'greenhouse gases' and causes an extra heating effect – global warming.

Figure 2. Global climate causes bullet points: extracted from IPCC (2007)

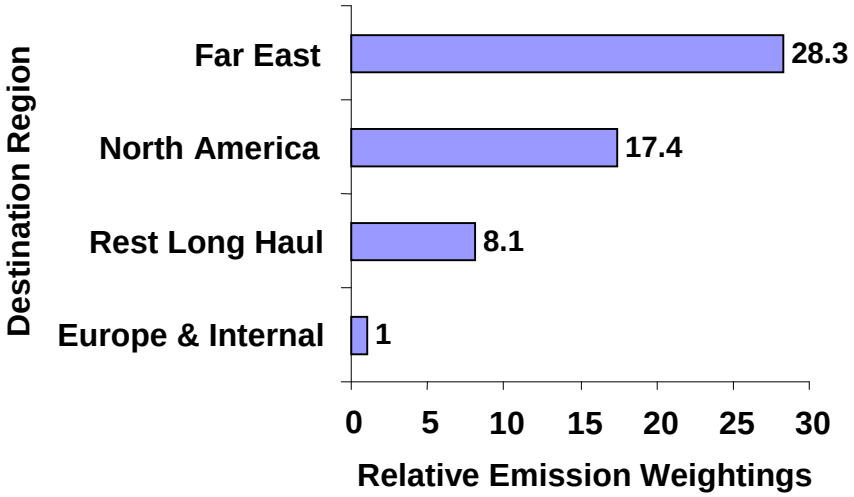

Figure 3. Relative Emission Weightings (calculated from 'Pagoda' data in Graichen and Gugele, 2006).

[Note: Europe & Internal is the EU 25 plus the rest of Europe plus Unknown destinations (~0.2% of total) minus the EU's Ultra Peripheral Regions (UPR), eg the Canaries, Madeira]

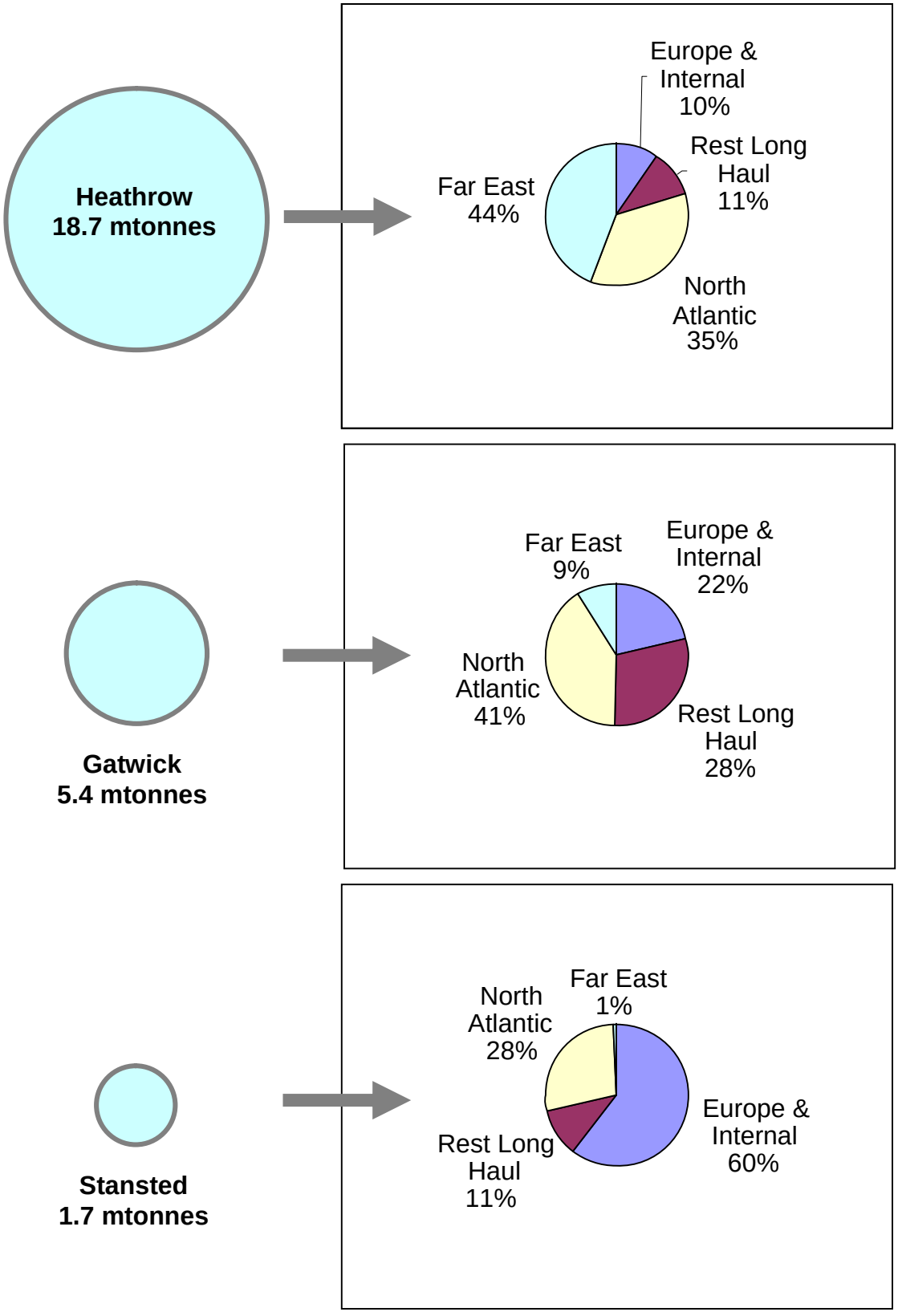

Figure 4. Rough estimates of CO_2 emissions and their make-up at some UK airports