Aviation and Global Warming

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Executive Summary

Aviation and Global Warming is a technical paper describing background analysis, in support of ***The Future of Air Transport*** White Paper, on the contribution of aviation to global warming.

The carbon dioxide forecasts in paragraph 2.14 of ***The Future of Air Transport*** White Paper draw upon information presented in ***Aviation and Global Warming***.

The evidence base reviewed in ***Aviation and Global Warming*** includes the impact of technological and other 'supply side' improvements to 2030 and to 2050 on fuel burn, and hence global emissions, as well as airline response to economic instruments.

Aviation and Global Warming also considers the projected total level of carbon emissions in the UK, so as to put aviation's global emissions in context, as well as the more specific details of global emissions due to aviation.

Finally, the impact of air traffic growth on global emissions – and the corresponding cost using Defra's 'social cost of carbon' – is compared in ***Aviation and Global Warming*** with the economic benefits arising from airport development scenarios.

1. Introduction

1.1 In December 1999, the Intergovernmental Panel on Climate Change (IPCC) Special Report**, *Aviation & the Global Atmosphere***[1] said that, '*the balance of evidence suggests there is a discernible human influence on global climate*.'

1.2 In January 2001, the IPCC ***Third Assessment Report***[2]***,*** reviewing the scientific evidence on climate change from all sources concluded that '*an increasing body of observations gives a collective picture of a warming world and other changes in the climate system*.' It noted in particular that:

- the global average surface temperature had increased over the 20th century by about 0.6 degrees C;
- temperatures appeared to have risen during the past four decades in the lowest 8 km of the atmosphere;
- the extent of snow and ice had decreased;
- the global average sea level had risen and ocean heat content had increased.

1.3 The 1999 IPCC Special Report made an assessment of aviation's contribution to global warming. Although it is not possible to detect the aircraft-specific contribution to global climate change, few seriously suggested that the sector did not contribute to climate change. Since then, successive Government documents have referred to aviation's contribution, including the ***Future of Aviation***[3] consultation paper, with its supplementary paper ***Valuing the External Costs of Aviation***[4]; the ***Future Development of Air Transport in the United Kingdom***[5] series of regional consultation documents; and the discussion document ***Aviation and the Environment: Using Economic Instruments***[6]*.*

1.4 During the second half of 2003, the Department for Transport revised its analysis of future trends in aviation's contribution to global warming, in the light of responses to the various consultation and discussion documents, reassessment of earlier material, and continuing inter-departmental discussions. The revised analysis helped to inform the ***Future of Air Transport*** White Paper[7] published on 16 December 2003. This report summarises the Department's revised analysis, and how it was derived.

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[1] *Aviation and the Global Atmosphere* (eds. Dokken, Griggs, Lister, McFarland, Penner), Cambridge University Press, 1999.

[2] *IPCC Third Assessment Report: Climate Change 2001*, Cambridge University Press, 2001.

[3] *The Future of Aviation*, December 2000, DETR.

[4] *Valuing the External Costs of Aviation*, December 2000, DETR.

[5] *The Future Development of Air Transport in the United Kingdom*, DfT, July/August 2002. The revised South East consultation document was issued in February 2003.

[6] *Aviation and the Environment: Using Economic Instruments*, March 2003, DfT and HM Treasury.

[7] *The Future of Air Transport*, Cm 6046, December 2003.

2. UK Domestic Carbon Emissions and Targets

2.1 This chapter briefly examines the UK's overall domestic carbon emissions and associated reduction targets, illustrating their recent evolution. Table 1 below shows the UK's 1990 carbon dioxide emissions for each sector expressed in million tonnes of carbon (MtC):

Table 1: Total 1990 CO_2 emissions in the UK

Sector	**1990 level CO_2 emissions (MtC)**
Business	57.4
Industrial Processes	8.0
Transport	39.7
Residential	41.7
Public	8.7
Agriculture	2.0
Land use change emissions only	4.9
Waste Management	0.5
Exports	1.8
Total[8]	**164.8**

Source: *Derived from UK Greenhouse Gas Inventory, 1990 to 2001*, NETCEN, July 2003.

2.2 The National Environmental Technology Centre's (NETCEN's) ***UK Greenhouse Gas Inventory, 1990 to 2001*** records the UK aviation sector, including all domestic flights plus international passenger departures and freight air traffic movements (ATMs) as having emitted 4.6 MtC in 1990.

2.3 In 2001 UK carbon emissions were about 5.3 per cent below the 1990 level, reflecting fuel switching in the electricity supply industry, the policies in the Climate Change programme, including promotion of greater energy efficiency, and industrial restructuring. Emissions of all UK greenhouse gases reported to the United Nations Framework Convention on Climate Change[9] fell by 12.3 per cent over the same period.

Kyoto Protocol

2.4 At Kyoto in 1997, European Union Member States collectively agreed to reduce their greenhouse gas (GHG) emissions by 8 per cent. below 1990 levels, by 2008-2012, in the context of an overall reduction by developed of an

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[8] The forest sink accounted for about 2.9 MtC/year 1990, so net emissions were about 161.9MtC/year, falling about 5.6% over the period to 2001.

[9] ie carbon dioxide, methane, nitrous oxide, the hydrofluorocarbons, the perfluorocarbons and sulphur hexafluoride.

average of 5.2 per cent over the same time frame. Following agreement with other Member States on how to share out the EU target, the UK's legally binding target is to reduce its emissions by 12.5 per cent. over this period. The six GHGs covered by the Kyoto Protocol are carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), sulphur hexafluoride (SF_6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs). The UK's Climate Change Programme published in 2000 also sets out policies designed to meet a domestic goal to reduce CO emissions by 20 per cent below 1990 levels in 2010, and, following the 2003 Energy White Paper, the UK intends to put itself on track to reduce CO2 by 60 per cent by 2050, consistent with the RCEP report mentioned below.

2.5 Emissions from *domestic* flights are included within countries' targets agreed under the Kyoto Protocol. But emissions from international aviation are not, because agreement has not yet been reached on how to allocate emissions from these sources. The UN Framework Convention on Climate Change's (UNFCCC) Subsidiary Body on Scientific and Technical Advice (SBSTA) is currently considering this issue. In the meantime, Parties to the UNFCCC are required to limit or reduce emissions from international services working through the International Civil Aviation Organisation (ICAO).

RCEP 22nd Report

2.6 The Royal Commission for Environmental Protection (RCEP) published its 22nd report, ***Energy - the Changing Climate*** on 16 June 2000. The report discussed the need for, and the potential in each sector, for reducing UK carbon emissions, with particular emphasis on energy efficiency both in the home and industry. The report presented 19 key recommendations, and a number of further suggestions. The headline recommendation (number 5) was for a 60 per cent. overall reduction in domestic UK carbon emissions over the next 50 years. This target is linked to 550 ppm as a maximum tolerable atmospheric CO2 concentration, based on the analysis presented in the IPCC Second Assessment Report 1995 [see **ANNEX A**]. The European Union had already proposed 2°C as a maximum tolerable temperature increase and linked this to 550 ppm, although the IPCC's Third Assessment Report suggests that a rather lower concentration limit would in fact be required.

2.7 The 22nd RCEP report did not specify the contribution that each individual sector should make to emissions reductions over this period, and made no specific recommendation regarding the treatment of emissions from international aviation.

The Energy White Paper

2.8 The Government published its Energy White Paper (EWP) ***Our Energy Future - Creating a Low Carbon Economy***[10] in February 2003. This confirmed an additional national goal to move towards a 20% reduction in

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[10] *Our Energy Future - Creating a Low a Carbon Economy*, Cm5761, February 2003, Department for Trade and Industry

CO_2 emissions below 1990 levels by 2010. The EWP further states, in paragraph 1.10: '*our ambition is for the world's developed economies to cut emissions of greenhouse gases by 60 per cent. by around 2050. We therefore accept the RCEP's recommendation that the UK should put itself on a path towards a reduction in carbon dioxide emissions of some 60% from current levels by about 2050'*. The EWP acknowledged in paragraph 1.9 that '*climate change is a global problem. It has to be tackled globally. The UK will show leadership but it cannot solve this problem alone*.' To this end, the EWP declared in the same paragraph that the UK will aim to '*continue to work with other countries to establish a consensus around the need for change and for firm commitments to take action to reduce carbon emissions world wide within the framework of the United Nations Framework Convention on Climate Change (UNFCCC).*'

The 60 Per cent. Reduction Target

2.9 The key figures in the EWP are :

- In 2000, the UK emitted **147** Million tonnes of carbon (MtC). On the basis of current policies, UK expects to emit some **135** MtC in 2020, rising to 145 MtC in 2050.
- To show leadership and to aim for the RCEP 60 per cent. reduction by 2050, the EWP aims for a **15-25** MtC reduction below this 135 MtC level by 2020, *i.e*. to 110-120 MtC.

2.10 Kyoto targets were set using 1990 as the baseline. The EWP uses *'around 65 million tonnes'* to describe the level of carbon emissions which a 60 per cent. cut would deliver in 2050.

Table 2: UK Emission Forecasts Under Various Scenarios[11]

Year	Business as Usual Emissions/ MtC	RCEP Reduction Target from 1990 levels/ %	Target Emissions Level/ MtC
2010	**136[12]**	**20**	**131.6**
2020	**135[13]**	**30**	**115.2**
2030	**138**	**40**	**98.7**
2050	**145**	**60**	**65.8**

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[11] These UK national emission forecasts were calculated by assuming a percentage reduction in UK CO_2 emissions per decade based on the RCEP reduction target of 60 per cent. by 2050, and using the UK's 1990 level of CO_2 emissions as the base year.

[12] From the UK's Third National Communication excluding the additional measures in the Climate Change Programme

[13] Assuming full impact of measures in the Climate Change Programme

3. Aviation Emissions

Aviation Emission Estimates for 2000 and 2030

3.1 The CO_2 forecasts published by DfT in ***The Future Development of Air Transport in the United Kingdom*** and in ***Aviation and the Environment: Using Economic Instruments*** [see **ANNEX C**] were conservative in so far as potential fuel efficiency improvements are concerned. For example, they took no account of potential reductions in fuel consumption from more efficient airspace management (such as reducing the time aircraft are held in 'stacks') or the effects of the introduction of any economic instruments.

3.2 It is important to understand that, in the DfT forecasts, CO_2 emissions from 'UK passenger aviation' are taken as those arising from all domestic passengers within the UK plus all international passenger departures from UK airports. This allocation of international aviation emissions to UK aviation is, however, an analytical device only; there is no existing international convention that attempts to divide international emissions into national contributions (see paragraph 2.5 above). Given that one fifth of all international air passengers in the world are on flights to or from a UK airport, it is not surprising that CO_2 emissions from UK aviation are high – both in relative and absolute terms[14].

3.3 However, the UNFCCC has commissioned, along with the Department for Environment, Food and Rural Affairs (Defra), a project to identify various methods for allocating emissions to countries and the effects that such policy measures would have on those countries.

3.4 It should also be noted that the metric used by NETCEN to measure the UK's CO_2 emissions (paragraph 2.2 above) is an approximation since NETCEN estimates the total fuel uplifted by aircraft in the UK as the UK's CO_2 emissions from aviation. In practice, part of the uplifted fuel could be used on flights not departing from the UK but used, for example, on a return flight back to the UK from a different country (or *vice versa*).

3.5 In ***Aviation and the Environment: Using Economic Instruments***, the cost of UK aviation carbon emissions in 2000 was calculated as:

8 MtC x 2.5 x £70/tC = £1.4bn

The calculation was derived in the following way:

- for 2000, UK civil aviation including freight produced 32.2 $MtCO_2$, figures provided by NETCEN[15]. Of this total, UK civil passenger aviation produced 30 $MtCO_2$. This figure was converted into tonnes of carbon using the

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[14] A similar result would occur if small countries like the Netherlands and Singapore, with large international hub airports, used the same analytical device.

[15] UK Greenhouse Gas Inventory, 1990 to 2001. NETCEN, March 2003.

relationship that 1 tonne of carbon corresponds to 3.67 tonnes of carbon dioxide. This gives a figure of approximately 8 MtC of carbon emissions. (This figure does not include the carbon contribution from air freight, which is 0.6 MtC, nor emissions from surface access transport to and from airports);

- at high altitudes, aviation's other emissions such as NO_x and contrail formation give an additional contribution to climate change above that due to CO_2 alone. To account for this extra impact, a radiative forcing impact (RFI)[16] factor of aviation at altitude needs to be applied. In ***Aviation and the Environment: Using Economic Instruments***, this factor was taken as 2.5 times that of CO_2 alone. However, higher values of the RFI would result in higher emissions overall. ***The Future of Air Transport*** [see box below paragraph 3.36 there] refers to the global emissions impact of aviation being between 2 and 4 times greater than that from that CO_2 alone;

- the product of the amount of carbon and the RFI is then multiplied by the illustrative midpoint social damage cost of carbon, given as £70/tC. The mid point figure of £70/tC sits within the range of £35 to £140, which takes account of climate change uncertainties. The £70/tC rises at £1 per tonne of carbon per annum as the future damage costs of carbon increase. Although the £70/tC is a damage cost, the underlying analysis done by Defra in the 2002 Government Economic Service (GES) paper 140, ***Estimating the Social Cost of Carbon Emissions*** also sees this figure and its rise over time as consistent with mitigation costs in the long term[17]. It should be noted an interdepartmental group chaired by Defra is currently reviewing the illustrative estimates for the social damage cost of carbon, and the interim advice is that it is important to examine sensitivity across the whole range of values.

3.6 The climate change costs of UK aviation for 2030, under the ‘high airport capacity’ scenario (480 mppa) ***in Aviation and the Environment: Using Economic Instruments*** was calculated as:

19 MtC x 2.5 x £100/tC = £ 4.8bn

The figure of 19 MtC again excludes air freight and surface access carbon contributions. Freight contributes 1.84 MtC and surface access 0.89 MtC, thus a gross 2.73 MtC. The 2030 social cost of carbon of £100/tC was used in the 2030 calculation.

DfT CO_2 Forecasts

3.7 The NETCEN figures for the year 2000 were calculated on the basis of fuel take up by airlines. In contrast, the DfT estimates – which are lower –

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[16] For a fuller explanation of radiative forcing, see Annex B of *Aviation and the Environment: Using Economic Instruments*

[17] For example, the 15-25 MtC reduction by 2020, as set out in the Energy White Paper, is broadly cost-effective against this benchmark.

assumed that aircraft use 'great circle' routes[18]. In reality, journeys are *circa* 10 per cent. longer on average because of airspace constraints and meteorological factors.

3.8 The DfT emission forecasts, as set out in ANNEX D of ***Aviation and the Environment: Using Economic Instruments***, took fuel burn data for representative aircraft 'types' used on domestic, short haul and long haul services. These aircraft 'types', with the exception of the A380[19], were represented by aircraft already in service. No improvement in fuel efficiency for these aircraft 'types' was assumed in deriving the 2030 forecasts. So the 2030 forecasts made no allowance for fuel efficiency savings from any new aircraft types such as the forthcoming Boeing 7E7[20], or enhanced performance from, in particular, fitting more fuel-efficient engines to existing aircraft types.

3.9 There are four key factors for consideration in reviewing future fleet fuel efficiency:

- operational improvements;
- fleet renewal leading to greater fuel burn efficiency;
- the effect of economic instruments;
- the impact of 'stretch' research targets, especially from the Advisory Council for Aeronautics Research in Europe (ACARE), which may still be in prototype by 2020.

Operational Improvements

3.10 The DfT carbon estimates for international aviation in 2000 were over 10 per cent. lower than those estimated by NETCEN. Apart from a less wide coverage of UK airports by DfT, which should not be quantitatively significant, the likeliest principal reason for the discrepancy is that the modelling for the DfT assumed that all aircraft fly great circle distances. For 2030, therefore, the DfT modelling implicitly assumed that operational improvements not yet available would become so. Such operational improvements could arise from developments in air traffic management such as reduced vertical separation (RSVM)[21]. There is also potential for efficiency savings from improvements in load factors (percentage of aircraft seats actually occupied by fare paying passengers), and from changes in the altitudes at which aircraft fly.

3.11 Potential reductions in flight time from improved air traffic management would be counter-balanced, at least in part, by higher traffic levels. However, chapter 8 of the IPCC 1999 special report, ***Aviation and the Global Environment*****,** concluded that improvements in communications, navigation,

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[18] i.e. the shortest distance between the two points.

[19] Airbus expects the A380 to commence operations in 2006.

[20] The formal authority to offer for sale the B7E7 'Dreamliner' was announced by Boeing on 16 December 2003. The company expects the aircraft will commence operations in 2008.

[21] Implementation of RSVM in pan-European airspace from January 2002 has resulted in fuel and associated emissions savings of around 5% in RVSM airspace (source: EUROCONTROL Skyway magazine issue 31, Winter 2003).

and surveillance/air traffic management (CNS/ATM) could give world-wide fuel savings of about 6-12 per cent.

3.12 The DfT forecasts did include a modest uplift in load factors over time. However, they did not take account of the (less than proportionate) increase in payload, which determines fuel burn.

Fleet Renewal Leading to Increased Fuel Efficiency

3.13 The DfT forecasts, because of the way they aggregated aircraft types, underestimated the potential for fuel savings. DfT has revised its views on the potential for fuel efficiency improvements, based on reports from IPCC, Oxford Economic Research Associates (OXERA) and Arthur D Little, as well as assessments from industry sources.

3.14 IPCC, in ***Aviation and the Global Atmosphere*** (1999) cites future trends in the fuel efficiency of the future aircraft fleet. These projections assume an annual improvement in the fuel efficiency of aircraft still in the fleet and all aircraft delivered since 2000, taken together, of 1.3 per cent. per annum from 2000 to 2010 dropping back to 1 per cent. per annum from 2010 to 2015. These assumptions would amount to an improvement in the fuel efficiency of the future aircraft fleet of 16.4 per cent. by 2015. If, beyond 2015, there were a continuing annual improvement of 0.5 per cent. per annum, the overall fuel efficiency of the future aircraft fleet could be improved by around 22 per cent. by 2030**.**

3.15 OXERA, in their report Financial Impact of Emissions Trading on Intra-EU Aviation , October 2003, assume fuel efficiency savings of 1 per cent. per annum to 2030 in the absence of any economic instruments.

3.16 Arthur D Little's study into the ***Potential Impact of Changes in Technology on the Development of Air Transport in the UK***, 2000[22], states that '*overall, advances in airframe, engine and operational developments are forecast to offer average fuel efficiency improvements of up to say 2 per cent. per annum until 2030*'. [See also **ANNEX B**]. Their baseline for savings appears to be the current fleet average.

3.17 ***Aviation and the Environment: Using Economic Instruments*** reported the fleet projections in 2030 [see **ANNEX C**], used to estimate the DfT CO_2 emission projections in ***The Future Development of Air Transport in the United Kingdom: South East***. The fleet projections included a high percentage of Boeing 747-400s in 2030.

3.18 In contrast, analysis undertaken by Rolls Royce, the aircraft engine manufacturer, has identified savings in fuel burn per passenger-km for the aircraft operated by UK carriers as:

- 34 per cent. between the Kyoto base year (1990) and 2012 ;
- 21 per cent. between 1990 and 2000;

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[22] Final report to the Department of the Environment, Transport and the Regions, November 2000.

- 16 per cent. between 2000 and 2012 – or more than 1 per cent. per annum.

3.19 Looking at the differences between fleet compositions in the Rolls Royce work for 2000 and 2012, the reasons for fuel savings include by the later date: fewer B747s and more B777s; more second/new generation B737s; more A320s; and small contributions from B7E7s and a 'new 175 seater' (See **ANNEX C**). DfT accepts that these appear to be more realistic assumptions on fleet renewal than those used in the Department's published forecasts.

3.20 Airbus' ***Global Market Forecast 2001-20***[23] provides a further source of evidence on the speed of future fleet replacement over the period to 2020, stating that, '*36 per cent. of the current [world] passenger fleet will be retired from active service'* adding that, *'In the near term, airlines have grounded record numbers of aircraft in an effort to reduce capacity in line with the sharp drop in demand for air travel resulting from the economic slow-down and the terrorist attacks. When demand returns, airlines are more likely to respond by adding new, efficient types than by recreating the infrastructure necessary to operate the older aircraft they have grounded'***.**

3.21 For each of 19 aircraft types identified in the forecast, Airbus looks at potential market development, so as to predict aircraft in demand in the market place. Not surprisingly, Airbus sees a switch over the next 20 years to bigger aircraft such as its own A380, with increasing load factors (4-5 percentage points higher). In 2020, Airbus think that the fleet will be similar – but more efficient – than today. Beyond 2020 "concept 'planes" currently on the drawing board will take an increasing market share.

3.22 Airbus considers fuel efficiency to be a key driver for all proposed new Airbus aircraft. Fuel efficiency not only impacts on the operational cost of any aircraft, but also has a knock-on effect on the payload capacity and range of the aircraft, *i.e.* upon how much fuel it needs to carry. Fuel cost is much more important to long haul aircraft (30 per cent. of Direct Operating Cost (DOC)) than it is to short haul aircraft (10 per cent. of DOC).

3.23 However, Airbus has revealed that the A380 will pay a 2 per cent. penalty from its optimum fuel efficiency in order to meet stringent noise restrictions – principally the Heathrow QC/2 night noise limit. New engines likely to be available in the future are expected to solve this problem and these could be retrofitted to first production A380s in 10-15 years.

3.24 Industry and ICAO estimates suggest that 75 per cent. of the aircraft flying worldwide in 2020 have not been built yet. But this must be balanced against the fact that the current EU fleet is young, and that the UK's biggest airport, Heathrow, is a particular magnet for newer aircraft types. For example, approximately 43 per cent. of aircraft using Heathrow are less than 5 years old, compared to a global average of 22 per cent.[24] Thus the potential for large fuel efficiency savings through enhanced fleet replacement is not as great at major UK airports as it may be elsewhere.

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[23] *Global Markets Forecasts 2001-2020*, September 2002, Airbus

[24] Source: QinetiQ, using BAA operational data for the six months up to 31 August 2001.

3.25 Improvements in environmental performance for major airlines tend to be cyclic and follow the introduction of new aircraft, approximately every 20 years. For example, BA introduced A320's in the early 1990's. The next significant step will be new engines on A320's, estimated to arrive in the next 5 years and then maybe a new aircraft in 10 years or so. The 2012 Heathrow fleet mix will contain the Boeing 7E7, which is predicted to achieve a 20 per cent. fuel efficiency saving on equivalent aircraft operating today (and arguably needs to achieve this target to be commercially viable). Even if the 7E7 was not successful, the engine technology developed for it would be available for other aircraft.

3.26 The trend for old, less fuel-efficient passenger aircraft to be converted into freighters is changing. New A380's have been ordered for freight use. The growth in the freight sector cannot be accommodated by the conversion of passenger aircraft alone.

3.27 No Frills Carriers nowadays replace their fleets quite frequently, order newly built planes, and overall grow faster than elsewhere in the aviation sector. All these factors help fuel efficiency.

3.28 Overall, a 15 per cent. saving in fuel burn due to fleet renewal was used in the revised forecasts for the Future of Air Transport White Paper, and described later in this paper. This remains a conservative assumption, so that any possible shortfall in operational savings already in the published DfT forecasts can be accommodated.

The Impact of Economic Instruments

3.29 The level of CO_2 reduction due to the implementation of any economic instrument will depend on both the demand side, the passenger response to any fare increase, and the supply side response of the industry seeking to reduce these costs. If supply-side or technological improvements are encouraged by economic instruments, part of any initial impact depressing passenger demand through higher airline costs would be ‘clawed back’ as more fuel-efficient planes are introduced. Supply side effects offer the prospect of lower CO_2 emissions for the same amount of air traffic.

3.30 The CE Delft study ***Economic Incentives to Mitigate Greenhouse Gas Emissions from Air Transport in Europe***, July 2002 [see **ANNEX D**] used a ‘fleet renewal model’ to assess the degree to which economic instruments could incentivise airlines to advance the replacement of less fuel-efficient aircraft, as well as fuel-efficiency savings from operating or modifying existing aircraft, in the period to 2011. The study suggested that half of the reduction in CO_2 due to an EU emissions charge would be due to supply-side improvements and half due to reductions in the demand for air travel due to higher net airline costs.

3.31 ***The Future Development of Air Transport in the United Kingdom: South East*** said that the 10 per cent. reduction in aviation demand resulting from the application of economic instruments internalising global warming damage costs of £70 per tonne of carbon rising at £1 per tonne of carbon per annum would be balanced by higher demand than in ***Air Traffic Forecasts***

for the United Kingdom 2000. This is due to lower costs and fares than previously forecast in that document, arising principally from increasing competition including No Frills Carriers.

3.32 The application of an economic instrument in line with Defra's illustrative social cost of carbon of £70/tC (rising at £1/tC per annum) would increase air fares by 10 per cent. assuming airlines passed on the cost of the economic instrument to the passengers. This would reduce passenger demand by 10 per cent. in 2030 (assuming a price elasticity of demand of –1). As discussed in paragraphs 5.5–5.12 of ***The Future Development of Air Transport in the United Kingdom: South East***, however, we estimate that increased competition, including the growth of No Frills Carriers, will reduce airline costs by about 10 per cent. by 2030, and hence increase demand by the same amount. The net effect of these two developments could therefore be close to zero.

3.33 However, the CE Delft study, cited at paragraph 3.30 above, suggested that half of the effect of an economic instrument will occur through a demand response and half through supply side responses. CE Delft believe that an equivalent 10 per cent. reduction in carbon emissions would be achieved through supply side improvements, specifically the development of more fuel efficient aircraft. These supply side effects would come about as airlines attempt to capture more of the market by being able to reduce fares to a greater degree than other airlines; if their aircraft are more fuel efficient, they would incur lower costs than their competitors after the economic instrument had been imposed.

3.34 The OXERA study, ***Financial Impact of Emissions Trading on Intra-EU Aviation***, produced an alternative method of modelling the possible effects of an economic instrument. This study claimed that at congested airports, the airlines already charge the maximum amount that customers are willing to pay. If an environmental charge were levied on airlines at congested airports, the charge would not be able to be passed on to the customers. Instead, the airlines would have to meet the costs of the charge themselves, reducing their profits. To offset this, airlines would be forced to purchase more fuel efficient aircraft, if this were cheaper than paying the charge, to regain profits.

Research Targets and Long Term Developments

3.35 In ***Air Traffic Forecasts for the United Kingdom 2000*** (May 2000), the growth rate of air traffic was forecast to fall, decade by decade, into the future. Beyond 2030, the decline in the growth rate would continue, reaching less than 1 per cent. per annum growth beyond 2040. Naturally, forecasts of air passenger growth so far ahead are particularly uncertain – but then so are forecasts of potential carbon savings in aviation and in other sectors. The remit of A D Little's ***Study into the Potential Impact of Changes in Technology on the Development of Air Transport in the UK***, 2000, extended only to 2030 and any of the 'efficiency concepts' are likely only to be taken up on a longer timescale.

3.36 The RCEP special report, ***The Environmental Effects of Civil Aircraft in Flight,*** tabulated some industry targets [see also **ANNEX E**].

Table 3: Future Aviation Target Reductions for Environmental Performance

	Industry	Engines			Engine/Airframes	
	ACARE	ANTLE	CLEAN	Rolls Royce	A IPCC/ ICCAIA	B IPCC/ ICCAIA
Year	2020	2008	2015	2010	2050	
CO_2 %	50	12	20	10	40-50	30-40
NO_x %	80	60	80	50	10-30	50-70
Noise %	50			50	50	

ACARE – Advisory Council for Aeronautical Research in Europe

ANTLE – Affordable Near-Term Low Emissions

CLEAN – Component vaLidator for Environmentally friendly Aero eNgines

ICCAIA – International Co-ordinating Committee of Aerospace Industry Associations

IPCC /ICCAIA Scenario A – emphasis on fuel efficiency

IPCC /ICCAIA Scenario B – material reductions in both CO_2 and NO_x

3.37 The DTI 'Aerospace Innovation and Growth Team' released ***An Independent Report on the Future of the UK Aerospace Industry*** in June 2003. The report highlighted the potential for the UK to lead the way in supporting the global effort for sustainable growth in aviation. In Chapter 8, Objective 5 states that: *'the UK must be at the forefront of the Aerospace Industry in the areas of safety, security, capacity and the environment'*. The report ratifies the ACARE targets for fuel efficiency, NO_x and noise given in table 3 above.

Advisory Council for Aeronautics Research in Europe (ACARE)

3.38 The technical content of ACARE's Strategic Research Agenda is driven by five major challenges including, under 'The Environment', *'the challenge of meeting continually rising demand whilst demonstrating a sensitivity to society's needs by reducing the environmental impact of operating, maintaining, manufacturing and disposing of aircraft and associated systems.'*

3.39 The aspiration 50 per cent. reduction in CO_2 emissions seen by ACARE comprises:

- **airframe**: 20-25 per cent. aerodynamics weight reduction, configuration improvements, new aircraft concepts;

- **engines**: 15-20 per cent. increased thermal and propulsive efficiency, more advanced materials and designs;

- **air traffic management**: 5-10 per cent. reduction in flight delays, route inefficiencies and taxiing times.

3.40 In achieving the global emission goals, the report states that:

- the environmental targets will not be fully met through straightforward evolutionary improvements of airframe, engine technology and further evolution of the Air Traffic Management System; and

- full achievement of the targets will require the employment of novel concepts and breakthrough technologies into commercial service.

3.41 In terms of airframe development, ACARE sees:

- **aerodynamic improvements**: improved computational modelling for design and concept validation, *e.g*. laminar flow techniques;

- **weight reduction**: using new lightweight alloys, metal matrix composites and polymer composites;

- **new aircraft concepts** with significant breakthrough after 2010, *e.g*. New Lifting Surface Aircraft, Lifting Body or Flying Wing;

- **aircraft capability evolution**: *e.g,* average aircraft size is growing.

3.42 Regarding engines, ACARE notes a steady increase to date in fuel efficiency of civil aircraft engines due to increased pressure ratio, higher temperature cycles, better materials and cooling, more efficient turbo-machinery and high bypass ratio (BPR) architecture. Only NO_x emissions have remained relatively steady, since the rising compressor delivery temperature associated with increasing overall pressure ratio favours NO_x production. NO_X reduction targets will impinge on the introduction of further increases in pressure ratio. ACARE also says: *'Hence the targets for CO_2, noise and NO_X are becoming highly interactive and for conventional engine architectures, improvements become more and more challenging. While the performance of the conventional engine cycle and architecture will continue to improve throughout the period to 2020, when the noise and NO_X targets are taken into account it is judged that non-conventional solutions will have to be evaluated, this will introduce different, higher risk technology requirements.'*

3.43 ACARE points out that there are possible propulsive efficiency improvements. Today's engines with bypass ratios of around 8 or 9 are already at or beyond the CO_2 emissions optimum in conventional installations. Higher BPR might be attainable with gearbox technology and unducted designs, although this might have an impact on noise.

3.44 ACARE suggest that thermal efficiency improvements could be possible. The temperature capability of the materials used in the rear stages of the compression system constrains the overall pressure ratio, and the overall pressure ratio is limited by material properties and cooling technology in the combustor and high-pressure stages. ACARE says that: *'The 2020 targets will not be achieved by developments of the current engine architecture and more radical changes will be required'*; and that the *'consensus view is that the rate of progress for conventional engines will slow down significantly in the next 10 years. To maintain the same rate of progress as today to 2020 and beyond will require breakthrough technologies and consequently higher risk approaches'.*

3.45 ACARE also says that: *'the drive to a more efficient system also has to be managed within the context of developing more capacity, as the amount of traffic that the system must handle in the future will be increasingly significant (threefold').* To achieve this, they point to*:*

- the 'free route concept': independent aircraft flight permitting the most direct route to be taken. This has been demonstrated in limited airspace but further research required into potential safety implications for large areas;

- flexible use of airspace and of restricted (military) airspace;

- optimised routes: increased route flexibility to take account for beneficial wind conditions;

- reduced holding and reduced taxiing.

3.46 ACARE says that the introduction of low carbon or zero carbon fuels would involve significant technical problems with aircraft design and fuel storage: there is no realistic alternative to kerosene before 2020. Alternative fuels include a hydrogen combustor, which is technologically easy to develop; the problem arises from the weight penalty of on-board hydrogen storage and its impact on payload and range. There is potential to use fuel cells for on board power generation to reduce the power load drawn from the engines themselves.

Other Concepts

3.47 A 'hydrogen plane' seems technologically much more difficult to produce than a 'hydrogen car'. Burning hydrogen produces large quantities of water – which contributes to cloud formation. As hydrogen burns at a higher temperature than kerosene, using hydrogen in a jet engine is likely to give rise to higher levels of NO_x, which at altitude also has an effect on climate change. Moreover, hydrogen has a very low density, so a hydrogen-fuelled aircraft would need to carry a much greater volume of fuel thus requiring a major redesign of the aircraft shape.

3.48 An EU research project called 'Cryoplane' looked at hydrogen-fuelled aircraft. The mock-up of such an aircraft looked very similar to the Beluga aircraft that Airbus use for transporting large items between their factories: very squat and dumpy in order to accommodate the vast quantities of hydrogen needed for each flight. It became apparent that the project was not viable and work on it has stopped.

3.49 Similarly, the ‘blended wing body' [BWB], essentially a triangular aircraft in which body and wings are merged, offers potential for lower drag and hence greater efficiency than conventional designs. However, current ideas for BWB aircraft suggest that it will be very large and hence radical redesign of airport infrastructure could be necessary. The BWB would have an optimum cruise altitude of over 41,000 ft with increased radiative forcing impacts as predicted for supersonic aircraft.

3.50 In a submission to the House of Commons Environmental Audit Committee (EAC), Greener by Design (GbD) said: *'modelling of a series of options has shown that projected reductions in fuel burn could range from 17 per cent. for a swept winged aircraft with hybrid laminar flow technology to more than 50 per cent. for a flying wing with wholly laminar flow. Looking forward 50 years, our projection for the most radical configuration was that its fuel burn would be between a quarter and a third that of today's long-range aircraft ’.*

3.51 Hybrid Laminar Flow Technology (HYLTEC) was being assessed by a wide ranging European Consortium research program which ended in 2001. The technological feasibility of HYLTEC was suggested by test flights with a modified tail fin on an A320 Airbus. Uncertainties remain as to the commercial viability, the time scale and funding of future research in this area but it has been suggested that extending the application of laminar flow to the upper surface of the wings, the tail and the engine nacelles would reduce fuel consumption on a typical long-haul transport by about 15 per cent.

3.52 The ACARE targets are designed to produce a step change in environmental performance against the trends of the past 40 years (see their figure 06 on page 19, volume I). There are significant uncertainties as to the time scale and impact through incorporation into the fleet of new technologies for engines and airframes. However, this is not a unique situation, as there are also significant uncertainties surrounding the feasibility and take-up of 'clean' technologies in other sectors, the ‘hydrogen car' for example. Against this uncertain background, particularly in the 2030-2050 period, forecasts need to be provided.

Revised DfT Forecasts to 2050

3.53 Revised forecasts were developed for ***The Future of Air Transport*** White Paper. The forecasts were built up step-by step. We first considered CO_2 forecasts with limited fuel efficiency improvements, limited fleet renewal, and no economic instruments. Apart from the years 1990 and 2000[25] which are based on NETCEN, the carbon emissions (Mt) below for the period to 2030 are based on ***Aviation and the Environment: Using Economic Instruments,*** Annex D, table D6, taking the ‘high airport capacity‘ case which gives a throughput of 480 mppa in 2030; including both passenger and freight ATMs but not including emissions from surface access to airports. This high capacity case is a scenario where three additional runways are built in the South East and there is unconstrained capacity in the regions. The forecasts in the following tables therefore represent an overestimate of the values that

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[25] Including contributions of CO_2 emissions from both passenger and freight ATMs.

represent the development scenario suggested in ***The Future of Air Transport*** White Paper, which involves the development of two further runways in the South East, one at Stansted and a subsequent runway at Heathrow, or Gatwick if a new runway at Heathrow proves environmentally unachievable. Only departures are counted for international flights. 2010 and 2020 figures were interpolated.

3.54 If the projected operational gain implicit in the DfT published forecasts is not achieved, the CO_2 forecasts may be viewed as consistent with only limited fuel efficiency improvements. No impact from economic instruments is assumed in the table below, and neither this nor the other Tables in this section take account of radiative forcing, which could increase the impact of aviation emissions by a factor of between 2 and 4 times [see paragraph 3.5 above].

Worst Case Emissions Forecast

Year	Carbon Emissions (Mt)
1990	4.6
2000	8.8
2010	11.4
2020	16.5
2030	20.9
2040	25.1
2050	29.1

3.55 Passenger demand growth underlying the table above forecasts growth at a lower rate decade by decade the further we are from the present, reflecting growing market maturity.

Year	Passenger Demand (mppa)
2000	180
2010	263
2020	379
2030	480
2040	577
2050	670

3.56 The next CO_2 forecasts shown below – which are central unconstrained 'high capacity' forecasts without the effect of any economic instruments - are on the same basis as at paragraph 3.54 above, except that the fuel efficiency improvements envisaged by IPCC and by ACARE are factored into the forecasts. Thus the ACARE 50 per cent. fuel efficiency improvement between 2000 and 2050 is taken to comprise a 15 per cent. fuel efficiency improvement between 2000 and 2030, with a further 25 per cent. of the savings occurring between 2030 and 2050, with 12.5 per cent. over each decade. The remaining 10 per cent. of the fuel efficiency savings are already factored into the original DfT figures, and arise from the assumed improvement in operational measures in aviation.

Central Case Emissions Forecast

Year	Carbon Emissions (Mt)
1990	4.6
2000	8.8
2010	10.8
2020	14.9
2030	17.7
2040	18.2
2050	17.4

3.57 In the final forecast shown below, economic instruments, in line with paragraphs 3.29-3.34 above, are assumed to produce an additional 10 per cent. fuel efficiency saving in 2020 onwards, with half that in 2010.

Best Case Emissions Forecast

Year	Carbon Emissions (Mt)
1990	4.6
2000	8.8
2010	10.3
2020	13.4
2030	15.9
2040	16.4
2050	15.7

Comparison with Longer Term DTI Forecasts

3.58 Defra has used carbon emission figures based on the work done by DTI in the Inter-Departmental Analysts Group (IAG) report, ***Long Term Reductions In Greenhouse Gas Emissions In The UK*** (February 2002). The DTI used a methodology based, so far as air traffic was concerned, on UK GDP growth and fuel prices, to estimate domestic and international aviation emissions (see paragraph 2.23 and Annex B of the IAG report). Forecasts of traffic did not use DfT's ***Air Traffic Forecasts for the United Kingdom 2000***, May 2000, but relied on relationships such as air travel growing at 1.5 times GDP.

3.59 The average of DTI's forecasts, assuming no economic instruments in place, is 8 Mt of carbon in 2000; 11.2 MtC in 2010; 14.5 MtC in 2020; and, on an extrapolated basis, 18 MtC in 2030. These forecasts are quite close to the revised DfT forecasts at paragraph 3.56 above.

4. Aviation's Contribution to Global and UK Emissions Targets

Aviation’s Contribution to Worldwide Global Emissions

4.1 The IPCC report ***Aviation and the Global Atmosphere*** found that aviation’s projected contribution to worldwide global CO_2 emissions was dependent on which of the scenarios developed for the report was considered. Thus aviation’s CO_2 emissions when measured as a proportion of total global economy emissions could be within a 2-10 per cent. range by 2050, depending on the scenario chosen. The percentage is higher with aviation's radiative forcing is taken into account.

4.2 The RCEP November 2002 Special Report ***The Environmental Effects of Civil Aircraft in Flight***, drawing on the IPCC report ***Aviation and the Global Atmosphere***, stated in paragraph 3.38 that *'In 2050 the contribution of aviation to the total radiative forcing would be in the range 4 – 17 per cent’.* Paragraph 3.35 of the RCEP report refers to a radiative forcing factor of ' some 3 times. '

4.3 The RCEP report recommended that international aviation emissions be included in the emissions trading scheme that is envisaged as one of the Kyoto Protocol's implementing mechanisms, adding *‘if the recommendations on CO_2 emissions from ground level activities predicted in the Commission's 22nd report are achieved, and the growth in air transport projected by IPCC materialises, then air travel will become one of the major sources of anthropogenic climate change by 2050.’* Further information about underlying IPCC estimates is given in **ANNEX A**.

EU

4.4 Intra-EU aviation CO_2 emissions in 1992 were 24.5 MtC according to CE Delft (1997), ***European Aviation Emissions Trends and Attainable Reductions,*** rising to 71 MtC in 2025. Total EU emissions on a Kyoto basis *(i.e.* excluding international aviation) were estimated to be 245 MtC by 2030.

UK

4.5 As noted previously, the 60 per cent. target reduction in the Energy White Paper does not include international aviation. The Kyoto Protocol assigns the problem of aviation's contribution to climate change to states working through ICAO. No decisions have thus far been taken over the allocation of international aviation emissions, although Defra has commissioned research on international allocation.

4.6 As an analytical convenience, the ***Future Development of Air Transport in the United Kingdom*** allocated all international departures from UK airports, as well as all domestic air transport movements, to the UK emissions total. Aviation CO_2 emissions for passenger and freight air traffic movements and surface access in that document increase to 22 MtC in the 'high airport capacity case' (480 mppa) in 2030. EWP target emissions in 2030 are around 98.7 MtC, or 40 per cent. below 1990 levels [see table 2 above]. On this basis, aviation CO_2 emissions in 2030 would be 22 per cent of the EWP target (and greater than this if radiative forcing is taken into account - see paragraph 4.9 below).

4.7 The RCEP, in a letter dated 9 June 2003, say that aviation's share of greenhouse gas emissions in the economy will increase to 35 per cent. in 2030 and to over 70 per cent. in 2050. The letter assumed that international aviation emissions, including radiative forcing, count against the EWP targets [98.7 MtC in 2030 and 65.8 MtC in 2050] as they stand, without including international aviation.

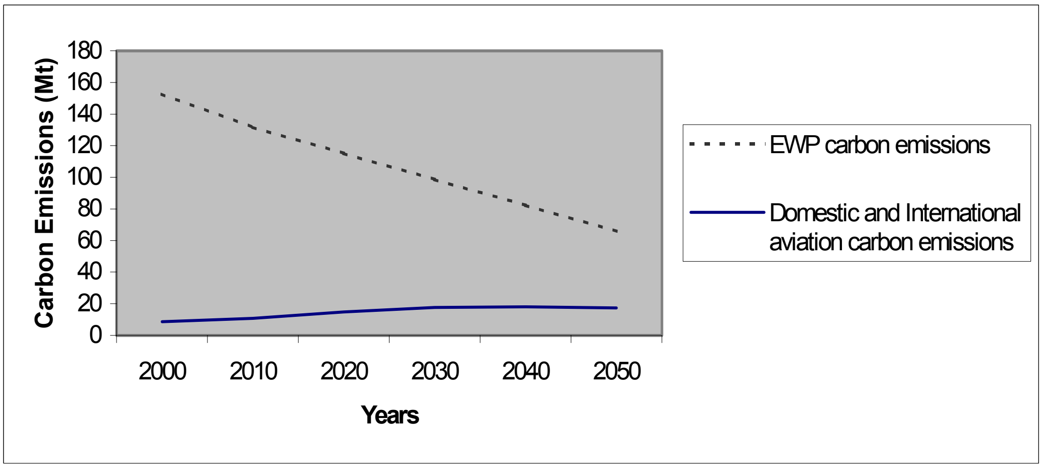
Contributors to Radiative Forcing

The contributors to radiative forcing from aviation are NO_x, soot and contrails (from H_2O), none of which is included in the six GHGs included in the Kyoto Protocol basket. CO_2 is therefore the only common emission for a direct comparison with UK domestic emissions. This is not to say that the additional impact due to radiative forcing should not be explicitly recognised, but that care should be taken when making direct comparisons.

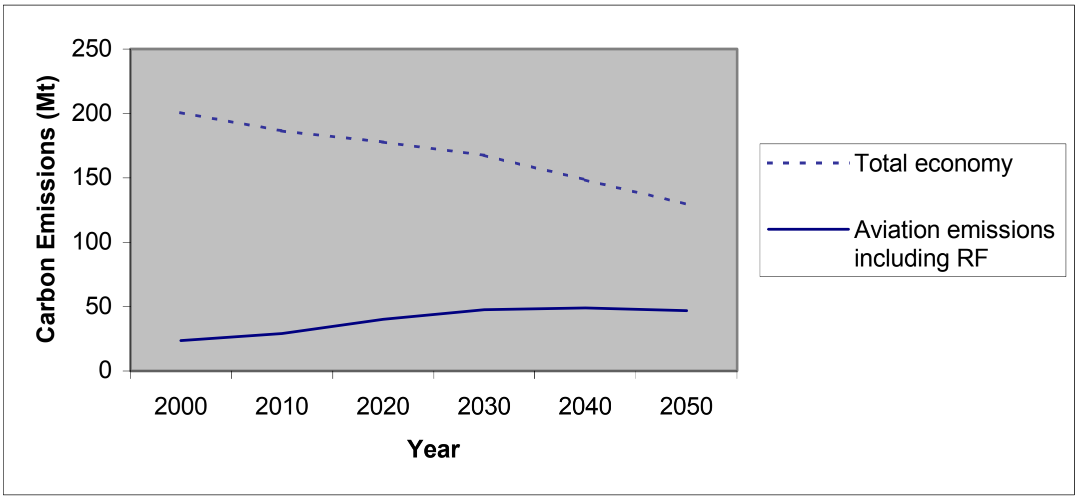
4.8 The percentage contributions quoted in the letter involved a UK denominator including radiative forcing for aviation and also the remaining Kyoto Protocol GHGs. (Strictly the global warming potentials [GWPs] for the six GHGs in the Kyoto Protocol basket is not equivalent to the UK's radiative forcing total).

4.9 However, the CO_2 from aviation is netted off in the denominator, which makes the aviation share look high. If aviation CO_2 were added to the denominator, the aviation share would fall to around 28 per cent in 2030 (and 36 per cent. in 2050 too).

4.10 The graph below illustrates the contrast between the growth in carbon emissions in the UK aviation sector out to 2050, against the EWP target reduction in carbon emissions in the UK domestic economy [see Table 2 above]. The 'EWP carbon emissions' incorporate the 2020 EWP savings implied by the 60 per cent. reduction by 2050 [see Table 2]. 'UK Aviation' is given by the forecasts at paragraph 3.56 above ie the central case but without economic instruments. .



4.11 The graph below shows emissions from aviation, including radiative forcing, as a percentage of total aviation emissions, plus CO_2 and other GHGs from the UK economy. The UK aviation line is the CO_2 forecasts at paragraph 3.56 times a 2.5 radiative forcing factor. The 'total economy line' comprises CO_2 from the EWP target envelope plus GHGs at a constant 25.8 MtC equivalent from 2020 onwards plus the UK aviation line in this graph.



4.12 The forecasts for aviation emissions including radiative forcing in 2020 in the graph above approach 40 MtC, or about 15 MtC more than actual in 2000. This increase would correspond to more than the reduction in baseline for other sectors in the EWP envelope (see Table 2 above).

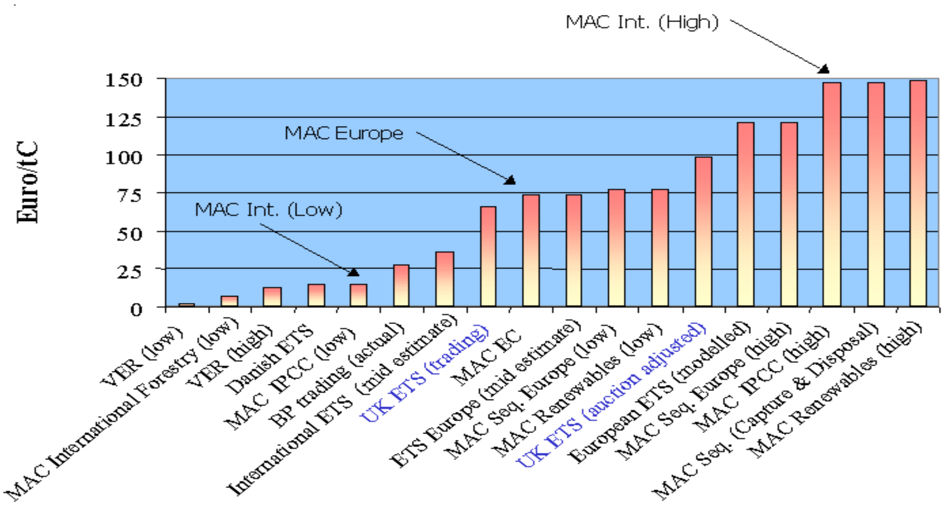
4.13 If aviation were faced with the same 30 per cent. reduction in emissions as in the EWP envelope over the 1990-2020 period, the cutbacks in aviation and/or other sectors clearly would be significantly greater.

5. Costs of Reducing Aviation's Greenhouse Gas Emissions

Introduction

5.1 A paper entitled ***The Marginal Social Costs of Carbon in Policy Making: Applications, Uncertainty and a Possible Risk Based Approach*** by Downing and Watkiss, presented at a Defra seminar on the social cost of carbon in June 2003, notes that '*the uncertainty over the Marginal Social Cost of Carbon numbers has led to widespread use of marginal abatement costs for policy making'*. This paper includes the illustration below indicating the spread of values for permit prices and marginal abatement costs.

Summary of Permit Price (trading) and Marginal Abatement Costs



Key:

VER – Verified Emission Reductions. MAC = Marginal Abatement Costs.

ETS – Emission Trading Scheme (permit price).

Seq. – Sequestration. Low prices will be based on forestry. Higher value for Capture and Disposal.

5.2 The graph above shows the potential for very low cost abatement measures through international forestry in comparison with permit prices for domestic-based trading, as in the UK Emissions Trading Scheme (ETS).

5.3 The trading prices presented in the graph above for the UK Emissions Trading Scheme (ETS) and for the auction-adjusted ETS seem high compared with recent 'real life' experience[26]. The latest trading price of UK allowances (1 allowance = 1 tonne CO_2 equivalent) is between £2.20 and £2.30 per tonne of CO_2 equivalent (or £8.07/tC to £8.40/tC) depending on the

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[26] For further details see the DEFRA progress report at www.defra.gov.uk/environment/climatechange/trading/pdf/trading-progress.pdf

volume traded[27]. Defra's and DTI's working assumptions on the price of emissions allowances in 2010 under the EU ETS translate to £ 11 - 55 /tC.

Scope for Carbon Emission Savings in Other Sectors

5.4 Annex 1 to the EWP compares marginal abatement costs per tonne of carbon saved for different options for reducing carbon emissions:

- Low Cost: (with some benefits): domestic and industry efficiency savings;
- Moderate Cost: renewables (*e.g.* wind, tidal) biofuels and nuclear energy;
- High Cost: transport and hydrogen fuel applications.

5.5 The table below illustrates how cuts of 15-25 MtC could be achieved by 2020. The exact target figure will be determined in the light of international negotiations, and the actual mix of measures needed will be shaped by economic and technological developments.

Measure	Estimated reductions by 2020/ MtC	Range of cost of carbon savings in 2020, £/t
Energy efficiency in households	**4-6**	**- 300 to + 50**
Energy efficiency in industry, commerce and the public sector	**4-6**[28]	**- 260 to +50**
Transport: Continuing voluntary agreements on vehicles; use of biofuels for road transport	**2-4**	**+140 to + 680**
Increasing renewables	**3-5**	**-80 to +230**
EU carbon trading scheme	**2-4**[29]	**+10 to + 25**

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[27] Price on December 2nd 2003, provided by the brokers $CO2_e$.com.

[28] The savings in industry and commerce relate to technical improvements that will be stimulated by a range of measures, of which the most significant is likely to be the expected EU cap and trade scheme for greenhouse gases.

[29] The savings of 2-4MtC attributed to the EU emissions trading scheme relate specifically to carbon savings in power stations and refineries, and are in addition to the energy efficiency savings expected to be achieved by end users. Natsource-Tullet estimate prices approaching £25/tC for an EU scheme in 2010.

5.6 Beyond 2020, there are greater uncertainties regarding the scope for carbon savings. The Interdepartmental Analysts Group [IAG] estimates of 'emission reduction potential' and the social cost of carbon to achieve them are given in Annex 1 to the EWP as:

Measure	**£/tC 2050**		**Emission reduction potential (MtC)**
	Low	**High**	**2050**
Domestic	**-100**	**20**	**11**
Services	**-250**	**20**	**8**
Industry	**-80**	**35**	**7**
Onshore wind	**0**	**50**	**6**
Offshore wind	**0**	**100**	**10**
Municipal waste	**-50**	**70**	**1**
Landfill gas	**-50**	**70**	**1**
Energy crops	**100**	**210**	**3**
Nuclear	**60**	**200**	**25**
CCGT sequestration	**50**	**100**	**25**

CCGT – Combined Cycle Gas Turbine

5.7 The work for DTI by Future Energy Solutions (FES), ***Modelling Gaseous Emissions from the UK Energy System*** used a 'MARKAL' model to estimate the potential cost (in terms of £/tC reduced) of reducing carbon emissions.

5.8 The FES estimates for the social cost of carbon savings (£/tC) in 2040 range from, for ***electricity generation***, onshore wind: -100 – 100; offshore wind: 10 – 240; energy crops: 30 – 100; nuclear: 70 – 140; wave: 80 – 310; tidal: 210 – 560; photovoltaics: 140 – 800; combined cycle gas turbine: 160 – 180. For ***road transport***, FES has: hybrids: 220 – 700; hydrogen fuel cells: 360 – 580; and biodiesel 220 – 380. Generally, the FES modelling is at the conservative end of costs of reducing carbon emissions and is higher than other sources for onshore and offshore wind electricity generation and – exceptionally so – for photovoltaics.

5.9 There are great uncertainties in the 2020-2050 period. Full replacement of fossil fuels in ***electricity generation*** may be possible. Depending on how costs develop, there is potential for substantial savings in ***surface transport***, including conceivably a near-total conversion of road transport to hydrogen by the end of the period. If that could be achieved, and assuming the hydrogen was produced from renewable energy sources, the 2050 goal of a 60 per cent. fall in domestic CO_2 emissions over the period 1990-2050 could be surpassed.

Surface Transport

5.10 The EWP analysis carried out for the transport sector looked at the potential CO_2 savings from hybrid and fuel cell cars and biofuels. This analysis produced the 2-4MtC of additional savings from transport by 2020. The potential of hydrogen fuel cells, and biofuels, further to reduce CO_2 emissions up to 2050, and consideration of any support the Government would need to offer to accelerate the introduction of these technologies, are the subject of ongoing work[30].

5.11 In 1990, circa 400 billion vehicle kilometres (vkm) of road transport accounted for carbon emissions of 35 MtC, with rail about 2 MtC. Road forecasts are 523 billion vkm in 2020 (598.4 billion vkm in 2050).

5.12 The take-up of new technologies is likely to be a function of capital costs, fuel efficiency improvements, price of fuels and the potential carbon savings over the lifetime of the new technology. As can be seen from the table below, EWP identifies a very wide range of costs per tonne of carbon saved for these new technologies. Fuel cell technologies, provided their costs can be contained, could make a very large contribution to national carbon savings in the further future. They are, however, not likely to make a material contribution by 2020.

5.13 Hybrid solutions are not as 'clean' a technology as fuel cells, as carbon based fuels are still required to power vehicles: hence the estimated carbon savings in 2050 are smaller for hybrids than fuel cells. They do however provide scope for worthwhile savings by 2020.

Aviation

Open and Closed Emission Trading Schemes

5.14 Work by the ICAO's Committee on Aviation Environmental Protection (CAEP) ***Report on Economical Analysis of Potential Market-Based Options for Reduction of CO_2 Emissions from Aviation'***, 2000, shows the possible effects of aviation operating in an open or closed trading scheme. Evidence of permit prices from modelling studies in the literature was used as an input assumption into the CAEP modelling of emissions trading options. No analysis has been performed within CAEP on abatement costs outside the aviation sector; work has focussed on drawing up an abatement cost curve for emissions reduction measures available to airlines.

5.15 The CAEP work investigated the following:

- the system of trading (open/closed and grandfathered/auctioned);
- the geographical coverage (developed countries/Global);

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[30] Details can be found at www.dti.gov.uk/energy/sepn/futuretransport.shtml

- the level of the emission cap;

- results from the AERO modelling [***Emissions Charges and taxes in Aviation, Report of the Focal Point in Charges (FPC) to CAEP/4***] and Centre For Energy Conservation and Environmental Technology [***A European Environmental Aviation Charge Feasibility Study***] to provide a range of estimates for a levy and hence for permit prices in a closed trading regime ;

- the closed permit trading prices for aviation give similar results as a levy or tax on aviation fuel;

- advantages from trading between sectors arise from those users who face higher costs being able to buy permits from those with lower costs.

5.16 For open trading, the CAEP work found that:

- aviation would be a net purchaser of permits;

- largest all-sector CO_2 emissions reduction would result from an **$100/tC** permit price;

- open market permit prices were assumed in the range of $50/tC to $100/tC, assuming distribution of permits to developed countries. But, lower permit prices lying in the range $20/tC to $30/tC result from global trading;

- a permit price of $100 resulted in a global reduction in carbon emissions of 24.2MtC from sectors other than aviation in 2010.

5.17 For Closed Trading, the results were:

- permit prices of **$125/tC to $300/tC** required to meet the aviation targets;

- all targets difficult to achieve without significant increases in costs;

- considerable annual windfall gains or auction revenues to allocating authorities but these would not encourage the adoption of newer technologies by the industry.

5.18 Overall, CAEP found that open permit trading would be the only economic instrument option realistically capable of meeting the Kyoto Protocol target of a 5 per cent. reduction in emissions below 1990 levels in 2010.

5.19 The table below gives various permit prices and prevention costs as described and calculated in the literature reviewed.

Paper	Estimated Prevention Cost To Meet Kyoto Protocol Targets	Estimated Market Clearing Permit Price
CAEP (2003) *Estimates of The External Costs and Abatement Costs of Carbon Dioxide Emissions.* External Costs Task Group (all aviation related estimates).	**\$5/tCO$_2$** - **\$15/tCO$_2$** with global trading.[31] **(\$1.36/tC** - **\$4.09/tC**) **\$4/tCO$_2$** - **\$40/tCO$_2$** (**\$0.33/tC** - **\$10.90/tC**) with Annex B[32] country trading.[33] **\$180/tC**.[34] **\$20/tCO$_2$**, (**\$5.45/tC**) assuming flexible mechanisms are in place and emissions trading between Annex B countries.[35]	**\$0/tCO$_2$** - **\$120/tCO$_2$ (\$0/tC** - **\$32.70/tC**). variability in the price dependent on the ex and timing of sales from Russia and Ukrai air sales). These figures estimated assum USA involvement). Generally the figures estimated range from close to **\$0/tCO$_2$** to **\$20/tCO$_2$ (\$0/tC** - **\$5.45/tC**).
R. Clarkson and K. Deyes (2002). *Estimating the Social Cost of Carbon Emissions.* Government Economic Service Working Paper 140. Estimated costs from other sources *e.g.* Dames and Moore [see below]	**\$39/tC** (for UK in 2000 prices) ≈ **\$143/tCO$_2$**. **\$0/tC** - **\$539/tC** (for OECD countries, Japan, Australia, New Zealand, and European OECD countries not in EU – using 2000 prices).	**\$79/tC** (in 2000 prices using a 2.5 per cent. inflation rate translated from 1995 prices)[36] from the Annex B (AB) scenario. **\$181/tC** (2000 prices), for the UK to meet its Manifesto target of a 20 per cent. reduction of CO$_2$ from 1990 levels (the AB_UK_20 scenario in Dames and Moore).
Dames and Moore (1999), '*The Implications for the UK of an International Carbon Emissions Trading Scheme.'*	**£100/tC** for a 20 per cent. reduction on the base year 1990 level of CO$_2$. (see Graph 2: assuming 66p = \$1 exchange rate).	Numerous permit prices have been estimated for various scenarios. See study for further details.
Committee on Aviation Environmental Protection (CAEP). Working Group 5 (Market Based Options). (2000). *'Initial Economic Analysis of Market-Based Options'*.	N/A	**\$125 - \$300/tC** for closed trading system to meet Kyoto target. **\$80** - **\$150/tC** for closed trading system to reduced projected emission growth by 50 per cent. **\$50** - **\$100/tC** for open trading, only for Annex B countries for both Kyoto and 50 per cent. reduction on projected growth. **\$20** - **\$30/tC** for open trading for global trading for Kyoto Commitments. **\$20/tC** for open trading on a global scale to reduce 50 per cent. of emissions from projected growth.

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[31] Working Group III of the IPCC, in '*Climate Change 2001: Mitigation*'.

[32] Annex B countries: Group of countries included in Annex B in the UNFCCC target that have agreed to a target for their greenhouse gas emissions, including all Annex I countries (as amended in 1998) but Turkey and Belarus.

[33] Working Group III of the IPCC, in '*Climate Change 2001: Mitigation*'.

[34] 1998 report of the focal point on charges, prepared for CAEP/4.

[35] Dames and Moore (1999), *The Implications for the UK of an International Carbon Emissions Trading Scheme*. A similar value is used in Maibach and Schneider (2002), *External Costs of Corridors. A Comparison between Air, Road and Rail*, published by the Air Transport Action Group. Their figure is based on the abatement costs of meeting UNFCCC targets in Europe.

[36] Dames and Moore (1999), *The Implications for the UK of an International Carbon Emissions Trading Scheme.*

The EU Scheme

5.20 The EU Greenhouse Gas Emission Trading Scheme (ETS) begins operation on 1 January 2005. In the first stage to 2007, the scheme will cover CO_2 emissions from power plants over a threshold size, oil and gas facilities, pulp and paper plants, building material facilities and iron and steel plants. Experiences of the first phase of the EU Scheme are likely to set precedents in the second phase, when other sectors, possibly including aviation might be included.

5.21 The Government published for consultation on 19 January 2004 its draft National Allocation Plan for the first phase of the EU scheme. This sets out the provisional allocation of allowances to each sector covered by the scheme and provisional allocations to each installation. The sectoral allocation of permits is based on updated energy predictions (UEP) for the industry sector involved. The draft Plan also explains the Government's proposals for dealing with new entrants, plant closures, banking and auctioning of allowances.

5.22 Whatever the initial allocation of permits, a plant with worse emissions performance than its allocation would have to purchase permits. Unused permits by plants with better emissions performance than its allocation would sell permits (or bank them for future periods). The second phase of the scheme – for which the commission may propose introducing additional sectors, including aviation – will run from 2008-2012. Such participation will need to take account of future demand and the extent of saving fuel burn through fleet renewal.

5.23 From 2008 onwards, the EU trading scheme is expected to allow use of credits earned from projects to reduce emissions outside the EU. Thus credits from the Clean Development Mechanism (CDM) in developing countries and Joint Implementation projects (JIs) in developed countries, both concepts within the Kyoto Protocol, could be used.

5.24 OXERA's study ***Assessment of the Financial Impact on Aviation of Integration in the EU Greenhouse Gas Emissions Trading Scheme***, has assessed the financial impact on airlines of inclusion in the Intra-EU trading scheme for both 2000-2012 and 2050 under various tax /trading options. However, the analysis is in terms of abatement costs determined in 'open' trading which are exogenous and hence not justified within the study. The supply-side response by aviation is also not clear. Tight targets for 2050, in particular, assume that sufficient carbon offsets can be obtained from other sectors. This may not be the case.

Costs of Global Emissions from Aviation Packages Compared with Net Economic Benefits

5.25 New airport capacity will bring economic benefits to the UK, particularly from reduced air fares and greater time savings for journey times, amongst others. Additional runways in the South East not only enable an increased number of passengers nationally; they also claw back passengers who would prefer to use airports in the South East but who have to travel via the regions with South East capacity constrained.

5.26 Environmental disbenefits which can be monetised arise mainly from higher global emissions. The package for new capacity in the South East described in ***The Future of Air Transport*** White Paper is considered. This package is one additional runway at Stansted and a subsequent additional runway at Heathrow over and above maximum use of runways in the South East and unconstrained capacity in the other UK regions.

5.27 Overall, there are an extra 35 mppa in the national UK airport system as a result of this package compared to the base case: 463 mppa – 428 mppa = 35 mppa. Thus the amount of additional national traffic as a result of adding additional runway capacity in the South East is less than the capacity provided by those South East runways. The principal economic benefit of adding capacity in the South East is to add capacity where it is most in need.

5.28 The net present value (NPV) of direct economic benefits of this package is £17.1 billion over the 2003-2060 period, taking account of the standard civil engineering upper bound optimisation bias of 44 per cent. for a three year delay in completion of construction. (In addition, mitigation/compensation costs for noise and local air quality should be netted off, although these are minor in comparison.)

5.29 This NPV is compared with the present value of the social damage cost of the global emissions due to the additional departing passengers arising from this package. This present value is calculated by discounting (at 3.5 per cent.) the social damage cost of carbon (as derived from multiplying Defra's social cost of carbon (£70/tC rising at £1 p.a.) ***times*** the radiative forcing factor of 2.5 (as appropriate) ***times*** the quantity of carbon emitted from additional departing flights due to this package) over the period 2003-2060. (For comparison, the £4.8bn cost in 2030 reported in ***Aviation and the Environment: Using Economic Instruments*** is undiscounted and is for all departures, *i.e.* not just those arising from additional runways in the South East). Carbon dioxide per additional departing passenger is estimated as 0.3 tonnes in the year in which the first new runway opens.

5.30 Table A below shows the NPV of net benefits of the package for new capacity at Stansted (one new runway) and Heathrow (one new runway) over and above the benefit arising from the maximum use of current capacity. There are no fuel efficiency improvements for this calculation and a constant share of CO_2 per passenger is assumed for each year. The far-right column gives the social cost of carbon required to raise the present value of global emissions to the present value of the benefits arising from this package. So, in Table A below, this amounts to roughly £250/tC more each year than

Defra’s illustrative social cost of carbon (*i.e.* £70/tC in the year 2000 plus £1/tC per annum in later years).

Table A

Option of new capacity	NPV of net benefits of option in addition of maximum use of existing runways (billion £)	NPV of cost of global emissions (billion £)	Benefit net of cost	Threshold social cost of carbon needed in 2000 for net benefit = 0
1 new runway at Stansted opening 2011/12, 1 new runway at Heathrow opening 2015	17.08	5.17	11.91	306/tC

5.31 Table B below uses central carbon forecasts with some fuel -efficiency savings built in [but no impact from economic instruments] :

Table B

Option of new capacity	NPV of net benefits of option in addition of maximum use of existing runways (billion £)	NPV of cost of global emissions (billion £)	Benefit net of cost	Threshold social cost of carbon needed in 2000 for net benefit = 0
1 new runway at Stansted opening 2011/12, 1 new runway at Heathrow opening 2015	17.08	4.07	13.01	393/tC

5.32 Table C below uses the same assumptions as in Table B above, but with fewer emissions because of the effects of economic instruments.

Table C

Option of new capacity	NPV of net benefits of option in addition of maximum use of existing runways (billion £)	NPV of cost of global emissions (billion £)	Benefit net of cost	Threshold social cost of carbon needed in 2000 for net benefit = 0
1 new runway at Stansted opening 2011/12, 1 new runway at Heathrow opening 2015	17.08	3.28	13.80	489/tC

5.33 Table D below gives the largest 'benefit net of cost.' This is because the radiative forcing factor of 2.5 has not been included in calculating the social damage cost of carbon and hence the recorded costs of associated global emissions are less. Otherwise, Table D uses the same assumptions as Table A.

Table D

Option of new capacity	NPV of benefits of option in addition of maximum use of existing runways (billion £)	NPV of cost of global emissions (billion £)	Benefit net of cost	Social cost of carbon needed in 2000 for net benefit = 0
1 new runway at Heathrow opening 2011, 2 new runways at Gatwick opening 2018 and 2024	17.08	2.07	15.01	814/tC

5.34 As can be seen from this series of tables, the threshold social cost of carbon is higher the fewer emissions are produced from the given airport package.

5.35 The above figures represent the development scenario as in ***The Future of Air Transport*** White Paper. If a larger development package such as the three additional runway scenario were considered, both economic benefits net of costs would be larger but so too would be associated increases in the costs of global emissions.

6. Summary

6.1 The UK is committed to reducing its emissions of carbon dioxide by 20 per cent by 2010. The UNFCCC's Protocol sets no targets for international aviation but requires international action through ICAO.

6.2 In the Energy White Paper the Government committed itself to putting the UK on a path to reducing carbon dioxide emission by some 60 per cent. by 2050 as recommended by the RCEP 22nd Report. It said that aviation should be "…encouraged to take account of, and where appropriate reduce, its contribution to global warming…"

6.3 The UK aviation CO_2 forecasts published by the DfT used an analytical method to allocate half of the UK's international emissions and are conservative in their projections of fleet replacement and fuel efficiency. Forecasts in this paper take fuller account of fuel efficiency savings arising from accelerated fleet renewal, new technology, and the effects of economic instruments.

6.4 A reduction of 15 per cent. of the emission forecasts may be predicted on the basis of the IPCC report and more recently analysis (e.g. by Rolls Royce), based on future fleet mixes. A further 25 per cent, between 2030 and 2050 is envisioned by ACARE aspirations for new technology. Supply side effects of any economic instrument put in place could make a further 10 per cent. reduction in the 2030 UK CO_2 forecasts, with half that reduction in emissions between 2010 and 2030. There are grounds to believe that, with the above savings factored into the emissions forecasts, there could be an absolute decrease in emissions from aviation by 2050 relative to 2040, despite rising demand. However, there is considerable uncertainty as to the timing of further technological developments, as in other sectors. Of course, the level of emissions in 2050 would still be substantially higher than at present.

ANNEX A

Technical Note on Global CO_2 Forecast Scenarios

Aim

A.1 This technical note attempts to explain the audit trail relating the IPCC climate change stabilisation scenarios (as described in the second and third assessment reports) to the targets used in the RCEP's 22nd report on energy and subsequently in the special report on aviation.

Global Emissions Benchmarking

A.2 The RCEP 22nd report had made its recommendation for a CO_2 target reduction based on the IPCC **Second Assessment Report (SAR) 1995** scenario of a stabilisation of global emissions to 550 parts per million in volume terms [ppmv]. The RCEP Special Report on aviation uses the B1 scenario contained within the **Third Assessment Report (TAR) 2001**, which it considers is consistent with the approach of the 22nd report. The emissions projections from each approach are broadly equivalent but not identical.

A.3 The two main differences between the SAR and TAR figures are that the latter show a higher level of global fossil fuel emissions in 2050 (due to a lack of global response since the SAR was published) but a somewhat faster reduction in emissions post 2050. The scenarios show the flux of global GHG emissions, therefore the stock of global GHGs does not stabilise till much later due to the cumulative effect of long lived CO_2 e.g. 2100 to 2200 (see figure 2-VI of the RCEP 22nd report).

A.4 The implications are that a greater reduction in global emissions would now be required to meet the 550 ppmv stabilisation level by 2050. Secondly, and on this basis, the global per capita target from the RCEP 22nd report (used as a basis for the 60 per cent. reduction target) would now give global stabilisation at a level above 550ppmv.

RCEP 22nd Report: *Energy - the Changing Climate*

A.5 The report says in **paragraph 9.1**, *We have assumed that such [future global] agreements will have the objective of limiting the concentration of carbon dioxide in the global atmosphere to not more than twice the pre-industrial level, that is, to not more than 550ppmv, and that they will be based on convergence by 2050 on a common figure for carbon dioxide emissions per head…'If so the requirement on the UK might be to reduce its present* *level of carbon dioxide emissions by almost 60 per cent. by 2050 and by almost 80 per cent. by 2100'.*

A.6 These statements form the basis for the RCEP's key recommendation (number 5) that *'The Government should now adopt a strategy which puts the UK on a path to reducing carbon dioxide emissions by some 60 per cent. from current levels by about 2050'* which in turn is the basis for the DTI's Energy White Paper target.

Justification of the 550ppmv Level

A.7 The RCEP 22nd report uses future emission scenarios from the IPCC SAR (1995), and these are shown in **figure 2-VI** on **page 26** of the report. Three hypothetical scenarios were shown in comparison to the IS92a scenario, which was regarded as *'a reasonable central case projection for global emissions'.* The other scenarios showed how hypothetical reductions in emissions might eventually stabilise the carbon dioxide concentration at 450 ppmv, 550 ppmv or 750 ppmv. Modelling indicated that the increase in global mean surface temperature by 2100 would be 2.3 C under the 550 ppmv scenario.

A.8 The 22nd report recognised that the IPCC TAR would further examine emission scenarios up to 2100. The report then presented its own extensions of the SAR scenarios, entitled 'total exhaustion' and 'partial exhaustion' (with reference to fossil fuels) and 'late adjustment' and 'earlier adjustment'. Importantly, these extensions incorporated projections for emissions both of carbon dioxide and a range of other greenhouse gases. In the 'earlier adjustment' scenario, the rise in carbon dioxide emissions slows much more quickly. At their peak in 2060, global emissions are two-thirds as high again as today. The concentration in the atmosphere rises to nearly double the pre - industrial level by 2100 and then becomes nearly constant at about 600 ppmv. In **paragraph 4.30**, the report says that the 'earlier adjustment' scenario, 'would have broadly similar effects to the earlier [IPCC SAR 1995] scenario for stabilising the concentration of carbon dioxide alone at 750 ppmv. However, the report goes on to base its recommendations on the IPCC 1995 scenarios.

A.9 The report goes on to say in **paragraph 4.31** that *'analyses of the effects of climate change* ***based on the 1995 scenarios*** *have shown that, while limiting the carbon dioxide concentration to 750 ppmv would bring benefits, there would be much greater benefits if it is limited to 550 ppmv, more especially in reducing the rate of change'.*

A.10 This is summarised in **paragraph 4.32** : *'on the basis of current scientific knowledge about human impact on climate, we support the proposal that an atmospheric concentration of 550 ppmv of carbon dioxide should be regarded as an upper limit that should not be exceeded '.*

A.11 Further technical points are included in Chapter 4, **Paragraph 4.36** states that *'there can still be debate about the point in time at which global* *emission should start to fall', i.e. an early peak in emissions with a slow reduction could have the same effect as a later peak with a faster reduction'*.

A.12 Table 4.1 (shown below) provides details of how the contraction and convergence approach to carbon dioxide emissions in 2050 has been applied to give the UK's emission quotas in 2050 and 2100. This assumes that 2050 would be both the date by which nations would converge on a uniform per capita emission figure and the cut-off date for national populations. If 550 ppmv is selected as the upper limit, UK carbon dioxide emissions would have to be reduced by almost 60 per cent. from their current level by mid century, and by almost 80 per cent. by 2100. Even stabilisation at a very high level of 1000 ppmv would require the UK to cut emissions by some 40 per cent. by 2050.

Table 4.1

Maximum atmospheric concentration ppmv	**Permissible UK emission in 2050** **% of 1997 level**	**Permissible UK emissions in 2100** **% of 1997 level**
450	21	11
550	**42**	**23**
750	56	47
1000	58	61

A.13 The RCEP 60 per cent. recommendation can be directly linked to the IPCC 1995 scenario for a 550 ppmv global stabilisation in carbon dioxide on a per capita basis in 2050.

RCEP Special Report

A.14 In **paragraphs 3.37 and 3.38**, the special report uses the updated IPCC TAR scenarios to express the contribution of aviation to the total (global) radiative forcing. In **paragraph 3.37**, the report states that '*one scenario (B1 in IPCC terminology) gives an approach to stabilisation of climate with carbon dioxide capped at about twice the pre-industrial level, consistent with the target recommended by us in our Twenty-second Report'*.

A.15 Here we use the 2050 radiative forcings from this scenario as a benchmark for the aviation scenarios.

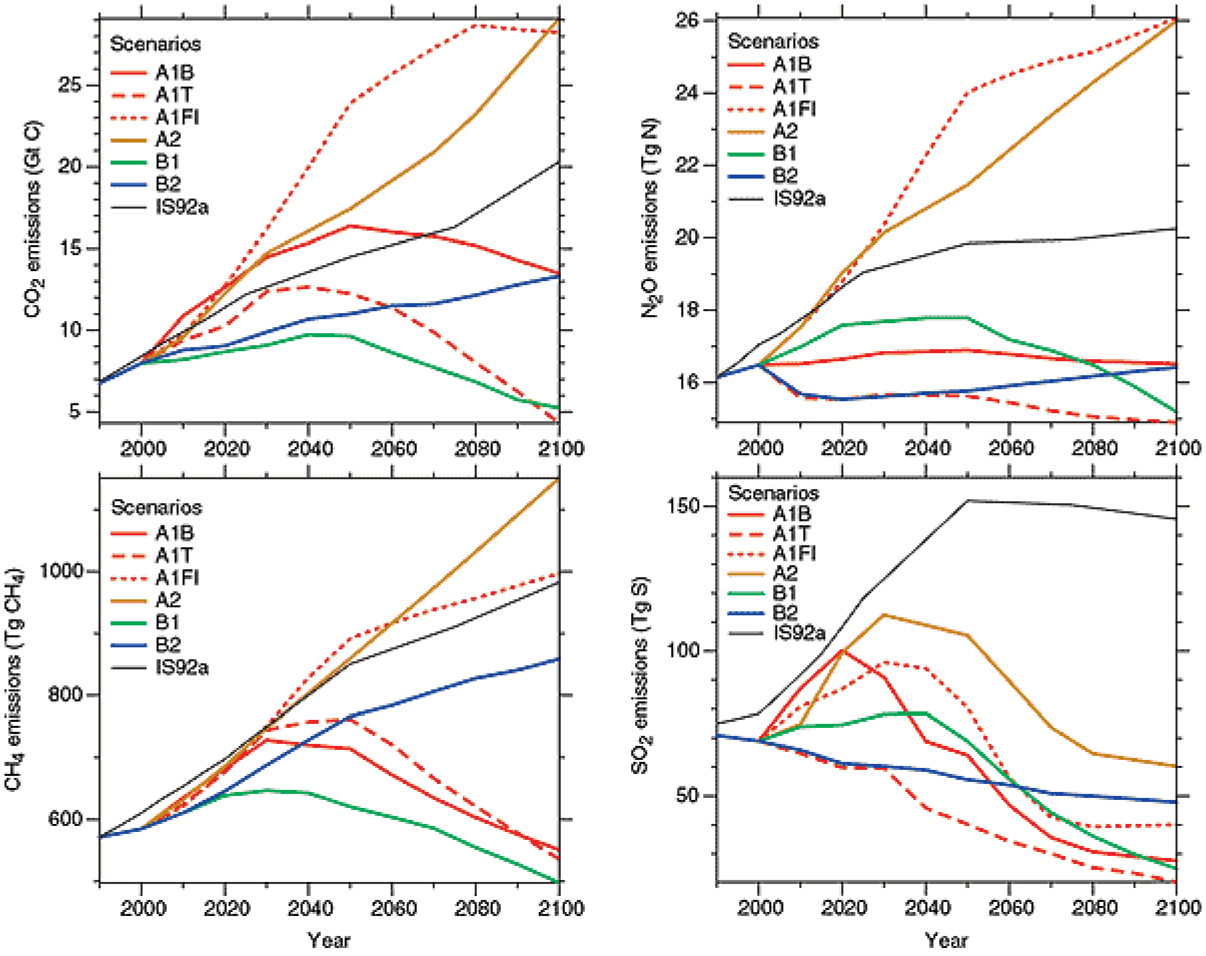
A.16 **Paragraph 3.38** goes on to say that: *'compared with this benchmark stabilisation scenario, in 2050 the contribution of aviation to the total radiative* *forcing would be in the range 4 per cent. – 17 per cent, with the reference aviation scenario contribution being 6 per cent'*.

The TAR B1 Scenario

A.17 The TAR gives the following summary of the B1 scenario : *'The B1 storyline and scenario family describes a convergent world with the same global population, that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives'.*

A.18 It also makes the following general remarks about the scenario approach: *'The SRES [Special Report on Emissions Scenarios] exemplifications do not include additional climate initiatives, which means that no scenarios are included that explicitly assume implementation of the United Nations Framework Convention on Climate Change or the emissions targets of the Kyoto Protocol. However, greenhouse gas emissions are directly affected by non-climate change policies designed for a wide range of other purposes (*e.g*, air quality). Furthermore, government policies can, to varying degrees, influence the greenhouse gas emission drivers, such as demographic change, social and economic development, technological change, resource use, and pollution management. This influence is broadly reflected in the storylines and resulting scenarios'*.

A.19 The figure below is taken from the TAR and shows the emissions forecast by the B1 and other scenarios,



A.20 The profile of CO_2 emissions for the B1 emissions can be compared to, and has 'reasonable' agreement with the IPCC 1995 stabilisation 550 scenario shown in Figure 2-VI of the RCEP 22nd report. That determines the correlation between the assertions in the RCEP 22nd and Special Report.

Conclusion

A.21 The RCEP 22nd report makes its target recommendation based on the IPCC Second Assessment Report scenario of a stabilisation of global emissions to 550 ppmv. The RCEP Special Report on aviation uses the B1 scenario contained within the Third Assessment Report, which it considers is consistent with the approach of the 22nd report. The emissions projections from each approach are broadly equivalent but not identical.

A.22 The two main differences between the SAR and TAR figures are that the latter show a higher level of global fossil fuel emissions in 2050 (due to a lack of global response since the SAR) but a somewhat faster reduction in emissions post 2050.

A.23 The implications are that a greater reduction in global emissions would now be required to meet the 550 ppmv stabilisation level by 2050. Secondly and on this basis, the global per capita target from the RCEP 22nd report (used as a basis for the 60 per cent. reduction target) would now give global stabilisation at a level above 550 ppmv.

ANNEX B

Arthur D Little's Technology Assumptions

B.1 Arthur D Little's ***Study into the Potential Impact of Changes in Technology on the Development of Air Transport in the UK***, 2000, summarised the following new technology improvements over varying future periods against the baseline of the current fleet .

- New technology for reducing weight of aircraft, principally from new structures and materials and new engine designs with improved efficiency.

- New combustor concepts being developed to achieve substantial NO_x reductions.

- Fuel efficiency improvements, and therefore CO_2 and NO_x emission reductions of up to 2 per cent. per annum are forecast from engine, airframe and operational developments.

- NO_x reduction technology is forecast to improve individual aircraft NO_x emissions by up to 80 per cent. per landing and take off (LTO) cycle by 2030. Future advances in low NO_x technology must be offset against development of higher pressure ratio engines, which improve fuel efficiency but also lead to higher NO_x per unit of fuel burnt.

B.2 On engine developments, Arthur D Little said:

- Specific fuel consumption has improved by 50 per cent. over the last 40 to 45 years but at a decelerating rate. Future gains are becoming increasingly unlikely. Research into alternative future fuels, which are not fossil-based, [37]is ongoing.

- In the period to 2015, fuel efficiency gains of 10-20 per cent. are predicted and, subject to significant technological breakthrough, with up to 30 per cent. gains by 2020. These gains are from increasing the bypass ratio, or enlarging the diameter of the propulsor.

- In the period 2006-2015, improvements of NO_x could yield a 30 per cent. reduction, whilst longer term (2016-2030) ultra low NO_x technology could achieve up to 80 per cent. reduction in NOx. Ultra low NO_x technologies, such as lean premixed prevapourised (LPP technology) are currently not envisaged from high-pressure ratio aero-engines, although it does offer potential for supersonic aircraft where operating pressures are low.

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[37] However, there has been little progress since the Arthur D Little report was published.

Engine Developments	Short Term <2005	Medium Term 2006-2015	Long Term 2016-2030
High altitude CO_2 and NOx emissions	10-15% cumulative reduction in specific fuel consumption	15-20% cumulative reduction in specific fuel consumption	20-30% cumulative reduction in specific fuel consumption

- Even with very advanced combustion technologies that minimise NO_x formation, there will still remain trade-offs between CO_2 and NO_x as a result of high combustor exit temperatures.

B.3 On Airframe Developments, Arthur D Little said:

- Aerodynamic improvements and weight reduction strategies have resulted in 30 per cent. fuel efficiency between 1950 and 1997.
- Increased use of composite materials throughout the airframe offers continued fuel saving opportunities. NASA estimates that composite material technology and AAW (Active Aeroelastic Wing) technology can offer up to 30 per cent. reduction in take-off weight and associated fuel saving.
- Aerodynamic improvements can also add to fuel savings. Cumulatively, these could offer up to 20 per cent. fuel savings. In addition Boeing has developed a new winglet technology that can be retrofitted to existing aircraft for further savings of 2-3 per cent, though performance improvement dependent on aircraft type and route flown.
- Longer term development relies on active laminar flow devices which are predicted to additionally deliver up to 15 per cent. fuel efficiency improvements.

Airframe Developments	Short Term <2005	Medium Term 2006-2015	Long Term 2016-2030
High altitude CO_2 and NO_x emissions	Cumulative net fuel efficiency gain of 10% ASK/kg fuel on current trends	Cumulative net fuel efficiency gain of 10-20% ASK/kg fuel on current trends	Cumulative net fuel efficiency gain of 30-40% ASK/kg fuel on current trends

B.4 On ATC and Operational Developments, Arthur D Little said:

- Better ground operations through the introduction of Advanced Surface Movement, Guidance and Control System [A-SMGCS] and surface managers could significantly improve local air quality. The introduction of A-SMGCS and other related ground management systems could bring savings of up to 90,000 tonnes per annum of fuel burning at Heathrow from significantly reducing aircraft spent on the ground, running engines.

- Introduction of direct routing in the en-route flight phase could reduce fuel burn significantly through enabling aircraft to fly optimal flight paths. For a typical short-haul flight, the estimated reduction in flight time could be as much as 20 minutes, saving around 12 per cent. of fuel consumption from the journey.

- Improvements in CNS/ATM (a system which improves the identification and predicted movement of aircraft and vehicles in the airport movement area) could reduce fuel burn per trip by 6 – 12 per cent. on average.

- Improvements in aircraft utilisation, cruise speed optimisation, operational weight reduction and improved taxiing could lead to potential reduction in fuel burn per trip of 2-6 per cent.

- Some air traffic control practices will reduce the potential environmental mitigation benefit of new technologies. This is due to a trade-off between operational procedures and the desire to minimise the environmental impact of aircraft. For example to maximise the capacity at airports, the best operational measure is to have aircraft stacks. This is however detrimental to the environment as greater fuel is burnt while aircraft are forced to wait in stacks for a landing slot.

- Another example of operational measures and environmental benefit trade-off is the congestion of en-route airspace. Thus aircraft cannot gain clearance to the optimum flight level for their journey.

B.5 Overall, advances in airframe, engine and operational developments are forecast to offer average fuel efficiency improvements of up to say 2 per cent. per annum until 2030. The improvements below are cumulative through time, but the sum of the improvements may be optimistic as interactions between engine and airframe technologies are likely to reduce overall benefits.

High Altitude CO_2 and NO_x Emissions Fuel Savings

<2005		**2006-2015**		**2016-2030**	
Component	**Gain**	**Component**	**Gain**	**Component**	**Gain**
Engine	10-15%	Engine	15-20%	Engine	20-30%
Airframe	5-10%	Airframe	10-20%	Airframe	30-40%
ATC	3-6%	ATC	6-12%	ATC	6-12%
Operational	2-3%	Operational	3-6%	Operational	3-6%
Total	**20-34%**	**Total**	**34-58%**	**Total**	**59-88%**

B.6 Arthur D Little also says:

- Aviation is characterised by high development, capital and maintenance costs, long payback periods and low production volumes, limiting new product entry and take-up. High capital costs in the industry provide a strong business incentive to extend the lifetime of existing fleets.

- Uncertainties about economic and performance benefits of new technologies limit the opportunities for their implementation. Unless a new technology provides cost benefits (*e.g.* NOx reduction technology on fleets), product acceptance could be difficult. Given the high investment costs and long payback times, these factors mean that operators will demand significant performance improvements, of the order of 20 per cent. before considering fleet upgrading or replacement.

- Technology developments are often dependent on parallel advancement of numerous ‘enabling’ technologies. Alternative ATC infrastructure technologies may be possible which all provide the same basic function making it difficult to choose the best one.

- Agreed standards and stringent certification processes impose additional costs and lengthy lead times on developing new products and technology.

- Future technologies may not fit within present day airport infrastructure, imposing financial and practical constraints on their take-up.

ANNEX C

Fleet Mix and Fuel Burn Projections

C.1 The following table, table D8 from ***Aviation and the Environment: Using Economic Instruments***[38], which describes the fleet mix in 2000 and the likely fleet mix in 2030, was in the published DfT forecasts. These data were used to estimate the carbon dioxide emissions for the high and constrained capacity cases in 2030 for the consultation document, ***The Future Development of Air Transport in the United Kingdom***.

Seat band	2000		2030	
	Aircraft	Proportion of aircraft in seat band	Aircraft	Proportion of aircraft in seat band
1	Fokker 50 Falcon 2000 Embraer 145	75% 14% 11%	Falcon 2000 Embraer 170	67% 33%
2	B 737-400 A320 BAe 146 MD 80	50% 26% 14% 10%	A320 BAe146	71% 29%
3	B757-200 B767-300 A306	55% 27% 18%	B767-300ER B757-200	56% 44%
4	DC10 B777-200 A340 A330	44% 35% 13% 9%	B777-200 A340 A330	46% 37% 17%
5	B747-400 B747-200	68% 32%	B747-400 B777-300	74% 26%
6	A3XX	100%	A3XX	100%

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[38] A fuller description of the DfT's 2030 emission forecasts for UK aviation are given in ANNEX D of *Aviation and the Environment: Using Economic Instruments*.

C.2 The industry has its own view on fleet composition over a shorter time period. The evolution of airline fleets is difficult to predict as the development and roll out of new aircraft and aircraft upgrades occur. However the conclusion of some industry insiders is that many aircraft types in service in 2000 will no longer be so in the early 2010's as newer aircraft replace them. This conclusion fits with the trend of aircraft use between the 1990 and 2000.

CE Delft: Economic incentives to mitigate greenhouse gas emissions

Introduction

D.1 This study only looks at developments to 2010. An environmental charge could result in a headline cut of about $10MtCO_2$ or 2.72MtC in 2010 on emissions forecasted. This is the result of technical and operational measures (supply side effects of 4.4 per cent. by airlines) and reduced air transport demand of 4.5 per cent.

D.2 CE Delft use somewhat lower external costs for carbon than ***Aviation and the Environment***. Their €30/t/ CO_2 cost of carbon is close to £70 per tonne of carbon. But their cost of NO_x gives a lower cost of the climate change envelope [carbon times the radiative forcing index] in ***Aviation and the Environment***. The closest comparison with the costs in ***Aviation and the Environment*** is taken by using the CE Delft case of €50/t plus €6.0/kg, although this is still an underestimate.

Methodology

D.3 CE Delft used the Aircraft Performance and Direct Operating Costs models (APD model) to calculate the supply-side responses. By contrast, AERO modelling assumes only two technology levels – 'old' (aircraft older than 12 years) and 'current' (aircraft younger than 12 years). The APD model is designed to measure the fuel consumption and quantity of emissions of predefined aircraft types. Data were taken from aircraft manuals, with defined aircraft categories covering both long haul and short haul types.

D.4 If aircraft emission profiles play a greater role in airline economics, the replacement of old aircraft will be brought forward in time. As newer aircraft generally have lower emissions than older aircraft, an emission charge would cause more rapid fleet renewal. Decisions on aircraft replacement would though also include market forecasts, the capital position and the expected rate of return of the new aircraft.

Technical Measures For Reduced Emissions For Existing Aircraft

D.5 In the period to 2010, various options are available for the reduction of fuel consumption in existing aircraft. As well as accelerated fleet renewal, this includes the retrofit of winglets, riblets and also operational measures, but engines or their fine-tuning in any material way are not included.

D.6 The CE Delft study also includes in the period up to 2010 operational measures:

- at the individual flight level, including changes to flight path and speed to minimise emissions. At an emissions-minimising speed CO_2 emissions may be reduced by as much as 15-25 per cent. and a reduction of tankering of fuel);

- at the network level, in particular, frequencies of flights and different destinations. Also included are increases in load factors through either larger aircraft or lower frequencies in flights and changes in flight distance to improve environmental efficiency.

Supply Side: Accelerated Fleet Renewal

D.7 Depreciation costs, decreasing with age of the aircraft, are seen as one of the main cost items involved in aircraft replacement. Also of importance are fuel costs and maintenance costs, which tend to increase with the age of the aircraft.

D.8 Total fuel, maintenance and aircraft capital costs are lowest for aircraft of typically 10-12 years of age (assuming a baseline fuel price of about $0.28 per kg). This applies to aircraft used on average stage lengths with average utilisation. For aircraft with higher than average utilisation (low-cost carriers) the 'minimum-cost age' is lower, while for aircraft with lower utilisation (express carriers), the 'minimum-cost age' is higher. This explains the large differences in fleet ages between different types of airlines.

D.9 This analysis shows that the 'lowest cost age' moves downward by about 1 year when an incentive of ε30/tCO_2 is introduced. With a greater incentive of ε50/tCO_2 this age goes down about 1.5 years. Historic fuel efficiency improvement of aircraft amounts to about 1.7 per cent. per annum, and each year of accelerated fleet renewal leads to a further 1.7 per cent. emission reduction. Impacts due to accelerated fleet renewal prompted by environmental incentives are:

	CO_2 variants		CO_2 + NO_x variants	
Valuation CO_2	ε30/t	ε50/t	ε30/t	ε50/t
Valuation NO_x	0	0	ε3.6/kg	ε6.0/kg
Average fleet age reduction (years)	1	1.5	1.5	2
CO_2 emissions reduction (%)	1.7%	2.5%	2.5%	3.4%
NO_x emissions reduction (%)	1.2%	1.8%	1.8%	2.4%

Winglets

D.10 Below are C E Delft 's estimates of accelerated application of winglets prompted by economic incentives:

	CO_2 variants		CO_2 + NO_x variants	
Valuation CO_2	ε30/t	ε50/t	ε30/t	ε50/t
Valuation NO_x	0	0	ε3.6/kg	ε6.0/kg
Total emission reduction estimates for 2010				
CO_2	0.15%	0.27%	0.23%	0.38%
NO_x	0.23%	0.41%	0.35%	0.57%

Operational Factors

D.11 CO_2 emissions reduction estimates in 2010 following flight speed and altitude adaptations to optimise direct operating costs are reported by CE Delft:

Valuation, CO_2 €/t	Valuation, NO_x €/kg	Emissions reduction estimates following from flight speed/altitude adaptations	
		CO_2 emissions	NO_x emissions
30	0	-0.6%	-1.2%
50	0	-1.0%	-2.0%
30	3.6	-0.9%	-2.5%
50	6.0	-1.5%	-4.0%

Network Level

D.12 CO_2 emission reductions in 2010 following from frequency and load factor measures in the emission charge variant are suggested by CE Delft as:

Valuation, CO_2 4 €/t	Valuation, NO_x €/kg	CO_2 and NO_x emission reduction emissions following from load factor/frequency measures
30	0	-0.3%
50	0	-0.5%
30	3.6	-0.5%
50	6.0	-0.8%

Summary of Environmental Impacts

D.13 Overall, CO_2 emission reductions in 2010 could amount to:

Valuation CO_2 and NO_x (€/t and €/Kg)	Emission charge variant			
	Supply side %	Demand side %	Total	
			%	Mt CO_2
30 & 0	-2.9	-3.1	-5.9	-6.9
50 & 0	-4.6	-4.9	-9.3	-10.9
30 & 3.6	-4.4	-4.5	-8.7	-10.2
50 & 6.0	-6.6	-7.2	-13	-15.6

ANNEX E

RCEP Special Report: 'The Environmental Effects of Civil Aircraft in Flight', 2002: Summary of Main Relevant Points

Emissions

E.1 Subsonic aircraft fly close to the tropopause. There is variation of environmental impact between emissions released in upper troposphere or lower stratosphere. Dominant physical/chemical processes and timescales vary largely in the troposphere and the stratosphere. The height of the troposphere varies with latitude and is lowest in Polar regions. This height also varies seasonally and with weather. Many factors influence the actual impact of each individual flight.

E.2 CO_2 is a 'conservative' gas and becomes well mixed. NO_2 reacts rapidly to give O_3 and CH_4. O_3 has a short lifetime and its movement is restricted, whereas CH_4 also becomes well mixed. So the effect of CH_4 and CO_2 varies little with latitude. Uncertainty over contrails has increased, if anything, since the IPCC report.

E.3 Tropospheric water emissions are a negligible fraction of total water vapour, but combined with other particles can trigger contrail formation. Contrails and O_3 effects are regional and are more dominant in the Northern Hemisphere. Tropospheric NO_x causes an increase in O_3, decreasing surface ultra violet (UV) light. Emissions in the stratosphere have the opposite effect. The projected effect depends on the fraction (if any) of supersonic aircraft in the future.

E.4 Very roughly, CO_2 improvements are expected to be 1 per cent. per annum. NO_x improvements are potentially twice this, although IPCC identifies the potential trade off between progress on these two emissions.

E.5 As the aircraft fuel load decreases, it can move to a higher altitude (constant lift over reduced weight). At higher altitude the air is less dense and drag is lower – therefore more fuel-efficient. This links back to the altitude and illustrates how aircraft impacts are dependent on individual flight profiles.

E.6 A large proportion of fuel burn by short-haul flights occurs on take off and landing. Specific reference is made to 'Greener by Design' estimates that 60 per cent. of fuel used on flights shorter than 5000km and 50% used on shorter than 2800km. The 'most efficient' flight length is 2300nm (4260km). There are problems with very long-haul flights due to the large amount of fuel to be carried on take off. This report emphasises that short haul flights have a disproportionate environmental impact.

Airframes, Engines, and Operations

E.7 The report estimates 20 years as the timeframe needed for new airframe introduction. Phase-out of old airframes will be reduced by growth of aviation in developing countries, where old aircraft tend to finish up.

E.8 The report provides a useful summary of industry targets for emission reduction, with various combinations of the engines, airframes and operational changes:

	Industry	Engines			Engine/Airframes	
	ACARE	ANTLE	CLEAN	Rolls Royce	A IPCC/ ICCAIA	B IPCC/ ICCAIA
Year	2020	2008	2015	2010	2050	
CO_2 %	50	12	20	10	40-50	30-40
NO_x %	80	60	80	50	10-30	50-70
Noise %	50			50	50	

ACARE – Advisory Council for Aeronautical Research in Europe

ANTLE – Affordable Near-Term Low Emissions

CLEAN – Component vaLidator for Environmentally friendly Aero eNgines

Technological Advances

E.9 The report discusses the Blended Wing Body (BWB) concept: lighter and with less drag, more fuel-efficient and able to fly at alternative altitudes. But there would be a long lead-in time, and the size of the aircraft would make it applicable to long haul only.

Fuel Emissions and Engine Design

E.10 RCEP finds no serious suggestion of really major change in engine design in the foreseeable future. Major reductions in emissions have been achieved but engine technology is now relatively mature. Increasing problems are identified with the trade-off between fuel efficiency, NO_x and noise.

Hydrogen Fuel

E.11 Hydrogen fuel would have many disadvantages: it would be used in combustion engines (less efficient than fuel cells used for ground transport); a heavier on board fuel system would be required – insulated/pressurised for cryogenic temperatures; a greater volume of fuel would be needed and the squat appearance would require higher altitude flight for lower drag. Finally, the impact of water vapour at altitude (through increased contrails) is thought to be potentially large .

Biofuels

E.12 Biofuels are considered 'too difficult': ethanol has a lower calorific value so more volume would need to be carried. Difficult combustion characteristics mean formaldehyde pollutant would be produced. Thus, kerosene will remain as the only realistic fuel.

Operations

E.13 Higher load factors, reduced delays and optimal routings may bring 10 per cent. reduction in environmental impacts. Harmonisation of EU airspace is identified as essential. Routeing of flights on the basis of the position of tropopause may be a long-term possibility.