Final Report to DfT Aviation Environmental Division and the Environment Agency

The Impacts of the Use of Different Benchmarking Methodologies on the Initial Allocation of Emission Trading Scheme Permits to Airlines

July 2007

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Reviewed/checked by	Dft, EA, DEFRA, CAA
Report no.	CATE-2006-3(C)-2
Date of issue, Version no.	29-07-2007 v1.3 Customer and Steering Committee (Dft, EA, DEFRA, CAA) reviewed version

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Executive Summary

The European Commission has issued a proposal for the inclusion of aviation emissions of carbon dioxide (CO_2) in the European Emission Trading Scheme (EU ETS) (COM(2006)818 final). According to the proposal, airlines will have to surrender allowances for CO_2 emissions on flights within the EU (in 2011) and on all flights departing from or arriving at EU airports (from 2012 onwards). Domestic flights and international flights will be treated alike. Like other participants in the EU ETS, airlines will be given a number of free allowances.

Scope of the study

This study was commissioned by the UK Department for Transport and the Environment Agency, and was conducted by Manchester Metropolitan University and CE-Delft. The study sets out to develop a detailed understanding of the implications of different possible allocation methodologies for emissions allowances to participating airlines with regard to economic efficiency, environmental effectiveness and the distributional impacts on the airlines themselves. The study does this by assessing the impacts of different benchmarks on different illustrative airline types, relative to one another. As a result, this research is not intended to assess the impacts on specific airlines. This study has used UK data to analyse generic UK airline types, consequently some of the results may not be directly applicable to the EU as a whole.

Allocation methodologies

In principle, there are three ways to allocate allowances among aircraft operators:

1. *grandfathering*, i.e. free allocation on the basis of an airlines' historical emissions;
2. *auctioning*, i.e. no free allocation;
3. *benchmarking*, i.e. free allocation on the basis of an indicator of the output, efficiency, or fleet characteristics.

Grandfathering has the advantage that every existing airline will face the same relative shortfall but the disadvantage of this method is that it does not reward early action for decreasing emissions. In fact, airlines that have increased their efficiency may have exhausted the cheapest options to reduce emissions and may thus be disadvantaged under grandfathering.

Auctioning can be an efficient non-discriminatory way of allocating permits, is consistent with the 'polluter pays' principle, and can generate revenues for environmental expenditure.

Benchmarking can be a good way to reward early action whilst making free allocation of allowances possible at the same time. It is also the allocation method proposed by the European Commission and supported by most Member States. Therefore, it is the focus of this study.

The European Commission’s Proposal

The European Commission has proposed to allocate a large proportion of emission allowances to airlines at no cost, based on a ‘benchmark’. More specifically, it proposes to allocate to each airline a share of the total amount of allowances that equals the share of Revenue Tonne Kilometres of that airline within the boundaries of the system (where a Revenue Tonne Kilometre is defined as either one tonne of freight or the equivalent weight of passengers transported over one kilometre).

Modelling approach

Any free allocation of emission allowances to aircraft operators will transfer assets to aircraft operators. Since benchmarks cannot be designed in a way that is neutral to all business models of airlines, benchmarking will inevitably create winners and losers. Therefore, it is important to analyse which types of airlines can be expected to gain and lose, and what the size of these gains and losses is likely to be, so that an informed decision can be taken over the relative merits of the different benchmarking options.

For this purpose, using UK Civil Aviation Authority data on flights to and from the UK, a parameterized spreadsheet model was developed to calculate the emissions and allowances allocated under different benchmarks of ten generic aircraft operator types that represent a cross-section of airline business models. These generic airline types are:

- large network carriers,
- medium sized network carriers,
- low-cost carriers,
- non-EU network carriers,
- regional airlines and
- freight-only airlines.

In defining the airlines, care was taken to mimic typical existing airlines as closely as possible, in order to ensure that the results of this study are representative for the airlines considered. It has not been possible within the scope of this study to model every existing type of airline. Business aviation, for example, is not included from the analysis, as it is a small sector in terms of emissions and number of flights. Charter carriers are not included explicitly, although it could be argued that they are represented by one of the low-cost carriers modelled.

For the different generic airline types, emissions and allowances were calculated for nine different benchmarks. These nine benchmarks can be categorized into three groupings:

- ‘**Output-based benchmarks**’: allocating allowances in proportion to the output generated by an airline. The most common output benchmark parameter is RTK (as defined above). This study has calculated results for this benchmark, as well as several variants in which passengers are assigned higher equivalent weights than

100 kg in order to account for seats, catering, overhead bins, and other items on board for use by the passengers.

- '**Input-based benchmarks**': allocating allowances in proportion to the transport capacity offered by an airline. The most common input benchmark parameter is ATK (available tonne kilometre – the capacity to transport either one tonne of freight or ten passengers over one kilometre). Other input-based benchmark parameters considered in this study were maximum payload kilometres and maximum take-off weight kilometres.
- '**Fleet age benchmarks**': allocating more allowances to airlines with a relatively young fleet. Fleet age benchmarks reward airlines with a fleet younger than average with 1% or 2.5% more allowances per fleet age year. Some parties have argued that a fleet age benchmark would be close to a technology-based benchmark: if technology would constantly improve, i.e. aircraft would get ever more fuel efficient, a younger fleet would mean a more efficient fleet. However, there seems to be very little empirical evidence for this claim.

The results

The results have been evaluated for distributional impacts (the sizes of the gains and losses), rewards for early action (be it load factor improvement, fleet efficiency improvement or technical and operational improvements), and incentives for emission abatement.

The results are presented in terms of percentage variation from the average, resulting in positive (i.e. relative over-allocation) and negative (i.e. relative under-allocation) data. Put differently, the results are represented as if the cap was set at the level of actual emissions. Note that this was done because it makes it easier to identify which airline types win and which lose, not because is was assumed that the cap would be equal to business as usual emissions. It should be noted that an over-allocation in this analysis does not mean that some airlines receive more allowances than they need and therefore have surplus ones to sell; it means that some airline types may receive more than the aviation average as a whole. As aviation emissions will most likely continue to grow, at some point all airline types are expected to face a shortfall of allowances; however, this shortfall is larger for the airlines that are relatively under-allocated whilst the airlines that are relatively over-allocated will need to buy fewer allowances from the market. The analysis showed that different benchmarks varied considerably with respect to their distributional impacts on generic airline types and rewards for early action.

The RTK benchmark with a passenger weight of 150 kg and the fleet age benchmark with an age factor of 1% had the smallest distributional impacts of the different benchmarks considered. It should be noted that the age factor 1% benchmark has the least distributional impacts because it closely resembles grandfathering; without the age factor of 1%, this benchmark would be identical to allocating based on historical emissions. Other benchmarks, such as the RTK with a passenger weight of 100 kg and the ATK benchmarks create larger gains and losses for different airline types. The largest distributional impacts of the benchmarks studied were created by the maximum payload kilometres, the maximum take-off weight kilometres and the age factor of 2.5%.

The main project results are summarised in the table below in terms of percentage deviation from the mean.

ES Table 1: Relative over-allocation and shortfall of generic airline types – static situation

Carrier type	**RTK100**	**RTK150**	**MPK**	**MTOWK**	**ATK/MSCK**	**ATK/ASK**	**AF2.5%**	**AF1%**
Large Network Carrier A	3%	1%	4%	9%	1%	-4%	-4%	-1%
Large Network Carrier B	-2%	-2%	-3%	2%	-3%	-2%	-4%	-1%
Mid-sized Network Carrier A	2%	1%	7%	3%	9%	-1%	4%	1%
Mid-sized Network Carrier B	-2%	-2%	-2%	-2%	0%	2%	4%	1%
Low-cost Carrier A	-9%	-4%	-24%	-45%	-6%	7%	11%	4%
Low-cost Carrier B	-7%	-2%	-8%	-34%	9%	25%	11%	4%
Large US based network carrier	13%	9%	21%	23%	6%	-4%	-11%	-4%
Large Far East based network carrier	1%	-1%	0%	26%	-10%	-12%	4%	1%
Regional airline	-33%	-28%	-31%	-53%	-13%	-7%	-11%	-4%
Freight Airline	-1%	-26%	-13%	-5%	-4%	33%	-23%	-9%

Note 1: Benchmark abbreviations can be found in section 3.3.2.

Note 2: For information; if grandfathering were added to this table, it would be represented as 0% for each generic airline.

In considering the impacts on the different generic airline types under the scope of the UK arriving and departing flight data, low-cost carriers were found to be more sensitive to benchmark choice than network-carriers. Network carriers were found to have either small over- or under-allocations under a RTK benchmark, which is principally the result of their long-haul flights, which tend to have high load factors (and thus generate a large amount of RTKs). Such flights are relatively fuel-efficient because of the proportion of time spent in the cruise phase of flight and the large sizes of the aircraft employed.

Freight-only airlines were under-allocated in all benchmarks with the notable exception of an available tonne kilometres benchmark and an RTK100 benchmark. This is due to their relatively inefficient fleet, the assumed load factor, and to the UK situation for which there are a relatively large number of short-haul freight flights.

Regional airlines faced a considerable shortfall under all the benchmarks considered, which partly arises from the fact that this generic airline type tends to travel only short distances. This is likely to be a particular situation for the UK, owing to the nature of its outlying island territories and is likely to be in contrast to the situation for some other EU Member States. Adding a constant to the flight distance in RTK benchmarks would significantly reduce the shortfall of the UK type regional airlines. It would also make some low-cost carriers better off, while non-EU network carriers would be negatively affected. There is some empirical evidence for adding a constant of about 100 km.

Note that in an intra-EU scheme, network carriers would not benefit from the fuel efficiency of their long-haul flights. With such a geographical scope, low-cost carriers would be relatively over-allocated while network carriers would be relatively under-allocated.

In addition to the strongly varying distributional impacts of the technology age factor benchmarks (i.e. for 1% yr^{-1} and 2.5% yr^{-1}), a detailed examination of data and the origin of such a factor could not support improvements of even the lower order rate of 1% yr^{-1}.

Output-based (RTK) benchmarks generated relative over-allocation for airlines with high load factors, especially on their long-haul flights. Input-based benchmarks (be it ATK or other) are less predictable. If they were based on actual seating capacities, they over-allocated airlines with high seating capacities; but if they were based on maximum or standardised seating capacities, they over-allocated airlines with an actual number of seats that is lower than the standard.

A number of sensitivity tests were conducted to ascertain the robustness of the results with regard to the assumptions made in the modelling: changes in the assumptions within boundaries of what might be considered as ‘likely’ resulted in maximum changes of approximately 2%, such that confidence could be placed in the modelling assumptions.

Rewarding early action

When considering these benchmarks against the criterion for rewarding early action, the analysis showed that output-based benchmarks reward load factor improvement, fleet optimisation and operational measures to reduce emissions. By contrast, input-based benchmarks slightly penalise load factor improvement but rewarded fleet optimisation and operational measures to reduce emissions. Fleet age benchmarks only reward fleet optimisation, and only insofar as aircraft efficiency correlates with age.

ES Table 2: Reward for early action

	Output based	**Input based**	**Fleet age**
Load factor improvement	+	0 (-)	0
Fleet optimisation	+	+	+ (-)
Operational measures	+	+	0

Note: '+' *= rewarded,* '*0*' *= not rewarded,* '-' *= penalised*

Conclusion

In summary, this study argues that an output-based benchmarking method is more consistent with encouraging environmental efficiency than other benchmarks. At the same time, the RTK-based metrics had relatively small distributional impacts, with the exception of those on UK-type freight-only carriers and UK-type regional carriers.

1 Introduction

As a part of its ongoing commitment to combat climate change, the European Commission has implemented an emissions trading scheme as a market-based mechanism in order to bring about reductions in greenhouse gas emissions across Europe. Initially, the scheme included the power sector and large industrial installations. More recently, there has been discussion over how aviation might be included in the scheme in terms of pollutants/effects and geographical scope (Wit *et al*., 2005).

In December 2006, the European Commission issued a proposal for the inclusion of aviation in the European Emission Trading Scheme (ETS) (COM(2006)818 final). According to this proposal, airlines will have to surrender allowances for CO_2 emissions on flights within the EU in 2011 and on all flights departing from or arriving at EU airports from 2012 onwards. Both domestic flights and international flights will be treated alike. Like other participants in the EU ETS, airlines will initially be allocated a number of free allowances.

The amount of free allowances that each airline receives depends upon the *allocation method*. In earlier studies (e.g. Wit *et al*., 2005) and stakeholder consultations (EC 2006) three allocation methods have been discussed:

1. grandfathering, i.e. allocation on the basis of an airline's historical emissions;
2. auctioning, i.e. no free allocation;
3. benchmarking, i.e. allocation on the basis of an indicator of the output, efficiency, or fleet characteristics.

According to economic theory, neither the environmental effectiveness (“is the target met?”) nor the economic efficiency (“what does it cost to meet the target?”) is affected by the initial allocation of allowances (Tietenberg, 2006). This theory only holds when transaction costs (the costs involved in trading) are low. The incentive to reduce emissions is purely a result of the price of the allowances, which in turn are determined by the cap, i.e. the total amount of emissions permits. However, recent analyses of the economics of the EU ETS have shown that *repeated* free allocation may affect the economic efficiency of emission trading (Neuhoff *et al*., 2006, CE Delft 2007).

The method by which emissions permits are initially allocated determines, largely, the distributional impacts of emission trading. Under both grandfathering and benchmarking, some airlines will be better off than others will, i.e. they will receive a larger share of free emission allowances relative to their actual emissions. Under auctioning, all participants can be expected to cover their needs and face the same costs per unit of emissions. However, if proceeds are invested back into the sector, there may be distributional impacts.

In this work, different possible allocation methodologies have been studied in order to develop a detailed understanding of their implications for economic efficiency, environmental effectiveness and distributional impacts.

1.1 Aim and objectives of the study

The overall aim of this project is to develop a detailed understanding of the implications of the different possible allocation methodologies for economic efficiency, environmental effectiveness and distributional impacts for the airlines themselves. This will help the UK Government understand the relative benefits of the different methodologies. The research did not consider any effects arising from the expenditure of revenue from any auction of permits.

The scope of this research was to set out an indicative analysis that would provide an assessment of the impacts of different benchmarks on different illustrative airline types, relative to one another. As a result, this research is not intended to assess the impacts on specific airlines. This study has used UK data to determine generic UK airline types, consequently some of the results may not be directly applicable to the EU as a whole.

The research had three objectives:

1. to identify possible allocation methodologies;
2. to model these different methodologies;
3. and to assess the impact of the different methodologies on economic and environmental efficiency, and on the different types of airlines.

More specifically, the research made clear the distributional impacts, the rewards for early action and the practicability of different benchmark methodologies.

1.2 Outline of the report

Chapter 2 outlines the research methods applied in this report. Chapter 3 presents the results, which are discussed in Chapter 4. This chapter also assesses the limitations of the analysis. Chapter 5 summarises and concludes.

2 Allocation methodologies

In theory, the efficiency of an emissions trading scheme is independent of the choice and design of the initial allocation scheme. However, the allocation of emission rights determines the financial burden to be borne by the sector as a whole as well as by individual entities. Given these distributive implications, allocation of emission rights is a highly sensitive design issue that will be crucial for the acceptance of the emissions trading scheme.

In general, three allocation methodologies can be distinguished:

1. grandfathering, i.e. allocation on the basis of an airline's historical emissions;

2. auctioning, i.e. no free allocation;
3. benchmarking, i.e. allocation on the basis of an indicator of the output, efficiency, or fleet characteristics.

These methodologies are summarised and outlined below.

2.1 Grandfathering

In the *grandfathering* approach, emission rights are allocated free of charge, based on historical emissions. This approach fundamentally contradicts the polluter-pays principle. Moreover, it strengthens vested interests and is therefore attractive for incumbents and usually unfavourable for newcomers. In general, airlines using relatively polluting technologies will be relatively better off than operators that have already invested in cleaner technology.

In grandfathering, it is common practice to allocate emissions allowances in proportion to past emissions, with reference to the emissions of a single year, an average value for recent years or a maximum value of recent years. The aviation sector is rather volatile; the sector as a whole, as well as individual aircraft and airport operators, is susceptible to economic circumstances in individual countries and regions, and to isolated local and regional events such as terrorist attacks, epidemics and natural/environmental disasters. Against this background, it is therefore considered more appropriate – in order to have a sufficiently representative base period – to take a period of several years rather than a single year. In general, the earlier the base period is, the more early actions will be honoured. Accordingly, the base period should be as early as possible; e.g.10 to 5 years before the start of the scheme. However, the major disadvantage of this approach is that it leaves entities that have entered the market after the base period without sufficient allocation or even no allocation at all. Moreover, the fastest growing entities would face the largest shortfall. In the EU ETS (which has adopted grandfathering for allocating allowances) most Member States have therefore opted for a more recent base period (1998-2003, 2001-2003, etc.) and some States have introduced specific provisions for the consideration of early action.

If the grandfathering approach were adopted, emissions data for the base period is a prerequisite. The flight and emission data must be of high reliability and comparability, moreover. EUROCONTROL – as an independent European Agency – has at its disposal CO_2 emission estimates for all individual flight relations within the European Airspace for the years 1995 to 2004. However, these emission data are generated by models that determine fuel consumption based on aircraft/engine-dependent fuel flow data and on flight plan data combined with radar data of actual flights performed. Records of fuel consumption on an individual flight basis are only available from the aircraft operators. Usage of EUROCONTROL CO_2 emissions data may be contested by airlines. One feasible strategy would be to oblige the affected entities to provide the data on fuel consumption for all flight relations. The data provided could then be verified against the computed EUROCONTROL data.

2.2 Auctioning

From an economic perspective, *auctioning* – which is consistent with the polluter-pays principle – has a number of advantages, notably that permits are allocated on a non-discriminatory basis that also extends to new entrants. The revenue raised by auctioning could be substantial. These revenues could be used, in principle, to reduce taxes elsewhere or to finance other climate control measures. Alternatively, they could be recycled to the aviation sector, in which case the effects would be similar to those of a revenue-neutral charge (IATA, 2001).

2.3 Benchmarking

With *benchmarking*, emission allowances are distributed free of charge but in contrast with grandfathering, based on specific values – so called benchmarks – relating to a typical output factor of a sector or another parameter. Whilst in the grandfathering approach emissions data must be available for a base period, in the case of benchmarking, activity data must be collected and multiplied by a selected benchmark.

A clear advantage of the benchmark over the grandfathering approach is that it favours entities with low-emissions aircraft, so that taking early action relative to other airlines would be rewarded. If designed properly, the benchmark should provide incentives for investments in new technologies.

In contrast to grandfathering, benchmarking appears to favour the use of a late base year. Early action, vis-à-vis efficiency and high load factors, would not need to be explicitly considered by adopting an early base year, since once the benchmark is applied, entities that have made efforts in this regard are automatically better off. Another practical aspect arguing for a late base year is data availability. Until recently, data used to calculate the benchmark have not been monitored and verified by an independent institution.

Any free allocation of emission allowances to aircraft operators will transfer assets to aircraft operators. Since benchmarks cannot be designed in a way that is neutral to all business models of airlines, benchmarking will inevitably create winners and losers. Therefore, it is important to analyse which types of airlines can be expected to gain and lose, and what the size of these gains and losses is likely to be, so that an informed decision can be taken over the relative merits of the different benchmarking options.

Furthermore, benchmarks should reward early action – otherwise other allocation methodologies could be preferred. Moreover, benchmarks should be practicable in the sense that they should be based on unequivocally verifiable parameters. It is these properties of benchmarks that this reports sets out to investigate.

3 Method to assess the impacts of different benchmarks

3.1 Introduction

The basic tool for the analysis presented in this study is a tailor-made spreadsheet model specifically designed to assess the differential impacts of various allocation methods on different airlines. The model has been applied to calculate the distributional impacts of a number of different possible benchmarks.

This chapter first describes the spreadsheet model in section 3.2. After that, section 3.3 defines the benchmarks studied in this report.

3.2 Spreadsheet model design

The spreadsheet model calculates CO_2 emissions under ETS for different generic airlines, as well as the amount of free allowances that different airlines receive under the different allocation methods. The model uses data from two databases. The first database is a tailor-made database of generic airlines, outlining the route network, fleet and, if applicable, seating capacities. The second database has CO_2 emissions of different aircraft types with different load factors on different mission lengths. This database was created using the PIANO model (Simos, 1993; 2004).

A graphical presentation of the model is show in Figure 1.

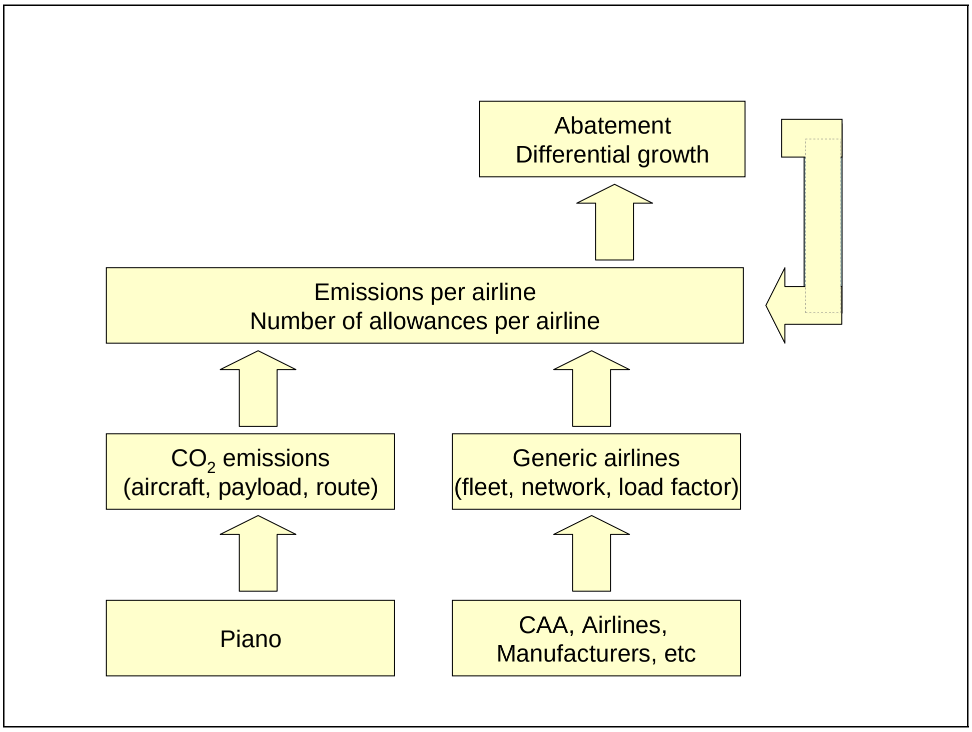

Figure 1: Graphical presentation of the spreadsheet model

The remainder of this section provides a brief description of the design of the generic airlines and the emission modelling. A more detailed description is given in Appendix A.

3.2.1 Design of generic airlines

The spreadsheet model includes several different airline types:

- Large EU-based network carriers
- Medium sized EU-based network carriers
- Low-cost carriers
- Non EU large network carriers
- Regional airlines
- Freighter airlines

In 2006, these airline types accounted for 88% of all flights to and from the UK and 87% of passengers (see Table 1) (other flights were carried out by charter airlines, business aviation airlines, involved helicopter flights or could not be identified). It has not been possible within the scope of this study to model every existing type of airlines. Business aviation, for example, is not included from the analysis, as it is a small sector in terms of emissions and number of flights. Charter carriers are not included explicitly, although it could be argued that they are represented by one of the low-cost carriers modelled.

Table 1: Share of generic airline types in aviation to and from the UK, 2006

Generic airline type	**Percentage of flights**	**Percentage of passengers**
Large EU-based network carriers	26%	25%
Medium sized EU-based network carriers	12%	12%
Low-cost carriers	36%	42%
Non EU large network carriers	4%	7%
Regional airlines	10%	2%
Freighter airlines	1%	0%
Other	12%	13%

Source: UK CAA

For the four most prominent generic airline types, the model distinguishes two different airlines for each type. The airlines, labelled A and B, have different fleet (for network carriers) and different route networks (for low-cost carriers). These variants reflect actual differences between airlines. Of the four largest network carriers in Europe, for example, two have a fleet that consists largely of Boeings, whereas the other two have a large share of Airbus aircraft in their fleet. A detailed description of the different airlines is given in Appendix A.

In the model, all the generic airlines operate on a maximum of six different routes. The route lengths were chosen to reflect actual routes with relative high frequencies. The UK Civil Aviation Authority (CAA) provided comprehensive data of flights to and from the UK in 1990, 2004, 2005 and 2006. An analysis of the 2006 data showed that much of the traffic is on sector distances of 250 km, 550 km, 1500 km, 2900 km, 5500 km and 9500 km[1]. Figure 2 shows the number of flight kilometres for all sector distances.

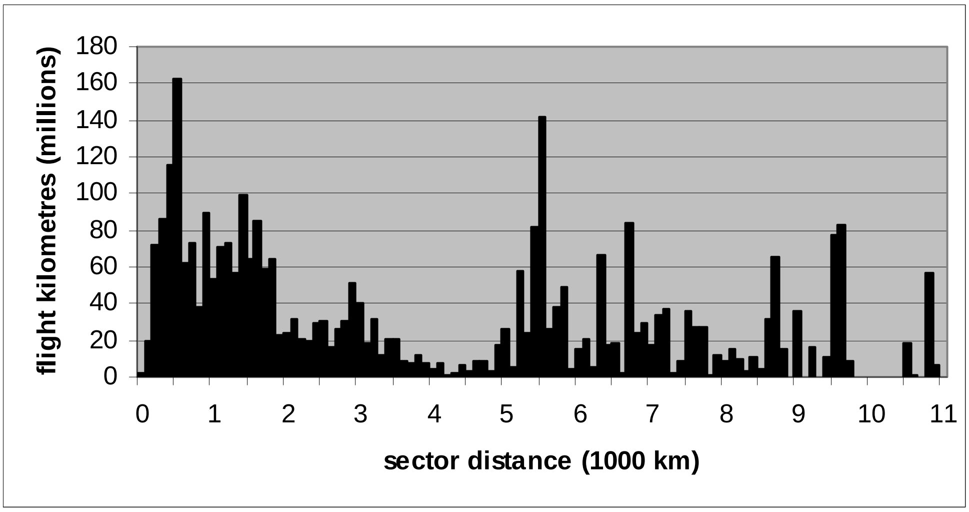

Figure 2: Flight kilometres as a function of sector distance (UK CAA 2006)

On these routes, airlines operate aircraft that have frequently been used on flights to and from the UK in 2006. Again, CAA data was the main source for this. Table 2 presents the most commonly used aircraft in each of the different distance bands.

Table 2: Most widely used aircraft on flights to and from the UK (2006)

Sector lengths, aircraft and fractional share		
0–400 km	**400–1000 km**	**1000–2000 km**
Dash 8 Q400 (17% of flights in distance	Airbus A319 (15%)	Boeing 737-800 (18%)
Airbus A319 (7%)	Boeing 737-800 (9%)	Airbus A319 (16%)
Saab Fairchild 340 (7%)	Airbus A320-100/200	Airbus A320-100/200
Boeing 737-300 (6%)	Embraer RJ145 (9%)	Boeing 737-300 (11%)
Fokker 50 (5%)	Boeing 737-300 (6%)	Boeing 757-200 (8%)
Airbus A320-100/200 (5%)	Dash 8 Q400 (6%)	Boeing 737-700 (7%)
Boeing 737-800 (5%)	Boeing 737-700 (5%)	Airbus A321 (5%)
Embraer RJ145 (5%)		Boeing 737-500 (5%)
2000–4000 km	**4000–7500 km**	**>7500 km**
Boeing 757-200 (23%)	Boeing 777-200ER (25%)	Boeing 747-400 (49%)
Airbus A320-100/200 (23%)	Boeing 767-300ER/F	Boeing 777-200ER (19%)
Boeing 737-800 (12%)	Boeing 747-400 (13%)	Airbus A340-300 (7%)
Airbus A321 (11%)	Boeing 757-200 (9%)	Airbus A340-600 (7%)
	Airbus A330-200 (8%)	Boeing 767-300ER/F
	Airbus A340-300 (6%)	

Source: UK CAA

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[1] Analysis of CAA data on 2004 and 2005 shows a very similar pattern. The pattern for 1990 is very different, however. In that year, there were relatively fewer flights of 1500 - 3000 kilometres sector distance.

Aircraft of different generic airlines have different seating capacities. For example, network carriers typically have lower seating densities than low-cost carriers and the spreadsheet model reflects this. Table 3 gives exemplary seating densities for selected aircraft types.

Table 3: Observed seating capacities of aircraft types

Aircraft	Observed capacities of network carriers	Observed capacities of low-cost carriers	Seating capacities in one class configuration according to manufacturers	Spreadsheet model seating capacities
Airbus A319	105-144	156	124	126 – 130 (network carriers)
Airbus A321	154-212		185	185 – 190 (network carriers)
Boeing 737-300	126	149	134	125 (network carriers) 149 (low-cost carriers)
Boeing 737-800	142 – 148	189	184	170 – 171 (network carriers) 187 (low-cost carriers)

Sources: annual reports and websites of British Airways, Lufthansa, Air France, Finnair, CSA, BMI Midland, EasyJet, Ryanair, Sky Europe, Boeing and Airbus.

The generic airlines also have different load factors. Passenger load factors are typically very high for low-cost carriers. Low-cost carriers report passenger load factors between 76% (Sky Europe, 2006) and 84% (Ryanair, 2005, Easyjet, 2005). Network carriers have different load factors on different routes; load factors on short and medium haul routes are typically lower than on those for intercontinental routes. In 2005, network carriers had a 66% passenger load factor on operations in geographical Europe and an 80% passenger load factor on long haul flights (AEA, 2006). The overall load factors, including freight, were 59% and 73%, respectively. This implies that in geographical Europe, the average amount of freight in the hold of passenger aircraft is small. By contrast, a considerable amount of freight is carried in the hold on long haul routes.

The generic airlines are assumed to have load factors as presented in Table 3.

Table 3: Load factors of generic airline types

	Passenger load factor		Overall load factor
	Short and medium haul	Long haul	Long haul
Network carriers	68%	80%	78%
Low-cost carriers	70% – 80%	n.a.	n.a.
Regional airlines	68%	n.a.	n.a.
Freighter airlines	n.a.	n.a.	68% (all distances)

The generic airline types are also characterised by different mean fleet ages. Fleet ages are reported by airlines in their annual report. A summary of mean fleet ages is given in Table 4.

Table 4: Observed average fleet ages

Airline type[2]	**Average fleet age (years)**
Large EU network carrier	10.4
Medium sized EU network carriers	7.3
Low-cost carriers	3.8
North American network carriers	13.5
Far East network carriers	6.5
Regional airlines	16.7
Freighter airlines	13.7

3.2.2 Emission modelling

This section describes the methodology by which CO_2 emissions were calculated, and provides the underlying assumptions.

The objective was to calculate CO_2 emissions per aircraft on a typical mission distances (i.e., 250 km, 550 km, 1500 km, 2900 km, 5500 km and 9500 km), the selection of which are described in Appendix A.

The aircraft types for which calculations were made were: Airbus A300-600, Airbus A300B4-100/200, Airbus A310-300, Airbus A319, Airbus A320-200, Airbus A321-100, Airbus A330-300, Airbus A340-300, Airbus A340-600, ATR-42, ATR72, Avro RJ85, Boeing 737-300, Boeing 737-400, Boeing 737-500, Boeing 737-600, Boeing 737-700, Boeing 737-800, Boeing 737-900 Boeing 747-400, Boeing 757-200, Boeing 757-300, Boeing 767-300, Boeing 767-300ER, Boeing 777-200IGW, Bombardier Dash 8 series Q400, Embraer E145, Fokker F-100, MD-11, MD-81, Saab 340B,

The model that was used to calculate fuel flows for this work was aircraft performance model, ‘PIANO’[3] (Project Interactive ANalysis and Optimisation) which simulates aircraft performance and fuel-flow, amongst many other things (Simos, 1993; 2004). PIANO is a sophisticated aircraft performance model that is widely used within the aviation industry. It has been applied in inventory-type work and data produced from it underlie the fuel-flow calculations in many global aviation inventories including ANCAT/EC2, AERO2K and FAST.

The data on available seats for the aircraft was taken from internal model data and used in terms of calculating emissions of CO_2 per passenger kilometre. Engines for individual aircraft are automatically loaded from 32 discrete types within PIANO. Some of these engines are specific (e.g. CFM56-7B22), whilst many are generic types with typical performance

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[2] Sources: most recent annual reports and websites of British Airways, Lufthansa, Air France, KLM, Finnair, CSA, BMI Midland, Malev, Austrian airlines, EasyJet, Ryanair, Air Berlin, Sky Europe, Delta Airlines, American Airlines, Singapore Airlines, Cathay Pacific, Air Southwest, CityJet, Cargolux, DHL, UPS.

characteristics (e.g. Medium-BPR Fan 90s, Advanced BPR 10). The variability of fuel performance between individual types of engine fitted to aircraft should be much smaller than their NO_x characteristics.

A number of factors affect the calculated fuel usage over a mission for a given aircraft type, they include the flight altitude(s) assumed, the speed and the weight of the aircraft.

For speed, a 'standard' assumption of 99% of maximum specific air range (SAR) was specified. In the model, the Mach number for 'max SAR' was determined in order to maximise the specific air range, the distance travelled per unit of fuel burn. For '99% max SAR', this increases the above Mach number slightly until only 99% of the maximum SAR is achieved and corresponds to typical operational long range cruise conditions (Simos, 2004).

In terms of the weight of the aircraft, the maximum payload mass was taken from PIANO internal data (and corresponds to the 100% payload in the spreadsheets) for individual aircraft types. Calculations were then iterated in 10% increments from 50% payload to 100% payload as the fuel usage over a given mission is rather sensitive to this assumption. For general global inventories, a single percentage load factor is generally assumed from global statistics. However, for this work, in which different load factors were assumed for different business models, the load factor needed to be differentially applied.

Lastly, the cruise altitude assumption needs to be set. Three possibilities are available within PIANO: an operating ceiling, a drift-up profile, and a specific cruise altitude or altitudes. Of these, the drift-up profile was used. This allows the aircraft to fly at optimal altitudes to minimise fuel usage, so that as more fuel is used, the aircraft is able to ascend and minimise drag. In practice, this has only limited possibilities for aircraft within European airspace because of aircraft-traffic management constraints.

For calculation of CO_2 from fuel, the standard, fixed factor of 3.156 was used.

3.3 Identifying the possible benchmarking methodologies

ENTEC/NERA (2005) have provided an overview of different benchmarking methodologies that have and potentially could be applied in the EU ETS. They distinguish input, output and capacity-based benchmarks, further categorized as output measures and energy efficiency measures.

Applied to the aviation sector, this leads to three benchmark categories:

1. output-based benchmarks;
2. input-based benchmarks; and
3. technology-based (energy efficiency) benchmarks.

Each of these benchmark types is analysed in more detail below.

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[3] http://www.lissys.demon.co.uk

3.3.1 Output-based benchmarks

Aircraft operators may be characterised as producing two forms of output, i.e.:

1. economic output—turnover or profit;
2. physical output—transport of passengers or cargo.

Economic output would be a good basis for a benchmark from an economic efficiency viewpoint in that it would encourage aircraft operators to maximise profits or turnover even more than at present. However, such a benchmark is unsuitable as a base for a system with a limited geographical scope since airlines would have a large amount of freedom to assign profits to different routes by allocating cost items to certain routes and not to others. This would seriously hamper verification of the benchmark and thus undermine the credibility of the scheme. Turnover would be a better basis for a benchmark than profit, as it can be verified more easily but it would require airlines to report sensitive information, i.e. turnover per route, to which they may object. Therefore, neither turnover nor profit is considered a good basis for a benchmark.

Physical output would also be a reasonable basis for a benchmark from an economic efficiency viewpoint, since it can be assumed that in efficient markets physical output is correlated with economic output. In aviation, the correlation may be stronger within particular business models (low-cost carriers, network carriers) than across them for example a business jet operating on a same route as a low-cost carrier. The advantage of using physical output is that it would be easier to verify. Common measures of physical output in the aviation sector are Revenue Passenger Kilometres[4] (RPK – one paying passenger transported over one kilometre), Revenue Freight Tonne Kilometre (RFTK – one tonne of freight transported over one kilometre), or Revenue Tonne Kilometre (RTK – either one tonne of cargo or one tonne equivalent of passengers transported over one kilometre)[5]. Using RTK would have the advantage that the same benchmark could be used for both passenger and freight transport.

If a benchmark based on RTK were to be used, passengers would have to be assigned with a specific average weight. Usually, it is assumed that one passenger (including luggage and catering) weighs 100 kg, so 10 passengers constitute one tonne. This is slightly higher than the regulatory weights in use for safety requirements. However, there is evidence that the total weight of passengers and their luggage and all the other items carried on board for use by passengers (seats, galleys, toilets and service items such as in-flight meals and newspapers) is greater than 100 kg, e.g.:

- Airlines use equivalent values ranging from 83 kg/pax to 185 kg/pax in their annual reports (Cathay Pacific, 2006, Singapore Airlines, 2006).

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[4] The term revenue in this refers not to the actual revenue raised per passenger or tonne cargo but the fact that the airline will receive payment for the transport of that passenger or cargo.

- The operating empty weight (OEW) of freighter aircraft is generally lower than that of an equivalent passenger aircraft[6]. The difference may be as much as 8% per aircraft in the case of a Boeing 747-400 with GE engines, or about 30 kg/pax (747-400/-400ER Document D6-58326-1 (Revision D, December 2002), Boeing website). This figure depends on the type of aircraft. For example, a Boeing 737-700 in a freighter configuration is approximately 4% lighter than the equivalent passenger aircraft, which results in approximately 10 kg per passenger. This figure excludes catering and flight attendants on passenger aircraft but also excludes items used for carrying freight on freighter aircraft, such as pallets.
- It has also been suggested that the weight of all the items needed to carry a passenger (for example; seats, toilets, electronics, oxygen) is approximately 50 kg per passenger.

In summary, information from several sources warrants a closer look into different passenger weights over a *de facto* value of 100 kg per passenger. Thus, as a sensitivity analysis, passenger weights of 100 kg, 125 kg and 150 kg have been utilised.

When emission allowances are allocated according to an output-based benchmark, aircraft operators would receive a share of the total amount of allowances in proportion to their share in total output, i.e.:

$$AA_n = AA_{TOT} \times \left(\frac{RTK_n}{RTK_{TOT}} \right)$$

Where:

AA_n = aviation allowances allocated freely to airline *n*

AA_{TOT} = aviation allowances allocated freely to all aircraft operators

$\underline{RTK_n}$ = Verified Revenue Tonne Kilometres produced by airline *n*

RTK_{TOT} = Verified Revenue Tonne Kilometres produced by all aircraft operators

3.3.2 Input-based benchmarks

The 'input' that aircraft operators provide is aircraft with certain characteristics that fly on certain routes. Input-based benchmarks can be based on several quantitative indicators of the input. For routes, mission distance is the most appropriate indicator. For the aircraft

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[5] Trade associations such as AEA and IATA report their members' transport performance in these or similar measures.

[6] The operating empty weight is defined as 'Weight of structure, powerplant, furnishing systems, unusable fuel and other unusable propulsion agents, and other items of equipment that are considered an integral part of a particular airplane configuration. Also included are certain standard items, personnel, equipment, and supplies necessary for full operations, excluding usable fuel and payload' (747-400/-400ER Document D6-58326-1 (Revision D, December 2002), Boeing website).

characteristics, several indicators can be used to quantify the amount of input provided. Among the indicators that aircraft manufacturers report, the following could be suitable[7]:

- **Maximum Design Take-off Weight (MTOW)**. Maximum weight for take-off as limited by aircraft strength and airworthiness requirements. (This is the maximum weight at start of the take-off run.)
- **Maximum Design Zero Fuel Weight (MZFW)**. Maximum weight allowed before usable fuel and other specified usable agents must be loaded in defined sections of the aircraft as limited by strength and airworthiness requirements.
- **Operating Empty Weight (OEW)**. Weight of structure, powerplant, furnishing systems, unusable fuel and other unusable propulsion agents, and other items of equipment that are considered an integral part of a particular airplane configuration. Also included are certain standard items, personnel, equipment, and supplies necessary for full operations, excluding usable fuel and payload.
- **Maximum Payload**. Maximum design zero fuel weight minus operational empty weight, i.e. the maximum amount of payload a fully equipped aircraft can carry.
- **Maximum Seating Capacity**. The maximum number of passengers specifically certificated or anticipated for certification.
- **Maximum Cargo Volume**. The maximum space available for cargo.
- **Usable Fuel**. Fuel available for aircraft propulsion.

Any of these characteristics could be used for a benchmark. Maximum Payload is a good measure of capacity of the aircraft that is available for both passenger and freight aircraft and does not depend much on the actual seating configuration of the aircraft. The latter is also true of Maximum Take Off Weight (MTOW), but this is arguably a cruder measure of capacity.

A commonly used metric for input in the aviation sector currently is Available Seat Kilometres (ASK) or Available Tonne Kilometres (ATK). The former can be defined in two ways:

- As Maximum Seating Capacity Kilometres (MSCK), based on aircraft manufacturer characteristics. This means that the number of seats available would be constant for a certain aircraft, and would not depend on the actual number of seats in the aircraft.
- As Actual Seat Kilometres (AASK), based on the actual number of seats in the aircraft. Since airlines may change the number of seats in an aircraft due to changing market conditions (e.g. putting in more seats in the summer season), and have different seating lay-outs of the same aircraft to match demand on specific routes, this would mean that the AASKs would have to be calculated for every flight.

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[7] See for example Boeing (2005), 737/BBJ Document D6-58325-6 (NEW, Oct 2005)

Such metrics would be inapplicable to freighter aircraft, so in order to apply the benchmark metric to both passenger and freighter aircraft, one could express the available seats in tonnes by applying the equivalence factor and use maximum payload for freighters. In that way, both metrics would be expressed in tonnes. One could then label the benchmark indicators as ATK indicators. Alternatively, one could use maximum payload directly as a parameter for both passenger and freighter aircraft. Or, as has been suggested, one could use the maximum take-off weight as a parameter.

The following capacity-based benchmarks, each of which has been suggested as an alternative, were selected for further analysis:

1. Maximum Payload Kilometres (MPK)
2. Maximum Take-Off Weight Kilometres (MTOWK)
3. Available Tonne Kilometres based on Maximum Seating Capacity Kilometres (MSCK)
4. Available Tonne Kilometres based on Available Seat Kilometres (AASK)

(A large number of other parameters are conceivable, such as floor space kilometres, but these do not seem suitable for a benchmark for which data collection has to start in January 2008, as ‘floor space’ of an aircraft is not clearly defined, let alone certified.)

In all these cases, when emission allowances are allocated according to an input-based benchmark, aircraft operators would receive a share of the total amount of allowances in proportion to their share in total input, i.e.:

$$AA_n = AA_{TOT} \times \left(\frac{MPK_n}{MPK_{TOT}} \right)$$

Where:

AA_n = aviation allowances allocated freely to airline n
AA_{TOT} = aviation allowances allocated freely to all aircraft operators
MPK_n = Verified Maximum Payload Kilometres produced by airline n
MPK_{TOT} = Verified Maximum Payload Kilometres produced by all aircraft operators

The same formula has been used to calculate other input based benchmarks. In doing so, MPK has been substituted by MTOWK, ATK/MSCK and ATK/ASK respectively.

3.3.3 Technology-based benchmarks

A technology-based benchmark would have the advantage that operators of the most fuel-efficient aircraft would be rewarded for their early (prior) action than if another benchmark had been used. Of course, under any benchmark that is not related to historical CO_2 emissions, operators of the most fuel-efficient aircraft would already be rewarded since they would face a smaller shortfall of allowances compared to other, less efficient operators on the same routes.

The design of a technology-based benchmark is not straightforward. The most important obstacle is that aircraft technology depends on capacity and range. Aircraft are optimised for operations on certain ranges and have optimal fuel efficiencies on these ranges. Larger aircraft have better fuel efficiencies per available amount of payload but it would be inefficient to operate large aircraft on routes with little demand, as the amount of fuel consumed per RTK would increase.

Two types of technology-based benchmarks were envisaged. Both assume the average fleet age of an aircraft as a proxy for technology, based on the crude assumption that modern aircraft represent the best available technology and disregarding differences in routes and capacities.

The first benchmark, suggested by a major airline and a Member State, would also take the average fleet age of an aircraft as a proxy for technology. In contrast to the first benchmark, it would not apply the technology factor to an input parameter but rather to historical emissions, i.e.:

$$AA_n = AA_h\left(1+\left(FA_n - FA_{av}\right)\times AF\right)$$

Where:

AA_n = aviation allowances allocated freely to airline n in the trading period
AA_h = emissions of operator n in the base year
FA_{av} = average fleet age of all airlines
FA_n = fleet age of airline n
AF = Age Factor (technology scaling factor)

Two values for the age factor have been proposed; one was put forward by a major airline as around 1% per annum and the other by a Member State working document as around 1.5% per annum.[8]

In subsequent trading periods, the base year can be updated and multiplied by a factor relating total emissions in the new base year to total emissions in the former base year.

A second benchmark could account for route networks. Best available technology could be defined in terms of CO_2 emitted per MPK on each route. Such a benchmark would be determined in four steps:

1. For different flight lengths, the most fuel efficient aircraft in terms of fuel use per MPK would be determined;
2. For each airline, the share of flights of a certain length in their network would be determined;

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[8] Working Document 5154/07 ENV 7 AVIATION 15 MI 7 IND 3 ENER 8 CODEC 11 (Article 3d paragraph 3 and Annexes IV and V)

3. For each airline, emissions would be calculated under the assumption that they use the best available technology in their network;
4. Airlines would be allocated allowances for a fixed share of these emissions. The share is calculated as the aviation cap (2004–2006 emissions), divided by the calculated aviation emissions, assuming the use of the best available technology

The benchmark is defined as:

$$AA_n = AA_{TOT} \times \left(\frac{\sum_{r=1}^{R} \left(MPK_r \times CO_{2,BAT(r)} \right)}{\sum_{n=1}^{N} \sum_{r=1}^{R} \left(MPK_{n,r} \times CO_{2,BAT(r)} \right)} \right)$$

Where:

AA_n = aviation allowances allocated freely to airline n

AA_{TOT} = aviation allowances allocated freely to all aircraft operators

$MPK_{n,r}$ = Maximum Payload Kilometres of airline n in distance band r

$CO_{2,BAT(r)}$ = CO_2 emissions per MPK on route r assuming BAT

N = total number of airlines in ETS

R = total number of flight distance bands

It was concluded that this second technology benchmark would be difficult to implement in regulation because of the complexity of the data required. Therefore, this report concentrates on the first technology benchmark.

3.3.4 Summary of benchmarking methods used for further analysis

This study analyses the impacts of the following nine benchmarks

- Three benchmarks based upon Revenue Tonne Kilometres with assumed passenger weights of 100 kg, 125 kg and 150 kg, respectively.
- One benchmark based on Maximum Payload Kilometres (MPK), defined as Maximum design zero fuel weight minus operational empty weight.
- One benchmark based on Maximum Take-Off Weight Kilometres (MTOWK).
- Two benchmarks based upon Available Tonne Kilometres (ATK): ATK defined as Maximum Seating Capacity Kilometres (MSCK) for passenger aircraft and MSCK-equivalent for the freighter versions of the aircraft; and ATK defined as Max Payload Kilometres for freighters and actual Available Seat Kilometres (ASK) for passenger aircraft.
- Two technology based benchmarks: each multiplying actual historical emissions by an age factor, where the age factor is either 1% per annum or 2.5% per annum, respectively.

4 Results – impacts of different benchmarks

4.1 Introduction

This chapter presents two sets of results of the spreadsheet calculations. Section 4.2 presents the results in a static situation, assuming that relative sizes of the generic airlines remain constant over time. Section 4.3 presents the results of a dynamic situation, in which generic airline types have differential growth rates. The results of the dynamic situation differ from the static results, but they are of course dependent on the growth assumptions used.

4.2 Static distributional impacts

This section presents the relative over-allocation and shortfall of generic airline types assuming that the free allowances would be allocated on benchmarks calculated on 2006 UK data. Relative over-allocation is defined as receiving a larger number of allowances per unit of emissions than the industry average. Put differently, the results are represented as if the cap was set at the level of actual emissions. Note that this was done just because it makes it easier to identify which airline types win and which lose, not because is was assumed that the cap would be equal to business as usual emission. A relative shortfall implies that the generic airline receives fewer allowances per unit of emissions than the industry average. Table 5 presents the main results, in which positive numbers equate to over-allocation and negative to under-allocation, relative to the mean.

Table 5: Relative over-allocation and shortfall of generic airline types – static situation

Carrier type	**RTK100**	**RTK150**	**MPK**	**MTOWK**	**ATK/MSCK**	**ATK/ASK**	**AF2.5%**	**AF1%**
Large Network Carrier A	3%	1%	4%	9%	1%	-4%	-4%	-1%
Large Network Carrier B	-2%	-2%	-3%	2%	-3%	-2%	-4%	-1%
Mid-sized Network Carrier A	2%	1%	7%	3%	9%	-1%	4%	1%
Mid-sized Network Carrier B	-2%	-2%	-2%	-2%	0%	2%	4%	1%
Low-cost Carrier A	-9%	-4%	-24%	-45%	-6%	7%	11%	4%
Low-cost Carrier B	-7%	-2%	-8%	-34%	9%	25%	11%	4%
Large US based network carrier	13%	9%	21%	23%	6%	-4%	-11%	-4%
Large Far East based network carrier	1%	-1%	0%	26%	-10%	-12%	4%	1%
Regional airline	-33%	-28%	-31%	-53%	-13%	-7%	-11%	-4%
Freight Airline	-1%	-26%	-13%	-5%	-4%	33%	-23%	-9%

If aviation as a whole faces a shortfall of allowances (i.e. emits more CO_2 than it receives allowances) even airlines that are *relatively* well off may face an *absolute* shortfall. In the same way, in the unlikely case that aviation as a whole would be over-allocated, even airlines with a relative shortfall could face an absolute over-allocation.

4.2.1 Summary of the results for generic airline types

Low-cost carriers

In general, low-cost carriers were more sensitive to choice of benchmark than were network carriers. Looking at the different categories of benchmark in turn: under input-based benchmarks that are not based on the actual number of seats, low-cost carriers are under-allocated. Yet age factor benchmarks are favourable as low-cost carriers currently tend to have relatively young fleets.

In terms of output-based benchmarks, given that low-cost carriers tend to have high load factors and therefore an efficient output, it might be expected that they would be over-allocated. However, this is not the case (see Table 5) as two counteracting factors are in operation. Firstly, low-cost carriers have higher passenger load factors on their networks and higher overall load factors than network carriers on short and medium haul routes. However, network carriers have high overall load factors (including freight) on their long haul routes that are comparable with those of low-cost carriers. Second, long haul flights are much more fuel-efficient in terms of overall fuel per passenger km or payload km than short haul flights for a number of reasons (larger aircraft, a smaller share of landing and take-off in the total flight). Low-cost carriers do not currently operate long haul routes unlike network carriers (although there are indications that such a low-cost market is developing), so this works in favour of the network carriers. When these two counteracting factors are combined, the result is that network carriers have slightly fewer CO_2 emissions per RTK than low-cost carriers.

It should be noted that this result depends on the geographical scope of the system. In an intra-EU scheme, the low-cost carriers would be comparatively better off than the network carriers under output-based benchmarks since the beneficial effect of long-haul flights of network carriers would be absent. In an all-departing scheme, the differences between network carriers and low-cost carriers would be smaller, but the benchmark would still work in favour of the network carriers in this calculation model.

Network carriers

Table 5 indicates that network carriers are less affected by the choice of the benchmark than other types of airlines. Although network carriers are relatively over-allocated under some benchmarks (and face a shortfall under others), the over-allocations and shortfalls are smaller than the relative over-allocations and shortfalls of other generic airline types. The reason for this is that network carriers dominate both input and output based benchmarks (because of their long haul flights, they dominate the number of revenue tonne kilometres or available tonne kilometres generated by aviation from, to and within Europe). So in fact, the benchmark is for a large part set by the network carriers.

Non-EU network carriers

Non-EU network carriers from the US fare well under most benchmarks. This is principally because they only have long haul flights in the scheme (which are more fuel-efficient than short haul flights). Moreover, the US carriers (as modelled here) have an efficient fleet, comprising Boeing B767-300ER and Boeing B777-200ER aircraft, which produce fewer emissions per passenger kilometre or payload kilometre than the Boeing B747-400. This explains their relative over-allocation under the MPK and MTOWK benchmarks, since they fly only intercontinental flights in the ETS and their load factors are high, these characteristics also explain their relative over-allocation under the RTK benchmarks. Since the modelled generic airlines have relatively low seating capacities and an older average fleet age, they are less well off under ATK and technology based benchmarks. It should be noted, however, that these sorts of carriers have relatively few flights under the scheme, and operate only two aircraft types on one route in the spreadsheet model. As a result, the outcomes for these carriers are much more affected by modelling assumptions than the outcomes for most other airline types.

Non-EU network carriers from the Far East fare less well than their North American counterparts. Again, because these carriers only have few flights under the scheme, it should be noted that the outcomes are more dependent on modelling assumptions than the outcomes for most other generic airline types. The difference between the Far Eastern carriers and the North American carriers can be explained by the dominance of Boeing B747-400s in the Far Eastern fleets. These aircraft emit more per passenger or payload kilometre, which explains the lower average over-allocation: they emit more, so they need more allowances to cover their emissions. Furthermore, the Boeing B747-400 stands out for having a relatively high MTOW per unit of payload or passenger. As a result, the Far Eastern airlines fared much better under the MTOWK benchmark than under other input-based benchmarks.

Regional carriers

Regional carriers face a relatively large shortfall under all benchmarks. This is partly because in the UK, regional airlines have a large number of very short haul flights (0–400 km), which are relatively fuel- inefficient. In other EU Member States, regional airlines may fly greater distances, resembling medium haul routes (e.g. the Portuguese mainland to the Azores or Spanish mainland to the Canary Islands) with different aircraft types to those modelled. Some of these more typical European, regional airlines may resemble small network carriers instead of the UK-type regional airlines. Furthermore, since regional airlines operate only on two route distances in the calculation model and operate only four aircraft types, the findings are more sensitive to assumptions about the fleet than is the case for other generic airline types. However, it should be noted that carriers with a large share of short haul flights are disadvantaged under both input- and output based benchmarks.

Freighter carriers

Freighter-airlines are also under-allocated in almost all cases. One of the main reasons for this is that they typically operate old and relatively inefficient fleets. Moreover, most airfreight in the UK is carried over small distances, either within the country (48% of all cargo flights in 2006 had an average sector distance of 332 km) or to freight hub-airports in Europe, of which there are almost none in the UK (33% of all flights in 2006 had an average sector distance of 619 km). Since this study is based upon UK data, the generic freight airline is consistent with this predominantly short-haul network. If the study had been based on EU-wide data, it is possible that long haul freight would constitute a larger proportion of total flights of the generic freight airline, as it would also include flights from the freight hubs to other continents. Consequently, its shortfall of emissions would have been much smaller. Another reason for the under-allocation of freighter airlines could be that their actual load factor is higher than the load factor assumed in these calculations (68%). In contrast to passenger airlines, no reliable data could be found on load factors of freighter carriers.

4.2.2 Summary of the benchmark results

The results presented in Table 4 show that different benchmarks have different distributional impacts on different generic airline models. As can be seen, some airlines do better under some benchmarks than others and some benchmarks create larger gains and losses than others across the industry.

The smallest average gains and losses were produced by the RTK150 and the AF1.0 benchmarks. Apart from the regional airline and the freight-only airline, which are probably primarily representative of these airline types in the UK, these benchmarks create the smallest average gains and losses. In the case of the AF1.0 benchmark, this is hardly surprising, as this benchmark so closely resembles grandfathering (in effect, the closer the age factor is to 0%, the more the benchmark becomes identical to grandfathering).

The largest distributional impacts were created by the input benchmarks, MPK and the MTOWK. The remaining benchmarks are somewhere in between. Of these, the RTK100 and ATK/MSCK have the least distributive impacts and ATK/ASK and AF2.5 have slightly greater distributive impacts.

4.2.3 A closer look at RTK benchmarks

Passenger mass

As noted in section 3.3.1, there are good reasons for calculating RTKs based upon a mass assigned to passengers of being more than the *de facto* standard of 100 kg. This is because passengers require a number of items (toilets, catering, overhead-bins, seats, windows, etc.) that result in additional mass and as a result, passenger aircraft are heavier than equivalent freighters. This section compares the different distributional impacts of RTK benchmarks with assigned passenger masses of 100 kg, 125 kg, and 150 kg respectively.

Table 6: Relative over-allocation and shortfall under different RTK benchmarks – the static situation

Carrier type	RTK100	RTK125	RTK150
Large Network Carrier A	3%	2%	1%
Large Network Carrier B	-2%	-2%	-2%
Mid-sized Network Carrier A	2%	1%	1%
Mid-sized Network Carrier B	-2%	-2%	-2%
Low-cost Carrier A	-9%	-6%	-4%
Low-cost Carrier B	-7%	-4%	-2%
Large US based network carrier	13%	11%	9%
Large Far East based network carrier	1%	0%	-1%
Regional airline	-33%	-30%	-28%
Freight Airline	-1%	-15%	-26%

The relative over- and under-allocations under different RTK benchmarks given in Table 6 demonstrate that the distributive impacts are smaller when greater passenger weights are assumed.[9] This is true for all generic airline types other than the large network carrier based in the Far East and the freight airline. However, it should be remembered that this airline type is based upon UK data only and on arbitrary assumptions about load factor. A freight airline with more long haul flights or with a higher load factor would see its over-allocation reduced with increasing assumed passenger weights.

The analysis of different passenger mass could be extended to other benchmarks, such as ATK. This was, however, out of the scope of this report and it is not immediately clear how it would affect the distributional impacts of ATK benchmarks.

Great circle distance vs. actual flight distance

As mentioned previously, short haul flights are generally less fuel-efficient than long haul flights, because, for example, of the higher passenger capacity of long haul flights and also, they spend a higher fraction of the flight time in the cruise phase (the landing/take-off phase and climb out use relatively more fuel per km). This is one of the causes of the relatively large shortfall for UK regional airlines under almost any benchmark. Furthermore, as noted in section 5.2, actual distances flown are greater than the corresponding great circle distances due primarily to airspace restrictions or stacking at airports. To ensure that the benchmark is more representative of real life scenarios, a constant could be added to the great circle

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[9] For some generic airline types, gains and losses are reduced more than for others. This is because some aircraft have higher freight capacities. The calculation model assumes that the overall load factor on long haul flights is between 60% and 65% (based on a passenger weight of 100 kg). As a result, some long haul aircraft carry more freight than others do, and since different passenger weights do not influence freight, the impacts of different passenger weights are different.

distance when calculating the benchmark. This section explores the sensitivities of adding two constant distances, i.e. RT(K+100 km) and RT(K+200 km).

Table 7 gives the relative over allocation and shortfall of the different generic airline types under an RTK150 benchmark and RT(K+100) and RT(K+200). In all cases, the assumed mass of a passenger was taken to be 150 kg.

Table 7: Relative over-allocation and shortfall under different RTK benchmarks – the static situation

Carrier type	RTK150	RT(K+100)	RT(K+200)
Large Network Carrier A	1%	0%	-1%
Large Network Carrier B	-2%	-3%	-4%
Mid-sized Network Carrier A	1%	0%	0%
Mid-sized Network Carrier B	-2%	-2%	-3%
Low-cost Carrier A	-4%	5%	13%
Low-cost Carrier B	-2%	0%	1%
Large US based network carrier	9%	6%	3%
Large Far East based network carrier	-1%	-5%	-8%
Regional airline	-28%	-13%	1%
Freight Airline	-26%	-25%	-24%

As can be seen in Table 7, regional airlines (UK-type) benefit the most from adding a constant distance onto the great circle distance. Their relative shortfall decreases from -28% to -13% for RT(K+100), and even yields a small over-allocation for RT(K+200). The reason for this is that UK regional airlines fly exclusively on routes of only 250 km and 550 km, such that an extra 100 km or 200 km is a large proportionate increase. This is a larger fraction than would be the case for a large network carrier which generates over 70% of its RTKs on routes longer of 5500 and 9500 km. Low-cost carriers with a significant amount of short haul routes also benefit substantially. Freight airlines do not benefit as much as regional airlines, reflecting the fact that they have long haul flights. It can be concluded that the relative shortfall of freighter airlines is caused primarily by their arbitrary load factor and their relatively fuel-inefficient fleet.

For carriers that exclusively fly long haul routes in the scheme, adding a constant to the great circle distance increases their shortfall or decreases their over-allocation; i.e. they are worse off relative to the mean (but not in absolute terms).. This is because for them, adding a constant 100 or 200 km does not substantially alter their amount of RTKs, whereas for most other airlines, the amount of RTKs is increased.

Again, this analysis could be extended to input based benchmarks. Like in the case of output-based benchmarks, it would result in airlines with a larger proportion of short haul flights being relatively better off.

Whilst the distributional effects of the RT(K+100) and RT(K+200) have been described above, the choice of the constant has not been justified, except on a qualitative basis. Appendix II sets out the justification based on evidence for the use of 100 km constant based on an analysis of 5000 flights covering the range of distances studied here. The results show that the mean constant for all flight lengths over the great circle distance was 106 km. We can conclude therefore, that a constant of 200 km cannot be justified, overestimating the actual situation by a factor of two.

4.3 Dynamic distributional impacts

The results in Section 4.2 are based on 2006 UK flight movement data and assume a static situation with regard to the relative sizes of airlines. In other words, allowances are allocated as if the cap is set in 2006, the benchmark is calculated in 2006 and emissions are generated in 2006. The Commission Proposal differs from this in three respects:

1. a cap will be set for all aviation allowances on the basis of average 2004-2006 emissions; this cap will be constant even when emissions rise;
2. the benchmark will be first calculated in 2008 and subsequently in 2010 and every five years after that;
3. allowances will be distributed on the basis of the benchmark in the period two to seven years after the calculation of the benchmark.

The first item above will affect, in principle, all airline types in the same way. Aviation as a whole will face a shortfall in allowances if its emissions continue to grow, as is expected. This means that the total amount of allowances to be freely allocated will only cover a part of the total allowances required (see Figure 3). As such, this will not affect the distributional impacts for the different airlines; it will only affect the average shortfall or over-allocation. Since this work focuses on the distributional impacts, and the calculation tool was developed to analyse them, it does not address aspects of whether a general shortfall or over-allocation occurs.

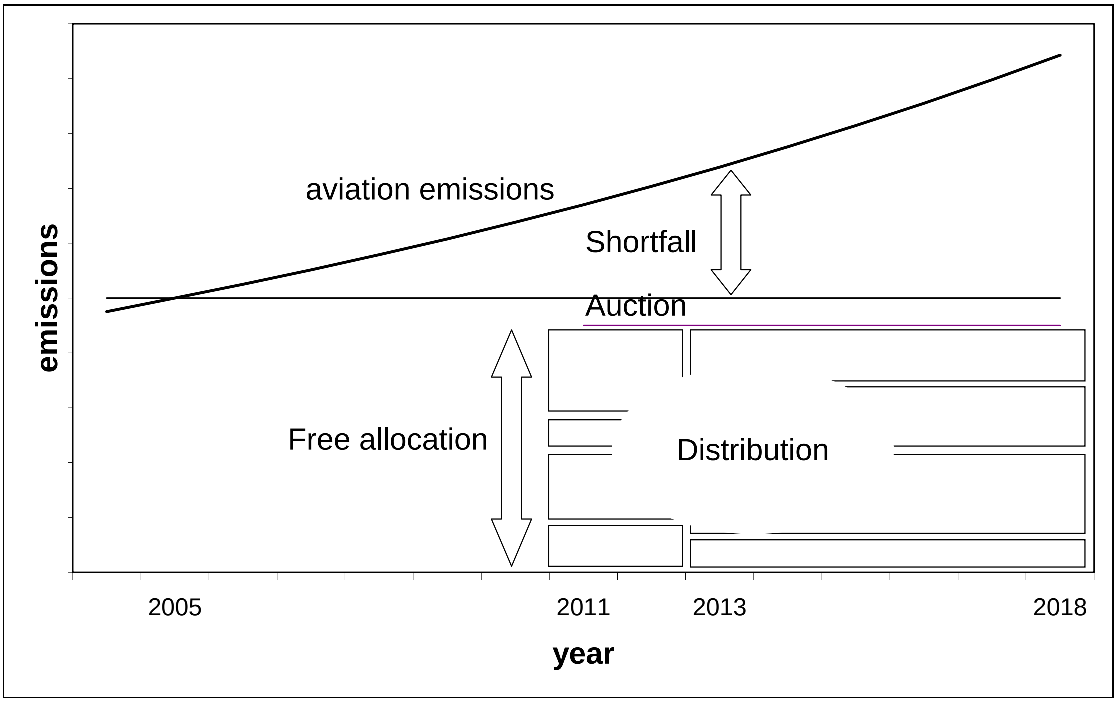

Figure 3: Average shortfall and distribution of free allowances under ETS

The second item in the list above may change the results of the calculations presented here. The situation in 2008 or 2010 will differ from the situation in 2006. Between 2006 and 2008 or 2010, some airline types may grow faster than others do and this will have an impact on the benchmark. This section explores how differential growth rates of airline types may affect the results.

A dynamic analysis differs from the static one by taking into account differential growth rates between 2006 and the year of the calculation of the benchmark. This section forecasts the 2008 situation based on differential growth rates of generic airline types. Analysis of UK CAA data for 2004 and 2006 shows that regional airlines and low-cost carriers have increased their number of flights and passengers considerably over the past two years. By contrast, large network carriers have experienced much smaller growth, while medium sized network carriers have experienced a reduction of flights and passengers to and from the UK (see Table 8).

Table 8: Average annual growth rates of generic airline types in UK aviation, 2004 – 2006

Carrier type	**Flight growth rates**	**Passenger growth rates**
Large EU-based network carriers	0.1%	1.7%
Medium sized EU-based network carriers	-1.6%	-3.1%
Low-cost carriers	10.7%	10.8%
Non EU large network carriers	6.4%	5.4%
Regional airlines	8.4%	15.2%
Freighter airlines	-4.4%	-
Total	3.6%	4.4%

Source: UK CAA

If recent rates of growth continue in 2007 and 2008, the changes would not lead to substantially different outcomes of the calculations. The average difference would be 0.1% and the maximum difference for any airline type under any benchmark would be 1.1%. Both figures are within the range of confidence of the results presented here (see section 5.1.2).

The third item, differential growth of different airline types *after* the calculation of the benchmark, will only affect the airlines considered. They will face a larger shortfall if their emissions grow faster but this change will not affect the allocation of allowances to either the faster growing airline or the other airline types. Furthermore, the relative shortfall that a faster growing airline might face would only be temporary: as soon as the benchmark is updated, the distribution of allowances would be calibrated to the new situation.

If it would be preferable to calculate the benchmark using data from a period as close as possible to the start of the phase in which the benchmark will be used to allocate allowances. Furthermore, fast growing airlines would favour a more frequent calculation of the benchmark (e.g. every year or every two years instead of every five years). A more frequent calculation would decrease the distributional impacts between fast growing and slower growing airlines but it would come at a price: it could increase the administrative burden and could also lower the economic efficiency of the scheme (see CE Delft, 2007).

4.4 Rewarding early action

One of the main reasons for using a benchmark to allocate is that it could reward early action, as opposed to grandfathering based on historical emissions, which would reward operators with relatively high emissions.

In the aviation sector, there seems to be different opinions on what constitutes ‘early action’. Here, three definitions are provided, which may interact, but will be considered separately for analytical purposes:

- *Early action defined as the improvement of load factors*. Improving the load factor, i.e. transporting more people and/or cargo on the same aircraft, increases the fuel efficiency and decreases CO_2 emissions per amount of transport work.
- *Early action defined as fleet optimisation*. Optimising a fleet is defined as using only the most fuel-efficient aircraft on each route. If a fleet has been optimised before setting the benchmark, this would constitute early action. (Please note that fleet optimisation is not the same as fleet renewal; see Section 4.4.2 on the assumption that new aircraft are more efficient than older ones).
- *Early action defined as operational measures to reduce emissions*. Aircraft operators can take a wide range of operational measures to reduce emissions. For example, some airlines have recently introduced more regular engine

washes, by which they claim to reduce fuel use by an average of 1%. Other airlines have optimised catering to reduce the weight of food and drinks taken on board, thereby reducing fuel use. Other operational measures include taxiing with one engine shut off, training pilots and rewarding them for flying efficiently, et cetera. If such actions are taken before the benchmark, they would constitute early action.

In the remainder of this section, results are presented that contrast the situation where one operator has taken early action and others have not.

4.4.1 Improvement of load factors

An improvement in load factors prior to the calculation of the benchmark is rewarded under the RTK benchmarks. This is not surprising as higher load factors result in better RTK performance. Equally unsurprising is the finding that an improvement in load factors is penalised under the input-based benchmarks. These latter benchmarks do not depend on the amount of passengers or cargo transported but the CO_2 emissions increase as the aircraft carry more load. As a result, any shortfall of allowances increases and over-allocations decrease.

Table 9 gives the differences in allocation between several generic airline types and their counterparts that have increased their passenger load factor prior to the calculation of the benchmark by 5% (i.e. there would be a higher allocation of around 3 to 4% with a 5% increase in load factor if other airlines' actions remained constant). The airlines that have improved their load factor are indicated by ‘LF+’.

Table 9: Impact of increased load factors on allocation

	RTK100	**RTK150**	**MPK**	**MTOWK**	**ATK/MSCK**	**ATK/ASK**	**AF2.5%**	**AF1%**
LNA	3%	1%	4%	9%	1%	-4%	-4%	-1%
LNA LF+	6%	4%	3%	9%	0%	-5%	-4%	-1%
LNB	-2%	-2%	-3%	2%	-3%	-2%	-4%	-1%
LNB LF+	1%	1%	-4%	2%	-4%	-2%	-4%	-1%
MNB	-2%	-2%	-2%	-2%	0%	2%	4%	1%
MNB LF+	1%	2%	-2%	-2%	-1%	1%	4%	1%
LCCA	-9%	-4%	-24%	-45%	-6%	7%	11%	4%
LCCA LF+	-5%	0%	-25%	-46%	-7%	6%	11%	4%

The percentage changes presented in Table 9 show that airlines are rewarded for improving their load factors under output-based benchmarks. On average, an improvement of the load factor by 5% yields a 3% higher free allocation.

By contrast, under input-based benchmarks, airlines that improve their load factor are slightly penalised. The reason is that they use more fuel to carry a larger number of passengers on the same number of flights (the heavier an aircraft, the more fuel it needs to fly a certain mission). The amount of extra emissions is small, but since the number of ATKs, MPKs or MTOWKs stays the same, the extra emissions are not compensated for by extra allowances. On average, the penalty for a load factor improvement of 5% is an extra 1% shortfall or a 1% lower over-allocation.

4.4.2 Fleet optimisation

Fleet optimisation has been modelled as operation of the most fuel-efficient aircraft (in terms of kg CO_2 emitted per kg payload) on every route. This appears not to be the same as the introduction of the newest aircraft (in terms of first year in service) on every route. Table 10 gives the fuel efficiency of different aircraft types on different routes.

Table 10: Fuel efficiency of selected aircraft types

Route length (km)	**Aircraft type**	**First year in service**	**Fuel efficiency (g CO_2/kg payload, at 70% load factor)**
250	Boeing 737-800	1997	298
	Boeing 737-700	1997	325
	Airbus A321	1993	339
	Airbus A319	1995	340
550	Boeing 737-800	1997	507
	Boeing 737-700	1997	-
	Boeing 757-200	1982	522
	Airbus A321	1993	524
1500	Airbus A321	1993	1081
	Boeing 757-200	1982	1084
	Airbus A320-100/200	1988	1094
2900	Boeing 767-300ER	1986	1728
	Airbus A340-600	2001	1771
	Airbus A330-300	1992	1781
5500	Boeing 767-300ER	1986	3270
	Airbus A330-300	1992	3306
	Airbus A340-600	2001	3346
9500	Airbus A340-600	2001	6074
	Boeing 777-200ER	2005	6472

Note: On the 250 km mission distance, only jets have been included in the comparison

The effect of fleet optimisation is less straightforward than improving load factors. Replacing one aircraft with another often involves changing the capacity offered on a certain route, since new aircraft seldom have exactly the same capacity as older ones. When mimicking airlines with an updated fleet, it has been assumed that the passenger capacity on each route should remain constant. Therefore, on long haul flights, this meant increasing the frequency, as possible alternatives to the Boeing B747-400 have fewer seats. On short and medium haul fleets, the frequency was sometimes reduced as larger aircraft such as the B737-300 and A319 were replaced with the B737-800 and A321.

It should be noted that fleet optimisation is not identical to operating a younger fleet. The most efficient aircraft on a certain route is not always the newest aircraft. Rather, fleet optimisation here is taken to be only flying the most efficient aircraft on the network defined. Still, by updating the fleet, it was assumed that the average fleet age was reduced by 4 years for network carriers and 3 years for low-cost carriers.

Table 11 gives a comparison of the outcomes for the generic airline types and their competitors with an optimised fleet. The airlines with an optimised fleet are indicated by 'FU'.

Table 11: Impact of fleet optimisation on allocation

	RTK100	**RTK150**	**MPK**	**MTOWK**	**ATK/MSCK**	**ATK/ASK**
LNA	3%	1%	4%	9%	1%	-4%
LNA FU	32%	24%	-1%	-11%	11%	10%
LNB	-2%	-2%	-3%	2%	-3%	-2%
LNB FU	7%	7%	10%	5%	5%	5%
MNB	-2%	-2%	-2%	-2%	0%	2%
MNB FU	4%	4%	9%	2%	6%	6%
LCCA	-9%	-4%	-24%	-45%	-6%	7%
LCCA FU	-4%	1%	-15%	-34%	-1%	12%

The comparisons show that optimising the fleet is rewarded under most benchmarks (Table 11) since fewer emissions are produced. Only the MPK and MTOWK benchmarks show mixed results, because more efficient aircraft do not always have lower emissions per MPK or MTOWK, even though they have lower emissions per ATK.

Note that table 11 has no information on fleet age factor. The reason is that a more fuel-efficient is not always a younger fleet. Thus, it is impossible to assess what optimising a fleet would do to an airline’s average fleet age. In some cases, the fleet age could actually increase, resulting in a penalty for early action. Admittedly, this would probably be an exception rather than the rule.

4.4.3 Operational measures to reduce emissions

Airlines can take a large number of operational measures to reduce fuel emissions, such as improved maintenance, optimising catering facilities, flight-crew training, continuous descent approach, etc. (see e.g. ICAO circular 303). These measures have been categorised as 'early action'. Emissions are reduced but since they do not affect transport performance or fleet age, they do not affect allocation in the case of either output- or input-based benchmarks. So on the balance, operational measures are rewarded under input- and output-based benchmarks, as the shortfall decreases or the over-allocation increases, In fleet age benchmarks, however, operational measures to reduce emissions are not rewarded. These measures do not affect the fleet age, but they reduce historical emissions, thereby reducing the amount of allowances allocated to the airlines that have taken these measures.[10]

4.4.4 Conclusion

Table 12 summarises the rewards for early action under various types of benchmarks. All types of early action are rewarded under output-based benchmarks. Thus, under output-based benchmarks, airlines that have taken measures in either of these categories receive more allowances than airlines that have refrained from taking measures. Input-based benchmarks reward fleet optimisation and operational measures but slightly penalise load factor improvement. Under input-based benchmarks, airlines that have improved their load factor receive fewer allowances relative to their need but other measures are rewarded. Fleet age benchmarks reward fleet optimisation only and only insofar as aircraft efficiency is correlated with age.

Table 12: Reward for early action

	Output based	**Input based**	**Fleet age**
Load factor improvement	+	0 (-)	0
Fleet optimisation	+	+	+ (-)
Operational measures	+	+	0

Note: + rewarded, 0 not rewarded, - penalised

4.5 Concluding comments

If the purpose of using a benchmark is to reward early action, RTK benchmarks have a clear advantage over other types, as they reward all types of early action irrespective of the business model. Input-based benchmarks tend to reward fleet optimisation and operational measures but slightly penalise load factor improvement. Fleet-age benchmarks only reward fleet optimisation.

If the desired outcome is that a benchmark should have the least distributional impacts, fleet-age benchmarks stand out, since they resemble grandfathering. Output-based benchmarks

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[10] The spreadsheet model does not allow for a calculation of this effect. Therefore, we were not able to quantify this effect.

seem to have relatively small distributive impacts, whilst input-based benchmarks tend to create large gains or losses for different airlines.

5 Discussion

5.1 Validity of the results

5.1.1 Geographical scope of the flight data

The calculations presented in this report are based on data of flights to and from the UK. The situation in the EU as a whole may differ, which could result in a different outcome.

The UK CAA has provided comprehensive data of flights to and from the UK. However, it could be that the flight data for the whole EU may look somewhat different to the UK in terms of airline type, frequency of long haul versus short haul etc. For example, it may be expected that flight data for the whole EU contain relatively fewer intra-EU flights. This is most easily explained using an example. In the case that there are two large network carriers, one based at Heathrow, the other based at Frankfurt, both perform intra-EU flights as well as intercontinental flights. Flight data for the whole EU would list the intra-EU and the intercontinental flights of both the Heathrow-based and the Frankfurt-based carrier. The CAA data list the intra-EU and the intercontinental flights of the Heathrow-based carrier, as well as the Frankfurt-UK flights of the Frankfurt-based carrier but not its intercontinental flights. This would lead to an overrepresentation of intra-EU flights in the UK data compared with data for the whole EU. A brief quantitative analysis shows that for most airlines, halving the number of flights with mission distances of up to 2000 km would affect the over-allocation or shortfall by less than 2%. Larger impacts were found for the non-EU network carriers (-3% to -4%) and for the regional and freight-only airlines.

Another concern is that in the UK, most airfreight is carried over small distances, either within the UK (48% of all cargo flights in 2006 at an average sector distance of 332 km) or to airports in Europe (33% of all flights in 2006 with an average sector distance of 619 km). Since this study is based on UK data, the generic freight airline is consistent with this predominantly short-haul network. If the study had been based on EU-wide data, it is likely that long-haul freight would have had a larger share of flights of the freight airline and its shortfall of emissions would have been much smaller.

The generic regional airline is based on UK regional airlines. As the UK has a relatively large number of islands close to the mainland, UK regional airlines have a short-haul network, with two thirds of their flights in the 250 km distance band and one third of their flights in the 550 km distance band. Because UK regional airlines operate almost exclusively on these short distances, they face a large shortfall of emission allowances. It is expected that regional airlines from other EU countries would not face this problem to the same extent because they generally operate on longer distances than UK regional airlines. For example, some regional airlines in Portugal operate short-haul flights between the Azores but also medium haul flights between the Azores and mainland Portugal. These latter flights would generate fewer emissions per RTK and thus reduce the shortfall. Furthermore, the differences between regional airlines are large and the precise impacts that a benchmark would have on a regional carrier depends largely on the specific characteristics of that carrier.

5.1.2 Sensitivities of the spreadsheet model

In order to test the model's sensitivity to changes in the assumptions, a number of tests were undertaken. These tests involved assigning different fleets to carriers, changing the relative size of carriers and changing carriers' route networks. The tests show that most changes in assumptions result in changes in the order of 2% as a maximum. However, some assumptions were found to affect the outcomes more substantially.

Firstly, introducing substantial changes in the route network (deleting one distance and spreading the flights on that distance over all other distances or over adjacent distances) led to substantial changes in the outcomes for all benchmarks, with the exception of the age factor. However, the route network – although parameterised – is based upon empirical data, so testing this represents a rather extreme variation in the input data.

Secondly, substantial changes in the number of flights or passengers of large network carriers or low-cost carriers affected the MTOWK benchmark. In general, MTOWK benchmark results were more affected by changes in the assumptions than was the case for other benchmarks. This is because the fuel use per ton of MTOW decreases as the MTOW increases and larger aircraft (i.e. higher MTOW) tend to be used on longer distances. Combined with the fact that long-distance flights tend to have lower fuel use per km (more flying, relatively less take-off and landing), this causes the MTOWK benchmark to be disproportionately advantageous for long-distance flights. Therefore, the MTOWK benchmark is very sensitive to changes in route network. Because the large network carriers have very different route network characteristics to the low-cost carriers, substantially changing the size of either one leads to substantial changes in the overall route network of the model. This in turn affects the MTOWK benchmark more strongly than for any of the other benchmarks.

One assumption that could influence the result is the load factor of the freighter airline. It was taken to be equal to the load factor of the network carriers (68%). However, there is little empirical data to corroborate this assumption. Whereas passenger airlines and their associations regularly publish load factor figures, only very few freighter airlines do.

Finally, changes in the composition of the long haul fleet, especially in the use of the B747-400, had a large impact on all benchmarks (except for age factor). This is because the differences between the aircraft used on the 9500 km missions with regard to number of seats, MTOW, max payload and fuel use, are relatively large. A single flight of 9500 km has a larger effect on benchmarks than one of 250 km, so that changing a carrier's long-haul fleet had a substantial impact on all benchmarks. Because of this sensitivity, close attention to the composition of the fleets of airlines was paid, in order to be sure that reasonable assumptions about the use of Boeing B747-400s were made.

5.1.3 Sensitivities of the emissions model

The emissions model, PIANO, has been sensitivity tested for its performance in terms of both load factor and cruise altitude selection methodology. In general, fuel consumption over a specific mission is more sensitive to load factor than cruise-height selection methodologies. Without showing specific data, the variation (in terms of the Coefficient of Variation statistic) for emission rates in terms of g CO_2/pkm for load factors varying between 50 and 100% was of the order 20-25%, whereas the variation (for a fixed load factor) between the three different cruise-height selection methodologies was of the order 3-5%. The drift-up optimisation procedure may not reflect some of the realities of air-traffic management constraints: however, by using the design optimisation, no bias in the modelling is introduced by selecting cruise altitudes. This represents 'optimal' performance.

In terms of the accuracy of the emissions model, this is harder to establish rigorously since aircraft performance data are proprietary to manufacturers. However, the PIANO model is widely used and accepted by the industry and individual validation exercises (e.g. Eyers *et al*., 2004) to have demonstrated good agreement for fuel flow between the limited available measured data and modelled data from PIANO.

5.2 The basis for a 'technology factor'

The benchmarks 'AF1%' and 'AF2.5%' were suggested by some stakeholders and are based upon the supposition that a 'technology factor' which accounts for year-on-year improvements in the fleet's fuel efficiency should be accounted for in formulating a benchmark.

The question that needs to be posed is whether there is evidence for such a historical fleet fuel efficiency that may be attributed to changes in technology, as is implicit in the age factor proposals. The figure of 1% per year, or thereabouts, appears to have its origin in the IPCC (1999) report '*Aviation and the Global Atmosphere*' (Chapter 9, Table 9-15, Henderson *et al*., 1999), where fuel efficiency trends implemented in the DTI scenario for 2050 were set out. However, underlying (and explicit) in the aforementioned table is the work of Greene (1992) that provides a fuel efficiency trend of 1.3% yr^{-1} for the period 1991 – 2000 and 2001 – 2010.

If the original work of Greene is studied, it is clear that this 'fuel efficiency trend' incorporated a number of factors applied and accounted for the performance of the global fleet as a whole. Greene's (1992) trends accounted for trends in evolutionary technology, introduction of more revolutionary technologies, fleet roll-over rate and changes in fleet (aircraft size) composition. In examining historical trends between 1970 and 1990, Greene found that the improvements came in two distinct ‘waves’ with different causes. The first ‘wave’ was the result of changes in technology from 1970 – 1980 from turbojet aircraft to first generation turbofans, along with improved load factor. The second ‘wave’ of improvements from 1980 – 1990 was more the result of increasing load factors and seat reconfiguration to higher densities for the same airframe types.

The load factor for Greene’s 1989 fleet was 62.3%, increasing to 65.8% in 2000 and 67% in 2010 (Greene, 1992). Also implicit in his projections was the introduction more revolutionary technologies such as the widespread uptake of unducted propfan engines, development of blended wing body aircraft and use of laminar flow control technology.

The above précis of Greene’s (1992) foundational work reveals that many factors underlie the global fleet improvements in fuel efficiency, including trends in technologies that have not as yet been introduced (e.g. unducted propfans) that would result in significant fuel savings, and importantly, changes in average aircraft size. Thus, applying a *technology only* fuel-efficiency trend of 1% per year and citing Greene’s (1992) work would be a misrepresentation of his work. In terms of a benchmark of ‘AF2%’, long-term historical annual improvements of 2% fuel efficiency are unprecedented unless load factor is taken into account.

The change in technological improvements may be examined using data produced by the PIANO model for different aircraft over time, where ‘time’ is represented by date of entry into commercial service. Improvements in technological efficiency in terms of CO_2/pkm were calculated for a range of aircraft, using an early turbojet, e.g. the Boeing 707, as a benchmark (as is commonly used by the industry) through to more recent second-generation turbofan aircraft. This was undertaken for a fixed load factor (70%) to remove this as a variable and for a variety of mission distances. The results are shown in Figure 4 in terms of absolute emissions and as a percentage relative to a reference aircraft (the Boeing 707) in Figure 5.

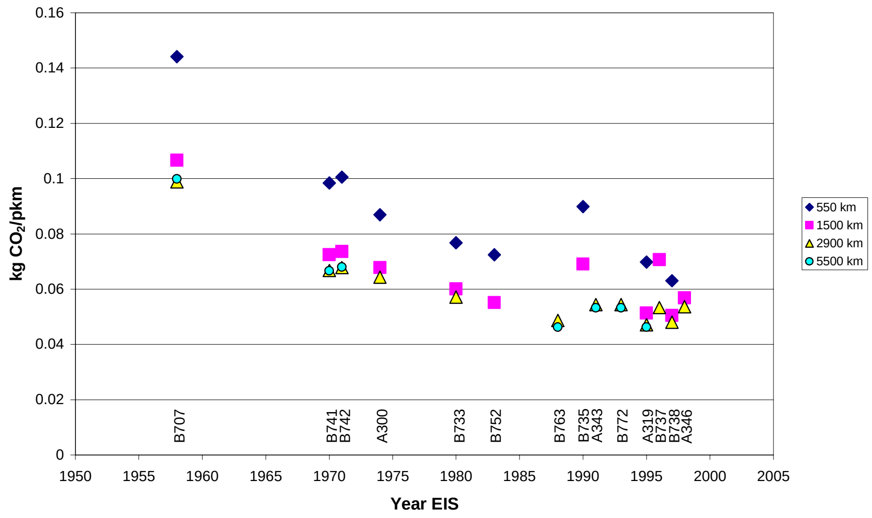

Figure 4: Emissions of CO_2 per passenger km for a variety of aircraft at 70% load factors and a variety of mission distances

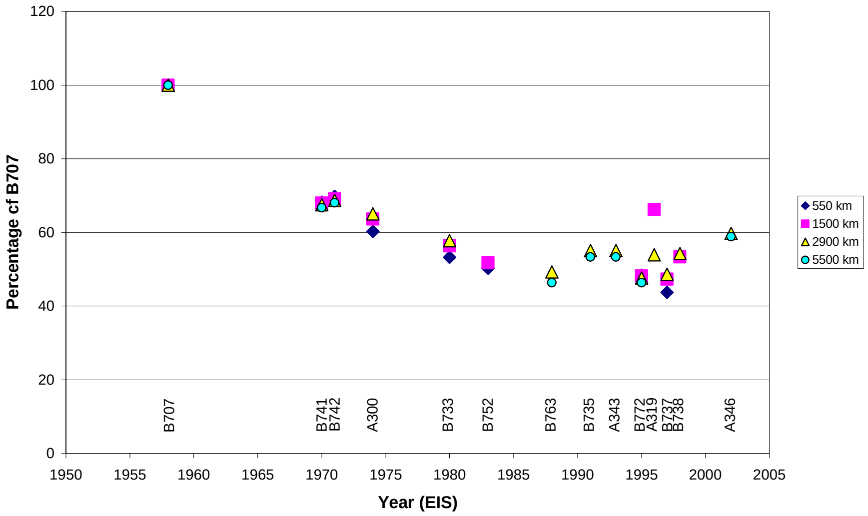

Figure 5: Emissions of CO_2 per passenger km for a variety of aircraft at 70% load factors and a variety of mission distances, relative to the Boeing 707

Figures 4 and 5 clearly show that there have been significant gains in both fuel efficiency and the resultant reductions in CO_2 emissions per passenger km since the entry into service of the Boeing 707. However, this trend is clearly not linear over time and the gains in more recent years have been small and diminishing.

In conclusion, both modelled data and a detailed examination of the origins of a ~1% yr^{-1} improvement in fuel efficiency reveal that a projected *technological* improvement of 1 or 2% yr^{-1} projected forward on a linear basis cannot be supported by empirical evidence.

5.3 Feasibility of implementation of the different benchmarks

Thus far, no attention to the *feasibility* of the different possible benchmarks has been given. It has simply been assumed that all the necessary data could be monitored and verified. In practice, this is not the case. Here, a brief analysis of the feasibility of the different benchmarks is given, which focuses on the question as to whether the indicators of which of the various benchmarks can be monitored in an unequivocal way.

All of the benchmarks discussed include a **distance** parameter. Distance can be calculated either as the Great Circle Distance (GCD), or as the Actual Distance Flown (ADF). The GCD is the shortest distance between two points on a sphere and is readily calculated for any airport pair. However, in practice aircraft deviate from the great circle route. The ADF is therefore longer than the GCD. However, the ADF can only be determined from radar data or flight-plan data[11]. If actual, as opposed to flight-plan data were required, then in cases where flights are performed across one or more air-traffic control domains, radar data would have to be compiled from more than one air traffic authority. For example, a flight from the EU to the

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[11] All flights under visual flight rules are required to submit a flight plan prior to departure.

US would require the compilation of radar data from the US FAA and EUROCONTROL. This has recently been done with success by EUROCONTROL. Flight-plan data would be somewhat easier to compile although it adds complexity to the task of determining distance flown. The GCD can be determined unequivocally but tends to be an underestimate of the ADF (particularly on shorter distances in Europe). Determining the ADF would be more difficult and would require involving air-traffic control authorities or the carriers to submit their flight plans for analysis.

Output-based benchmarks are based on **revenue tonne** data. These data are based upon the number of passengers and the weight of the freight carried. Both are registered for every flight for safety purposes. The feasibility of using this parameter therefore seems to be good.

Input-based benchmarks are based on **maximum payload, maximum take-off weight, and available tonne kilometres**. Each of these has a different basis.

- The **maximum payload** is generally defined as the maximum zero fuel weight (MZFW) minus the operating empty weight (OEW). The MZFW is certified with regulators (EASA for example) both for aircraft types and for specific aircraft. According to a major aircraft manufacturer, specific aircraft of a certain type may have a lower MZFW than the maximum permissible weight per the Type Certificate for the airplane. According to the same manufacturer, the OEW will depend on a number of factors: seating arrangement, flight crew, installed options (e.g. winglets), cargo handling equipment, etc. This implies that the OEW is specific for an aircraft and may change as the aircraft is put to a different use. In general, there are no public sources of OEW data. This means that maximum payload cannot be observed in an unequivocal way and the feasibility of this parameter is therefore limited.
- The **maximum take-off weight** (MTOW) is certified with regulators, both for aircraft types and for individual aircraft. Like the MZFW, an operator may certify an aircraft at a lower than maximum permissible MTOW. However, this would not reduce the feasibility of MTOW as a parameter in a benchmark, since if an operator chooses to certify their aircraft at a lower than permissible weight, they would receive fewer allowances, which would be to their disadvantage. The feasibility of this parameter seems to be good.
- As indicated in section 3.3.2, **available tonnes** can be defined in a number of ways. For freighter aircraft, this can be either the maximum payload in tonnes (of which the data availability and therefore the feasibility is limited) or the equivalent number of tonnes based upon the number of seats potentially fitted to an equivalent passenger aircraft, much in the same way that passengers and freight are placed upon an equivalent basis in revenue tonnes. The latter would be more feasible than the former, which would share the shortcomings of the maximum payload parameter. The number of available seats on an aircraft can either be taken to be the *maximum*

> number of available seats, the *typical* number of available seats or the *actual* number of available seats. For the latter, the *actual* number of seats on a specific aircraft is variable. An operator may choose to put in more seats when demand is high, and reduce the number of seats in periods of lower demand. This would be hard to monitor. The *typical* number of seats is often reported by aircraft manufacturers. However, it is not certified in any way and for particular aircraft types, several typical number of seats may exist, e.g. for two- and three-class configurations. In order to make this a feasible parameter, the regulators would have to assign typical numbers of seats to different aircraft types. This procedure would inevitably create winners and losers according to the business model. Finally, the *maximum* number of seats is currently defined by regulators (e.g. as the FAA exit limit). However, for some aircraft types, the exit limit hardly ever reflects the actual number of seats. For example, for a Boeing B747-400, the FAA exit limit is 660, whereas amongst the airlines consulted for this study, none had a higher number of seats than 428. This parameter may be available from a regulators perspective but it is unlikely to be viewed more widely as being realistic.

The definition of fleet age would need to be clarified before it could be used as a parameter. In its simplest form, this would be the arithmetic average of the ages of all the aircraft in an operator’s fleet, either leased or owned. However, this could be calculated in two ways in that it could be the actual age of the aircraft, or the age as defined by date of entry into service of a particular type. Determining the average fleet age across all operators may be difficult in practice as age data would need to be collected from a large number of sources. It does not also take into account the improvements in fuel efficiency gained from retrofitting newer technology. Therefore, whilst the feasibility of this parameter is straightforward in theory, it may present some difficulties in practice.

6 Conclusions

Conventional economic theory would imply that neither the environmental effectiveness (‘*is the target met?*’) nor the economic efficiency (‘*what does it cost to meet the target?*’) of an emissions trading scheme is affected by the initial allocation of emissions allowances (as long as transaction costs are low). The incentive to reduce emissions is a result of the price of the allowances, which in turn is determined by the cap.

Nonetheless, the *initial allocation* does have an impact on the costs of the system imposed on the trading entities and may also have distributional impacts, in that some entities are rewarded whilst others are penalised. In some cases, there may be a good reason to reward some entities, especially when that entity has taken measures to reduce emissions prior to the introduction of the trading scheme, i.e. ‘early action’.

In principle, three allocation methodologies for emission permits can be distinguished:

1. grandfathering, i.e. free allocation on the basis of an airlines’ historical emissions;
2. auctioning, i.e. no free allocation;
3. benchmarking, i.e. free allocation on the basis of an indicator of the output, efficiency, or fleet characteristics.

Grandfathering has the advantage that every airline will face the same relative shortfall but the disadvantage of this method is that it does not reward early action. Rather on the contrary, airlines that have already increased their efficiency may have exhausted the cheapest options to reduce emissions and could be disadvantaged under the grandfathering approach.

Auctioning can be an efficient non-discriminatory way of allocating permits, is consistent with the 'polluter pays' principle, and can generate revenues for environmental expenditure.'

Benchmarking can be a good way to reward early action whilst making free allocation of allowances possible at the same time. It is also the allocation method proposed by the European Commission and supported by most Member States.

Based on flight data for the UK, a parameterised model of the effects of different benchmarking methods was constructed for the following nine benchmarks:

- One benchmark based on Revenue Tonne Kilometres with an assumed passenger weight of 100 kg
- One benchmark based on Revenue Tonne Kilometres with an assumed passenger weight of 125 kg
- One benchmark based on Revenue Tonne Kilometres with an assumed passenger weight of 150 kg

- One benchmark based on Maximum Payload Kilometres (MPK), defined as maximum design zero fuel weight minus operational empty weight.
- One benchmark based on Maximum Take-Off Weight Kilometres (MTOWK)
- Two benchmarks based on Available Tonne Kilometres (ATK): first ATK defined as Maximum Seating Capacity Kilometres (MSCK) for passenger aircraft and MSCK-equivalent for the freighter versions of the aircraft;
- A second ATK defined as Maximum Payload Kilometres for freighters and actual Available Seat Kilometres (ASK) for passenger aircraft.
- Two technology based benchmarks: each multiplying actual historical emissions by an age factor, where the age factor is first 1% per annum and second, 2.5% per annum.

The distributional impacts of the different benchmarks were very different. The RTK benchmark with a passenger weight of 150 kg and the fleet age benchmark with an age factor of 1% had the smallest distributional impacts of the different benchmarks considered. Other benchmarks, such as the RTK with a passenger weight of 100 kg and the ATK benchmarks created larger gains and losses for different airline types. The input-based benchmark with the smallest distributional impact is the ATK with a standardised seating capacity per aircraft type. The largest distributional impacts of the benchmarks studied were created by the maximum payload kilometres, the maximum take-off weight kilometres and the age factor of 2.5%.

A detailed examination of the evidence for a historical technology-based improvement in fuel efficiency of the order 1 – 2% per year that may be projected into the future showed that such improvement rates cannot be supported.

In considering early action, output-based benchmarks rewarded operators' efforts to improve load factors and fleet optimisation. By contrast, input-based benchmarks were found to penalise slightly load factor improvements but rewarded fleet optimisation.

In considering the impacts on different airline types, low-cost carriers were found to be more sensitive to the choice of benchmark than network-carriers were. Network carriers were relatively well off under a RTK benchmark, because of the predominance of long haul flights that generally have high load factors (and thus generate a large amount of RTKs) and their relatively high fuel-efficiency, thereby creating fewer emissions on this basis. Freight-only airlines and regional airlines were faced with a considerable shortfall under all the benchmarks considered, which was partly due to very short flight distances and the types of aircraft used on these routes. These generic airline types have different characteristics in the UK to other EU member states.

A wide range of sensitivity tests was conducted to ascertain the robustness of the results. In general, it was found that varying input assumptions within reasonable bounds altered the outcome to a maximum of 2% in distributional impacts. More extreme tests such as changing the route network distances invoked larger changes in the benchmarks. However, this sensitivity test was considered to be beyond the bounds of a ‘reasonable’ change in input assumptions, since the distances selected for the base-case analysis were derived from empirical data. It was also found that the results were sensitive to the fleet composition of long haul network carriers, i.e. usage of B747-400 *cf* large twin-engined aircraft. Because of this, careful attention was paid to this aspect in the base-case calculations.

In conclusion, given that the view is widely taken (including as argued here) that RTK as a benchmark is the most consistent with encouraging environmental efficiency of individual operators in the European Emissions Trading Scheme, it is encouraging that the RTK-based benchmark did not cause large distributional impacts for an all arriving/departing scheme and is a feasible benchmark to implement. The freight-only and regional carriers were exceptions but both these types are low volume and also have rather unique characteristics in terms of UK traffic.

Acknowledgements

We would like to acknowledge the UK Department for Transport and the Environment Agency for funding this study. We would particularly like to thank Helen McGill (Dft), Sara Harrison (Dft) and Caroline Watson (Environment Agency) for their guidance and help in conducting this study. Martin Johnson of the UK Civil Aviation Authority kindly arranged for the UK flight data to be made available. Stefano Mancini of EUROCONTROL kindly provided supporting UK and European data; Ted Elliff of EUROCONTROL Experimental Centre gave kind permission to use the flight data in the analysis of distances travelled.

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Appendix I: Definition of airlines

In the spreadsheet model, airlines are defined by their route network, their business model and their size. This appendix discusses each of these aspects separately. The last section gives an overview of the characteristics of the mimicked airlines.

A1. Routes

The number of routes in this study was limited to six because of time and budget constraints.

The choice of routes was based on actual flight distances. The UK CAA provided data on flights from UK airports in 1990, 2004, 2005 and 2006. These data show that, in general, few flights are operated on very short distances: approximately 2% of all flights were on distances shorter than 100 km and less than 4% of all flights were made on distances less than 150 km. Most flights were operated on distances of between 200 and 600 kilometres (46% of total) (see Figure A1). These were flights mainly to and from northwest European airports and domestic flights. At longer distances, the number of flights tended to decrease with the distance but there are clusters of flight distances that are clearly above the general trend. These were found to be at ~1500 km (UK to west Mediterranean), 2900 km (UK to east Mediterranean), 5500 kilometres (UK to US east coast) and 9500 kilometres (UK to the Far East).

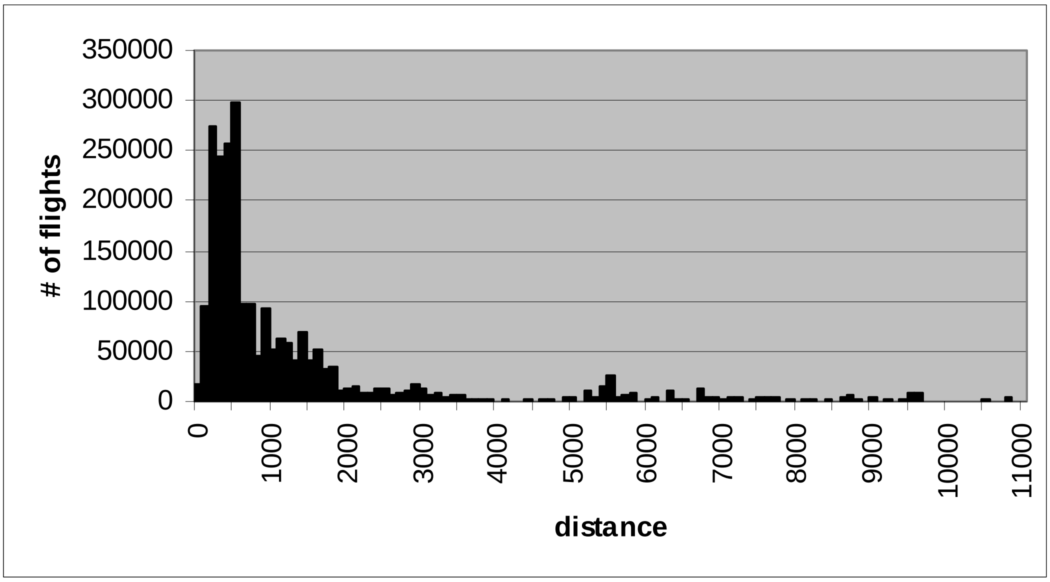

Figure A1: Number of flights per flight distance band in km (UK CAA, 2006 data)

Airlines generally operate different aircraft for different mission distances. An analysis of the UK CAA data showed that the aircraft operated on short haul routes of up to 300 km differed from the aircraft operated on short haul routes of 500+ km. Therefore, two routes of less than 600 kilometres were included in the analysis. Two long haul routes were included in the network in order to be able to discern potential differential impacts on North Atlantic and Far East routes. Four medium haul routes with the highest frequency, i.e. 1500 kilometres and 2900 km were also included.

Based on the above analysis, the following mission distances were selected for modelling:

- Short haul, domestic and regional: 250 kilometres
- Short haul, intra-EU: 550 kilometres
- Medium haul: 1500 kilometres
- Medium haul: 2900 kilometres
- Long haul North Atlantic: 5500 kilometres
- Long haul Far East: 9500 kilometres

A2. Airline types

Airline types are defined by the network on which they operate, by their size, their fleet and by their business model.

With respect to network, we distinguish between airlines that operate on all the route lengths selected in section A1, and networks that operate only on the shortest routes, or on all but the intercontinental routes. These networks reflect actual networks of network carriers, regional airlines and low-cost carriers, respectively. Non-EU network carriers operate on all the route lengths but only their long haul flights to and/or from the EU are included in ETS, as is currently proposed.

Some airlines are larger than others. Data presented in Table A1 indicate that the European network carriers associated in AEA can be grouped into the largest carriers, with 60% to 100% of the transport of the largest carrier, Lufthansa; a middle group generating 9% to 32% of the traffic of the largest carrier and a large number of smaller airlines.

Table A1: Relative size of AEA members (RTK, 2006)

LH – Lufthansa	100%
AF – Air France	93%
BA – British Airways	83%
KL – KLM - Royal Dutch Airlines	62%
IB – Iberia	32%
AZ – Alitalia	27%
VS – Virgin Atlantic	25%
SK – SAS Scandinavian Airlines	17%
LX – Crossair	17%
TK – Turkish Airlines	14%
OS – Austrian Airlines	13%
TP – TAP Portugal	10%
AY – Finnair	9%
BD – British Midland	5%
OA –Olympic Airlines	4%
LO – LOT Polish Airlines	4%
JK – Spanair	4%
OK – CSA Czech Airlines	3%
SN – SN Brussels	3%
MA – Malév	2%
FI – Icelandair	2%
CY – Cyprus Airways	2%
AP – Air One	2%
KM – Air Malta	1%
RO – TAROM	1%
JU – JAT – Yugoslav Airlines	1%
OU – Croatia Airlines	1%
JP – Adria Airways	0%
LG – Luxair	0%

Source: AEA monthly traffic statistics

For network airlines, the number of RTKs (the basis of Table A1) probably correlates well with the number of flights. For low-cost carriers and regional carriers this correlation would break down, since these do not provide long haul flights. It was assumed that low-cost carriers have a greater number of flights, this assumption was based upon UK CAA flight data for 2006.

Airlines have different business models with regard to freight. Some airlines are freight-only airlines, others have freighters in their fleet or carry freight in the hold of their passenger aircraft and others carry no freight at all.

This study defines five airline types.

Table A2: Airlines used for mimicking model airlines

Airline type	Network	Size	Fleet	Freight
Large EU network carriers	Full	Largest (100%)	Varies	In freighters and belly
Small EU network carriers	Full	Medium (30% and 15% of flights of largest)	Varies	In freighters and belly
Large non-EU network carriers	Long haul only	Large (3% and 1,2% of traffic under ETS)	Boeing only	In freighters and belly
Low-cost carriers	Short and medium haul only	Medium (77% of flights of largest)	Varies	No
Freight-only carrier	Full	Large	Freighters only	Only freight
Regional airline	Short haul only	Small	Regional aircraft only	No

Table A3: Networks of model airlines

Airline type	no of flights	250 km	550 km	1500 km	2900 km	5500 km	9500 km
Large EU network carrier (Airbus)	300000	19%	52%	14%	5%	6%	4%
Large EU network carrier (Boeing)	300000	19%	52%	14%	5%	6%	4%
Small EU network carrier (Airbus)	150000	22%	43%	21%	6%	5%	3%
Small EU network carrier (Boeing)	150000	22%	43%	21%	6%	5%	3%
Low-cost carrier (short distance)	550000	25%	60%	10%	5%	0%	0%
Low-cost carrier (medium haul)	270000	0%	0%	100%	0%	0%	0%
non-EU network carrier (USA)	50000	0%	0%	0%	0%	82%	18%
non-EU network carrier (far east)	20000	0%	0%	0%	0%	50%	50%
regional airline	230000	67%	33%	0%	0%	0%	0%
Freight-only carrier	3300	50%	35%	5%	0%	10%	0%

A3. Aircraft types

Airlines have different fleets. Some airlines operate almost exclusively Boeing aircraft, sometimes supplemented by other aircraft types for regional routes. Examples of such airlines are Ryanair and American Airlines. Other airlines have fleets for which Airbus aircraft predominate (such as BMI and Finnair), and others have a mixed fleet (British Airways and Easyjet).

Seats

Depending on their business model, airlines may equip their fleet with different seat configurations. For example, some European airlines have 110 seats in an Airbus A319 (Swiss, for example), whereas others have 156 seats in the same aircraft (EasyJet). Boeing 737-800s are operated with capacities ranging from 132 (SAS) to 189 seats (Sterling).

Based on annual reports of over ten different airlines, typical seating configurations were identified for different aircraft types. The airlines are identified in Table A4, together with the airline type they represent.

Table A4: Airlines used for establishing seating capacities of aircraft

British Airways	Large EU network carriers
Lufthansa	
Air France	
Finnair	Small EU network carriers
CSA	
BMI	
Delta	Large non-EU network carriers
American Airways	
Cathay Pacific	
Ryanair	Low-cost carriers
Easyjet	
Sky Europe	
(not applicable)	Freight-only carrier
Highland Airways	Regional airline
Loganair	

Operation of aircraft types on network

An analysis of the UK CAA data showed that some aircraft types are predominantly operated on particular flight lengths.

Table A5 gives all aircraft types that account for over 1% of flights from and to the UK and how they are distributed over flight lengths. Large Airbuses are absent from this table, but they are probably operated more often from other airports in Europe, such as Frankfurt, the main hub of Lufthansa, which has many larger Airbuses in its fleet.

Table A5: Aircraft per distance category

Aircraft type	0–400 km	400–1500 km	1500–3500 km	3500–7500 km	>7500 km
ATR72	19100	11081	1	0	0
AVROLINER RJ100/115	742	33195	220	0	0
FOKKER 50	32877	4742	3	0	0
BOEING 767-300ER/F	2398	3585	5778	22708	4212
BAE 146-300	21206	17046	661	0	0
BAE 146-200/QT	14781	25423	729	0	0
AEROSPATIALE AS332 SUPER PUMA (L1/L2)	33514	9017	0	0	0
SAAB FAIRCHILD 340	44124	3942	0	0	0
BAE JETSTREAM 41	25255	23596	0	0	0
BOEING 777-200ER	19	37	6	39268	12301
BOEING 747-400	22	351	17	20205	32026
BOEING 737-400	7195	35538	12326	0	1
DE HAVILLAND DASH 8-300/Q300	50246	12093	2	0	0
BOEING 737-500	20870	48467	7918	2	0
AIRBUS A321	9884	45097	27627	2376	0
BOEING 737-700	24499	65075	17868	632	1
BOMBARDIER DASH 8 Q400	58601	50085	0	0	0
BOEING 757-200	5555	35804	53164	17146	2
EMBRAER RJ145	28348	87494	166	1	0
BOEING 737-300	38986	78765	32602	15	0
AIRBUS A320-100/200	31693	112605	61180	2423	4
BOEING 737-800	29315	141539	43986	1617	0
AIRBUS A319	44480	181719	28998	11	1

Source: CAA 2006

Table A6 provides an overview of the aircraft types that are used on the various flight lengths by the various airlines that are defined above. Small aircraft, such as the Bombardier Dash 8 Q400, the Saab Fairchild 340 and the ATR 72 are only operated over short distances. The Airbus A319, A320 and A321 as well as the Boeing 737-series are operated on short and medium flight distances. On longer distances (5500 and 9500 km), the Airbus 330 and 340 are used, as well as the Boeing 747-400, 767-300ER and 777-200ER. The numbers of seats were based on annual reports and websites of airlines[12]. Average load factors were based on data of AEA and IATA.

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[12] Annual reports of British Airways, Delta airlines, American Airways, Finnair and CSA and websites of Lufthansa, Air France, Cathay Pacific, BMI, Ryanair, Easyjet and Sky Europe

Table A6: Fleet and network of mimicked airlines

Airline type	250 km	550 km	1500 km	2900 km	5500 km	9500 km
A (large EU network carrier)	Airbus A319	Airbus A319	Airbus A319	-	Airbus A340-300	Airbus A340-300
	Airbus A320-100/200	Airbus A320-100/200	Airbus A320-100/200	Airbus A320-100/200	Airbus A340-600	Airbus A340-600
	Airbus A321	Airbus A321	Airbus A321	Airbus A321	Boeing 747-400	Boeing 747-400
B (large EU network carrier)	Boeing 737-300	Boeing 737-800	Boeing 737-800	Boeing 737-800	Boeing 777-200ER	Boeing 777-200ER
	Boeing 737-800	Boeing 737-500	Boeing 757-200	Boeing 737-700	Boeing 747-400	Boeing 747-400
	Boeing 757-200	Boeing 737-300	Boeing 737-300	Boeing 737-300	Boeing 767-300ER	Boeing 767-300ER
C (medium sized EU network carrier)	Airbus A319	Airbus A319	Airbus A319	-	Airbus A340-300	Airbus A340-300
	Airbus A320-100/200	Airbus A320-100/200	Airbus A320-100/200	Airbus A320-100/200	Airbus A340-600	Airbus A340-600
	Bombardier Dash 8 Q400	Fokker F100	Airbus A321	Airbus A321	Airbus A330-300	Airbus A330-300
D (medium sized EU network carrier)	Boeing 737-500	Boeing 737-800	Boeing 737-500	Boeing 757-200	Boeing 777-200ER	Boeing 777-200ER
	Saab Fairchild 340	Boeing 737-500	Boeing 737-700	Boeing 737-800	Boeing 747-400	Boeing 747-400
	Boeing 757-200	Boeing 737-300	Boeing 737-800	-	Boeing 767-300ER	Boeing 767-300ER
E (Low-cost carrier)	Boeing 737-800	Boeing 737-800	Boeing 737-800	Boeing 737-800	-	-
	Boeing 737-700	Boeing 737-700	Boeing 737-700	Boeing 737-700	-	-
	Boeing 737-300	Boeing 737-300	Boeing 737-300	Boeing 737-300	-	-
F (Low-cost carrier)	-	-	Boeing 737-500	-	-	-
	-	-	Boeing 737-700	-	-	-
	-	-	Boeing 737-300	-	-	-
G (Large US-based network carrier)	-	-	-	-	Boeing 777-200ER	Boeing 777-200ER
	-	-	-	-	Boeing 767-300ER	Boeing 767-300ER
	-	-	-	-	-	-
H (Large Far east based network carrier)	-	-	-	-	Boeing 747-400	Boeing 747-400
	-	-	-	-	-	Boeing 777-200ER
	-	-	-	-	-	-
I (regional airline)	Saab Fairchild 340	-	-	-	-	-
	Bombardier Dash 8 Q400	-	-	-	-	-
	ATR72	-	-	-	-	-
J (freight only airline)	Boeing 737-300	Boeing 757-200	Boeing 757-200	-	McDonnell-Douglas MD11	-
	ATR42-300	Boeing 737-300	Boeing 737-300	-	Boeing 747-400F	-
	Airbus A300B4-100/200	BAE 146-200/QT	Airbus A300B4-100/200	-	Boeing 767-300ER/F	-

Conclusion

Ten different generic airline types were mimicked based on the above analyses. The main characteristics of each airline are given in Table A7 below.

Table A7: Summary of characteristics of airlines analysed

Airline	Description
A	Large EU based network carrier with a size and route network comparable to the largest European carriers. No cargo operations. Fleet consists predominantly of Airbuses with two or three class seating configurations (low seating densities). Load factors comparable to European network carriers.
B	Large EU based network carrier with a size and route network comparable to the largest European carriers. No cargo operations. Fleet consists predominantly of Boeings with two or three class seating configurations (low seating densities). Load factors comparable to European network carriers.
C	Medium sized EU based network carrier with a size and route network comparable to typical European flag carriers. No cargo operations. Fleet consists predominantly of Airbuses with two or three class seating configurations (low seating densities). Load factors comparable to European network carriers.
D	Medium sized EU based network carrier with a size comparable to typical European flag carriers and relatively more domestic short haul flights. No cargo operations. Fleet consists predominantly of Boeings with two or three class seating configurations (low seating densities). Load factors comparable to European network carriers.
E	Large low-cost carrier with many domestic flights and no intercontinental flights. No cargo operations. Fleet entirely Boeings 737s. High seating densities and high load factors.
F	Smaller low-cost carrier with no intercontinental flights and relatively fewer domestic flights. No cargo operations. Fleet entirely Boeings 737s. High seating densities and medium load factors. This carrier could also be seen as representing charter airlines.
G	Large non-EU network carrier, based in US. Only long haul flights under ETS. No cargo operations. Fleet consists predominantly of Boeings with two or three class seating configurations (low seating densities). Load factors on intercontinental flights comparable to European network carriers.
H	Large non-EU network carrier, based in Far East. Only long haul flights under ETS. 25% of flights are cargo. Fleet consists predominantly of Boeings with two or three class seating configurations (lowest seating densities). Load factors on intercontinental flights comparable to European network carriers.
I	Regional carrier based in EU. Only short haul flights operated with turboprops. Low load factor based on UK CAA 2006 data.
J	Freight only carrier based in EU. Size comparable to UPS. Route network average of all freight flights in UK CAA 2006 database. Aircraft types based on most commonly used freighters in CAA 2006 data. Load factor based on AEA data for freight.

Appendix II: Analysis of distances flown

Data

Sample data on distances flown from approximately 5,000 flights were taken from a dataset kindly provided by T. Elliff of EUROCONTROL Experimental Centre. These data summarise actual missions performed, along with a number of other parameters that were distributed for analysis with the ICAO-CAEP Modelling Task Force (MODTF) and are used here with permission.

Some stakeholders have suggested that either an ATK or RTK benchmark should be supplemented by a constant distance to be added (100 km and 200 km have been suggested) to flights in order to allow for deviation from great circle distances, and an allowance for holding patterns etc. No evidence has been presented for any particular distance.

Here, the EUROCONTROL data of 5,000 flights, which included a range of missions from short-haul to long-haul, were analysed for the actual distance flown and the equivalent great circle distance.

Results

Frequency distributions of actual distances and equivalent computed great circle distances are shown in Figure A2.

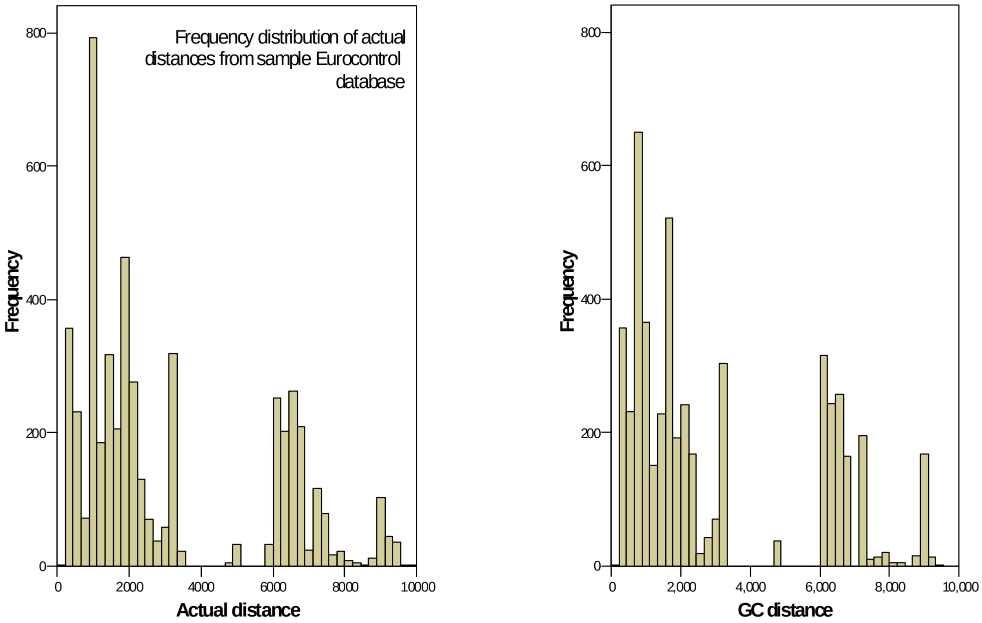

Figure A2: Frequency distributions of sample flight data analysed; actual distances (left hand panel) and equivalent great circle distances (right hand panel)

Subtraction of the great circle distance from the actual distance yields the ‘excess’ distance. A frequency distribution of this quantity is shown in Figure A3.

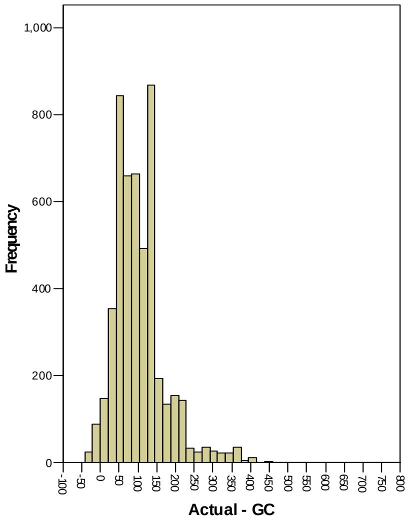

Figure A3: Frequency distribution of excess distance (actual – great circle)

Figure A3 shows a mean excess distance of 106 km. This mean excess includes all flights, which range from 81 to 9,800 km. Thus, it may be speculated that some relationship may exist between the actual distance flown and the excess distance. This relationship is shown in Figure A4.

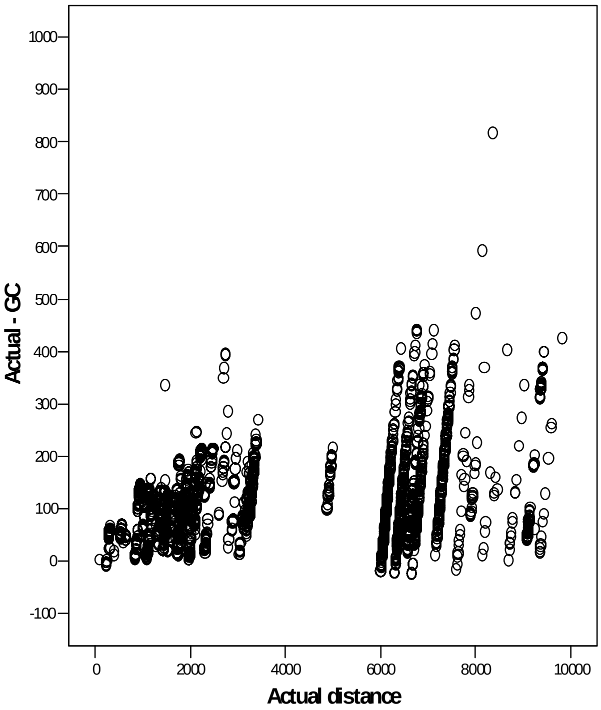

Figure A4: Actual distance vs ‘excess’ distance (actual – great circle)

Whilst the correlation is significant at the $P \leq 0.01$ level, the R^2 value is low, at 0.249. Table A8 gives the excess distance grouped by different mission distances.

Table A8: Mission distance ranges and mean excess distances

Mission distance ranges (km)	Mean excess distance (km)
0 – 550	50.8
550 – 1500	99.7
1500 – 2900	110.6
2900 – 5500	121.8
5500 – 9500	123.0

Conclusions

The data presented in Table A8 indicate that for short to medium haul trip distances (550 – 5500 km). The excess distance is of the order 100 – 120 km. Thus, a suggestion of 200 km is an overestimate by approximately a factor of two.