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Economic incentives to mitigate greenhouse gas emissions from air transport in Europe

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Brief summary

1 This study examines the feasibility of economic incentives to mitigate greenhouse gas emissions from air transport in Europe, with a view to encouraging airlines to integrate such emission reduction into their business objectives.

2 The incentives considered are designed to add the external costs of greenhouse gas emissions to the en route charges already collected by Eurocontrol. The following two policy variants were developed:

   a **An environmental charge**
   Under this methodology an aircraft would incur a charge proportional to the volume of greenhouse gas emissions it discharged in the airspace of the European Union. Revenues would therefore be raised.

   b **A Performance Standard Incentive (PSI)**
   Under this methodology the better an aircraft performed relative to a ‘performance standard’, the more money it would receive, and the worse it performed, the more it would pay. This variant is designed to be revenue-neutral, with the sum of payments and revenues equalling zero.

3 The incentive *level* adopted in this study for both policy variants is based on the external costs of the climatic impacts of aviation. This suggests mid-range working values of € 30 per tonne of CO_2 and € 3.6 per kg of NO_X emitted; in a sensitivity analysis, low (€ 10 and € 1.2, respectively) and high (€ 50 and € 6) variants were also considered. It is to be stressed that the ultimate choice of incentive level is a political issue.

4 The main impacts of the **environmental charge** would be:

   a a cut in forecast aviation CO_2 emissions in EU airspace of about 10 Megatonnes (9%) in 2010, the result of technical and operational measures by airlines (4.4 percentage points) and reduced air transport demand (4.5 points) .

   b a rise in average ticket prices of roughly € 3 to € 5 for short one way flights (500 km) and € 10 to € 16 for long flights (6000 km).

5 The main impact of a **revenue-neutral PSI** would be a cut in forecast aviation CO_2 emissions in EU airspace of almost 6 Mtonne (5%) in 2010. This would accrue almost entirely from technical and operational measures by airlines. The impact on ticket prices depends very much on the precise definition of the ‘performance standard’. The PSI does not place a net financial burden on the industry as a whole. By its very nature, though, introduction of the PSI may mean that some market segments benefit and others suffer.

6 The study also shows that no significant economic distortions are likely to arise among airline companies as a result of the policy options and incentive levels considered.

7 An **environmental charge** would generate annual revenues of € 1 bn - € 9 bn, depending on financial valuation of emissions. The revenues generated could be allocated to individual EU Member States or to a supranational fund for financing emission abatement measures. By definition, a **revenue-neutral PSI** will not generate any revenues.

8 From the point of view of international law and bilateral air service agreements there are no legal obstacles to introduction of a charge or Performance Standard Incentive in EU airspace. However, there are several conditions that should be taken into due account.

Executive summary

Feasibility study

Background and aim

Emissions of greenhouse gases from aircraft engines contribute to climate change. The climatic impact of aviation is expected to grow in the coming decades and a variety of mitigating actions have been proposed. ICAO's Committee on Aviation Environmental Protection (CAEP) has developed an action plan which considers use of improved technologies, better operational procedures and market-based measures.

In 1999 the Commission Communication "Air Transport and the Environment: towards meeting the challenges of sustainable development" (COM(1999)640) noted that the European Commission would be carrying out preparatory work with a view to possibly introducing proposals to establish economic incentives to mitigate the greenhouse gas emissions of air transport in Europe. The European Commission has subsequently taken the initiative of launching a study on the feasibility and effectiveness of alternative policies to mitigate the global environmental impact of aviation in Europe, one such policy being a levy on greenhouse gas emissions. This feasibility study is an essential part of that preparatory work and its aim is:

To design and assess practical options for economic incentives to mitigate greenhouse gas emissions from air transport in Europe, and to formulate proposals for actual implementation of such incentives.

Project organisation

The study was carried out by CE Delft and its partners to present facts and professional estimates regarding the scientific and policy effects of such incentives. Selection of a particular policy line or variant is the sole prerogative of the client, however.

Four preliminary studies were carried out, on the following topics:

- Design of the incentives[1], including analysis of potential calculation methods and physical units to provide a volumetric basis for the charge and Performance Standard Incentive (PSI).
- Analysis of possible supply-side responses by airlines to reduce greenhouse gas emissions[2].
- Defining legal conditions, to ensure compatibility of the charge and PSI with the international legal framework[3].
- Identification and evaluation of options for the collection and use of the revenues of an environmental aviation charge[4].

The assessments and analyses underlying this study benefited enormously from contributions from EU Member States and key stakeholders, including representatives of CAEP's Working Group on market-based measures. The authors therefore wish to extend special thanks to these contributors for their constructive discussions and comments. Notwithstanding, the content of the report is the sole responsibility of the authors.

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1 See chapter 2 and Annex B of this report.

2 Summarised in chapter 3 and described in detail in Annex F of this report.

3 Summarised in chapter 5 and described in detail in Annex D of this report.

4 See chapter 6 of this report.

Design of the incentives
In drawing up environmental policy for the aviation sector, economic incentives such as levies and tradable allowances form an attractive option because they give the sector the flexibility to take steps to reduce greenhouse gas emissions at least cost. Here, analysis of such incentives is restricted to:

1 An environmental charge.
In this variant a charge is levied proportional to the absolute emission (e.g. kilograms CO_2) of an aircraft in European Union airspace. This generates revenues, and the challenge here is to design options for revenue use that are broadly perceived as fair and economically efficient.

2 A performance standard incentive (PSI).
This variant is a revenue-neutral scheme that aims to reward aircraft (operators) that are relatively environmentally efficient, i.e. better than a specific performance standard, and penalise aircraft that perform worse. The main challenge here is to define this standard such that the environmental efficiency of air transport operations is quantified both fairly and in a manner permitting ready comparison. Aircraft emissions must therefore be related to an operational output parameter, i.e. tonnes of CO_2 and/or kg of NO_X **per unit** of air transport performance.
This study discusses three possible options for the unit of air transport performance to be used in the PSI:
1 CO_2 and/or NO_X emissions *per aircraft kilometre*.
2 CO_2 and/or NO_X emissions *per actual payload-kilometre.*
3 CO_2 and/or NO_X emissions *per potential payload-kilometre (MZFW.km)*.

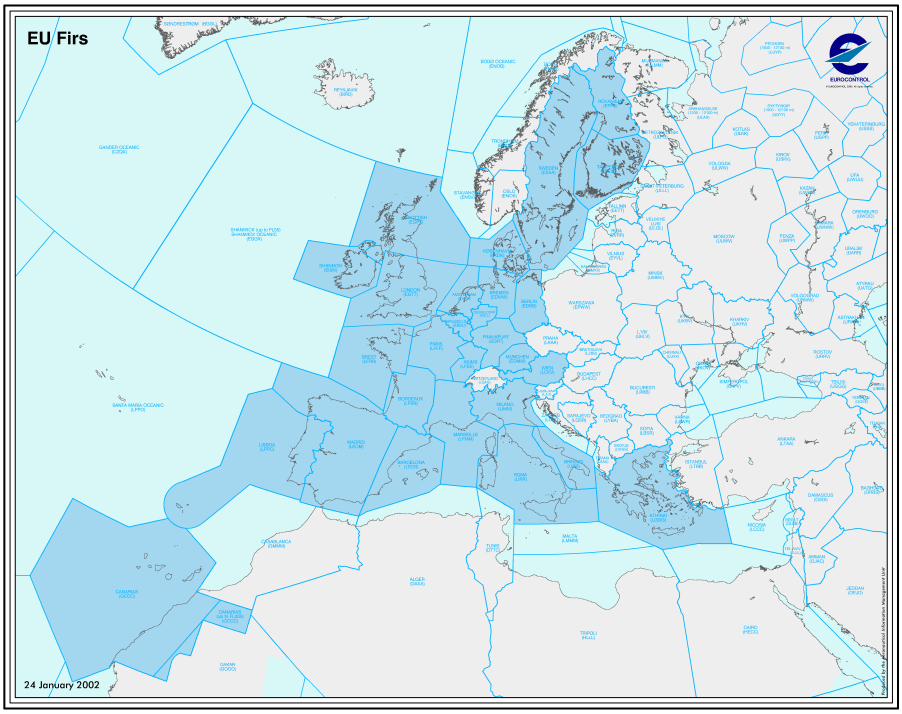
Aircraft emitting more greenhouse gases per unit of air transport production than the industry-average performance standard must pay. The better an aircraft performs relative to this standard, the more money it would receive. Since payload kilometres (passengers and freight) are what aircraft produce, the most accurate option would be to define *the unit of air transport performance* as the amount of payload kilometres actually performed[5].

Besides these two main policy variants there are several other important choices with respect to design of the two policy options:

Scope: EU airspace
In this study we focus on a charge or PSI on each tonne of CO_2 and/or kg of NO_x emitted in a predefined airspace of the EU Member States (hereafter referred to as EU airspace). This implies that emissions on *intra*-EU routes are subject to the charge or PSI on the whole flight, while emissions from aircraft flying to and from the EU will be subject to the incentive scheme only over the distance flown in EU airspace. The study concludes that it is legally feasible to base the definition of EU airspace on the Flight Information Regions (FIR) of EU Member States, as employed by Eurocontrol and officially agreed within ICAO. Flight Information Regions not only include the national territory of an EU Member State, but may also include particular parts of seas and oceans outside the 12-mile zone. Figure 1 shows EU airspace as defined for the purposes of this study.

5 In the remainder of this study the results of the PSI are therefore presented for option 2: emissions per actual payload.km.

Figure 1 EU airspace



Administrative agent: Eurocontrol
The administrative agent is the body that undertakes the tasks necessary to make the emission charge or PSI work in practice. These tasks include: (i) registration and calculation of emissions in EU airspace; (ii) operation of the charging/rebate and invoicing procedure; and (iii) collection and disbursement of revenues.
The present infrastructure of Eurocontrol appears to allow use of Eurocontrol current Route Charge System for these administrative tasks. This implies that an emission charge or PSI could be implemented in the same way as the current route charges covering the cost of air traffic management (ATM) and associated services.

Level of the incentive
Following a discussion of suitable levels for the charge and PSI, this study opts, in both policy variants, to base the incentive level on the *external costs* of the climatic impacts of aviation, leading to a mid-point assumption of € 30 per tonne CO_2 and € 3.6 per kg NO_X. In a sensitivity analysis low (€ 10 and € 1.2, respectively) and high (€ 50 and € 6) variants were also considered. An incentive of € 30 per tonne of CO_2 is equivalent to € 0.08 (8 Euro cents) per litre of fuel.

Impacts on operating costs and ticket prices
Impacts of the environmental charge variant
Below, the various incentive levels are translated into estimated charges per aircraft trip and hence charge or rebate per passenger, for both the charge variant (Table 1) and the PSI (Table 2). Both tables show the initial changes in operating costs for different aircraft types (passenger capacity) and illustrative load factors. Further, as only emissions in EU airspace are chargeable, the tables also show the percentage fraction of the stage length taken to be subject to the charge or PSI.

Table 1 **Emission charge level** for different aircraft types, flight distances and load factors, for the middle working variant: € 30 per tonne CO_2 + € 3.6 per kg NO_X

Aircraft pax capacity	Load factor (%)	Distance (km)	EU air-space (%)	€ per aircraft per flight (change operating costs)	€ per pax per one way flight (initial ticket price change)
146	40%	500	95%	300	5
	40%	1500	70%	443	8
	80%	500	95%	315	3
	80%	1500	70%	476	4
224	45%	1000	80%	769	10
	45%	3000	55%	1228	17
	85%	1000	80%	832	6
	85%	3000	55%	1366	10
269	50%	2000	60%	1094	14
	50%	6000	25%	1218	16
	90%	2000	60%	1213	9
	90%	6000	25%	1407	10
416	50%	4000	35%	2185	15
	50%	10000	16%	2499	17
	90%	4000	35%	2316	9
	90%	10000	16%	2700	10

At a charge level of € 30 per tonne CO_2 + € 3.6 kg NO_x, the total emission charge per flight ranges from € 300 for a short-haul flight to € 2700 for a long-haul flight. The emission charge *per passenger for a one way trip* would be between € 3 per passenger on short flights (e.g. by B-737) and up to € 17 on long flights (e.g. by B-747). It is important to note that long-haul flights only fly up to about 25% in EU airspace.

Table 2 Performance Standard Incentive (**PSI**) **level** for different aircraft types, flight distances and load factors, for the middle working variant: € 30 per tonne CO_2 + € 3.6 per kg NO_X

Aircraft pax capacity	Load factor (%)	Distance (km)	EU air-space (%)	€ per aircraft per flight (change operating costs)	€ per pax per one way flight (initial ticket price change)
146	40%	500	95%	152	3
	40%	1500	70%	117	2
	80%	500	95%	20	0
	80%	1500	70%	-177	-2
224	45%	1000	80%	247	3
	45%	3000	55%	151	2
	85%	1000	80%	-154	-1
	85%	3000	55%	-668	-5
269	50%	2000	60%	-81	-1
	50%	6000	25%	-250	-3
	90%	2000	60%	-901	-6
	90%	6000	25%	-1235	-9
416	50%	4000	35%	243	2
	50%	10000	16%	279	2
	90%	4000	35%	-1180	-5
	90%	10000	16%	-1295	-5

The main characteristic of the PSI is that the total financial burden on airlines is zero. This is due to the fact that under this scheme, the better an airline performs relative to the average environmental performance of the fleet in EU airspace (performance standard), the more money it receives, and the worse it performs, the more it pays. In the table above, amounts below zero ('negative charge') imply a rebate.

As Table 2 shows, for the assumed aircraft types and load factors and at a charge level of € 30 per tonne CO_2 + € 3.6 per kg NO_X, the total PSI level per flight varies from a rebate of € 1295 to a charge of € 279. With respect to initial ticket price changes, table 2 shows furthermore that this change is between -€ 9 (i.e. reduced ticket price due to a rebate) and +€ 3.

Environmental effectiveness
Both the emission charge and the Performance Standard Incentive (PSI) are expected to substantially reduce greenhouse gas emissions in EU airspace. Table 3 shows the total reductions in CO_2 emissions resulting from the emission charge and PSI as a percentage of total emissions in EU airspace in 2010. The table also shows the estimated contribution to these emission reductions by *supply-side* responses (operational and technical measures) and *demand* effects (fewer passengers and less freight).

Table 3 Estimated CO_2 emission reductions resulting from emission charge and PSI, as a percentage of total emissions in EU airspace in 2010. The shares of supply-side and demand-side responses in emission reduction are also indicated

Valuation of CO_2 / NO_X, € tonne/kg	Emission charge variant				Performance Standard Incentive (PSI)			
	supply side, %	demand side, %	total %	total Mtonne	supply side, %	demand side, %	total %	total Mtonne
10 / 0	-0.9%	-1.0%	**-1.9%**	-2.2	-0.9%	-0.1%	**-0.9%**	-1.1
30 / 0	-2.9%	-3.1%	**-5.9%**	-6.9	-2.9%	-0.4%	**-3.3%**	-3.9
50 / 0	-4.6%	-4.9%	**-9.3%**	-10.9	-4.6%	-0.4%	**-5.0%**	-5.9
10 / 1.2	-1.5%	-1.7%	**-3.1%**	-3.6	-1.5%	-0.2%	**-1.7%**	-2.0
30 / 3.6	-4.4%	-4.5%	**-8.7%**	-10.2	-4.4%	-0.4%	**-4.8%**	-5.6
50 / 6.0	-6.6%	-7.2%	**-13%**	-15.6	-6.6%	-0.6%	**-7.2%**	-8.4

Conclusions:

- The **emission charge** reduces forecast CO_2 emissions from aviation in EU airspace in 2010 by almost 2% (2.2 Mtonne CO_2) at the lowest charge level, up to approximately 13% (15.6 Mtonne CO_2) at the highest charge of € 50 per tonne CO_2 and € 6 per kg NO_X. These reductions are roughly equally attributable to supply-side responses by airlines (technical and operational measures) and to reduced demand for air transport.
- A **revenue-neutral PSI** cuts forecast CO_2 emissions from aviation in EU airspace in 2010 by about 1% (1.1 Mtonne) at the lowest PSI rate to about 7% (8.4 Mtonne) at the highest. These reductions are almost entirely attributable to supply-side effects.
- By far the most important supply-side measure will probably be accelerated fleet renewal. The reduction of average fleet age is not easy to estimate, but will probably be 0.3 to 2 years. This would lead to an emission reduction of approximately 0.5% to 3% across the fleet. Other supply-side measures together add at most 3 percentage points to this figure.
- Supply-side measures are similar whether an emission charge or PSI is introduced. The only fundamental difference is the load factor / flight frequency response, which will probably differ significantly with a PSI in place that uses emissions per unit of actual payload as a basis for calculation.
- This study indicates no trade-off between CO_2 and NO_X emissions, and reduction of CO_2 emissions could indeed even lead to slightly greater reductions in NO_X emissions because of reduced engine loads. Even a charge or PSI based solely on CO_2 would reduce both CO_2 and NO_X emissions.

Environmental effectiveness: emission charge vs. fuel tax

An emission-based en route charge in EU airspace would not encourage ‘fuel tankering’. This contrasts with the case of an EU-wide *fuel tax*, which might encourage airlines to avoid taxation by taking additional fuel on board at airports outside the EU, i.e. over and above requirements for the current flight. The fuel taxation study carried out for the European Commission in 1999 showed that tankering might well reduce the environmental benefits of a fuel tax by 70%.

Economic and distributional effects

If these incentives led to economic distortions, the feasibility of a charge or Performance Standard Incentive (PSI) would be reduced. This study therefore investigated potential economic distortions and distributional effects. Of particular concern would be the effects on competition between EU and non-EU carriers.

It is important to note that a change in the competitive position of relatively clean airline companies compared to high polluters is not an economic distortion, but rather an efficiency improvement. In the short term, however, considerable distributional effects may occur.

Change in the competitive position of EU vs. non-EU carriers
EU and non-EU carriers are both assumed to be subject to exactly the same charge or PSI. Hence, both EU and non-EU carriers with the same emissions level would face the same cost increase on the same flight stage within EU airspace. However, as some airline companies achieve a greater share of their production in the EU than others, it is important to know whether carriers will respond in the form of price increases or reduced profit margins. This study did not identify any convincing arguments for higher air fares not being passed on to the customers. As a first-order effect, therefore, no distortion in competition among airline companies is expected. Calculations with the AERO model showed that for both the charge and the PSI, the profit margins of EU and non-EU carriers remain constant after introduction of the incentives.

Besides the profit margin, the competitive position of carriers might also be affected by changes in the size of their home market. Obviously, one second-order effect of the **charge** might be a slow-down in the growth of the European air transport market due to increased air fares. A smaller home market for European compared with non-European carriers might reduce economies of scale and may therefore weaken the competitive position of European airlines. This study shows that a charge level of € 50 per tonne CO_2 would decrease air transport volume by 2.1% for EU carriers and by 0.4% for non-EU carriers. This implies a differential reduction of 1.7% for EU compared with non-EU carriers. Based on this relatively small impact on market size, we conclude that introduction of a **charge** would not affect the operating efficiency of EU carriers significantly compared with non-EU carriers.

The **Performance Standard Incentive (PSI)** hardly affects the size of the home market, because ticket prices would not change significantly. However, impacts on ticket prices depend very much on the exact definition of the ‘performance standard’. The nature of the PSI is such that some market segments may benefit while others, operating less environmentally efficiently, may suffer until and unless they improve their environmental performance. However, the study concludes that the PSI would not lead to reduced economies of scale for EU carriers.

Tourism, remote regions and cohesion states
Consideration was given to the economic effects of these incentive schemes for countries strongly dependent on air transport. A **Performance Standard Incentive (PSI)** would not affect tourism or cohesion states, because the total financial burden and overall impact on demand would be almost zero. A **charge** variant would affect demand, however. A charge of € 30/tonne CO_2 would lead to a round-trip ticket price increase of some € 10 to € 20 for typical European charter flight stages of 1000-2500 km. If charter airlines opted to pass this on to their passengers, it would lead to an increase of 2 to 6% in the € 300 to € 600 price of a holiday package.

Any aviation charge, European or worldwide, would tend to favour nearby over long-distance tourism and could slow the current trend of long-distance travel.

A charge of € 30/tonne CO_2 would reduce the total tourist receipts of the Southern EU countries by about 0.01% to 0.1% per annum.

Legal issues
The legal analysis of the study addresses the legal position on implementation of an emission charge or PSI in EU airspace. Relevant international provisions include the Chicago Convention, the Bilateral Air Services Agreements, the legal framework of the European Union and the regulatory regime of Eurocontrol.

International aviation law and bilateral air service agreements pose no specific obstacles to introduction of a non-discriminative emission-based charge or PSI in EU airspace. However, the incentives will need to take due account of the following:
– the aim of the incentive should be to reduce greenhouse gas emissions;
– the principle of cost-relatedness, laid down in many bilateral agreements, should be respected, with a charge rate proportional to the (external) costs of greenhouse gas emissions;
– the terms of the proposed scheme should be clearly communicated to all parties;
– the principles of transparency and non-discrimination should be respected;
– any revenues collected should be used primarily for mitigating the climatic impact of aircraft engine emissions.

In legal terms it will be necessary to make clear that:
– the incentives in question are designed to mitigate greenhouse gas emissions and are certainly *not* taxes on fuel and have no fiscal aim whatsoever;
– the Polluters Pays Principle laid down in Article 16 of the Rio Declaration and Article 174 of the EC Treaty forms the legal basis for imposition of a charge or PSI on the greenhouse gas emissions of air transport in the EU;
– the emission calculation methodology underlying the charge or PSI is *not* based on a “direct and inseverable link” between fuel consumption and polluting substances such as carbon dioxide and nitric oxide. This condition is important, as an emission charge dependent essentially on actual fuel consumption is liable to be challenged under the same international regulations as fuel, which is exempted from charges and taxes in many bilateral agreements between EU Member States and third countries.

Eurocontrol
Use of Eurocontrol *infrastructure* for administering an emission-based en route levy would be feasible, subject to agreement among Member States to impose such an incentive.

Legal basis of EU airspace
The environmental effectiveness of an emission-based en route charge or PSI in EU airspace is co-determined by the size of the airspace, because:
– a large airspace means that a larger proportion of flights to and from the EU would be subject to the incentive;
– a large airspace would prevent changes in routes to avoid the en route emission charge.

For this reason the study investigated whether it was legally feasible to establish an EU airspace covering not only the national territory of the 15 EU

Member States, but also parts of the adjacent seas, the so-called high seas. The Flight Information Regions (FIRs) of Eurocontrol include parts of these high seas. The study concluded that there was no obstacle to use the Eurocontrol *airspace* (Including parts of the high seas*)* once the Community has adopted a measure designed to introduce an environmental charge, in co-operation with Eurocontrol and while taking into account the framework of ICAO for that purpose. Such a charge could be imposed on flights passing through the airspace covered by Eurocontrol/CRCO agreements and principles.

Use of the revenues

The primary aim of the policy instruments considered is to provide economic incentives to mitigate greenhouse gas emissions from air transport in Europe. Although not *designed* to raise revenues, an **environmental charge** would generate 1 bn - 9 bn each year. By definition, a **revenue-neutral PSI** will not generate any revenues (see Table 4).

Table 4 Revenues of the charge and PSI for different incentive levels

CO_2 valuation, € /tonne	NO_x valuation, € /kg	Emission charge (€ billion)	Performance Standard Incentive (€ billion)
10	0	1.1	0
30	0	3.3	0
50	0	5.4	0
10	1.2	1.8	0
30	3.6	5.3	0
50	6.0	8.6	0

Only in the case of a **charge** does the question of optimum use of revenues therefore arise. This study analysed the pros and cons of two options for disbursement of charge revenues (as well as studying the revenue-neutral PSI).

Allocation to Member States

Allocation directly to the general treasuries of the EU Member States according to prior politically agreed criteria could give rise to distributional complications. For example, allocation proportional to emissions in the airspace of each Member State – analogous to the disbursement rule of Eurocontrol for recovering the costs of air traffic control – would not be equitable, as they would be dictated by the country's size and position. There is no direct relationship between the damage costs of climate change for a particular country and the emissions occurring in its airspace.

Allocation to a supranational fund

Another option is for the revenues to be allocated to a supra-State body such as the European Bank for Reconstruction and Development (EBRD), European Investment Bank (EIB) or Global Environment Facility (GEF). Although these institutions cannot yet operate autonomously at the EU or global level with revenues from sectoral charges, they can certainly do so with funds raised independently of the Community budget and earmarked for specific policy objectives.

Revenue-neutral option (Performance Standard Incentive)
The revenue-neutral option avoids the problems of revenue redistribution among countries and does not affect sectoral competitiveness as a whole (although individual firms may be affected). However, this is not entirely compatible with the Polluter Pays Principle, as the PSI recycles revenues to the aviation sector, thus only partly 'internalising' external costs.

1 Introduction

1.1 Background

Emissions of greenhouse gases from aircraft engines contribute to climate change. The climatic impact of aviation is expected to grow in the coming decades and a variety of actions have been proposed to mitigate this impact. ICAO's Committee on Aviation Environmental Protection (CAEP) has developed an action plan which considers the use of improved technology, better operational procedures and market based measures.

Recent studies appear to show that introduction of a tax on aviation fuel at the European level would give rise to legal problems and considerable distortions in competition among airlines. The European Commission has therefore taken the initiative of launching a study on the feasibility and effectiveness of alternative policies to mitigate greenhouse gas emissions from air transport in Europe, one such policy being a levy on emissions. The 1999 Communication "Air Transport and the Environment: towards meeting the challenges of sustainable development" (COM(1999)640) notes that the European Commission will be carrying out this preparatory work with a view to possibly introducing proposals to establish economic incentives to mitigate the greenhouse gas emissions of air transport in Europe. This feasibility study is an essential part of that preparatory work.

1.2 Objective of the study

The objective of this feasibility study can be formulated as follows:

To design and assess practical options for economic incentives to mitigate greenhouse gas emissions from air transport in Europe, and to formulate proposals for actual implementation of such incentives.

In drawing up environmental policy for the aviation sector, economic incentives such as levies and tradable permits form an attractive option because they give the sector the flexibility to take steps to reduce greenhouse gas emissions at least cost. In this study, analysis of such economic incentives is limited to the following two main policy variants:

1. **An environmental charge**
   In this variant a charge is levied proportional to the absolute emission (e.g. kilograms CO_2) of an aircraft in the airspace of the European Union. This generates revenues, and the challenge here is to design options for revenue use that are broadly perceived as fair and economically efficient.

2. **A Performance Standard Incentive (PSI)**
   Under this methodology the better an aircraft performed in comparison with a precalculated 'performance standard', the more it would be financially rewarded, and the worse it performed, the more it would pay. This variant is designed to be revenue-neutral, with the sum of payments and revenues equalling zero.

This study does not consider a hybrid system, for the disadvantages of both options are then expected to prevail. The following two issues will clarify this.

First, a major advantage of the Performance Standard Incentive (PSI) is that no revenues would be raised and the difficult task of finding a formula for distributing the revenues would therefore be avoided. Second, one of the main challenges of the PSI is to find a performance parameter that provides an optimum incentive but can also be implemented without imposing significant extra administrative burden on airlines. Combining the two options would simply stack the two difficulties atop one another. By assessing them separately their individual pros and cons can be identified with maximum clarity.

1.3 Demarcation of scope

The scope of the present study is demarcated in a number of significant respects, most of which are discussed in greater detail in Chapter 2. The following are the most important:

1 The principal aim of the economic incentives considered in this study is to mitigate greenhouse gas emissions from air transport in Europe, taking as the point of departure the scientific knowledge on the climatic effects and related emissions of aviation presented in the Special IPCC report "Aviation and the Global Atmosphere", published in 1999.
2 The study focuses solely on economic incentives in the form of levies on each kilogram of pollutant (e.g. CO_2 and NO_x) emitted by aircraft flying in the airspace of the European Union.
3 This study does NOT consider charges or taxes on fuel.
4 This study considers only those emissions which, in the view of the IPCC (1999), contribute to climate change. No consideration is given to other emissions occurring during the Landing and Take-Off cycle (LTO), nor to emissions affecting local air quality in the vicinity of airports. It is assumed that these emissions are covered by airport-related instruments, such as those discussed by the ANCAT Sub-Group on Emissions Related Landing Charges Investigation (ERLIG).
5 Choosing to focus on emission reduction implies that the aim of the economic incentives is not to raise general government revenue, nor to reduce the volume of air transport. This is important to stress. Although unintended, emission-based incentives may still generate revenues or reduce the transport volume, however. The possible use to which these revenues can be put is therefore considered in this study.
6 To assess the feasibility of emission levies or incentives it is essential to be explicit about the countries participating. In this project it is assumed that the economic incentives will be levied in the 15 Member States of the European Union. However, because other countries such as Switzerland, Norway and EU-accession countries are members of Eurocontrol, the additional participation of these countries would be fairly easy.
7 This study considers, for obvious reasons, only so-called non-discriminative incentives. This implies that European and non-European airline companies with the same level of emissions are assumed to be subject to exactly the same emission levy. In other words, all airlines operating intra-EU flights and flights to and from the EU must pay the same charge or PSI.

1.4 Project organisation

The study was carried out by CE Delft and its partners in response to a European Commission request for technical guidance as a basis for policy development. It therefore presents facts and professional estimates regarding the scientific and policy effects of emission abatement incentives. Selection of a particular policy line or variant is the sole prerogative of the client, however. Besides CE, the following consortium partners have also made important contributions: the Institute of Air Transport (ITA) in France, the International Institute of Air and Space Law and Peeters Advies, both from the Netherlands, and Mr. Dan Greenwood and Professor Rigas Doganis, both from the United Kingdom. Furthermore, the kind cooperation of Eurocontrol, Brussels is gratefully acknowledged. Finally, the authors wish to extend their special thanks to the Dutch Civil Aviation Administration for making the AERO model available for this study.

Involvement of stakeholders
The draft results of the study were presented and discussed at several meetings with stakeholders. At the outset of the project, in April 2001, the project structure and main research questions were discussed at IATA in Geneva with several European and non-European airlines. Later, in January 2002, the draft results of the study were presented and discussed in detail with the 15 EU Member States as well as with stakeholders such as airlines, manufacturers and environmental NGOs. Finally, in February 2002, the draft final results were presented and discussed with the Market Based Options Group of the Committee on Aviation Environmental Protection (CAEP) of the International Civil Aviation Organisation (ICAO).
The assessments and analyses underlying this study benefited greatly from the contributions made during these discussions. The authors therefore wish to extend special thanks to these contributors for their constructive discussions and comments. Notwithstanding all the help received, the content of the report is the sole responsibility of the authors.

1.5 Report structure

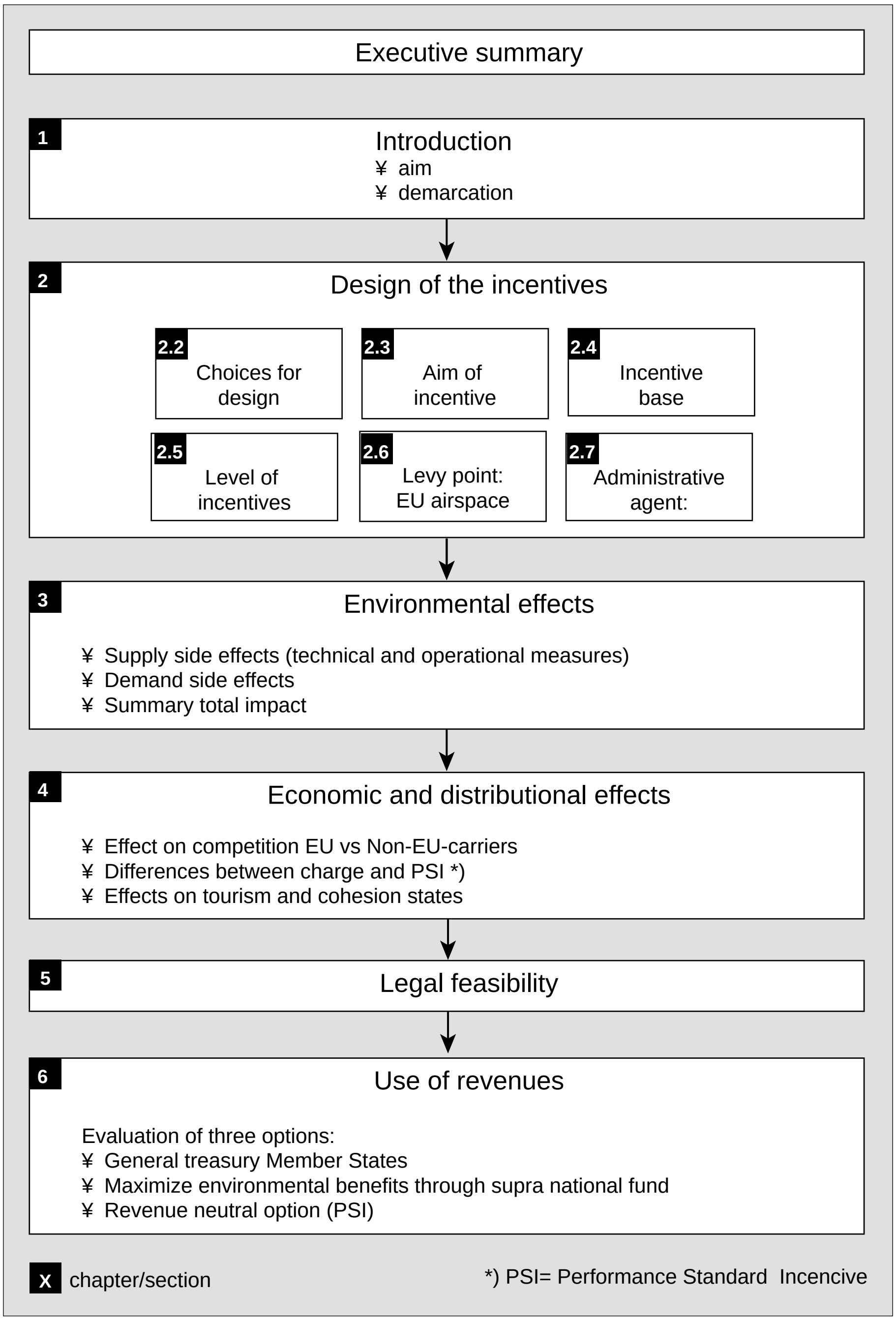
The structure of this report is as follows:

Chapter 2 discusses choices regarding the design of the two policy instruments: an emission charge and a Performance Standard Incentive (PSI), with respect to:
- Basic design choices (2.2);
- Aim of the incentives (2.3);
- Incentive base (2.4);
- Incentive level (2.5);
- Levy point: EU airspace (2.6);
- Administrative agent: Eurocontrol (2.7).

Chapter 3 presents an evaluation of the environmental effectiveness of the charge and the PSI and covers the following issues:
- Brief overview of models and data used;
- Analytical framework and impacts on direct operating costs (DOC);
- Supply-side responses (operational and technical measures) by airlines to reduce greenhouse gas emissions[6];
- Demand-side and substitution effects.

6 Summarised in chapter 3 and described in detail in Annex E of this report.

Figure 2 Structure of the report



Chapter 4 presents an evaluation of the economic and distributional effects of the two policy variants. The following aspects are discussed:

- impacts on transport volume;
- impacts on competitive position between EU and non-EU carriers;
- impacts on tourism and cohesion states.

Chapter 5 addresses legal conditions, in order to ensure compatibility of the charge and PSI with the international legal framework[7].

[7] Described in detail in Annex D of this report.

Chapter 6 presents an evaluation of the advantages and drawbacks of two options for allocation and use of the revenues of an emission-based charge. In addition, the pros and cons of a revenue-neutral PSI are discussed.

This report is supplemented by eight annexes (A to H) providing more detailed information on several key issues and descriptions of the models and databases used.

2 Design of the incentives

2.1 Introduction

There are many different ways to shape economic incentives such as the environmental aviation charge and Performance Standard Incentive (PSI) considered in this study. Choices with respect to design go a long way to determine the environmental impact, potential economic distortions, legal and institutional implications and distributional consequences of such incentives. A well-balanced design should therefore seek to improve the environmental performance of aviation in Europe in an efficient manner, while at the same time giving ample consideration to practical feasibility of implementation.

This chapter discusses the following important choices with respect to design:
- Basic design choices (2.2);
- Aim of the incentives (2.3);
- Incentive base, including an analysis of possible calculation methods and physical units providing a volumetric basis for the charge and PSI (2.4);
- Incentive level and impacts on operating costs and ticket prices (2.5);
- Levy point: EU airspace (2.6);
- Collecting agent: Eurocontrol (2.7).

The aim of this chapter is not to produce 'the best-designed economic incentive'. It merely presents alternative options and discusses their main advantages and disadvantages. In addition, consideration is given to aspects of practical implementation, clarifying what is feasible in the short and in the long term.

Before the principal choices with respect to design of the economic incentives are discussed in detail, a general overview is presented in section 2.2 of all the choices that can, in principle, be made with regard to the design of the policy options considered.

2.2 Basic design choices

There are many conceivable forms of economic incentives under the heading of levies and revenue-neutral incentives that might serve to reduce the main emissions contributing to the global environmental impact of aviation. In the design of such economic incentives there are many degrees of freedom with respect to incentive base, incentive level, overall scope and options for revenue collection, allocation and use. Within this broad 'playing field' the challenge is to identify a limited number of effective and feasible policy options for further assessment. Table 5 reviews the basic choices to be made with respect to design of an incentive scheme.

Table 5 Identification of basic design choices of an incentive scheme

Design characteristic	Degrees of freedom	
Type of incentive	- Charge - Performance standard incentive (revenue-neutral)	
Incentive base	*Which emissions?* - CO_2 - CO_2 and NO_x - Basket (CO_2, NO_x and other emissions)	
	What emission calculation method? - ex ante (before the specific flight) - ex post (after the specific flight)	
	What productivity parameter? (relevant for performance standard incentive only) - distance (kilometres) - MTOW*km - Actual payload*km - Maximum payload*km - Maximum Zero Fuel Weight (MZFW)*km	
Scope	*Which flights and carriers are to be subject to the incentive and over what geographical area?* - intra-EU + inter-EU flights - all carriers (non-discriminative) - Eurocontrol airspace (national territory or Flight Information Region)	
Incentive level	*What approach is to be followed to establish the level of the incentive?* - Internalisation of external costs - Environmental target - Equal to taxation levels in other sectors	
Collecting agent and levy point	*Which authority will levy and when?* - Eurocontrol / en route in EU airspace - Airport authority / landing of aircraft - Airline company / sale of ticket	
Allocation of revenues	*To which institutional scale are revenues to be allocated?* - EU budget or EU fund - EU Member States - Aviation sector	
Use of revenues	*How are revenues to be used?*	
	General treasury	- recycling to citizens - reductions of other taxes - earmarking for environmental investments
	Recycling to aviation sector (*indirect*, through EU body, new facility or Member States)	- R&D support to industry - Financial mechanisms (e.g. subsidies for ‘scrapping programmes’) - Support for improvement of Air Traffic Management (ATM) - Financing emission reduction in other sectors
	Revenue-neutral	- Performance Standard Incentive

Based on the results of the four preliminary studies carried out in the framework of this study, two main options were selected. Note, however, that none of these is necessarily the ‘optimum’. The results of the assessment phase may show, for example, that one of the options is less attractive because of less effective use of revenues, say, or legal barriers. In that event policy makers will be able to choose another variant and thus optimise the design of the economic incentive considered.

2.3 Aim of the incentives: to mitigate greenhouse gas emissions

A crucial choice in the design of any policy instrument is the precise objective to be pursued. The starting point of the present study is that the incentives are aimed at mitigating greenhouse gas emissions from air transport in the EU throughout the entire flight. The Special IPCC report “Aviation and the Global Atmosphere", published in 1999, provides the scientific basis for the study. This Special Report distinguishes two global environmental impacts of aviation: (i) climate change and (ii) changes in incoming UV radiation. This study focuses solely on the former, i.e. on designing incentives to mitigate the climatic impact of aviation. Impacts on incoming UV radiation have not been considered, because IPCC (1999) concludes that the operations of the current subsonic civil aviation fleet may even reduce the UV burden somewhat. However, supersonic aircraft will lead to an increase incoming UV radiation, although development of a supersonic fleet is very uncertain and will probably not take place in the coming decades.

Below we provide a brief, general review of the current status of climate science in general and the relationship with aviation in particular. Based on this review, we conclude at the end of this section which emissions contributing to climate change are to be included in the incentive base of the policy variants considered.

2.3.1 IPCC Third Assessment Report and Special Report on Aviation

In recent years scientific knowledge on the potential impacts of greenhouse gas emissions in general and aviation emissions in particular has improved substantially. This is reflected in the IPCC's 1999 'Special Report on Aviation and the Global Atmosphere' and its 'Third Assessment Report', published in 2001.

As reported in the latter, "There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities. (…) Most of the observed warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations. (…) Emissions of CO_2 from fossil fuel burning are virtually certain to be the dominant influence on the trends in atmospheric CO_2 concentration during the 21st century. (…) The globally averaged surface temperature is projected to increase by 1.4 to 5.8°C over the period 1990 to 2100." (Report from Working Group 1, Summary for policymakers)

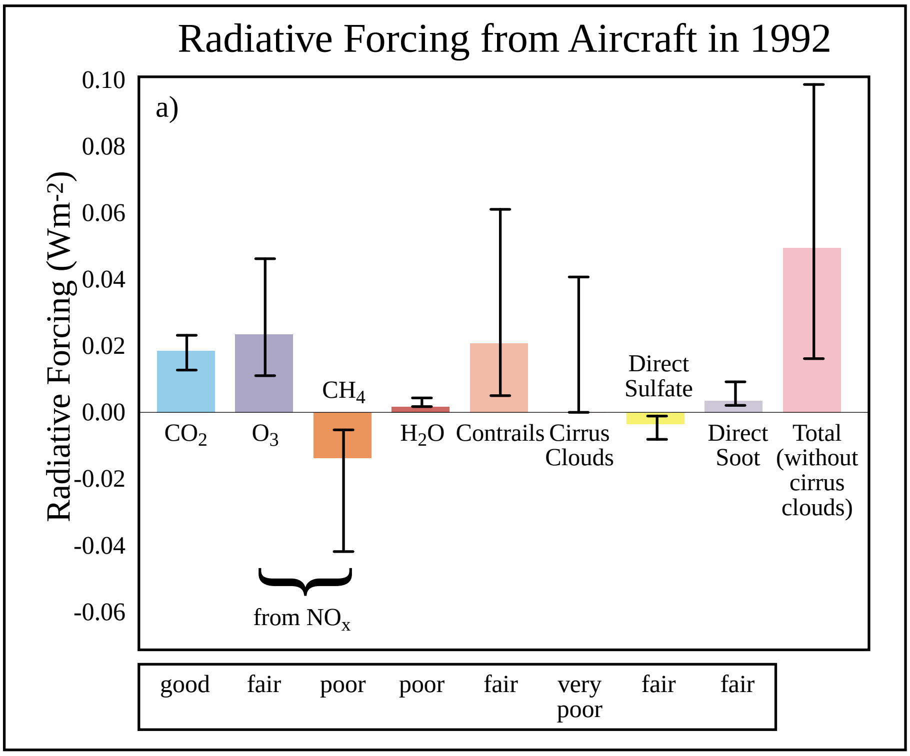
In a report requested by the American White House to help the Administration’s ongoing review of U.S. climate change policy, the U.S. National Academy of Sciences confirms the major findings of the IPCC:

> “The committee generally agrees with the assessment of human-caused climate change presented in the IPCC Working Group I (WGI) scientific report, but seeks here to articulate more clearly the level of confidence that can be ascribed to those assessments and the caveats that need to be attached to them. (…) The IPCC’s conclusion that most of the observed warming of the last years is likely to have been due to the increase in greenhouse gas concentrations accurately reflects the current thinking of the scientific community on this issue.”

The IPCC's 'Special Report on Aviation and the Global Atmosphere', issued in May 1999, describes the likely climatic impact of aviation in the base year 1992 and in the future. The report estimates that aviation's contribution to anthropogenic radiative forcing amounted to about 3.5% in 1992 and would, in a reference scenario, amount to 5% in 2050. In absolute terms, forcing in 2050 would be 3.8 times as high as in 1992. The band width is rather broad: the lower and upper scenarios considered give a factor of 1.5 less to 3 times greater than in the reference scenario, ranging from 2.6 to 11 times the value in 1992.

One of the key graphs from this report is reprinted below.

Figure 3 Impact of aviation emissions on the earth's radiative balance and hence on the forced greenhouse effect, in 1992 (IPCC 1999).



Radiative forcing (RF) is defined here as the degree to which emissions change the radiative balance of the atmosphere. Global mean RF is approximately linear to change in equilibrium mean surface temperature and is therefore a good proxy for the global warming potential of emissions.

The bars indicate the best estimate of forcing, while the line associated with each bar indicates a confidence interval: based on current scientific understanding, there is a 67% probability that the true value lies within this range. The confidence intervals are largely independent of the level of scientific understanding ('poor', 'fair', etc.)

Ozone (O_3) is not a direct emission but is formed by atmospheric reaction, triggered by NO_X. The lifetime of the potent greenhouse gas CH_4, on the other hand, is shortened as a result of NO_X emissions.

Table 6 presents the figures numerically, for calculations, and adds the figures for 2050.

Table 6 Perturbation of the radiative balance due to aviation emissions, in Watts per square metre (W/m^{2}), for the 1992 situation and a 2050 reference scenario, according to IPCC (1999)

Perturbation due to	1992, middle estimate	2050 reference scenario, middle estimate	Level of scientific understanding
CO_2	+0.018	+0.074	good
O_3 (from NO_X)	+0.023	+0.060	fair
CH_4 (from NO_X)	-0.014	-0.045	poor
stratospheric H_2O	+0.002	+0.004	poor
contrails	+0.02	+0.10	fair
cirrus	p.m. (0 - 0.04)	p.m. (0 - 0.16)	very poor
sulphate aerosols	-0.003	-0.009	fair
soot aerosols	+0.003	+0.009	fair
Total	**+0.049 + p.m.**	**+0.193 + p.m.**	

p.m.: *pro memoria,* 'item pending'

As the graph and table show:

- in the middle estimate of the reference scenario, total radiative forcing due to aviation will increase by a factor 3.8 between 1992 and 2050;
- emissions of NO_X lead to changes in tropospheric ozone (O_3) and methane (CH_4). On a globally averaged basis, these two effects have opposite signs: the net globally averaged impact on radiative forcing of O_3 is about half that of CO_2. IPCC (1999) states that "Changes in tropospheric ozone mainly occur in the Northern Hemisphere, while those of methane are global in extent so that, even though the global average radiative forcings are of similar magnitude and opposite in sign, the latitudinal structure of the forcing is different so that the net regional radiative effects do not cancel."
- the globally averaged impact of stratospheric H_2O emissions is about 11% that of CO_2 and its share in environmental impact is likely to decrease somewhat;
- the globally averaged impact of persistent contrails is much more uncertain but, according to best estimates of IPCC (1999), comparable to that of CO_2. Contrail formation can be accurately predicted for given atmospheric temperature and humidity conditions;
- the impact of the cirrus clouds that sometimes result from persistent contrails is known with even less certainty, but might be substantial, as upper estimates give twice the impact of CO_2 alone;
- the effects of sulphate aerosols and soot aerosols cancel; sulphate aerosols cool the earth and soot aerosols warm it, both at a rate of about 15% of that of CO_2 emissions;
- the total radiative forcing due to aviation, according to the middle estimate and excluding cirrus clouds, is about 2.7 times (2 to 4 times) as high as that due to CO_2 alone. In the 2050 scenario this factor is likely to remain fairly stable (2.6).

Conclusion

According to current understanding, as summarised above, the prime concerns with respect to the climate impact of aviation are: emissions of CO_2, contrail formation and emissions of NO_X. The contribution of sulphur and soot aerosol emissions is relatively small; there is also wide variation in emission factors, while the chemistry is complex. The impact of cirrus clouds is very uncertain.

Although the formation of contrails could be of prime concern with respect to climate change, here we focus solely on policy options aimed at reducing emissions of CO_2 and/or NO_X. Contrail formation has not been included in the incentive base for two reasons. First, because there is still too much scientific uncertainty on this point. Second, because we do not consider a charge or PSI a suitable or efficient incentive for reducing aviation contrail formation, for contrails are not caused by all flights and arise only during a limited portion of flight time.

In the following sections, which discuss the base of the incentives (section 2.4) and their level (section 2.5), we consequently focus primarily on CO_2 and NO_X emissions.

2.4 Incentive base

Once the aim of the economic incentives has been established (see section 2.3), another important choice with regard to design relates to the incentive base or charge base. The incentive base determines the volume on which the charge is to be levied.

As mentioned earlier, this study considered two options for economic incentives:
- an environmental charge for each kg of emission produced. This system generates revenues;
- *a Performance Standard Incentive (PSI)* that 'rewards the best and punishes the worst'. The average amount to be paid is zero, so the system generates no net revenues.

In designing both variants the following key main choices must be made with regard to charge base:
1. Which emissions are to be included (CO_2, NO_X, other)? (section 2.4.1)
2. What (certified) information is available for calculating emissions over the entire flight? (section 2.4.2)
3. What calculation methods are most suitable? (section 2.4.3)
4. What productivity parameters can be used to define the average environmental performance of all aircraft flying in EU airspace ('performance standard')? Obviously, this is only relevant for the Performance Standard Incentive (2.4.4).

These key choices are now discussed.

2.4.1 Type of emissions

Based on the scientific knowledge published in IPCC (1999) we concluded at the end of section 2.2 (aim of the incentive) that our focus would be on the climatic impacts caused directly by CO_2 and indirectly by NO_X emissions.

An incentive based solely on CO_2 appears to be the most practical and feasible option. However, in order to demonstrate the technical scope for including NO_X and indicate the pros and cons of including NO_X compared with CO_2 alone we have also included combined CO_2 and NO_X variants.

Including NO_X variants in the incentive base may also be attractive for several technical and legal reasons:
- for a given level of engine technology there may be a trade-off between CO_2 and NO_X emissions, as CO_2 generally decreases and NO_X increases with increasing engine pressure and temperature. Restricting

the incentive base to CO_2 alone may therefore bring with it the risk of sub-optimal shifts towards high-NO_X engines;
- if NO_X is included, the relationship between the incentive and fuel consumption becomes non-linear, possibly avoiding potential legal obstacles (see chapter 5).

We have consequently taken both CO_2 and NO_X emissions, separately and together, as a possible levy base for the incentives considered.

2.4.2 Available data

The data used for establishing flight emissions must be such as to ensure calculations in closest possible agreement with real emissions. In general terms, flight emissions of CO_2 and NO_X depend on:
- engine;
- airframe;
- flight path (including speed and altitude);
- flight distance;
- load.

Some of these factors may not necessarily have to be included in calculations, but might be approximated using average values. Obviously, an attractive option is to calculate CO_2 emissions from the actual fuel consumed during the flight in question. Below, we discuss data that are publicly available as well as data available within the aviation industry (airlines or manufacturers) that can be used for emission calculation.

Publicly available data

Eurocontrol
Eurocontrol currently has the following data on each flight handled:
- great circle distance flown in Eurocontrol airspace;
- aircraft type (and thus MTOW-average per user and aircraft type);
- airport of departure/airport of destination;
- aircraft call sign (aircraft registration, flight number or military call sign).

Eurocontrol is currently working on making actual MTOW and registration numbers available for each flight within its airspace. The availability of registration numbers is very important as this enables aircraft-specific emission data to be attached to each flight. Besides, if registration data are available, the engine characteristics of the aircraft will also generally be known.

Emission models and databases
Currently, numerous organisations like FAA, ANCAT, DLR, DERA, Dutch CAA, and Inrets all operate different models for estimating aircraft and aviation emissions. They all aim to estimate aviation emissions for the purpose of environmental impact studies and in doing so can be of great value in gaining first insights into the emission characteristics of most types of aircraft.
None of these models include more than a few dozen different aircraft configurations, however, while the actual number of configurations may be well over 1,000. In addition, none of the models have undergone a legal certification process.
A further key point is that the models are all limited by the data from the ICAO Engine Exhaust Emissions database. This database, available on the

internet, has LTO emission data on some 300 engine types certified as of the early 70s. However, it contains no data on turboprops or piston engines, nor on engines with a power output below 26.7 kN. For aircraft equipped with these kind of engines, data accuracy is generally quite poor.
As a result, the available models could be used only for establishing first-pass estimates for the emission characteristics of certain aircraft types for which data like MTOW, airframe type or engine type are available.
However, none of the models seems suitable for the purpose of the present study: to establish a definitive base for economic incentives, which requires much more specific data on different aircraft types, and requires these data to be certified.

Data available in the industry

Aircraft performance manuals
Every aircraft delivered to airlines has its own individual performance manual. The most relevant information in these manuals in our present context are the fuel consumption tables for the specific aircraft under different operational circumstances, such as climb angle and cruise speed. These data have been certified, mainly for safety reasons (reserve fuel), and are the property of the airlines. Airlines use these data to construct their own predictive models for fuel consumption.
The fuel tables are based on the manufacturer's in-house prediction codes, which are the property of the manufacturers and are not generally passed on to airlines (Lister, 2001).

Besides fuel consumption data, the manuals contain payload/range diagrams showing the capacity of an aircraft to carry certain loads over certain distances. In principle, such information would be useful for defining a productivity parameter, relevant for designing the second main variant considered in this study: the *Performance Standard Incentive (PSI)*
.
Unfortunately, the payload given is highly dependent on aircraft configuration: an aircraft type configured for passengers has a lower payload than the same type configured for freight. As configurations can be switched fairly easily, and some airlines do this frequently, this definition of payload is not very useful. There is as yet no payload definition available *independent of configuration*. Work on this is underway in CAEP Working Group 3.

Flight documentation
Finally, airlines have an obligation to prepare flight documentation on each flight and keep it filed for a certain period, generally 3 months. Trip fuel is probably the most important category of data registered.

2.4.3 What emission calculation method?

A crucial aspect of the design process is to find an emission calculation method providing an incentive for all possible optimisation mechanisms (new technology, operational measures, optimisation of load factor, etc.) for reducing emissions. In addition, the emission calculation method should preferably also be transparent, based on officially accepted documents (e.g. aircraft manuals, ICAO database, etc.) and implementation should not lead to too high an administrative burden for the stakeholders concerned.

Annex B sets out the pros and cons of several options for calculating emissions. An important distinction is thereby made between methods for calculating emissions ***ex ante*** and ***ex post***. By *ex ante* calculation we mean that the emission level of a given flight is determined *before* the flight has taken place, based on parameters like calculated distance and aircraft characteristics. By *ex post* calculation we mean that the emission level is determined *after* the flight has taken place, based on flight parameters like actual fuel use, or measured settings.

From the viewpoint of environmental effectiveness, *ex post* calculation of emissions is preferable to *ex ante* calculation, for it leaves operators a wider range of options to reduce emissions. For example, if the emissions of a certain flight are calculated *ex post*, there will be due incentive to optimise cruise speed for minimum fuel consumption during that specific flight, whereas this incentive will be absent if emissions are calculated *ex ante*.

In this study we considered, for both the environmental *charge* and the *Performance Standard Incentive* variants, the following four options for an incentive base:
- incentive based on *ex ante* CO_2 emission; CO_2 emission for the specific aircraft type on the specific flight is calculated *ex ante*, based on a certain standardised flight path and load factor;
- incentive based on *ex post* CO_2 emission; CO_2 emission for the specific aircraft on the specific flight is calculated *ex post*, based on actual flight data;
- incentive based on *ex ante* CO_2 and NO_X emissions;
- incentive based on *ex post* CO_2 and NO_X emissions.

Conclusions
We here present the main conclusions on the possibilities of *ex ante* and *ex post* methods of calculating CO_2 emissions and NO_X emissions for use as a basis for the incentives considered.

On the basis of the findings in Annex B the following conclusions can be drawn with regard to **ex ante** calculation methods:
- there is currently no official cycle similar to the official LTO cycle for calculating CO_2 and NO_x emissions from aircraft in the cruise phase;
- existing emission models are of limited use for the purpose of this study, as the available data are too limited to form a definitive base for the incentive. Models might be used, however, to establish a first-pass estimate of emissions, based for example on MTOW and great circle distance of the specific trip;
- the only option for arriving at accepted and specific *ex ante* emission figures for individual aircraft would be to use the fuel calculation methodology described in aircraft performance manuals, which are currently confidential.

Ex post calculation would have the following consequences:
- the environmental effectiveness of the incentives would certainly benefit if *ex post* methods were used, as would their economic efficiency, for operational measures to reduce emissions would be duly rewarded (lower speeds, less steep climb angles, higher load factors, etc.);
- emission classification of aircraft is of hardly any use for *ex post* calculation; some sort of continuous system is required;
- the number of checks to be performed by the relevant authority would increase substantially;

- the most attractive option for arriving at accepted and specific *ex post* calculated emission figures for individual aircraft would be to base the CO_2 emission on the carbon content of the trip fuel, which airlines are currently obliged to register in the weight and balance documentation;
- if emissions are calculated *ex post* airlines run the risk of paying emission penalties for delays resulting from ATM problems. This could be avoided by using an *ex ante* emission figure as a basis, to reward airlines if they do better, but *not* to punish them if they do worse (owing to congestion, for example);
- responsibility for making and acquiring detailed emission calculations for each individual aircraft type (probably over 1000) should not lie with the administrative body. This would lead to an excessive burden, and would require very considerable specific expertise that is currently readily available at aircraft manufacturers and operators. Additional *ex post* data should therefore be provided by airlines, on a **voluntary basis**¸ with the relevant authority merely performing checks on this industry data;
- actual trip data should be supplied by airlines, who will only do so if this is either obligatory or beneficial to them. The higher the *ex ante* emission estimate, the greater will be this incentive.

Three-step approach
Based on the potentials of the *ex ante* and *ex post* calculation methodologies presented above, we consider the following three-step approach to be the most feasible:
1 As a first step, the authority could define maximum emissions for a given MTOW and great circle distance for a flight in EU airspace.
2 If operators think their aircraft will emit less than the figure assumed by the authority, airlines would have the opportunity (voluntary approach) to provide ***ex ante*** calculated emission figures from their *performance manuals* for their specific aircraft on different distances along a standard flight cycle.
3 If they manage to operate their aircraft such that actual emissions are lower than the standard profile of step 2, operators could supply actual flight data on e.g. fuel consumption from which to calculate emissions on an **ex post** basis. This opportunity gives airlines an incentive to operate their aircraft as efficiently as possible. The more the *ex ante* emission calculated in step 2 approximates a 'worst case' figure, the greater the incentive for an airline to do better in step 3.

This three-step system has the following advantages:
- maximum incentive to airlines to reduce emissions;
- an upper limit of charges to be paid, according to step 2. This is relevant in cases where an aircraft causes excessive emissions owing to circumstances beyond its control, when it is forced to 'hold' near an airport, for example;
- a workable distribution of responsibilities: airlines supply methodologies and figures and authorities perform checks on fraud and consistency.

2.4.4 Performance Standard Incentive (PSI): productivity

This variant is a revenue-neutral scheme that aims to financially reward operations flown in a relatively environmentally efficient manner (i.e. more efficient than a certain performance standard) and financially penalise operations that are relatively inefficient in environmental terms (i.e. less efficient than the performance standard). Thus, the opportunity to reduce the charge burden or increase the level of rebate by improving efficiency provides *both* environmentally inefficient *and* efficient operators financial an incentive to improve their performance. These responses will therefore tend to push the standard (or industry average) toward best practice levels, and indeed improve current best practice.

To preserve the principle of revenue neutrality, the performance standard must reflect the average environmental efficiency of air transport operations for a given accounting period (normally one year). The challenge with this incentive variant is to define the performance standard such as to quantify the environmental efficiency of air transport operations both equitably and in a manner permitting accurate comparison. Emission levels must therefore be related to an operational output parameter: tonnes of CO_2 and/or kilograms of NO_x **per unit** of air transport performance.

PSI: three possible definitions
Below we discuss three possible options for defining a performance standard reflecting industry-average environmental performance in EU airspace. We focus here on the denominator because calculation of the numerator, the volume of emissions from different airframe/engine combinations, has already been discussed in sections 2.4.2 and 2.4.3.

Three possible performance standard indicators are:
1 CO_2 and/or NO_x emissions *per aircraft kilometre.*
2 CO_2 and/or NO_x emissions *per actual payload.km.*
3 CO_2 and/or NO_x emissions *per potential payload.km or Maximum Zero Fuel Weight.km*.

The advantages and drawbacks of these options are described below.

1 Ex ante *calculation using* ***aircraft kilometres***

PSI Definition: Emissions of all aircraft flying in EU airspace over one year divided by total kilometres flown by all aircraft in EU airspace; thus, average emissions per aircraft kilometre.

This definition of PSI seems logical and straightforward; it is familiar from the EU's energy and CO_2 labelling initiative for passenger cars, which uses an identical parameter (CO_2 emission per vehicle kilometre) to distinguish fuel-efficient from less efficient cars. However, this definition could be counterproductive when applied to public air transport, because distance, without reference to what is carried over that distance, is not a good proxy for air transport performance. Consequently, a PSI defined in this way does not provide an optimum incentive for improving the environmental efficiency of air transport. For example, it would put small aircraft at a relative advantage to large aircraft, owing to their lower emissions per *aircraft* kilometre, although smaller aircraft generally produce higher emissions per *passenger or tonne* kilometre than larger ones.
Splitting aircraft into classes, each with a different PSI level, does not seem to be the definitive solution to overcoming such anomalies. The economic efficiency of the measure would then be reduced, as it would

leave little incentive for reducing emissions by shifting to other aircraft and/or optimising the network[8].

2 Ex post *calculation using* ***actual payload-kilometres***

PSI Definition: Emissions of all aircraft flying in EU airspace over one year divided by total actual payload transported multiplied by total kilometres flown by all aircraft in EU airspace; thus, average emission per actual payload kilometre.

Since payload kilometres (passengers and freight) are the product aircraft produce, the most accurate performance standard for air transport would be the actual payload kilometres performed. In this way, there would be incentives both to reduce absolute aircraft emissions and to improve load factors, as both responses reduce the emissions level per unit of air transport performance.
An important issue related to this variant is development of a methodology to add passengers and freight to produce a single payload indicator. The usual definition of Revenue Tonne Kilometres (RTKs),hereby passengers including luggage are taken as 100 kg, is unsatisfactory. This is because it takes less energy, and thus produces less emissions, to carry one tonne of freight than ten passengers over a given distance, so that this kind of definition would give freight operations an advantage over passenger transport. Passenger transport requires seats, galleys, toilets and service items such as in-flight meals and newspapers, whereas freight does not. Some airlines, including Lufthansa and Air France, have developed methodologies to correct for this in their environmental reporting. Lufthansa concluded that on short-haul flights one passenger accounts for about 140 kg on average, on medium hauls 155 kg and on long hauls 173 kg. Air France arrived at figures of between 140 and 200 kg, depending on type of aircraft and load factor. For the purpose of this study we have used a consensual 160 kg per pax as a base estimate. In the present study we shall use the expression **ARTK** (Adjusted Revenue Tonne Kilometres) to refer to payloads calculated in this way[9].
Using actual (*ex post*) payload to calculate performance would mean operators having to report full details of the payload transported on every flight. This is not an unusual practice; for example, in the UK and the US (Form 41) airlines already face such obligations. Alternatively, reporting actual payload after each flight could be based on a voluntary approach: for flights that have *actually* performed better than a 'predefined' *ex ante minimum* ARTK estimate, airlines would have an opportunity to report their *actual* ARTK and thus reap the financial benefits (see above).

3 Ex ante *calculation using* ***potential payload-kilometres (MZFWkm)***

PSI Definition: Emissions of all aircraft flying in EU airspace over one year divided by potential payload capability multiplied by total kilometres

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[8] Broad classes (e.g. a class size of 50 seats) do not really solve the original problem of this option: the smaller aircraft within this broad class are still at a relative advantage. Narrow classes (e.g. a class size of 10 seats) have the disadvantage that there are hardly any alternative aircraft to choose from within each class, which seriously reduces the environmental effectiveness of the system.

[9] Although this is not a common international term, it has been used in this study for practical reasons.

flown by all aircraft in EU airspace; thus, average emissions per potential payload kilometre.

If the previous *ex post* option using actual payload kilometres is not deemed feasible, an alternative option that is an optimum proxy for *potential* payload comes into play.
The best *ex ante* definition of potential payload would be MZFW - MEW (Maximum Zero Fuel Weight minus Manufacturer's Empty Weight). However, MEW is not an officially certified value.
MZFW is a better metric than MTOW, as the trade-off between payload and range is better reflected in MZFW than in MTOW. Fuel capacity can be highly variable across different aircraft types, depending on the design range of the aircraft. Including MZFW in the definition gives incentives to use 'normal' versions (with normal fuel capacity and high payload) for short flights, and to use ER (extended range, with high fuel capacity and lower payload) versions of aircraft for extended ranges only.
On the other hand, use of MTOW as a proxy for potential payload has the practical advantage that this value is already incorporated in the Eurocontrol charging and billing system.
The main disadvantage compared with the previous option is that no account is taken of improvements to productivity (and thus to environmental efficiency) achieved by increasing the load factor. Another disadvantage of using MZFW as the unit for air transport production in the PSI is that it gives a theoretical incentive to use larger aircraft than necessary for a flight, although in practice existing commercial pressures probably militate against this. If it were felt necessary, a solution could again be to introduce aircraft classes for each of which a separate PSI would be defined, but as already discussed under option 1, that has its own drawbacks.

All three PSI definitions work identically in encouraging cleaner engines, lower drag and changes in operating speeds and altitudes. These measures only affect the PSI numerator (which is equal in all three options), not the denominator. However, each of the options 1, 2 or 3 provides different incentives with regard to aircraft size, load factor and flight frequency. They thus have different environmental and economic impacts.

Practical administrative aspects: treasury, charge and rebate
Eurocontrol is an appropriate vehicle for the administration of a revenue-neutral performance standard incentive scheme within European airspace. This organisation already has, or has the capability to develop and maintain, the requisite databases. Eurocontrol is also already experienced in the implementation of mechanisms for flight-by-flight en-route charges based on unit rates (of navigation service charge) applied to aircraft characteristics (MTOW) and distance flown.

Thus for each flight, including overflights, Eurocontrol would either:
- apply a rate of **charge** to each unit of emissions per unit of production (e.g. tonnes per payload-km) above the average or performance standard, since an aircraft producing above-average emissions per payload-km is operating at less than average efficiency; or
- apply a rate of **rebate** (negative charge) to each unit of emissions per unit of production below the average, indicating better than average efficiency.

Whether a charge is incurred or a rebate earned, as well as the level of charge or rebate, can vary for a flight over a given distance according to the aircraft used, and, with *ex post* calculation, the payload carried. Thus over an accounting period of (say) one year, each airline will have a net debit or credit balance in Eurocontrol's total PSI account according to the sum of the debits/credits resulting from each of its flights in the year. Eurocontrol will keep PSI accounts separate from navigation service charge accounts.

It is fundamental that the performance standard and the associated rates of incremental charge or rebate are flight-specific, not airline-specific. It is equally fundamental, however, if the scheme is to be an effective incentive for improving environmental efficiency, that real money charges/rebates are collected/paid, so that there are real impacts on airline costs/revenues. The scheme is designed to be revenue-neutral across the airline sector operating in European airspace, but within that sector there will be winners and losers.

Overall, if start-of-year forecasts of emissions and flights (and in the *ex post* case, payloads) are reasonably accurate, the balance for all air transport operations in European airspace will be zero. In that situation the performance standard will be so defined and the incremental unit rates of charge and rebate so calculated as to achieve perfect revenue neutrality after meeting administration costs. In practice such perfection is of course unlikely, and the rates set for the following accounting period will have to be adjusted to eliminate any accumulated positive or negative balances in the overall account.

Relationship between PSI and stage length

In our view the simplest and most transparent approach is to adopt a linear relationship between the performance standard and the distance flown, with actual payload-kilometre or potential payload-kilometre (MZFW.km) as the denominator. We recognise that this may put short-haul flights at a relative disadvantage over long haul, owing to the higher proportion of the flight profile comprising take-off and climb, and the generally lower altitudes achieved. Thus they inevitably tend to be less efficient than long-haul flights in terms of specific fuel consumption (and, consequently, in terms of emissions per actual payload or MZFW.km).

However, a negative impact on specific fuel consumption (and thus environmental efficiency as defined here) can also begin to appear on long-haul flights at stage lengths exceeding an optimum 4000 to 5000 km, owing to the emergence of trade-offs between fuel and payload.

Despite these apparent inherent inequities between short-haul, long-haul and ultra-long-haul flights, it should be recognised that these types of operations are not generally competitive with one another. Furthermore, airlines can reap benefits from the scheme by flying in a relatively environmentally efficient manner over any length of haul, compared with their *competitors on that distance*.

We have therefore based the economic and environmental assessments in this study on a straightforward linear relationship between PSI and stage length. A measure of the complexity of the distance correction factors that might be considered by policy makers is indicated in Annex D.

2.5 Level of the incentives

An important choice in designing an emission charge or PSI is the level or rate of the economic incentive. Determining the optimum level at which the incentive is to be set depends largely on the aim, which in this study is to encourage measures to mitigate the climatic impacts of air transport. The principles adopted in specifying this aim will have a decisive impact on the levy level. In this respect several principles may be distinguished:

1 *Principle 1: economic efficiency.*
  A level aimed at internalising external costs.
2 *Principle 2: effectiveness.*
  A level aimed at achieving a predefined emission target for aviation, corresponding with a political decision.
3 *Principle 3: Fairness or equity.*
  A level aimed at equalising tax rates relative to other, allied sectors.

In this study the level of the incentives is based on the first approach: internalisation of external costs. This means setting a charge level corresponding with the costs associated with the climate change impact of aviation.

The reason the second approach was not adopted is because no emission reduction targets are available for international aviation at the EU level. An alternative approach would be to set the incentive level equal to the marginal abatement costs of CO_2 that would result in achievement of the EU target agreed under the Kyoto Protocol. This alternative approach is linked to the principle of economic efficiency.

Neither was the third approach taken in this study. Under this methodology, levies would be introduced at levels more or less equivalent to levies in other, allied areas. The incentives might, for example, be linked to current levels of excise duty on road transport fuels or to current vehicle taxes. They might also embody a correction for the fact that no VAT is currently levied on aviation. The primary aim of incentives designed using this third approach is to achieve greater fairness or equity of treatment among transport modes. This is not in line with the aim of the incentives considered in this study, however, and was therefore not used for establishing incentive levels.

It is stressed that this section does not aim to draw any firm conclusions regarding the desired incentive level. There are many different considerations pertaining to this issue and the final choice of charge level is of a political nature. This section merely presents working levels that will be used for assessing the effects of the various policy variants.

2.5.1 Internalisation of (external) costs of climate change

The starting point of the external costs approach is the assumption of perfect markets and full competition. In that case, if prices correspond with the marginal costs, economic processes will lead to maximum welfare. Market prices in this case correspond with marginal costs and are thus generally accepted as the 'right' prices.

Air pollution, however, is not incorporated in the market mechanism. The main reason is that there are no established property rights and the atmosphere is therefore a so-called free good in the economic sense. As a consequence, pollution does not have a price and economic processes generate more pollution than the social optimum. This in turn calls for the development of environmental policy to reduce pollution levels. An economic approach to environmental policy is internalisation: bring pollution into market processes. This aim can be pursued through a variety of instruments, such as government regulation, allocation of property rights, tradable emission permits and environmental charges. The study at hand focuses on this last option. The crucial question is then what the proper price is for pollution. Because there are no established market prices for pollution, so-called shadow prices must be calculated.

2.5.2 Can external costs be estimated?

The challenge is to predict the probable prices ('shadow prices') that would occur if markets existed for clean air. Two developments facilitate this process.

First, in certain areas like climate change markets are beginning to emerge. Studies on probable shadow prices in this market are now abundant.

Second, there has been considerable progress in the science of establishing shadow prices on the 'imaginary' markets for clean air and peace and quiet. Knowledge of dose-response relationships has greatly improved and there is a growing consensus on methodologies for valuing these responses, especially health effects. As a result it has become increasingly feasible, after a careful study of the body of literature, to explain the differences found between individual studies, so that narrow-range estimates can now be provided for specific situations.

In the past few years a number of studies (ECMT 1998, CE 1999, Infras/IWW 2000) have been published in which the external costs of various modes of transport are calculated. Today there is widespread use of the results presented in those studies among policy makers. None of these reports focuses specifically at aviation, however. An important reason for this is that the environmental effects of aviation emissions are substantially different from those of land transport. A more specific approach for aviation is consequently needed. In March 2002 CE published such a study, entitled 'External costs of aviation'. This study aims at estimating shadow prices, with particular focus on the specific situation for aviation. This section is based on some of the results of that study. For a detailed discussion of the methodologies and findings we refer to that report.

However, as long as real markets do not exist, 'real' prices will never be known. The aim of the CE study was not to give definitive answers as to the level of external costs, but rather to present plausible ranges and explain them.

At the same time, though, policy development does not require a precise knowledge of external costs. The primary aim of 'internalisation' policies is to generate efficient market incentives to reduce negative impacts to optimum levels. This implies that, in the short term certainly, the s*tructure* of the incentive provided is at least as important as its *level*. In the longer term, it is easier to adapt incentive levels to the optimum than it is to change the incentive structure.

2.5.3 Estimating the costs of the climate impacts of aviation

Estimating a shadow price for CO_2 emissions

As a first step towards economic valuation of the climatic impact of aviation, a cost estimate of one tonne of CO_2 emission was established by preparing a compilation of both damage and prevention cost assessments[10].

With respect to the **damage cost approach**, it was found that the social discount rate employed is one of the main factors governing the calculated CO_2 shadow price (Table 7).

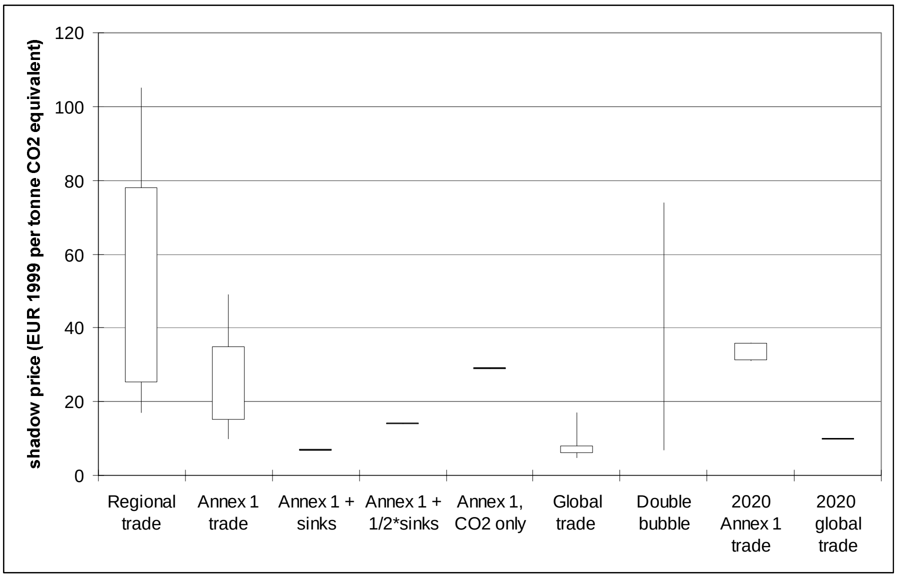
Table 7 Middle estimates of marginal cost of CO_2 emissions in often cited international literature as a function of social discount rate (extreme values omitted); values in € 1999 per tonne CO_2 emitted between 2000 and 2010

Discount rate:	0%	1-2%	3%	5-6%
CO_2 shadow price	47-104	17-56	7-20	2-8

With respect to the **prevention cost approach**, the only international reduction target on which political agreement has been reached is the Kyoto Protocol. Although separate emission ceilings for the aviation sector have also been considered, these have not (yet) been agreed upon; prevention cost estimates following from such ceilings are substantially higher than those following from the Kyoto Protocol. Figure 4 reviews the results of prevention cost studies completed *prior* to the COP meetings in Bonn and Marrakech.

10 There are two fundamentally different approaches to estimating marginal costs or, in other words, assigning a *shadow price* to a certain amount of environmental impact. The first is to assess the costs of damage/nuisance plus avoidance/adaptation resulting from one extra unit of impact. Direct damage costs can be estimated via direct dose-response relationships, questionnaires (stated preference) or changes in market prices (revealed preference). Avoidance or adaptation costs are the costs of avoiding exposure to environmental impacts without reducing the actual impacts themselves. A second - fundamentally different - approach, is the so-called prevention or abatement cost approach, use of which may be considered when across-the-board emission reduction targets are in place that have been politically agreed and are duly respected. In this case, one extra unit of emission does not lead to extra damage or avoidance costs, but rather to additional abatement measures - somewhere in the economy - to reduce emissions to the agreed target level. In such cases, the costs of emissions can therefore be represented by the marginal costs of reducing emissions to the agreed target. Given their different nature, the damage and prevention cost approaches do not necessarily lead to the same shadow prices. Only if the politically agreed target is at a theoretical optimum will shadow prices based on the two approaches be the same.

Figure 4 Overview of marginal prevention costs of one tonne of CO_2-equivalent under the Kyoto Protocol, under several assumptions with respect to scale of trade, mechanisms and timeframe



Ranges indicated by *lines* represent the extremes found in the literature, ranges in *boxes* the range disregarding the most extreme values found.

- regional trade: only trade *within* EU, US and Japan is permitted;
- Annex 1 trade: JI (Joint Implementation) permitted (trade between all Annex I countries);
- global trade: JI + CDM (Clean Development Mechanism) permitted, to be considered a variant with maximum use of Clean Development Mechanism;
- (1/2*)sinks: (half of) sinks may be used in addition to JI;
- CO_2 only: infinite prevention costs of non-CO_2 greenhouse gases;
- 'double bubble': trade permitted in two bubbles: one US/Japan/Australia, the other all other Annex 1 countries. Lower value represents costs for first bubble, higher for the second;
- 2020: Kyoto targets apply to 2020 as well.

As can be seen, the shadow price estimates yielded by the damage and prevention cost approaches are of a similar order of magnitude, ranging from around € 5 to over € 100 per tonne of CO_2. The Bonn and Marrakech agreements on sinks will certainly push down the shadow prices from the prevention cost approach to the lower end of the range. On the other hand, it is clear that 'Kyoto' is only an interim target. Figure 4 shows that mere stabilisation in 2020 will drive shadow prices up.

In this broad range of estimates, we have chosen to work with a middle estimate of € 30 per tonne of CO_2-equivalent and to perform sensitivity analyses using figures of € 10 and € 50 per tonne.

Valuation of NO_X emissions

The climatic impact of NO_X emissions arises from two entirely different processes: net production of tropospheric ozone (O_3) and net loss of methane (CH_4). On a globally averaged basis, these two effects have opposite signs: the net globally averaged impact on radiative forcing of O_3 is about half that of CO_2. IPCC (1999) states that "Changes in tropospheric ozone mainly occur in the Northern Hemisphere, while those of methane are global in extent so that, even though the global average radiative forcings are of similar magnitude and opposite in sign, the latitudinal structure of the forcing is dif-

ferent so that the net regional radiative effects do not cancel". This might imply that a charge or PSI to reduce the climatic impact of NOx emissions needs to be differentiated with respect to time, altitude and location. However, there is currently a lack of scientific evidence to support such a differentiated NO_X charge or PSI.
Summarising, the two mechanisms caused by NOx emissions should be valued separately. However, for reasons of practical feasibility (implementation) and lack of scientific knowledge we have opted here to work with a global average net result. Still, some types of charge or PSI offer the option of adding a differentiation at a later stage.

Subsequently, based on a radiative effect half that of CO_2, as indicated by IPCC for the year 1992, and based on an emission index of 13 g NO_X per kg of fuel (IPCC 1999), we arrive at low, medium and high valuations of 1.2, 3.6 and 6 € per kg of NO_X emissions[11].

Table 8 presents an overview of the working levels used in this study.

Table 8 Working levels for the incentive options

	Low	Medium	High
CO_2 (€ per tonne)	10	30	50
NO_X (€ per kg)	1.2	3.6	6.0

The most important parameters determining the external costs of greenhouse gas emissions are:
- the shadow price per tonne CO_2-equivalent. Estimates may vary by a factor 5, depending on the assumptions regarding the reduction target and the permitted flexible mechanisms;
- the level of aircraft technology;
- the question of whether or not contrails are formed; only a limited amount of flights lead to a climatic impact comparable to that of CO_2[12]. However, this factor is not addressed in this study as scientific uncertainties are still too large.

2.5.4 Initial impacts on operating costs and ticket prices

The next important question is: which shadow prices, reflecting external costs, should the incentive level be based on? For maximum efficiency the incentive should, ideally, be directly proportional to *all* aircraft emissions contributing to climate change. However, as we have here opted to explore policy variants for CO_2 and/or NO_X only (see section 2.3), incentive levels should be based on valuation of these two emissions only.

The incentive level might thus be based on the external costs of:
1. CO_2 alone;
2. CO_2 and NO_X;
3. average climate change impact of aviation, as presented in IPCC (1999).

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[11] Calculation: the share of emissions of NO_X vs. CO_2 per kg of fuel is 0.013/3.150 = 0.0041; since the radiative effect of NOx is estimated at half of CO_2; thus, we value the climate effect per kg of NO_X emission at 120 times the effect per kg of CO_2 emission.

[12] See 'External costs of aviation' (CE, 2002).

CO_2 alone
An advantage of this approach is that the relationship between emission of CO_2 and environmental impact is clear and broadly accepted by the scientific community (see IPCC 1999, 2001), and that the incentive is clear and transparent. In addition, valuation of the impact of CO_2 and hence estimation of the external costs can be based on a scientifically relatively well-studied range of values. However, this approach has two important disadvantages. First, a considerable part of the climate change impact of aviation would not be internalised, such as the impact of contrails and the indirect impact of NO_X. Second, a trade-off between CO_2 and NO_X emissions may be encouraged.

CO_2 and NO_X
A specific advantage of this approach is that it allows for a better optimalised incentive structure than the other two options, because separate incentives are given for the two types of emission. However, the relationship between emission of NO_X and climate change impact is uncertain and depends on flight circumstances. The shadow price of NO_X emissions can therefore be based only on the average climatic impact of NO_X emissions, which might in some cases lead to sub-optimal incentives.

Average climate change impact
This level reflects the full external costs of the average climate change impact of aviation, which according to IPCC (1999) is 2.7 times that of CO_2 alone. A major advantage of this approach is that the level of the incentive corresponds with the total impact on climate change due to aviation. If the aim of the incentive is to internalise the *total* climate costs of aviation, than this approach should be followed. However, the incentive structure of this approach is sub-optimal, as no separate incentive can be applied to all the individual emissions.

Below, in Table 10, the incentive levels calculated according to the three approaches are presented, expressed in aircraft-km for four types of aircraft. However, in order to calculate these levels, first typical emission indices and emissions of these aircraft are presented in Table 9.

Table 9 Typical emission indices (EI) per kg of fuel and greenhouse gas emissions for the four aircraft types considered, per aircraft-kilometre flown

Aircraft type	Fuel consumption (kg/km)	CO_2 (kg)		NO_X (g)	
		EI	emissions (kg/km)	EI	emissions (g/km)
40 sts, 200 km	1.6	3.15	4.9	10	16
100 sts, 500 km	3.0		9.6	12	36
200 sts, 1,500 km	5.1		13	13	66
400 sts, 6,000 km	12		37	14	168

Table 10 Financially valued greenhouse gas emissions per aircraft-km, in € 1999, based on a shadow price of € 30 per tonne CO_2-equivalent

	CO_2	NO_X	CO_2, and NO_x,	Total climate change impact
40 seats, 200 km	0.15	0.057	0.21	0.41
100 seats, 500 km	0.29	0.13	0.42	0.78
200 seats, 1,500 km	0.39	0.24	0.63	1.0
400 seats, 6,000 km	1.1	0.60	1.7	3.0

Impacts of the emission charge variant

Below, the various incentive levels are translated into estimated charges per aircraft trip and hence charge or rebate per passenger, for both the charge variant (table 11) and the PSI (table 12). Both tables show the initial changes in operating costs for different aircraft types (passenger capacity) and illustrative load factors. Further, as only emissions in EU airspace are chargeable, the tables also show the percentage fraction of the stage length taken to be subject to the charge or PSI.

Table 11 **Emission charge level** for different aircraft types, flight distances and load factors, in two variants: €10 per tonne CO_2, and € 50 per tonne CO_2 + € 6 per kg NO_X

Aircraft type	Pax capacity	Load factor (%)	Distance (km)	EU airspace (%)	€ p. aircraft p. flight		€ / pax / flight	
					€ 10/t CO_2	€ 50/t CO_2 € 6/kg NO_X	€ 10/t CO_2	€ 50/t CO_2 € 6/kg NO_X
type 3	146	40%	500	95%	77	499	1	9
		40%	1500	70%	115	739	2	13
		80%	500	95%	80	526	1	5
		80%	1500	70%	122	793	1	7
type 4	224	45%	1000	80%	168	1,281	2	17
		45%	3000	55%	276	2,047	4	28
		85%	1000	80%	178	1,387	1	10
		85%	3000	55%	300	2,277	2	16
type 5	269	50%	2000	60%	239	1,823	3	24
		50%	6000	25%	269	2,030	3	26
		90%	2000	60%	260	2,022	2	14
		90%	6000	25%	301	2,345	2	17
type 7	416	50%	4000	35%	518	3,641	4	25
		50%	10000	16%	586	4,165	4	29
		90%	4000	35%	543	3,860	2	15
		90%	10000	16%	624	4,501	2	17

The total emission charge per flight ranges from € 77 for a short haul flight to € 624 for a long haul flight in the case of a charge level of € 10 per tonne CO_2 and from € 499 to € 4,501 for the highest charge levels considered.
The emission charge per *passenger trip* can be regarded as an first-pass proxy for a single ticket price increase. The table shows that with a charge of € 10 per tonne CO_2, this increase is between € 1 per passenger for a short haul flight (e.g. by a B-737) and € 4 per passenger for a long haul return flight (e.g. by a B-747).
At a charge level of € 50/6 per tonne/kg CO_2/NO_X the range of the cost increase per passenger per trip is between € 5 for a return trip of 500 km and

€ 29 for a return trip of 10,000 km. It is important to note that long haul flights only fly up to about 25% in EU airspace.

Table 12 Performance Standard Incentive (**PSI**) **level** for different aircraft types, different distances and different load factors in the variants € 10 / tonne CO_2 and € 50/6 per tonne/kg CO_2 / NO_X, respectively

Aircraft type	Pax capacity	Load factor (%)	Distance (km)	EU airspace (%)	€ p. aircraft p. flight		€ / pax / flight	
					€ 10/t CO_2	€ 50/t CO_2 € 6/kg NO_X	€ 10/t CO_2	€ 50/t CO_2 € 6/kg NO_X
type 3	146	40%	500	95%	42	253	1	5
		40%	1500	70%	39	195	1	3
		80%	500	95%	11	34	0	0
		80%	1500	70%	-30	-294	0	-3
type 4	224	45%	1000	80%	46	411	1	6
		45%	3000	55%	25	252	0	3
		85%	1000	80%	-51	-257	0	-2
		85%	3000	55%	-173	-1,113	-1	-8
type 5	269	50%	2000	60%	-34	-135	0	-2
		50%	6000	25%	-72	-417	-1	-5
		90%	2000	60%	-232	-1,502	-2	-11
		90%	6000	25%	-313	-2,059	-2	-15
type 7	416	50%	4000	35%	66	405	0	3
		50%	10000	16%	70	466	0	3
		90%	4000	35%	-270	-1,966	-1	-8
		90%	10000	16%	-305	-2,158	-1	-8

The main characteristic of the PSI is that the total financial burden on airlines is zero. This is due to the fact that under this scheme, the better an airline performs relative to the average environmental performance of the fleet in EU airspace (performance standard), the more money it receives, and the worse it performs, the more it pays. In the table above, amounts below zero ('negative charge') imply a rebate.

Table 12 shows, for the assumed aircraft types and load factors, that the total PSI level per flight varies from a rebate of € 313 to a charge of € 70 in the case of a charge level of € 10 per tonne CO_2. With a PSI level of € 50/6 tonne/kg CO_2/NO_X the total amount per flight varies from a rebate of € 2,158 to a charge of € 466. Obviously, flights operating at least emission per unit actual revenue tonne kilometre will receive a rebate.

Furthermore, Table 12 shows that in the case of a PSI level of € 10 per tonne CO_2, the impact on costs per passenger per flight is between € -2 (reduced costs due to a rebate) and an increase of € 1.
For a PSI level of € 50/6 per tonne/kg CO_2/NO_x these charges range between € -15 and € +11. Flights with other aircraft types (and thus other emission characteristics) and other load factors might even show a bigger increase or decrease of the ticket price.

2.6 Levy point: EU airspace

'Levy point' refers to the administrative location where the charge or PSI is implemented; the choice has mainly practical implications. Examples of levy points include: (i) fuel bunkering, (ii) ticket, (iii) landing charge and (iv) air navigation route charge.
This study focuses on an emission charge or PSI on each kilogram of CO_2 and/or NO_x emitted by an aircraft in a predefined airspace of the EU member states (hereafter referred to as EU airspace). The administrative levy point is hereby assumed to be the same as that for the currently existing Route Charge collected by Eurocontrol to cover the costs of air traffic management control. Section 2.7 discusses the possible role of Eurocontrol as a collecting agent. Chapter 5 discusses the legal basis for the EU airspace as defined below.

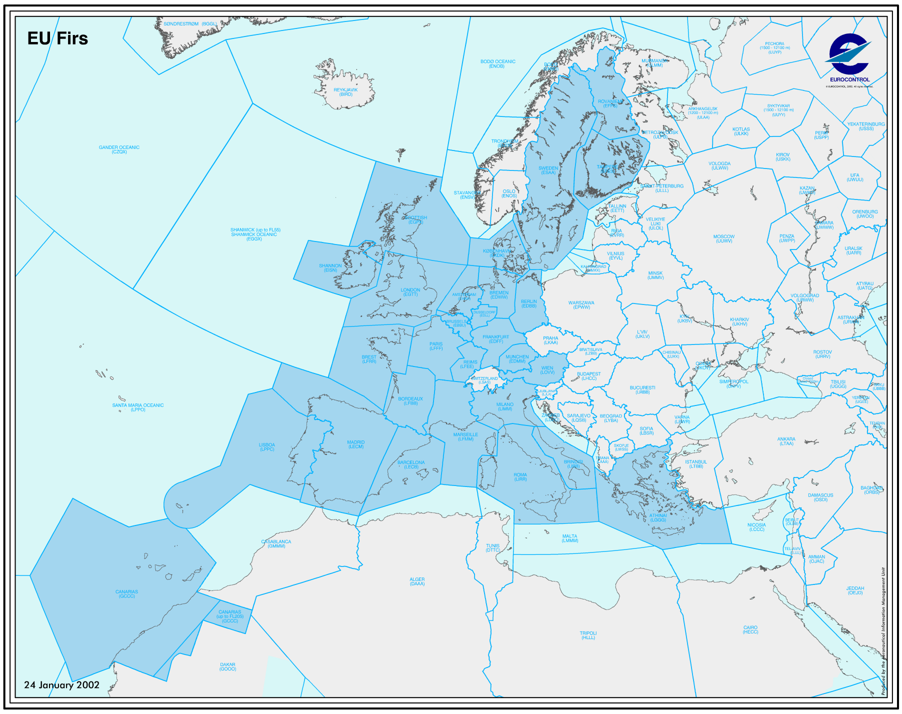
Definition of EU airspace
An important choice is to define the scope of the levy, which determines the working area of the system. Obviously, emissions of aircraft on intra-EU routes are subject to the charge or PSI on the whole flight. However, emissions of aircraft that fly to and from the EU will be charged only on the distance flown in EU airspace.
A remaining issue is then how exactly EU airspace is to be defined. Two possibilities can be distinguished:
1. The national territory of the 15 EU member states (including 12 miles-zone).
2. the Flight Information Regions (FIR) of EU member states as employed by Eurocontrol and officially agreed on with ICAO.

Flight Information Regions (FIRs) as employed by Eurocontrol encompass not only the national territory of a country, but may also include particular areas of seas and oceans. Under the Chicago Convention, seas and oceans are divided into territorial sea (12 mile zone) and 'high seas', outside this zone [13].

A major advantage of the second option – EU airspace based on Flight Information Regions – is that substantial parts of high seas are included, increasing the effectiveness of the economic incentives. This is for two reasons: first, a greater part of flights to and from the EU will be subject to the charge and, second, there will be less opportunity for avoiding the charge by adapting the flight path. In order to reduce avoidance behaviour further, we recommend that all emissions of intra-EU flights be charged, independent of whether they fly part of their route outside EU airspace. This is especially relevant for flight between Scandinavia and, for example, Greece. Figure 5 presents the EU airspace based on the Flight Information Regions as employed by Eurocontrol.

[13] See Chapter 5 and Annex D for a discussion of the regulations that provide a legal basis for the definition of the EU airspace.

Figure 5 EU airspace



2.6.1 Emission route charge: no tankering

A major advantage of an emission-based route charge in EU airspace compared to a fuel tax levied on all fuel sold at EU airports is that an emission charge will not encourage fuel tankering.
Introduction of a *fuel tax* in the EU may encourage airlines to avoid the fuel tax by taking more fuel on board at airports outside the EU than actually required for the execution of a flight[14]. The extra fuel can then be used for the next flight. This phenomenon is called 'fuel tankering'. The avoidance behaviour of fuel tankering reduces the effectiveness (in terms of emissions reduction) of a fuel tax. Obviously, a global fuel tax would not lead to extra fuel tankering.

Tankering reduces the environmental effectiveness of a fuel tax for two reasons. First, by avoiding the fuel tax and thus the price increase, traffic volumes would be maintained and airline responses towards using more fuel-efficient aircraft would be reduced. Moreover, additional adverse environmental impacts would be introduced by increasing the take-off weight of aircraft carrying extra fuel and possibly by introducing extra stops and increasing flight distances in order to take fuel on board at airports outside the EU.
The fuel taxation study carried out for the European Commission in 1999 showed that because of tankering, the environmental benefits of a tax of € 0.245 per litre on fuel bunkered by all carriers (EU and non-EU)[15] could be reduced by 70%. This result was based on a tankering analysis showing that, for short haul flights to the EU, tankering can cover the full return trip. On flights from North America, on average, tankering can cover about 25% of the fuel required for the return flight.

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[14] See 'A European aviation charge' (CE, 1998) and 'Analysis of taxation of aircraft fuel' (Resources Analysis, 1999).

[15] Taxation for all routes departing from the EU for all carriers (option 1).

An emission-based route charge or Performance Standard Incentive (PSI) will not cause any extra tankering behaviour by airlines because it will not change the charge to be paid, for the (calculated) emissions of an aircraft in EU airspace would remain unchanged.

2.7 Administrative agent: Eurocontrol

The administrative agent is the body undertaking the tasks required for the emission charge or PSI to actually work in practice. The following tasks can be distinguished:
- registration of the emissions of each aircraft flying in EU airspace;
- operation of the charging procedure (and rebate calculation in the case of the PSI) fort each flight;
- operation of the billing procedure;
- in the case of a charge: collection of the revenues;
- in the case of a PSI: organisation of an adjustment mechanism to ensure that payments and rebates are equal at the end of each year.

With regard to choice of administrative agent, this study focuses on the question of whether it is feasible to use the current Route Charge System operated by Eurocontrol for the administrative tasks described above. The main reason for this focus is that Eurocontrol appears to be the only organisation able to offer a suitable infrastructure for the charging and collection mechanism required for actual implementation of emission-based route charges.

In order to assess whether and how the Eurocontrol system might be used, we first analysed in detail the working of the current Route Charge System for ATM services. A description of this system is presented in Annex A. This description is based on Eurocontrol's own reports and consultations with Eurocontrol representatives.
Below, it is discussed whether and under what conditions the existing Eurocontrol Route Charge System could form a suitable mechanism for the collection (charging and billing) of the revenues of an emission-based route charge. Possible methods for calculating the emissions of an aircraft flying in EU airspace are discussed in section 2.4.

2.7.1 Who decides on changes to Eurocontrol policy and to the Eurocontrol system and is it possible to include an environmental levy in the system?

The decision-making body for the Eurocontrol Route Charges System is the General Assembly (Commission during the transitional period): Ministers of Transport and Defence, responsible for defining the general policy of the organisation.

Eurocontrol expressed its willingness to provide assistance to the European Commission (and its consultants) to investigate the possibility of implementing an emission-based levy using the Route Charges System. Introduction of instruments, such as emission levies, to mitigate the environmental impact of aviation is in line with policies formulated by Eurocontrol in pursuance of sustainable development. If the European Union decided to introduce an emission levy, Eurocontrol could act as a collecting agent upon approval by its Commission. The levy could apply to the airspace of the fifteen EU Member States. The technical flexibility of the Eurocontrol Route Charges System would allow non-EU Eurocontrol Member States to apply such a levy in their national airspace. Obviously, emission levies collected by Eurocontrol should comply with international agreements and ICAO policies (see also chapter 5, legal analysis).

2.7.2 How could an emission-based route charge be included in Eurocontrol's charging and billing system? And are there any restrictions on integrating a so-called 'revenue-neutral charge' with the current system?

Eurocontrol stated that the Route Charges System could facilitate the billing and collection of an *emission charge*, *but* emphasised that such a levy should if possible be identified and accounted separately from route charges. Transparency is the main argument here, while it also important to recognise that the purpose of route charges is to recover the costs of provision of Air Navigation Services. Aircraft operators should have full insight into how the emission levy is calculated and billed to them.

Eurocontrol confirmed that the second main variant, the revenue-neutral Performance Standard Incentive (PSI), could in principle also be implemented together with Route Charges, provided that a proper treasury mechanism is put in place. Such an emission levy would give a 'credit' to the least polluting aircraft and request payment from the most polluting. The estimated sum of all 'credits' and payments would of course be zero at the end of each period.

The Eurocontrol Member States attach great importance to full recovery of their en route costs. Any add-on to the present route charges system should not endanger this principle. Adding a revenue-neutral PSI to the air navigation en route charge would be feasible provided certain technical precautions were taken:

- 'credits' should not be paid out before the end of the year to which they relate;
- the treasury of the air navigation Route Charges System should be kept separate from that handling the emission charges and PSI;
- an adjustment mechanism should be set up to cater for differences in actual versus forecast payments and rebates in the case of the PSI.

3 Potential environmental benefits

3.1 Introduction

In this chapter we review the potential environmental benefits of the different incentive options considered in this study. Although the international literature provides a certain amount of insight into the potential environmental benefits of applying economic policies in the aviation sector, we opted to conduct an entirely fresh analysis. There are two main reasons. First, the available information resources are not suitable to assess the environmental effectiveness of instruments applied solely to EU airspace. Second, in our opinion these resources lack the scope and depth for drawing solid conclusions on the matter at hand.

In Section 3.2 we present an overview of the incentive variants studied and the data and models used for analysing their environmental benefits.

In Section 3.3 we develop an analytical framework for analysing these benefits, consisting of a well-structured list of responses that may be elicited by environmental incentives. At the end of this section we summarise which of the supply-side responses were calculated by the AERO model and which were estimated by additional analysis (using the APD model (see Annex E), ITA models and Eurocontrol databases).

In Section 3.4 we describe the impact of the various policy options on the Direct Operating Costs (DOC) of different aircraft types.

In Sections 3.5 to 3.7 we describe the potential environmental benefits of supply-side responses by the air transport industry.

Section 3.8 compares the estimated supply-side responses found in the analysis with the AERO model on the one hand, and with the APD model and ITA database on the other.

In Section 3.10 we present the demand effects and substitution effects.

Section 3.11 presents a summary of overall environmental benefits as well as more general conclusions for each of the four incentive options:
- differences between emissions charge and PSI;
- differences between CO_2 and NO_X base.

In three related annexes the ins and outs of this chapter are further elaborated:
- Annex E describes, in outline, the APD model and the Eurocontrol and ITA databases;
- Annex F describes in more detail the potential supply-side responses calculated with the APD model and Eurocontrol/ITA databases;
- Annex G describes the results of the AERO model calculations.

The analysis in this chapter focuses solely on CO_2 and NO_X emissions. Noise emissions are not treated.

3.2 Variants, data and models

Variants
The incentive variants assessed in this report are shown in Table 13.

Table 13 Overview of incentive variants studied

Incentive type	Emissions	Level (€ per tonne or kg)
emission charge	CO_2	10
		30
		50
	CO_2 & NOx	10 / 1.2
		30 / 3.6
		50 / 6.0
PSI, emissions per actual pay-load-kilometre (ARTK)	CO_2	10
		30
		50
	CO_2 & NOx	10 / 1.2
		30 / 3.6
		50 / 6.0

ARTK: Adjusted Revenue Tonne Kilometres = (#pax*0.16 + #tonnes freight)*kilometres

Eurocontrol / ITA database
The first key analytical tool used in the present study is a database compiled by Eurocontrol and ITA comprising the following data, for the year 2000, for 630 aircraft types, for flights between, to and from EU15 airports:
- MTOW, passenger capacity, number of engines;
- number of flights;
- aircraft-kilometres flown from origin to destination, in Eurocontrol air-space, and in EU15 airspace;
- Direct Operating Costs for each of 4 stage lengths.

The following aircraft categories are distinguished.

Table 14 Aircraft types by MTOW class

Type	MTOW (tonnes)	# seats (approx.)	Most used	Aircraft km EU15		ARTK EU15		MZFW km EU15 (bln)		CO_2 emis-sions	
				mln	%	bln	%	abs	%	Mton	%
1	< 55	< 110	BAe 146	1,642	25%	9.0	8%	30	7%	10.8	13%
2	55-70	110-140	MD87	1,945	30%	23.7	22%	90	20%	21.1	26%
3	70-100	140-170	A320	1,062	16%	14.9	14%	57	13%	11.1	14%
4	100-165	170-210	B757-200	707	11%	14.7	14%	60	14%	10.1	13%
5	165-250	210-280	B767-300	458	7%	12.9	12%	55	13%	8.3	10%
6	250-350	280-360	B777-200	414	6%	15.7	14%	70	16%	8.5	11%
7	> 350	> 360	B747-400	354	5%	17.3	16%	80	18%	10.4	13%
total				6,582	100%	108.3	100%	444	100%	80.4*	100%

According to AERO-MS calculations, CO_2 emissions in EU15 airspace *in 2010* amount to 117 Mtonne, which is 45% higher than the 80.4 Mtonne estimated from the EUROCONTROL/ITA databases for the year *2000*. This implies a - not unlikely - annual growth rate of 3.8%, suggesting that both sources lead to comparable results.

Table 15 Average stage lengths of the 7 aircraft types considered in this study, in kilometres

Aircraft type	Stage length O-D (origin-destination)	Stage length in Eurocontrol airspace	Stage length in EU15 airspace (charged)	Stage length EU15 as % of stage length O-D
1	491	424	390	79%
2	966	854	777	80%
3	1,075	934	840	78%
4	2,146	1,409	1,254	58%
5	4,333	1,523	1,340	31%
6	6,213	1,783	1,551	25%
7	6,878	1,730	1,488	22%
aver-age	1,238	772	696	56%

The ‘average’ row states that the average stage distance of *aircraft* is 1,238 km. The average distance an individual *passenger* is transported is longer, because larger aircraft make longer trips with more passengers on board.

As expected, the larger the aircraft, the longer its average trip, and the smaller the portion of the trip in EU15 airspace. On average, the largest aircraft landing and/or departing in the EU15 fly about 20-25% of their stage in EU airspace, and thus 20-25% of their average trip is charged.

NO_X emission indices per aircraft type were derived using APD and AERO emission indices for 4 sample aircraft and NO_X totals from the 1999 IPCC report.

Table 16 Average NO_X emission indices (EI) factors used for the different aircraft types in the different flight stages, in g/kg fuel

Aircraft type	500 km	2,000 km	6,000 km	10,000 km
1	10.0	9.0	n.a.	n.a.
2	11.0	10.0	10.0	n.a.
3	12.0	10.5	10.5	11.0
4	13.0	11.5	11.0	11.5
5	14.0	12.5	12.0	12.5
6	15.0	13.5	13.0	13.5
7	15.0	13.0	12.5	13.0

Table 17 Total CO_2 and NO_X emissions in EU15 airspace for the 7 aircraft types

Type	CO_2 (ktonnes)					NO_X (tonnes)				
	500	2000	6000	10000	total	500	2000	6000	10000	total
1	9335	1494			10829	29633	4269			33902
2	8788	12085	246		21119	30690	38364	781		69835
3	4361	6527	152	53	11092	16614	21757	505	183	39060
4	1221	7027	1647	213	10109	5041	25654	5752	778	37225
5	669	2327	4356	935	8287	2975	9232	16596	3710	32513
6	177	678	4731	2938	8524	844	2906	19524	12592	35866
7	259	598	4765	4805	10427	1233	2468	18909	19830	42439
total	24811	30736	15897	8943	**80387**	87031	104650	62067	37093	**290840**

APD model

The second main analytical tool used in this study is the APD model (Aircraft Performance and DOC), developed by Peeters Advies in the framework of the ESCAPE project[16]. The background report of the ESCAPE project contains a number of reviews from industry and scientific experts.

This model is designed to evaluate individual flights of certain predefined aircraft on certain predefined flight stages with respect to DOC, fuel consumption and emissions. Currently, four different aircraft have been defined with the aid of data taken from aircraft manuals, namely typical aircraft in categories 2, 4, 5, and 7 above.

The APD model is described in more detail in Annex E.

3.3 Analytical framework

To properly describe the actions that airlines and aircraft manufacturers might take in response to emission reduction incentives, we devised a list of potential mechanisms that might come into play if such incentives were in place. For each type of mechanism described, we also indicate how it is dealt with in the AERO model and how we decided to treat it in this chapter.

A Measures to the fleet mix

This category of possible measures implies shifts in fleet compositions towards cleaner aircraft, but only includes technologies that would also have been in the marketplace if the incentive had not been present. Two mechanisms are included:

A1 Accelerated fleet renewal

As new aircraft generally have lower emissions than old aircraft, the time for old aircraft replacement will arrive sooner if an emission charge or PSI is in place.

A2 Shifts in sales of new aircraft

Another mechanism that might be activated by environmental incentives is that environmental characteristics might come to play a more dominant role in the selection of new aircraft. The engine/airframe combinations currently sold in the market are the result of numerous factors. If environmental characteristics were to assume greater importance, it is likely that the environmentally soundest aircraft in a given sales range would become more popular relative to dirtier aircraft than is presently the case.

[16] ESCAPE: Economic SCreening of Aircraft Preventing Emissions, CE et al., 2000.

For each aircraft category the AERO Modelling System (AERO-MS) distinguishes two technology levels: 'old' (>12 years) and 'current' technology. Mechanism A1 is simulated by an earlier phase-out of 'older' aircraft (>12 years), implying an accelerated shift from 'old' to 'current' aircraft. A difference between the model and the real world is that the model includes only one alternative aircraft, whereas in the real world there are multiple options for accelerated renewal. Mechanism A2 is not directly simulated, as only one ('current') technology level aircraft is on the market.
In this study we estimated the possible effects of mechanism A1 by using the AERO estimates and making new analyses of optimum aircraft ages. Mechanism A2 was not quantified. Section F.4 shows, however, that mechanism A2 has quite some potential, as 5% differences in CO_2 emissions and several dozens per cent differences in NO_X emissions between different engine options for one and the same aircraft are quite normal.

B Technical measures to existing aircraft (short term)
There are various market options available for reducing the fuel consumption of existing aircraft, including retrofit of winglets, riblets and possibly engines. By default, the AERO-MS does not take these mechanisms into account. In this study we executed a new analysis on the potential effects of mechanism B (see section 3.6 and Annex F).

C Technical measures to new aircraft (long term)
This category includes technologies that cannot yet be made readily available to the aviation industry, but introduction whereof could be accelerated by an environmental incentive.

C1 Development of airframes with lower drag / lower design speed
Reduction of aircraft drag can be achieved by improving technologies or by lowering the design speed of aircraft.

C2 Development of airframes with a better empty weight/payload ratio
Especially in the policy variants with a productivity parameter related to payload, there will be a far greater incentive to use lighter materials;

C3 Development of more fuel-efficient engines
Especially if CO_2 is the only base for the incentive, an extra impulse will be given to fuel efficiency improvements. Higher NO_X emissions are a possible trade-off, however

C4 Development of engines with lower emission indices of $NO_{X,}$, etc.
This comes into play only if the incentive base includes NO_X. The balance between CO_2 and NO_X improvements depends on the relative weighting of the CO_2 and NO_X incentives.

By default, the AERO-MS does not take these mechanisms into account. In the last few years, several studies have been undertaken to estimate the possible long-term impacts of market-based environmental incentives in aviation. Examples include Nielsen (2001), CE (1997, 2000) and Stratus (2001). None of these studies managed to find robust relationships between market-based incentives on the one hand and technology development on the other, however.
Consequently, the present study gives no consideration to possible long-term technology development in response to environmental incentives. Given the time horizon of 2010 taken in this study, this assumption seems realistic.

D Operational measures (individual flight level)
This category includes operational options that can be executed on an individual aircraft basis, without changes in network or service frequencies.

D1 Changes to flight path and speed to minimise emissions

This comes into play only if emissions are calculated on an *ex post* basis, on the basis of real flight data. Given a certain aircraft and a certain flight, emissions can be lowered by adapting flight speed and altitude. A minimum-emissions speed leads to 15-25% lower CO_2 emissions than a maximum-emissions speed

D2 Reduction of empty weight (e.g. lower on-board service levels, less tankering)

Especially in the case of a PSI being applied that includes actual payload, there will be additional incentives to exchange empty weight for payload. Reduction of seat pitch and on-board service levels (food, number of staff, passenger provisions) could contribute to this aim. Optimum tankering levels will then probably also be smaller.

The AERO-MS does not take these mechanisms into account. We therefore took a different approach. Mechanism D1 was estimated by comparing the environmental performance of a DOC-optimised flight in a reference scenario with performance in a scenario with environmental incentives in place. Mechanism D2 was estimated by assessing the available literature on this topic.

E Operational measures (network level)

This category includes operational measures such as changing frequencies, networks, destinations and so on, which have impacts extending beyond individual aircraft.

E1 Increases in load factor (larger aircraft or lower frequencies)

Both the emission charge and the PSI variants give airlines extra incentives to increase their load factors. The emission charge does so by the increase in Direct Operating Costs (DOC), triggering reactions from airlines to bundle their passenger streams. The PSI does so if it is defined as emissions per unit of actual payload (*ex post*): in this case it rewards airlines for every passenger and every tonne of cargo taken.

E2 Changes in flight distance to improve environmental efficiency

In the case of the emission charge variant, it is likely that long-distance transport will be relatively harder hit. This is because at long distances the relative CO_2 emissions per $ ticket price are higher.

In the PSI variant, if the performance standard is expressed in ARTK or MZWF.km, it is highly likely that flying (generally more efficient) longer distances will become cheaper and (generally less efficient) shorter distances will become more expensive. As a result, a shift towards longer average trip lengths might occur. This effect follows from the demand effect, as discussed below.

The AERO-MS does not take these mechanisms into account. We based our estimates on a survey of international literature.

F Substitution of air transport demand to other modes (car, train)

This often-discussed category implies loss of transport demand in aviation and a comparable increase of transport demand in other modes of transport, notably (high-speed) trains and cars. Substitution might occur in both the emission charge variant and the PSI.

In the emission charge variant, the demand shift will come from the rise in final consumer prices of tickets that is triggered by the charge.

In the PSI variant – with the performance standard expressed in ARTK or MZWF.km - flying relatively short distances will also generally become somewhat more expensive, as these distances are environmentally less efficient per kilometre than long distances.

Naturally, emissions from the extra trains and cars should be added to arrive at a net environmental result.
The AERO-MS does take these mechanisms into account; we based our estimates on the outcome of the AERO-MS.

G Net loss of total transport demand

This category implies a loss of demand in aviation without this demand being substituted by other modes. In terms of volume this category is more important than substituted demand. Demand loss will occur primarily in the environmental charge variant, as in this case the final consumer price of tickets is likely to increase discernibly. In the PSI variant, the incentive does not itself lead to price increases; in this case the only price impacts are due to the costs of the abatement measures taken, and the size depends on the percentage of these costs that is passed on to customers.
The AERO-MS does take these mechanisms into account; we based our estimates on the outcome of the AERO-MS.

Overview

Table 18 briefly summarises the potential responses by airlines and aircraft manufacturers treated in this chapter.

Table 18 Overview of mechanisms and their treatment in this chapter. The last column shows the model used for each of the responses and the section in which the response is assessed

Case	Mechanism	plays a role in				Models /section
		emission charge		Performance Standard Incentive		
		CO_2 only	CO_2&NO_X	CO_2 only	CO_2&NO_X	
SUPPLY SIDE						
A	**measures to the fleet mix**					
A1	earlier phase-out	+	++	+	++	AERO & APD, 3.5
A2	shifts in sales of new aircraft					n.a.*
B	**technical measures to existing aircraft (short term)**					
	retrofit to existing aircraft	+	++	+	++	APD & ITA, 3.6
C	**technical measure to new aircraft (medium / long term)**					
C1	lower drag / design speed	+	++	+	++	n.a.*
C2	lower weight	+	++	+	++	n.a.*
C3	more fuel-efficient engines	+	?	+	?	n.a.*
C4	engines with lower emission indices	?	+	?	+	n.a.*
D	**operational measures, at individual flight level**					
D1	changes to flight path / speed	+	++	+	++	APD, 3.7
D2	reduction of empty weight	+	++	+	++	n.a.*
E	**operational measures, at network level**					
E1	changes to load factors / flight frequencies	+	++	+	++	AERO, 3.7
E2	changes in flight distance	?	?	+	+	AERO, 3.7
DEMAND SIDE						
F	modal shift to trains / cars	++	++	+	+	AERO,
G	net demand loss	+	++	0	0	AERO, 3.10

n.a.: not assessed in this study

All mechanisms and measures are expressed in *relative* terms compared with a situation *without* the introduction of the incentive in question. Many mechanisms, such as changes in load factors, are of course already heavily influenced as a result of market pressure. In these cases, we mean additional changes on top of those already accounted for by the market.

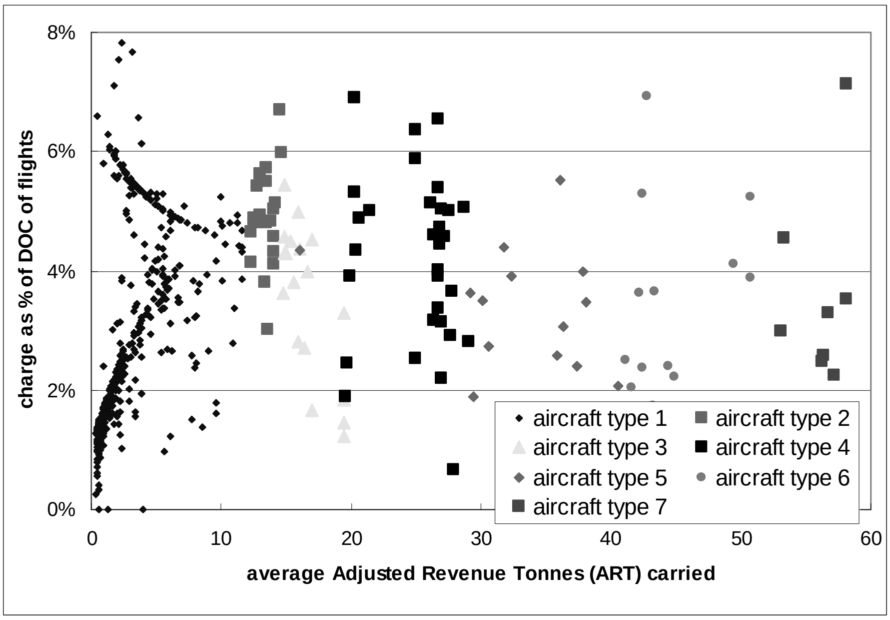
3.4 Impacts on Direct Operating Costs (DOC)

In this section the impacts of the two incentive variants on Direct Operating Costs (DOC) is presented.
In the emission charge variant, this DOC impact is directly related to the fuel consumption and NO_X emission indices of the aircraft concerned. By definition, this variant leads to higher DOC for all aircraft on all flight stages.
In the Performance Standard Incentive, DOC impacts are dependent on fuel consumption and NO_X emission indices, but also on the amount of passen-

gers and freight carried[17]. The PSI leads to higher DOC if the flight in question has higher than average emissions per ARTK, and to lower DOC if it has less than average emissions per ARTK.

Impacts of emission charge variants
Figure 6 reviews the DOC impacts of an emission charge based on a shadow price of € 30 per tonne of CO_2. All figures are expressed as a function of total DOC.

Figure 6 DOC impacts of an emission charge of € 30/tonne CO_2 for 7 different aircraft types on typical stage lengths (see Table 69)

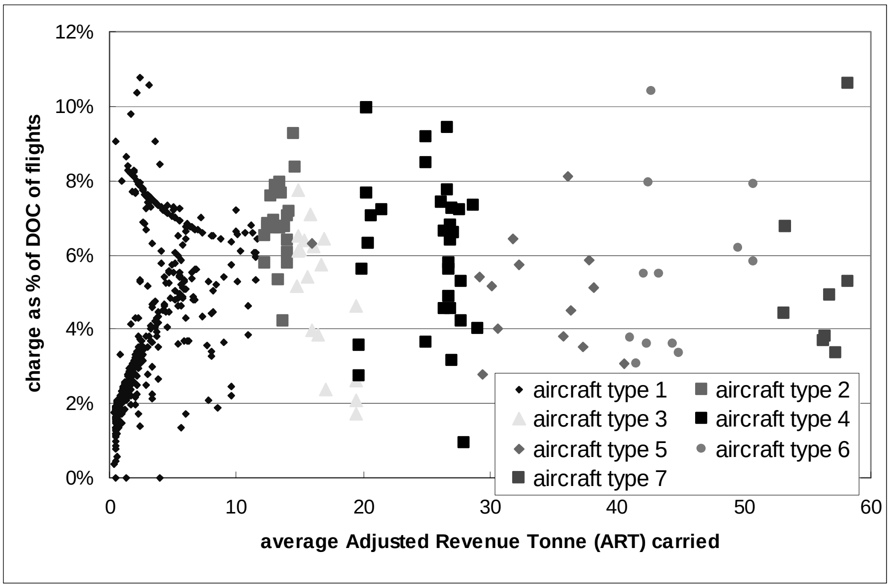


Not surprisingly, the emission charge leads to increases in DOC, by an average of about 4% for both small and large aircraft. Large aircraft have a higher share of fuel in their DOC, but they are charged over a smaller proportion of their flight kilometres.

Figure 7 shows the results for an emission charge on both CO_2 and NO_X.

[17] More precisely: emissions per ARTK = Adjusted Revenue Tonne Kilometre = (tonnes freight + 0.16*#pax)*km.

Figure 7 DOC impacts of an emission charge of € 30/tonne CO_2 and € 3.6/kg NO_X for 7 aircraft types on typical stage lengths

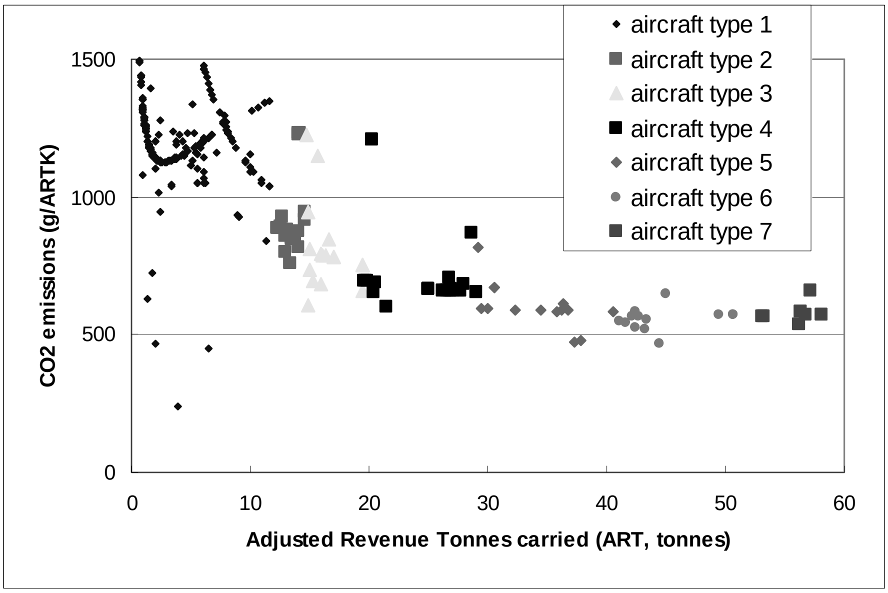


As can be seen, with NO_X included direct DOC impacts are on avarage about 50% higher than in the case of a charge on CO_2 only. This is a logical consequence of the fact that according to the IPCC's 1999 report the climatic impact of NO_X (O_3+CH_4) is on average about half that of CO_2.

Impacts of PSI variants

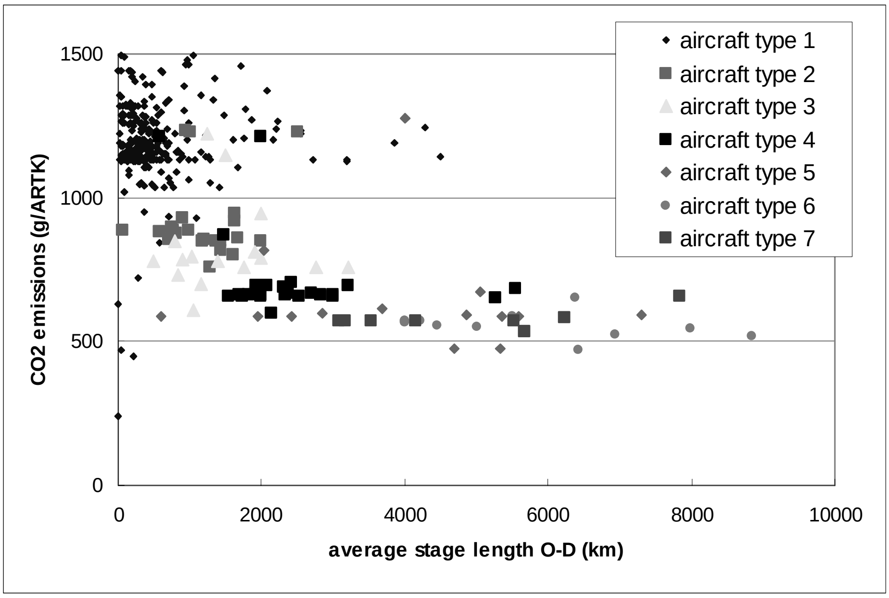
To provide an initial impression of how this variant could work out, Figure 8 presents specific CO_2 emissions per ARTK.

Figure 8 Specific CO_2 emissions per ARTK, plotted against average Adjusted Revenue Tonnes carried per aircraft type



This plot shows that aircraft carrying more Adjusted Revenue Tonnes generally have lower CO_2 emissions per ARTK. This is due to the fact that large aircraft are generally more efficient per tonne carried and generally fly longer, and thus more efficient, stages. The influence of typical stage length on specific CO_2 emissions is shown in Figure 9.

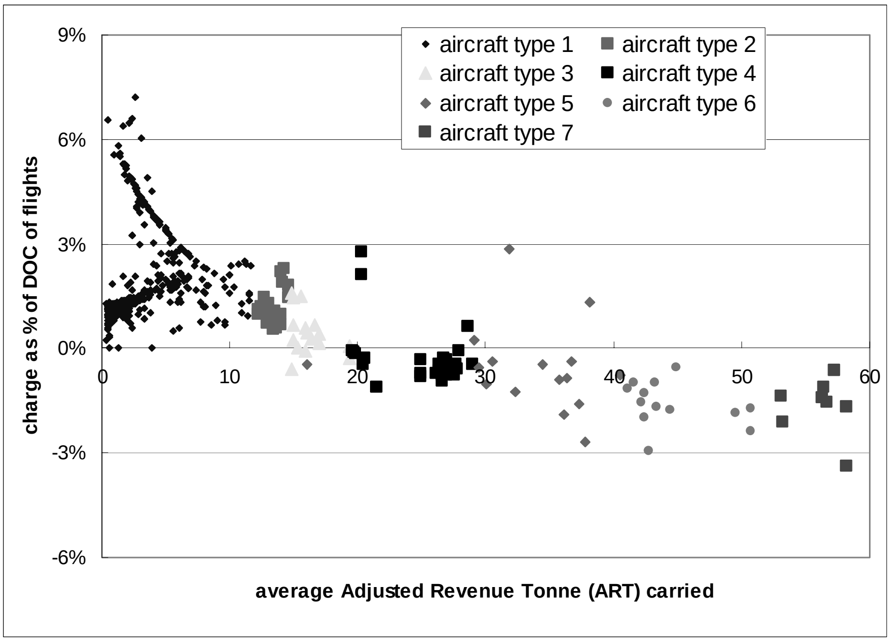
Figure 9 Specific CO_2 emissions per ARTK, plotted against average stage length flown per aircraft type



As can be seen, typical stage length is a key explanatory variable for specific CO_2 emissions.

The impacts on DOC of a PSI based on CO_2 efficiency are shown in Figure 10.

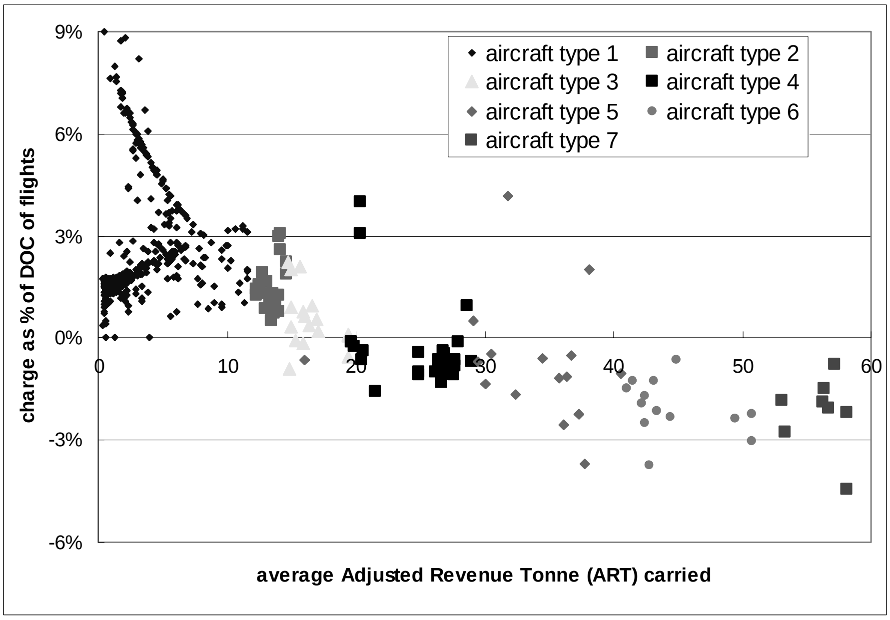
Figure 10 Impact on Direct Operating Costs of a PSI based on € 30/tonne CO_2 for 7 different aircraft types on typical stage lengths (see Table 69)



Note that DOC constitutes, on average, about 55% of Total Operating Costs.

It can clearly be seen that this Performance Standard Incentive benefits larger aircraft, which generally fly longer distances. On this type of flight DOC would be reduced by about 2%. Short-haul flights would become more expensive, by roughly 1 to 4%, depending on the environmental efficiency of the specific aircraft.

Figure 11 Impact on Direct operating Costs of a PSI based on € 30/tonne CO_2 and € 3.6/kg NO_X for 7 different aircraft types on typical stage lengths (see Table 69)



Note that DOC constitutes, on average, about 55% of Total Operating Costs.

Again, including NO_X in the incentive increases DOC impacts by about 50%.

3.5 Supply side: accelerated fleet renewal

If aircraft emission profiles play a greater role in airline economics, replacement of old aircraft will be brought forward in time. Decisions on aircraft replacement are highly complex and involve a wide range of issues, including market outlooks, capital position and expected rate of return of the new aircraft.

The main cost items involved in aircraft replacement are depreciation costs (decreasing with aircraft age), fuel costs and maintenance costs (both increasing with age). In Annex F.1 we develop insight into these costs by establishing proxies as a function of aircraft lifetime.

With these data we tentatively derived the sensitivity of aircraft costs to age, using average stage lengths, block hours etc. for each type (supplied by ITA). In Figure 12 and Figure 13 it is shown how the sum of depreciation, maintenance and fuel costs varies with aircraft age and how a scenario in which environmental incentives are in place could influence these 'minimum cost' ages. The figures take into account the fact that, on average, only about 56% of kilometres flown by the aircraft are flown in EU15 airspace. For aircraft types 1 and 2 this is virtually 100%, and for aircraft 7 this is typically 25%.

Figure 12 The sum of average depreciation, maintenance and fuel costs per ARTK for aircraft types 1, 2, 4, and 7 as a function of their age in the baseline scenario (fuel price € 0.28/kg, shown as *lines*) and 'minimum cost ages' in the baseline scenario and two emission charge variants (€ 30/tonne CO_2 and € 50/6 per tonne/kg CO_2/NO_X, shown as *dots*)

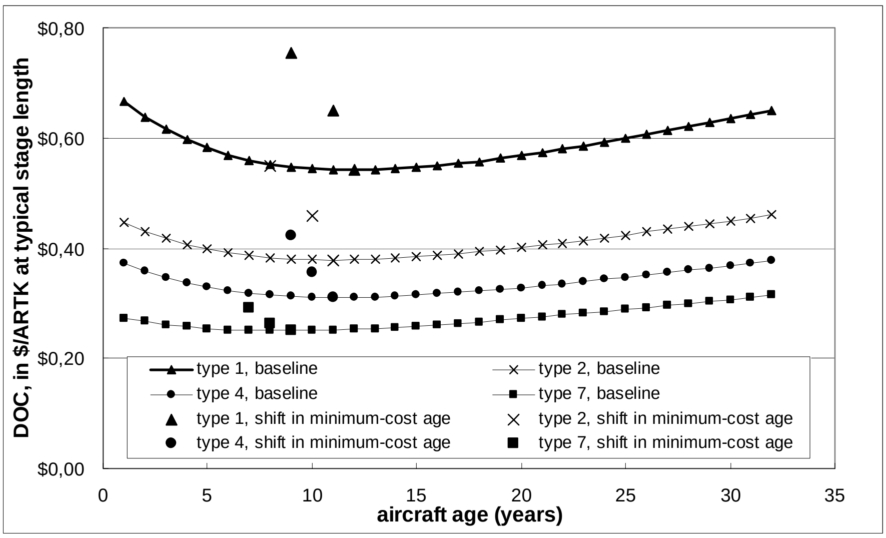
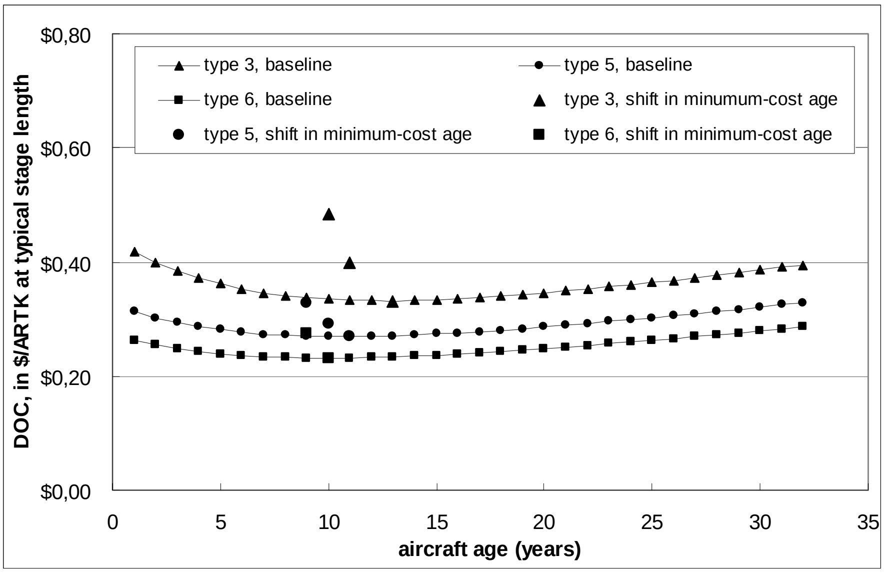


Figure 13 The sum of average depreciation, maintenance and fuel costs per ARTK for aircraft types 3, 5, and 6 as a function of their age in the baseline scenario (fuel price € 0.28/kg, shown as *dotted lines*) and 'minimum cost ages' in the baseline scenario and two emission charge variants (€ 30/tonne CO_2 and € 50/6 per tonne/kg CO_2/NO_X, shown as *dots*)



The *dotted lines* in the graph indicate how costs depend on aircraft age in the baseline scenario. For each aircraft type the *dots* indicate the 'minimum-cost aircraft age' in the baseline scenario and in the two emission charge variants.

From these figures it can be seen that with a baseline fuel price of about $ 0.28 per kg, total fuel, maintenance and aircraft capital costs are lowest for aircraft of typically 10-12 years of age. Note that this applies only to aircraft used on **average** stage lengths with **average** utilisation. For aircraft with higher than average utilisation (such as those of some low-cost carriers) the 'minimum-cost age' is lower, while for aircraft with lower utilisation (such as those of express carriers) the 'minimum-cost age' is higher, which goes a long way to explaining the large differences in fleet ages between different types of airlines.

This analysis shows that the 'lowest cost age' moves downward by about 1 year when an incentive of € 30 per tonne of CO_2 is introduced. With a greater incentive of € 50 per tonne of CO_2 and € 6 per kg NO_X, this age goes down again by about 1 year to, on average, about 10 years. For average aircraft this figure would go down at approximately the same rate. As the average historic fuel efficiency improvement of aircraft amounts to about 1.7% per annum, each year of accelerated fleet renewal leads to a 1.7% emission reduction. Reduction of NO_X is somewhat less certain. Recent engines generally have high pressure ratios and therefore often have higher NO_X emission indices than older engines. If we estimate the NO_X emission index to increase by 0.5% on average each year, the overall NO_X emission decreases by about 1.2% a year[18].

[18] 1.7% reduction of fuel consumption minus 0.5% increase of NO_X emission index.

Of course, the results of this analysis should be treated with caution. As already stated, in everyday practice many more factors play a role in aircraft replacement than the strict trade-offs between fuel, maintenance and capital costs. Nevertheless, we believe that the analytical framework used for the analysis provides useful insights into what *could* happen with average aircraft age across the aviation market as a whole. These considerations lead to the estimates for accelerated fleet renewal and emission reduction shown in Table 19.

Table 19 Overview of impacts due to accelerated fleet renewal prompted by environmental incentives

	CO_2 variants only			CO_2 + NO_X variants		
valuation, CO_2	€ 10/tonne	€ 30/tonne	€ 50/tonne	€ 10/tonne	€ 30/tonne	€ 50/tonne
valuation, NO_X	0	0	0	€ 1.2/ kg	€ 3.6/ kg	€ 6.0/ kg
average fleet age reduction (years)	0.3	1	1.5	0.5	1.5	2
CO_2 emission reduction (%)	0.5%	1.7%	2.5%	0.8%	2.5%	3.4%
NO_X emission reduction (%)	0.4%	1.2%	1.8%	0.6%	1.8%	2.4%

From these figures, although indicative, it can be seen that the price of fuel and emissions may reduce the age of aircraft retirement by a few months to about 2 years, depending on the variant.

3.6 Supply side: technical measures to aircraft

This section describes various technical options that can be applied to aircraft in order to reduce fuel burn and emissions. We have only looked at the likely application of a couple of indicative types of aircraft modification responses. In particular, wingtip devices to new or existing aircraft, application of riblets, re-engining and long-term technology impacts are discussed.

Wingtip devices

The aerodynamic design of wings has an important effect on the total drag during cruise and therefore on an aircraft's emissions, but also on performance characteristics like payload-range capability, take-off and climb-out behaviour and thus noise. As wing design is always the result of a compromise between construction and maintenance costs, weight and future fuel costs, CO_2 emission incentives could have an effect on optimal wing design.

There are two ways to improve the aerodynamic performance of a wing: extending wing span and adding a wingtip device. As adding wingspan on a retrofit basis is very complicated, in this chapter we focus on possible additions of wingtip devices.

The market for retrofitting existing wings with winglets already exists, due to their fuel reduction potential, improvesd aircraft payload-range capabilities, noise performance (due to the ability to attain the same climb angle with less power) and possibly also engine maintenance costs. The fuel reduction potential depends on the original size of the wing, the size and shape of the winglet and the stage length flown: the longer the stage length, the greater the benefit.

Two programmes are currently underway:
- Quiet Wing System's (formerly DuganAir) B727 retrofit (using 'blended winglets' developed by Winglet Systems, CT);
- Aviation Partner's (AP) winglet for the B737-NG series. Typically a B737 will save 3.5-4% on missions over 2,000 km (Aviation Partners, 2001) (Boeing, 2000, 2001). Both B737-800 with and without winglets are sold, depending on the customer and the stages flown.

On current aircraft endplates, winglets or raked wingtips are offered on B747-400, B777-200LR, B777-300ER, B767-400ER, the B737NG family (as an option only), A300-600, A310-300, A319/A320/A321, A330 (all models), A340 (all models) and probably also A380. All this implies that only part of the world airliner fleet - primarily smaller aircraft - may be suitable for retrofitting wingtip devices.

Downsides of winglet application are the potential wing span increase, leading to a higher airport 'box' category, and the possibly high costs associated with the certification and extra wing strengthening that may be required. The following cost indications were found:
- Gulfstream II in 1991 $520,000 (Aviation Partners, 2001);
- Gulfstream GII for $475,000 (Aviation Partners, 2000).

Under the assumptions mentioned in Table 20 the winglets were evaluated for aircraft types 3, 4, and 5.

Table 20 Assumptions made in the evaluation of winglets

	Aircraft type 3	Aircraft type 4	Aircraft type 5
% of market feasible	20%	20%	20%
Retrofit cost ($1,000[a]	900	1230	1400
Extra weight (kg)[b]	250	560	615
AR increase (%)[c]	20	20	20
Engine maintenance cost (%)	-1	-1	-1

a Taken as 2.3% of the new airframe price.

b 0.76% of empty weight.

c AR = Aspect Ratio (see box in Annex F.2).

Results are shown in Table 21. The effect on total block fuel consumption for Aircraft Type 3 compares conservatively with the figures given by Boeing (figure 6 of (Faye, R., Laprete, R. and Winter, M., 2001)).

Table 21 Impacts of application of winglets or advanced wingtip devices on DOC and emissions of 20% of aircraft on which application is most attractive. Investments are written off in 15 years.

Aircraft type	Stage length	Impact on DOC			Impact on emissions	
		baseline	CO_2 only, € 30 per tonne*	CO_2 & NO_X, € 30/ 3.6 per tonne/kg*	CO_2	NO_X
aircraft type 3	500	+0.2%	+0.1%	-0.1%	-2.3%	-3.1%
	2,000	-0.2%	-0.5%	-0.6%	-3.9%	-5.7%
	avg (1,075)	-0.1%	-0.2%*	-0.3%*	-3%	-4%
aircraft type 4	500	+0.3%	+0.1%	+0.0%	-2.3%	-3.1%
	2,000	-0.3%	-0.6%	-0.8%	-4.3%	-6.9%
	avg (2,145)	-0.2%	-0.4%*	-0.5%*	-4.3%	-6.9%
aircraft type 5	500	+0.2%	+0.0%	-0.1%	-2.3%	-3.7%
	2,000	-0.5%	-0.8%	-1.1%	-4.6%	-7.6%
	6,000	-1.8%	-2.2%	-2.7%	-6.4%	-11.1%
	avg (4,333)	-1.0%	-1.2%*	-1.3%*	-5.5%	-9.4%

* Corrected for % of km flown in EU15 airspace

It can be seen that the environmental impact of winglets is particularly substantial on longer distances, and in particular for NO_X emissions. This can be explained by the lower engine loads that can be applied, which reduce NO_X emission indices. Emission reductions per stage vary from 2% (CO_2, 500 km) to 11% (NO_X, long distances).

It can furthermore be seen that the economic attractiveness of winglets is also greatest for long distance flights. According to the calculations shown, application is already economically feasible at distances over 2,000 km. At distances of 500 km, they are not economically feasible under current circumstances. The environmental incentives increase the DOC savings by a rather limited margin. In the 'CO_2 only' variant (€ 30 per tonne), differences amount to 0.1 to 0.2%; if NO_X is included, DOC savings rise by about 0.1%. The DOC savings are rather limited because only a limited percentage of long haul flights (on which DOC savings from winglets are most substantial) is flown in EU15 airspace.

The fairly paradoxical situation may therefore arise of environmental incentives primarily triggering application of winglets in short-haul markets (i.e. primarily aircraft types 1-3), in which application is currently not very attractive. An analysis with the ITA database (Annex F) shows that application first becomes attractive for smaller aircraft, primarily type 2.

Finally, the case studies on winglets in Annex F show that the reduction of NO_X emission is on average about 1.5 that of CO_2 emission. When lower drag is achieved, a flight can be executed with lower engine loads and consequently lower NO_X emission indices (EI)[19].

From these analyses the following estimates were made vis-à-vis winglet assessment.

[19] This phenomenon is shown in quantitative terms for the case studies on operational measures at aircraft level (see Annex F).

Table 22 Estimates of accelerated application of winglets in the market prompted by economic incentives

	CO_2 variants only			$CO_2 + NO_X$ variants		
valuation, CO_2	€ 10/tonne	€ 30/tonne	€ 50/tonne	€ 10/tonne	€ 30/tonne	€ 50/tonne
valuation, NO_X				€ 1.2/ kg	€ 3.6/ kg	€ 6.0/ kg
market introduction of winglets accelerated by incentive						
aircraft type 1	2%	8%	14%	4%	12%	20%
aircraft type 2	4%	16%	28%	8%	24%	40%
aircraft type 3	2%	8%	14%	4%	12%	20%
aircraft type 4	1%	4%	7%	2%	6%	10%
CO_2 emission reduction, per aircraft type and total						
aircraft type 1	0.0%	0.1%	0.2%	0.1%	0.2%	0.3%
aircraft type 2	0.1%	0.3%	0.6%	0.2%	0.5%	0.8%
aircraft type 3	0.1%	0.2%	0.4%	0.1%	0.4%	0.6%
aircraft type 4	0.0%	0.2%	0.3%	0.1%	0.2%	0.4%
total emission reduction estimates for 2010						
CO_2	0.04%	0.15%	0.27%	0.08%	0.23%	0.38%
NO_X	0.06%	0.23%	0.41%	0.12%	0.35%	0.57%

It can be seen that winglet application is only accelerated to a minor degree by the incentives studied: several tenths of a per cent emission reduction can be achieved. See for a detailed description Annex F.

Riblets

Riblets are small grooves made on the surface of an aircraft in the direction of flow with the aim of reducing skin friction. Measured drag reductions - for an aircraft covered 100% with riblets, which is not practical - are in the range of 5-11%, most of the values converging to 8%. The ultimate drag reduction attainable on a real aircraft will be about 2-3% (Viswanath, P. R., 1999).
Currently the 3M company is offering Paint Replacement (Appliqué) Technology to replace normal aircraft painting (information from 3M Aerospace). Unknowns are costs and extra weight. If this option replaces a paint job, the extra weight will be rather limited: up to about 200 kg for a type 7 aircraft. The cost will probably not be much different from that of a paint job. At the moment the risk (it is not yet a commercially accepted strategy) and probably maintenance costs are the most important barriers to introduction. Table 23 shows the assumptions made in the evaluation of riblets.

Table 23 Assumptions made in the evaluation of riblets

Aircraft type	Net fuel savings at different stage lengths				Costs per 5 years
	500	2,000	6,000	10,000	
1	0.5%	1%	1.5%	1.5%	30,000
2					50,000
3					75,000
4					100,000
5					150,000
6					200,000
7					250,000

The results of the analyses (see Annex F) show approximately the same trends as in the case of winglets. The incentives make use of riblets more attractive primarily on short-haul flights and smaller aircraft, as these fly the greatest percentage of their time in EU15 airspace where incentives are in place. The difference is that riblets are not yet general practice, whereas wing tip devices have already been introduced in the bulk of the fleet. On the other hand, on a per-aircraft basis winglets are more effective. We estimate that the supply-side response with respect to riblets will have approximately the same environmental impact as in the case of winglets.

Re-engining

In the 80s and 90s, with prospects of high fuel prices and increasingly severe noise restrictions, re-engining aircraft was a control option regularly considered and sometimes executed.
it is necessary to approach this option from a case study level, and we did so for aircraft type 2 (B737-400) and type 7 (B747-400). The conclusion of this analysis is that although re-engining has environmental potential, it is extremely costly and the *regional* incentives studied here are probably not sufficient to trigger such costly measures.

Technical measures to new aircraft (medium/long term)

In the somewhat longer term, other options to reduce aircraft emissions might come into play. We mention the following:

- Accelerated development and introduction of ultra-high bypass engines. It is well known that aircraft engines face a trade-off between CO_2 and NO_X emissions. As a general rule, the higher the pressure ratio in engines, the better the fuel efficiency but the higher the NO_X emission index (EI) per kg of fuel burnt. Therefore, only including CO_2 in the incentive could lead to engines that are too optimised towards high pressure ratios.
- A renewed interest in turboprop engines. Turboprop-equipped aircraft fly slower but about 30% more efficiently than turbojet-equipped aircraft. In the longer term, greater focus on environmental efficiency could improve the outlook for this type of engine, which today is often regarded as obsolete.
- Increased wing aspect ratios.
- Increased application of light-weight materials such as GLARE.

In the recent report ‘ESCAPE; Economic Screening of Aircraft Preventing emissions' (CE et al., 2000) the attractiveness of new technologies and new aircraft concepts were assessed. It was found that environmental incentives could significantly increase the economic attractiveness of such technologies and designs. However, quantification of the long-term impacts of environmental incentives in this respect was found to be unfeasible.

3.7 Supply side: operational measures

Measures at aircraft level

Operational measures come into play only if emissions are calculated on an *ex post* basis, on the basis of real flight data. Given a certain aircraft and a certain flight, a flight path and speed leading to minimum emissions can be identified as well as a flight path and speed leading to maximum emissions. The difference between these can be as large as 15-25%.

Annex F contains the results of a number of APD model runs on optimising flight path and speed towards a DOC minimum. In other words we studied the trade-off between crew and depreciation costs on one hand and fuel savings on the other for several charge variants.

The following conclusions can be drawn from these calculations:

- The impacts of the charge on cruise speeds and altitudes, and thus on DOC and fuel consumption and emission, is highly variable across the four aircraft/typical range combinations studied. CO_2 is typically reduced by a few tenths of a per cent to about 2% at most;
- The reduction of NO_X emissions is generally about twice that for CO_2 if the incentive is for CO_2 only, and about 2.5 to 3 times as great if the incentive includes NO_X as well. The lower speeds require lower thrust and therefore lead to lower NO_X emission indices.

These conclusions have been assessed in Table 24.

Table 24 CO_2 emission reduction estimates in 2010 following from flight speed and altitude adaptations to optimise DOC

Valuation, CO_2 € /tonne	Valuation, NO_X € /kg	Emission reduction estimates following from flight speed/altitude adaptations in emission charge and PSI variants	
		CO_2 emissions	NO_X emissions
10	0	-0.2%	-0.4%
30	0	-0.6%	-1.2%
50	0	-1.0%	-2.0%
10	1.2	-0.3%	-0.8%
30	3.6	-0.9%	-2.5%
50	6.0	-1.5%	-4.0%

Measures at network level

Airlines continuously strive for an optimum balance between service costs (influenced by load factor) and service quality (influenced by flight frequency). There is a trade-off between the two: increasing frequencies improves quality - and thus will attract new customers - but will reduce load factors, at least in the short run.

In the case of an *emission charge* the marginal transport costs are increased. This pushes break-even load factors up, forcing airlines in the longer term to adjust their frequencies downward and/or their load factors upward. Use of larger aircraft with lower frequencies is also an option; such a strategy generally leads to lower environmental costs.

Hardly any studies have been done on the network impacts of environmental charging programmes in aviation. The only study known in which this effect has been explicitly dealt with is the ESCAPE study, jointly executed by a consortium consisting of CE, Peeters Advies, and Delft University of Technology (CE et al., 2000). The effects of a fairly extreme fuel price scenario were investigated (rise from \$0.25 to \$1.00 per kg). This increase was simulated in an airline's network. This price increase reduced travel demand by 10%, a result of a 16% reduction in flight movements and an increase in load factor of about 6%. Fuel savings amounted to about 4.5%. Assuming a linear relationship between cost rises and load factor/frequency developments, and correcting for the number of kilometres flown within EU airspace, we arrive at the estimates shown in Table 25.

The case of the *Performance Standard Incentive* is more complicated. In this variant marginal transport costs will not increase, but the variant provides a different incentive for raising load factors. As a result of its design the PSI - namely emissions per ARTK - gives an extra incentive to push load factors

upward. For example, in the € 50 per tonne CO_2/€ 6 per kg of NO_X variant every extra passenger kilometre is rewarded with about 0.9 €cts. This means that, on a 1,500 km return flight, the airline can earn about € 27 extra by taking an extra passenger on board, apart from the ticket revenues.
At the moment it is very hard to estimate the impact of such extra earnings from extra passengers on the airlines' yield management strategies. The PSI makes last-minute ticket sales at very low prices - maybe sometimes even for free - much more attractive. This effect might prove to be substantial, but it requires advanced yield management models to make something of a prediction[20]. Also, this shows that it is likely that through this mechanism the PSI variant could possibly lead to extra demand in terms of passengers and passenger-kilometres - not in terms of aircraft-kilometres. Because of all these uncertainties we chose to estimate this effect conservatively by assuming the same impacts on load factor as in the emission charge variant. See Table 25.

As no changes in NO_X emission index (EI) are to be expected from this mechanism, NO_X emission reduction has been taken equal to CO_2 emission reduction.

Table 25 CO_2 emission reductions in 2010 following from frequency and load factor measures in the emission charge variant

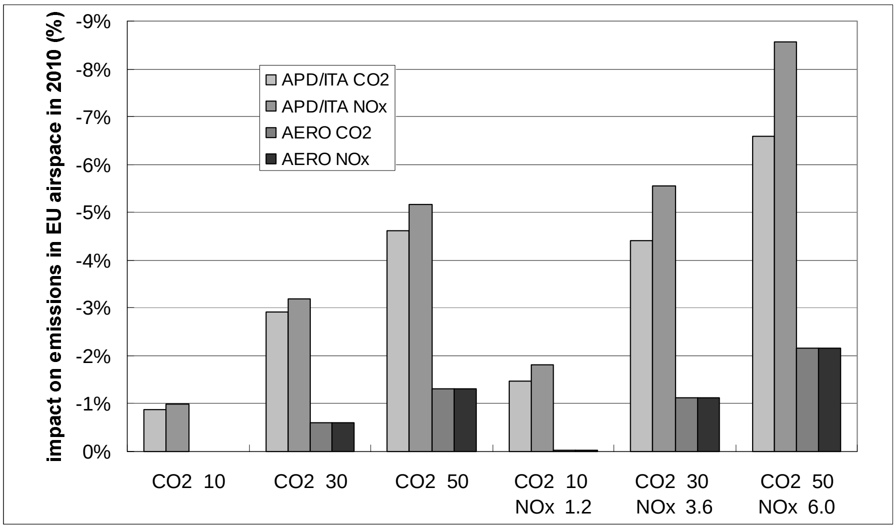
Valuation, CO_2 € /tonne	Valuation, NO_X € /kg	CO_2 and NO_X emission reduction estimates following from load factor/frequency measures in emission charge and PSI variants
10	0	-0.1%
30	0	-0.3%
50	0	-0.5%
10	1.2	-0.2%
30	3.6	-0.5%
50	6.0	-0.8%

3.8 Comparison of supply-side responses with AERO model calculations

In Figure 14 we show and compare aggregate estimates of the environmental impacts of *supply-side* responses as assessed in the previous sections and as found with the AERO model.

[20] The AERO model does not include this mechanism.

Figure 14 Total estimated CO_2 and NO_X emission reduction impacts in 2010 in the emission charge and PSI variants due to supply-side responses, as found in the analysis with the APD model and ITA databases on the one hand, and with the AERO model on the other



It can be seen that the AERO-MS leads to CO_2 reductions due to supply-side measures of around 0-2%, depending on the variant, compared with the approx. 1-6 calculated in this chapter.

The differences between the two approaches cannot readily be explained, as the mechanisms through which the emission reductions arise cannot be identified from the output of the AERO model. However, judging from the qualitative descriptions of the mechanisms addressed in the AERO-MS (Section 3.3), the differences can probably be explained by two factors:

- The AERO-MS takes fewer emission reduction mechanisms into account than this study. More specifically: impacts on aircraft technology, cruise speeds and load factors are taken into account in the calculations in this chapter, but not in the AERO-MS;
- The effect of accelerated fleet renewal is estimated in this chapter to be more substantial than in the AERO-MS. This is probably due to the fact that AERO-MS airlines have only one, quite radical, option to change aircraft technology (from 'old' to 'new'), which is not feasible in many cases, whereas in practice airlines have numerous options for arriving at a younger fleet.

For these reasons we chose to use the supply-side responses found in this chapter rather than the AERO results for further analysis.

Furthermore, both the AERO and ITA/APD model results suggest that all variants also reduce NO_X, in spite of oft-heard concerns about a negative trade-off between CO_2 and NO_X emission reduction. The reason for this is fourfold:

- first, reduced aircraft fuel consumption generally leads to both lower CO_2 and lower NO_X emissions;

- second, an aircraft flying at lower engine loads owing to operational measures or application of winglets or riblets has a lower NO_X emission index (amount of NO_X emission per kg of fuel burnt)[21];
- third, our analysis has shown that there is little reason to fear that the existing fleet will be retrofitted with 'low CO_2, high NO_X' engines;
- and finally, our analysis is for the year 2010 and has therefore not considered possible long-term impacts of incentives on engine development.

3.9 Supply-side responses in the light of regional scale

As already shown in the previous paragraphs, the fact that the environmental incentives apply only to EU15 airspace substantially limits their environmental potential, particularly where large aircraft flying long hauls are concerned.
Besides these considerations, it is sometimes argued that the environmental effect would be lower than calculated for the following reasons:
- It is said that airlines flying only a small proportion of flights in EU airspace can anticipate the incentives without really implementing any technical or operational measures by sending their cleanest aircraft to Europe. This could reduce the environmental effect somewhat, especially for non-EU airlines. However, it should be said that airlines do not generally have much scope for selecting an equivalent but cleaner aircraft from their current fleet for a specific route.
- It is said that aircraft retired under the European programme will be sold to airlines outside Europe, so that the net global environmental impact would be zero. However, in this case it should be taken into account that these airlines would probably have flown even older aircraft in the reference scenario.

3.10 Demand side: demand loss and shift to other modes

The environmental impacts of the incentives studied here stem not only from technical and operational responses by airlines and aircraft manufacturers but also from possible losses in demand for air travel. As the bulk of the air transport market does not seriously compete with other modes of transport, most such demand loss will be lost altogether. Only a minor fraction of demand loss is diverted to other modes, such as high-speed rail transport and road transport (*modal shift*). The demand effects are largely dependent on:
- the impacts of the incentives on airline costs; these cost impacts were assessed using the AERO model and largely correspond with the figures shown in Section 3.4;
- the degree to which these costs can be translated into consumer prices; for the analysis in this report it was assumed that all increases in costs are passed on to consumers;
- the price elasticities of specific markets, or the degree to which price increases lead to demand loss;
- the degree to which traffic is diverted to other modes and the environmental impact of these modes.

Table 26 shows the results of the AERO model calculations.

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21 This effect is taken into account in the ITA/APD calculations, but not in the AERO model.

Table 26 Total impact on CO_2 and NO_X emissions in 2010 due to demand-side responses according to the AERO model analysis, assuming extra costs can be transferred to consumers

Valuation, CO_2 € /tonne	Valuation, NO_X €/kg	Emission charge		Performance Standard Incentive (PSI)	
		emissions from aircraft	emissions from cars and trains	emissions from aircraft	emissions from cars and trains
10	0	-1.1%	+0.01%	-0.1%	+0.00%
30	0	-3.1%	+0.03%	-0.4%	+0.01%
50	0	-4.9%	+0.04%	-0.4%	+0.01%
10	1.2	-1.7%	+0.01%	-0.2%	+0.00%
30	3.6	-4.5%	+0.04%	-0.4%	+0.01%
50	6.0	-7.2%	+0.06%	-0.6%	+0.01%

From the table, the following conclusions can be drawn:

- Not surprisingly, the emission charge leads to far greater emission reductions due to demand effects than the PSI. With the emission charge, emission reduction due to demand effects ranges from 1 to 7%, whereas these figures are below 1% for the PSI.
- It can be seen that the environmental impact of the shift to other modes is very limited compared with the lower aircraft emissions;

3.11 Overview of environmental impacts

In this section, the supply and demand side findings are summarised in order to arrive at *total* environmental effects and briefly evaluated. Table 27 summarises the main results.

Table 27 Overview of $\mathbf{CO_2}$ emission reductions in the different emission charge and PSI variants, related to emissions released in EU15 airspace in 2010

Valuation CO_2 & NO_X, € /tonne & kg	Emission charge variant				Performance Standard Incentive (PSI)			
	supply side, %	demand side, %	total		supply side, %	demand side, %	total	
			%	Mtonnes			%	Mtonnes
10 & 0	-0.9%	-1.0%	**-1.9%**	-2.2	-0.9%	-0.1%	**-0.9%**	-1.1
30 & 0	-2.9%	-3.1%	**-5.9%**	-6.9	-2.9%	-0.4%	**-3.3%**	-3.9
50 & 0	-4.6%	-4.9%	**-9.3%**	-10.9	-4.6%	-0.4%	**-5.0%**	-5.9
10 & 1.2	-1.5%	-1.7%	**-3.1%**	-3.6	-1.5%	-0.2%	**-1.7%**	-2.0
30 & 3.6	-4.4%	-4.5%	**-8.7%**	-10.2	-4.4%	-0.4%	**-4.8%**	-5.6
50 & 6.0	-6.6%	-7.2%	**-13%**	-15.6	-6.6%	-0.6%	**-7.2%**	-8.4

The environmental impacts due to supply-side measures are taken from the analysis in this chapter. The impacts due to air transport demand effects are taken from the AERO model results described in Section 3.10.

Table 28 Overview of **NO_X** emission reductions in the different emission charge and PSI variants, related to emissions released in EU15 airspace in 2010

Valuation CO_2 & NO_X, €/tonne & kg	Emission charge variant				Performance Standard Incentive (PSI)			
	supply side, %	demand side, %	total		supply side, %	demand side, %	total	
			%	Mtonnes			%	Mtonnes
10 & 0	-1.0%	-1.0%	**-2.0%**	-9	-1.0%	-0.1%	**-1.0%**	**-4**
30 & 0	-3.2%	-3.1%	**-6.1%**	-26	-3.2%	-0.4%	**-3.6%**	**-15**
50 & 0	-5.2%	-4.9%	**-9.8%**	-42	-5.2%	-0.4%	**-5.6%**	**-24**
10 & 1.2	-1.8%	-1.7%	**-3.5%**	-15	-1.8%	-0.2%	**-2.1%**	**-9**
30 & 3.6	-5.6%	-4.5%	**-9.8%**	-42	-5.6%	-0.4%	**-6.0%**	**-25**
50 & 6.0	-8.6%	-7.2%	**-15%**	-64	-8.6%	-0.6%	**-9.1%**	**-39**

The environmental impacts due to supply-side measures are taken from the analysis in this chapter. The impacts due to air transport demand effects are taken from the AERO model results described in Section 3.10.

From the tables and the analysis made we can draw the following conclusions:

- The potential total CO_2 emission reduction in 2010 resulting from the different incentives ranges from approx. 1% (PSI, € 10 per tonne CO_2) to approx. 13% for the highest emission charge (€ 50 per tonne CO_2, € 6 per kg NO_X). The highest PSI achieves about 7% emission reduction. In absolute figures, we are talking about reductions of 1, 16, and 8 Mtonnes of CO_2 respectively.
- In the emission charge variant, supply and demand-side responses are about equally important, under the assumption that all charges can be passed on to customers. In the PSI variants, supply-side responses play a dominant role.
- By far the most important measure that will probably be taken on the supply side is accelerated fleet renewal. The reduction of average fleet age is not easy to estimate but will probably fall in the range of 0.3 to 2 years, depending on the variant. This leads to approximately 0.5 to 3% emission reduction for the fleet as a whole. According to our calculations, all other supply-side measures together add at most 3% to this figure.
- It is notable that supply-side measures are fairly similar in the case of both an emission charge and PSI. This can be explained by the fact that both variants provide exactly the same economic incentive for taking supply-side measures. The only exception is the load factor/flight frequency response, which is probably very different if a PSI is based on emissions per ARTK
- As a general rule, CO_2 emission reductions go more or less hand in hand with NO_X emission reductions. This implies that even 'CO_2 only' incentives will most probably reduce both CO_2 and NO_X emissions. In many cases reduction of CO_2 emissions even leads to further reductions in NO_X emissions because of reduced engine loads and thus lower NO_X emission indices. The only exception to this rule is new engine installation and design, where there is a CO_2/NO_X trade-off. As this study considers responses in the year 2010, it does not account for the long-term impacts of engine technology development.

4 Economic and distributional effects

4.1 Introduction

The potential economic and distributional effects of the economic incentives considered may be largely dependent on the geographical scale on which the incentive is applied. One important potential effect of an emission route charge or PSI imposed in EU airspace only is that it may lead to distortions in competition in the aviation industry as well as in other sectors of the economy. In the aviation industry the competitive position of EU airlines might be adversely affected compared to non-EU airlines. Other areas of the European economy where air transport plays an important role, such as tourism, might also be adversely affected by an emission route charge or PSI in EU airspace.

This chapter focuses on the potential economic distortions and distributional impacts resulting from the introduction of economic incentives to mitigate the climate impacts of aviation in Europe. Both potential side-effects are important for assessing the feasibility of the economic incentives.

It is important to remark that a change in the competitive position of relatively clean airline companies compared to high-polluters is not considered to be an economic distortion, but rather an efficiency improvement. However, in the short term considerable distributional effects may occur.

The economic and distributional effects have been quantified using the AERO modelling system. In addition, several interviews were carried out with airline companies and experts. Reference was also made to the scarce international literature of relevance to this topic. Finally, Professor Rigas Doganis, expert on airline economics, reviewed this chapter and added some useful comments.

This chapter presents the following:
- a definition of what, in this study, is considered to be an economic distortion (Section 4.2);
- fare adjustment behaviour of airlines (Section 4.3);
- impacts of the incentives on air transport on intra-EU routes and routes to and from the EU (Section 4.4);
- analysis of the change of the competitive position of EU carriers compared with non-EU carriers (Section 4.5);
- sensitivity analysis of fare adjustment behaviour (Section 4.6);
- potential economic impacts on tourism and cohesion states (Section 4.7).

In all sections relevant differences between the emission charge variant and the Performance Standard Incentive (PSI) have been made explicit.

4.2 Definition of 'economic distortion'

Economic distortions are defined in this study as distortions in competition between European and non-European airline companies caused by the limited geographical scale of the policy options. This definition implies that changes in the competitive position of companies that would also be prompted by a *global* aviation charge are not considered to be economic distortions in this study.

It is important to note that this study discusses two types of economic impact on competition of an emission charge or PSI in EU airspace. The importance of this distinction is that the policy implications may differ. An economic incentive on aviation in the EU could:

- distort fair competition among airlines, airports or other sectors. This will **reduce** economic efficiency and the appropriate policy response is to select options that minimise such distortions;
- change the relative competitive position of different suppliers in favour of those that are environmentally efficient (and against those that are environmentally inefficient). This will **increase** economic efficiency; there will clearly be winners and losers, however, and the appropriate policy response may therefore be to provide transitional support for a period of time to give companies sufficient opportunity to adapt to the new circumstances (e.g. by early announcement).

Examples of the first group (distortions to fair competition) arise in circumstances where it is not possible to apply the charge or PSI equally to all potential competitors (e.g. holiday suppliers inside and outside Europe). Examples of the second group (changes in relative competitive strength) will arise when a charge applied equally to all competitors has a differential impact on them (e.g. between airlines with more (or less) environmentally efficient aircraft or between holiday suppliers making more (or less) use of air transport).

4.3 Fare adjustment behaviour

A crucial assumption in the assessment of the impacts of the emission charge and PSI relates to the fare adjustment behavior of airlines. For example, if airlines fully absorb the cost increase due to the charge by lowering their profit margins, ticket prices remain unchanged and there will be no impact on demand.
Below we argue why we assume in this study that airlines will generally pass the cost increase due to the economic incentives on to passengers.

First, it should be stressed that all carriers, both EU and non-EU, are assumed to be subject to exactly the same charge or PSI. Because this study considers only non-discriminative economic incentives, this means that all carriers providing the same service are charged in the same way. This implies that both EU and non-EU carriers would face the same cost increase on the same flight stage[22]. In a situation of perfect competition in the international markets for air transport, both EU and non-EU carriers will then pass on the whole of the charge to their customers. This can be explained by the fact that in a perfect market there is no scope for airlines to absorb the charge (and reduce their fares) by reducing their profit margin or by cross-subsidising[23].
From the literature and interviews it was found that charter and low-cost carriers are likely to pass the entire cost increase due to the charge on to customers. The main reason is that these markets are highly competitive and consequently have small profit margins that do not permit higher costs. This is confirmed by two studies[24]: one on the impact of abolishing intra-EU duty- and

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[22] In practice, there will be winners and losers because airline companies with relatively old and inefficient aircraft have to pay higher total charges per flight.

[23] Cross-subsidising is defined as the situation whereby an airline company uses profits earned with activity A to finance a reduction of the fares of activity B.

[24] SH&E International Air Transport Consultancy (June 1997); Symonds Travers Morgan (June 1997).

tax-free allowances on charter airlines and another on the impact of such a move on low-cost scheduled airlines. In both studies a majority of airlines surveyed believed it would not be possible for them to absorb any increased costs. A questionnaire survey of airlines carried out by Alamdari and Brewer (1994) also indicated that the dominant reaction, besides improving environmental efficiency, would be to increase fare levels.
In addition, the fact that airlines pass the higher security costs faced after 11 September 2001 on to the customers illustrates that it is possible and likely that airlines will likewise pass the costs of the emission charge or PSI on to their customers.

Cross-subsidy
However, in the current situation, where not all markets are liberalised and monopolistic or oligopolistic markets exist, the question remains whether non-EU carriers would be encouraged by a economic incentives in EU airspace to engage in **extra** cross-subsidising of flight stages to and from the EU. If this were to happen, EU carriers would then be forced to reduce airfares as well and not pass on the whole of the charge to customers in order to hold their market share. Obviously, cross-subsidisation is common and is widely practised in all international air markets. Here, the question is not whether cross-subsidisation occurs but whether a charge or PSI allow for additional cross-subsidising by non-EU airlines competing with EU airlines.
It should be noted that cross-subsidising of *intra-EU routes* is not possible, because non-EU airlines are not allowed to operate between city pairs in the EU, or to a very limited extent only.
A strong argument for not expecting *extra* cross-subsidising by non-European carriers appears to be that a charge or PSI in EU airspace provides no extra incentive for it. This is mainly because a charge will not affect the profits of non-EU airline companies on routes outside Europe, thus freeing up no extra funds for cross-subsidising from protected markets.

On the basis of the above arguments we conclude that both EU and non-EU carriers will pass on the whole of the charge to their customers. Below, we present the economic and distributional effects to be expected, assuming full fare adjustment. Nevertheless, at the end of Section 4.5 (economic distortions between airlines) we present a sensitivity analysis of this crucial assumption of fare adjustment behaviour.

4.4 Impacts on transport volume

The table below illustrates the impact on transport volume in terms of revenue tonne kilometre (RTK) of the introduction of both an emission charge and a PSI in EU airspace.

Charge
Table 29 illustrates that demand on the intra-EU market decreases by 1.0 to 4.5% compared with the reference scenario in 2010 for a CO_2 *charge* of € 10 to 50 per tonne. Taking into account a predicted growth of 4% per annum for the intra-EU market, the reduction in demand due to the emission charge of € 50 per tonne CO_2 is thus equal to one year of autonomous demand growth. For routes to and from the EU the reduction of demand due to the charge is less than six months of autonomous demand growth.

Performance Standard Incentive (PSI)
The overall demand impact of introducing the PSI is approximately zero, reflecting the revenue-neutral design of this instrument. In the case of a PSI

some flights are charged and thus operating costs increase and if this is passed on to the consumers demand will be reduced. At the same time other flights will get a rebate, which will compensate the demand effect of the charged flights. According to the calculations with the AERO model, however, the overall demand effect of the PSI is not quite zero. This is illustrated in Table 29 by the small decrease of demand by up to 0.3% on the intra-EU market.
The first reason for this is that operating costs may increase somewhat compared with the autonomous scenario, because airlines will invest in certain supply-side measures. If these costs are passed on to customers, demand will be affected. This effect appears to be plausible for the intra-EU market because of the relatively strong market position of EU carriers in this market.
However, on routes to and from the EU, non-EU carriers can easily send the cleanest aircraft in their fleet to the EU, and we therefore expect that the competitive position of EU carriers on these routes would not permit ticket price increases in order to cover certain supply-side investments.
A second reason the PSI may have a small demand effect in the intra-EU market is that in the input assumptions of the AERO model we assumed that airlines receiving a rebate on flights would not pass this reward on to customers by lowering ticket prices. Consequently, no positive demand effects will occur that can compensate for the negative demand effect due to charges paid on relatively inefficient flights. The underlying assumption is that EU carriers have a strong market position in the intra-EU market. If this assumption is not true, the overall impact on demand will be zero.

Table 29 Effect on transport volume after introduction of an emission route charge or PSI in EU airspace, expressed as a percentage change of Revenue Tonne Kilometres (RTK) (source: AERO modeling system)

		Emission charge		Performance Standard Incentive (PSI)	
base	level	intra-EU routes	routes from and to EU	intra-EU routes	routes to and from EU
CO_2	50	-4.5%	-1.6%	-0.3%	0
	30	-2.6%	-0.8%	-0.2%	0
	10	-1.0%	-0.4%	-0.1%	0
CO_2/ NO_x	50/6	-6.5%	-2.4%	-0.3%	0
	30/3.6	-4.0%	-1.6%	-0.2%	0
	10/1.2	-1.4%	-0.5%	-0.1%	0

4.5 Change of competitive position of EU-carriers vs. non-EU carriers?

The question here is whether an emission-based route charge or PSI on aviation in EU airspace will create competitive disadvantages for EU airline companies compared with non-EU airline companies. Changes in competitiveness are best reflected in changes in the total operating results of EU vs. non-EU carriers. Total operating results are determined mainly by the **profit margin** per unit transported and the **market share** in combination with the **size** of the air transport market.

*Change in **profit margin** of EU vs. non-EU airlines*
The starting point of the analysis is the non-discriminatory character of the economic incentives, implying that both EU and non-EU carriers would face the same cost increase on the same flight stages. As a consequence and as already remarked in Section 4.3, airlines are then able to pass the entire

cost increase of a charge on to customers. This means that the profit margin (operating result as a percentage of total revenues) will remain unchanged after introduction of a charge, both for EU and non-EU carriers.
Table 30 confirms that the profit margin of EU carriers and other carriers will remain at 2.1% and 2.8%, respectively, equal to the profit margin of both carrier groups in a situation without an emission charge. Table 30 presents the results of AERO calculations of the economic impacts of the *emission charge*.

Table 30 Economic effects of an **emission charge** for EU carriers versus other carriers

	Unit	EU/other	Reference Scenario 2010	CO_2 / € tonne		CO_2/NOx € tonne/kg	
				10	50	10/1.2	50/6.0
Profit margin	Operating result as % of revenues	EU other	2.1% 2.8%	2.1%[25] 2.8%	2.1% 2.8%	2.1% 2.8%	2.1% 2.8%
Operating costs	Billion 1992 US$ p.a.	EU other	141 407	<0.05% 0.0%	0.3% 0.0%	0.1% 0.0%	0.5% 0.1%
Operating rev.	Billion 1992 US$ p.a.	EU other	144 419	0.05% 0.0%	0.3% 0.0%	0.1% 0.0%	0.4% 0.1%
Revenue Tonne Km (RTK)	Billion RTK p.a.	EU other	187 641	-0.5% -0.1%	-2.1% -0.4%	-0.8% -0.1%	-3.4% -0.6%
Airline employment	Employees (x1000)	EU other	760 2844	-0.6% -0.1%	-2.8% -0.3%	-1.0% -0.1%	-4.4% -0.5%

Table 31 illustrates that in the case of the PSI the profit margin of EU carriers and other carriers would remain stable or even increase somewhat after introduction of the incentive in EU airspace. The small increase can be clarified by the assumption that airlines receiving a rebate on relatively clean flights (minimum emissions per unit payload) will not pass this reward on to customers by lowering their ticket prices. As already remarked in Section 4.4, the underlying assumption is the strong market position of EU carriers in the intra-EU market. The profit margin will not change if this assumption is abandoned.

25 In contrast with the other parameters in the table this percentage does not give the percentage change compared with the reference situation. 2.1% presents the profit margin (operating result as a % of revenues) that results after introduction of the emission charge. The table illustrates that the profit margin will not change compared with a situation without an emission charge.

Table 31 Economic effects of a **Performance Standard Incentive (PSI)** for EU carriers versus other carriers

	Unit	EU/other	Reference Scenario 2010	CO2 / € tonne		CO2/NOx € tonne/kg	
				10	50	10/1.2	50/6.0
Profit margin	Operating result as % of revenues	EU other	2.1% 2.8%	2.2%[26] 2.8%	2.4% 2.9%	2.2% 2.8%	2.5% 2.9%%
Operating costs	Billion 1992 US$ p.a.	EU other	141 407	-0.1% 0.0%	-0.3% 0.0%	-0.1% 0.0%	-0.4% 0.0%
Operating rev.	Billion 1992 US$ p.a.	EU other	144 419	0.0% 0.0%	0.0% 0.0%	0.0% 0.0%	0.0% 0.1%
Revenue Tonne Km (RTK)	Billion RTK p.a.	EU other	187 641	-0.1% 0.0%	-0.1% 0.0%	-0.1% 0.0%	-0.2% 0.0%
Airline employment	Employees (x1000)	EU other	760 2844	-0.2% 0.0%	-0.8% 0.0%	-0.3% 0.0%	-1.1% 0.0%

Market share and size of air transport market
As already noted, besides the *profit margin*, the competitive position of carriers may also be affected by changes in the size of the home market and market share.
Obviously, a second-order effect is that increased air fares may slow down the growth of the EU air transport market somewhat, resulting in a smaller home market for EU compared with non-EU carriers. This might weaken the competitive position of EU airlines. Table 5.2 illustrates, for a charge level of € 50 per tonne CO_2, that the air transport volume of EU carriers (expressed in RTK) will decrease by 2.1% compared with the autonomous trend. This volume will decrease by 0.4% for non-EU carriers. This implies, for one year, a reduction in volume growth for EU carriers of 1.7% compared with non-EU carriers. This somewhat lower growth of air transport volume might lead to reduced economies of scale for EU compared with non-EU airline companies.
A Performance Standard Incentive hardly affects the size of the home market at all and we therefore conclude that no reductions in economies of scale would be prompted by introduction of a PSI.

Below, the consequences of a somewhat smaller home market for both low cost carriers and main scheduled carriers are discussed for the case of an **emission charge**.

Charters and low-cost carriers operate direct flights on origin/destination markets. Doganis (1991) indicates that airlines operating direct flights on origin/destination markets have little scope for achieving economies of scale or economies of density. This implies that reduced growth of the European market would not result in lower operating profits per unit on an isolated flight for European charters and low-cost carriers compared with those of non-European countries.
A probably even more convincing argument for not expecting competitive disadvantages after introduction of an emission-based route charge is that non-EU carriers hardly compete with EU low-cost carriers on the intra-EU market.
Given the unchanged profit margin, and on the basis of both arguments above with respect to the home market effect, we conclude that an emission-based charge would not create potential competitive disadvantages for charters and (low-cost) carriers serving only the intra-EU market.

[26] Ibid.

In contrast to low-cost carriers, which operate origin/destination services, scheduled carriers can often be regarded as multi-product firms, because they offer both direct and indirect destinations, implying that they operate on both origin/destination markets and transfer markets. Multi-product firms can achieve economies of scope and economies of information. A smaller European home market due to the charge may then reduce these scale advantages for European scheduled carriers. However, we assume that a smaller home market of less than one year growth (see change in RTK for each of the options in Table 30) will not reduce economies of scale for EU carriers significantly.

Besides the home market disadvantage, another potential competitive disadvantage is that non-EU carriers may shift their most efficient aircraft to routes to and from the EU and their oldest aircraft to other routes. Consequently, non-EU carriers may then fly relatively cleaner aircraft and thus pay less charges than EU carriers. This mechanism will occur for both the charge and the PSI variant.
The question is whether this mechanism could play a significant role. First, it should be stressed that long-haul trips to and from the EU are charged in EU airspace only, which is 25% or less of the flight distance. As a result, differences in total charges between old and new aircraft will be limited.
Second, in practice, on routes to and from EU airspace only a limited number of long-haul airframe/engine combinations are available (given the optimum payload/range), which reduces the scope for switching to other, more efficient aircraft. Current practice, which shows that global carriers use roughly similar aircraft types for long-haul operations to the EU, confirms this point.
Based on both aforementioned arguments, our preliminary conclusion is that this competitive disadvantage would be small for EU carriers. However, it was not possible to quantify this effect and definitive conclusions cannot therefore be drawn.

Potential disadvantage of the PSI
Many of the non-EU airlines flying into the EU – especially after enlargement of the Union – will be long-haul carriers (such as SIA, Cathay, Qantas) operating very large aircraft at high load factors of 75% or more. Under a PSI scheme, based on a linear relationship between the performance standard and the distance flown, most of these flights will be receiving substantial rebates paid for by charges raised on intra-EU air services operated by EU airlines with smaller aircraft and load factors of 50-65%. While this makes sense in terms of environmental efficiency, it does suggest that the competitive balance will shift in favour of long-haul carriers. Non-EU long-haul carriers with aircraft performing better than the performance standard might even be given an incentive to fly more in EU airspace in order to receive higher rebates. In order to prevent the competitive balance shifting in favour of non-EU long-haul carriers with an EU destination, the PSI should be corrected for stage distance (see also section 2.4.4 and Annex C). In this way the relative disadvantage of short-haul flights resulting from their operationally intrinsic lower environmental efficiency will be corrected.

4.6 Sensitivity analysis of fare adjustment behaviour

In section 4.3 arguments were presented for the assumption that airlines would pass on to customers the whole cost increase resulting from the charge. In the long run, it seems unavoidable for airlines to adjust their ticket prices. However, in the short run, it may be felt that it is temporarily not possible to pass on the charge fully to customers. This section therefore presents a sensitivity analysis with respect to the fare adjustment behaviour of airlines in relation to charge-induced cost increases.

Below, in Table 32, the impacts of an emission charge on the competitive position of EU compared with non-EU carriers are presented, assuming that airlines are able to pass on only about half the cost increase to customers.

Table 32 Economic effects of an **emission charge** for EU carriers versus other carriers, in the case of full fare adjustment (PAF=1) and partial fare adjustment (PAF=0.5) (for charge levels of € 10 and € 50 per tonne CO_2)

	Unit	EU/other	Reference Scenario 2010	PAF = 1 full fare adjustment		PAF = 0.5 partial fare adjustment	
				€ 10	€ 50	€ 10	€ 50
Profit margin	Operating result as % of revenues	EU other	2.1% 2.8%	2.1%[27] 2.8%	2.1% 2.8%	1.9% 2.8%	0.6% 2.6%
Operating costs	Billion 1992 US$ p.a.	EU other	141 407	<0.05% 0.0%	0.3% 0.0%	0.3% 0.0%	1.7% 0.2%
Operating rev.	Billion 1992 US$ p.a.	EU other	144 419	0.05% 0.0%	0.3% 0.0%	0.0% 0.0%	0.1% 0.0%
Revenue Tonne Km (RTK)	Billion RTK p.a.	EU other	187 641	-0.5% -0.1%	-2.1% -0.4%	-0.3% 0.0%	-1.2% -0.2%
Airline employment	Employees (x1000)	EU other	760 2844	-0.6% -0.1%	-2.8% -0.3%	-0.4% 0.0%	-1.9% -0.2%

Table 32 shows that, if airlines can only partially pass on the charge induced cost increases, fares are only partly increased and demand is affected less compared with full fare adjustment. Consequently, air transport volume will decrease less in the case of partial fare adjustment.
Obviously, the profit margin on intra-EU flight stages and on routes to and from the EU will be reduced in the short run if it is assumed that all airlines are unable to pass on their charge induced cost increase to customers. This might weaken the competitive position of EU carriers as they achieve a greater part of their turnover on intra-EU routes.

4.7 Tourism, remote regions and cohesion states

An important issue affecting the feasibility of economic incentives is the extent to which negative economic effects will impinge on countries that are strongly dependent on air transport related tourism or on regions, such as islands, that depend mainly on air transport for their economies. Consideration of cohesion states as an effect sub-category relates to the establishment of a Cohesion Fund in 1991 within the EU to help less developed member states achieve higher rates of economic development. Currently the fund is aimed at the following four countries: Spain. Portugal, Greece and Ireland. The first three

[27] In contrast with the other parameters in the table this percentage does not give the percentage change compared with the reference situation. 2.1% presents the profit margin (operating result as a % of revenues) that results after introduction of the emission charge. The table illustrates that the profit margin will not change compared with a situation without an emission charge.

can also be regarded as countries that rely substantially on tourist revenues. Below we therefore focus on these three countries.

In assessing the economic impact on these three cohesion states we distinguish two effects:

- economic distortions, and
- distributional consequences.

First, we stress that a **Performance Standard Incentive (PSI)** will not affect tourism or cohesion states because, given the basic design of the instrument, the total financial burden and the demand impact are almost zero. A **charge** variant will have demand effects and the analysis below therefore focuses on this economic incentive.

Potential economic distortions

If tourist destinations inside the EEA were to become more costly than destinations outside the EEA solely because of the charge being levied only on emissions in EU airspace, this would constitute a competitive distortion. Below, we therefore investigate the extent to which this effect occurs.

The majority of intra-EU charter passengers originate in Northern Europe and travel to Mediterranean holiday destinations. This charter flow from Northern Europe represents over 80% of the total EU charter market. These travellers go to Spain and Greece mainly for the sun and beaches, not available in their home countries. Their first reaction might therefore be to shift to destinations outside the EU instead of travelling to destinations closer to home: from Greece to Turkey, for instance, or from Spain to Tunisia.
Such behaviour might be induced if the route charge makes EU destinations more costly compared to non-EU tourist areas. However, to what extent is this the case? On first sight one would not expect European destinations to become more costly than non-EU destinations, because the distance travelled through EU airspace for EU destinations will, on average, not be systematically greater than for alternative destinations outside the EU. We therefore conclude that this effect of potential distortion will be negligible.

A competitive distortion of an emission charge in EU airspace might also arise if tourists from outside the EU change their destination from a EU to a non-EU country or region. It can be argued, however, that such a distortion is likely to be small, because many people tend to go to Europe to visit a capital city such as London, Paris or Rome. In this case, obviously, it is difficult to find an alternative outside the EU.

Distributional consequences

Any aviation charge, European or worldwide, will favour nearby over long-distance tourism. Thus, the considered charge will slow down the current trend of tourist destinations being chosen further and further away. This effect will increase environmental efficiency and is therefore *not* a competitive distortion. On the contrary, it leads the economy as a whole towards more efficient allocation.
However, the brake on the growth of long-distance tourism will have some impact on the spatial distribution of tourist activities. Clearly, there will be countries that gain and countries that lose. In CE (1998) we calculated these effects in detail. Recalculated to a charge of € 50 per tonne CO_2 we found that the total tourist receipts of the southern EU countries would fall by about 0.02 to 0.15% per annum. The study also shows that Greece would be affected most by a charge. Their total tourist receipts would decrease by about 0.15% per annum. The relatively large impact on the Greek economy can be

explained by the comparatively large share of air arrivals (82%). Obviously, tourists from most of the major tourist departure countries can reach Greece only by air. It is therefore to be expected that Greece will be hit relatively harder by imposition of an emission charge in EU airspace.

It is important to note that the overall effect on the European countries might be much smaller than the above results suggest. An important question in this context is where the lost tourist receipts might be diverted to. For example, what would happen to the tourist receipts lost by the Greek tourist industry? A small part of this sum will be diverted to holiday destinations outside Europe. Part will be diverted to holidays in other countries in the EU. This might even mean that countries like France and Italy are in fact overall gainers rather than losers. Finally, part will be diverted to expenditure on items other than holidays, with a resulting gain to other sectors of the EU economy.

5 Legal feasibility

5.1 Introduction

This legal analysis addresses the legal obstacles and conditions of relevance for implementing economic incentives to mitigate greenhouse gas emissions from air transport in Europe. The results of the legal study are based mainly on a study carried out by the International Institute for Air and Space Law of Leiden[28]. This legal analysis focuses on international provisions, including the Chicago Convention, Bilateral Air Services Agreements, the legal framework of the European Union and the regulatory regime of Eurocontrol.

The Chicago Convention is the fundamental treaty on international civil aviation. Most nations of the world, including the 15 EU member states, are parties to this treaty. Its provisions form binding international law, superseding bilateral ASAs and national air codes. Bilateral ASAs regulate the operation of air services between pairs of countries. They supersede national regulations. EU aviation law replaces the bilateral ASAs between the EU member states in areas in which it covers matters dealt with by these ASAs. It follows from this that EC aviation law does not replace, or supersede, the provisions of the Chicago Convention.

The following questions are analysed in this chapter in order to assess legal feasibility as outlined above:

1 Under what conditions is an emission-based charge on intra-EU flights and flights to and from the EU feasible under international law? (Section 5.2)
2 Is it legally feasible to use fuel consumption as a key parameter for calculating the charge base? (Section 5.3)
3 Is it legally feasible to use the administrative infrastructure of Eurocontrol for charging and collecting an emission-based en route charge? (Section 5.4)
4 What international laws and regulations pertain to definition of an airspace for application of an emission-based route charge? (Section 5.5)
5 Is it legally feasible to use the Eurocontrol airspace for an emission-based route charge? (Section 5.6)
6 Is it legally feasible to include the high seas outside the 12 nautical mile zone of Member States in the charge regime? (Section 5.7)

In Section 5.8 we present our **conclusions** on the legal feasibility of the economic incentives considered.

This chapter does not contain a legal assessment pertaining to the use of revenues accruing from the incentives. These results are discussed in Chapter 6 (Use of revenues).

[28] See Annex D for the full results of the legal analysis carried out by the International Institute for Air and Space Law.

5.2 Under what conditions is an emission-based charge on intra-EU flights and flights to and from the EU feasible under international law?

From the perspective of international aviation law there are no explicit obstacles facing introduction of a non-discriminative emission-based charge in EU airspace. Furthermore, with regard to the two levy points for the emission-based charge, the most commonly used clauses in ASAs likewise do not prohibit levying emission charges as a surcharge on landing fees and on tariffs for route air navigation services. This is confirmed by the fact that at a number of airports in the world noise charges, levied as part of landing fees, have been in effect for many years now.

However, there are many other conditions to be taken into account, laid down in The Chicago Convention, bilateral air service agreements, EC laws and so on. Annex D provides a detailed overview of relevant conditions.

5.3 Is it legally feasible to use fuel consumption as a key parameter for calculating the charge base?

In order to design a charge base it is essential to determine the volume on which the incentive is to be levied. A relevant question from a legal perspective is then: what legal conditions pertain to the methods that may be used to calculate aircraft emissions?

This question becomes even more important knowing that:

- Aircraft fuel consumption is an essential element of the emission calculation methods in use worldwide, because some types of emissions are directly related to the amount of fuel used, such as CO_2, H_2O and SO_2 (the latter depending on the sulphur content of fuel), *and*
- Adopting fuel use as a charge base is not legally feasible because many bilateral air services agreements between EU States and other States prohibit the taxation of fuel for international services[29].

Combining these two points raises the key question of whether it is legally feasible to use fuel consumption as a key element of the method used for calculating emissions that are (directly) related to the combustion of aviation fuel? To answer this question, below we analyse the Chicago Convention, bilateral air agreements and jurisprudence in the national legislative context.

The Chicago Convention

Article 24 of the Chicago Convention is entitled “Customs duty”. The first sentence of this provision deals with the fact that all aircraft flying in transit via a contracting state are free of duty, even if the aircraft lands in that contracting state.

Articles 24 goes on by stating the following:

> “Aircraft on a flight to, from, or across the territory of another contracting State shall be admitted temporarily free of duty, subject to the customs regulations of the State. Fuel, lubricating oils, spare parts, regular equipment and aircraft stores on board an aircraft of a contracting State, on arrival in the territory of another contracting State and retained on board on leaving the territory of that State shall be exempt from customs duty, inspection fees or similar national or local duties and charges.”

[29] See Resource Analysis (2000) and CE (1998).

It follows that fuel, which is kept on board and consumed on international transit services, is not taxable, a term that includes the imposition of taxes, charges and levies.

In the framework of the European Community, the European Court of Justice was confronted with the question whether a charge on en-route emissions is similar enough to a tax on fuel to invalidate such an environmental charge as violating the current exemption on taxing fuel under Community law. The same question arises in the context of Article 24 of the Chicago Convention. The ICAO Legal Bureau has suggested that Article 24 "might be interpreted to extend to an en route emission based tax because of the close link between emissions and fuel"[30]. It seems to us that ICAO takes a prudent stance as to the permissibility of imposing a fuel-related environmental charge, so that there may be scope for other, i.e. more flexible, interpretations of the legal restrictions bearing on imposition of such a charge.

Bilateral air services agreements

Restrictions under bilateral air service agreements go one step further than those imposed by Article 24 of the Chicago Convention. Fuel taken on board aircraft engaged in the operation of international air services falling under the scope of the bilateral air agreement is also exempted. If both states agree, this exemption can be lifted. To proceed from here towards lifting the exemption may be a complex procedure because the other party may either refuse the proposal to lift the exemption or ask for concessions. EC Member States are party to some 1100 bilateral treaties with third states.

If the argument of the ICAO Legal Bureau, set out above, can be upheld and applied to the exemption laid down in bilateral air agreements, then emissions produced by fuel taken on board on the territory of another state would also be exempted. In practice, proceeding from the correctness of the opinion given by the Legal Bureau of ICAO, emissions coming from both fuel in transit and kept on board the aircraft, and from fuel bunkered on foreign territory would be subject to the exemption from taxation.

National jurisprudence

This is not the place to examine the national law of EC Member States in relation to emission charges. Indeed, any EC measure designed to introduce an emission charge will overrule the national legislation of Member states. Subject to relevant international air regulations, non-Community airlines, upon entry into and passage through the airspace of EC Member States, are bound by EC law as well as by the national regulations of EC Member States

Obviously, EC and national regulations must comply with such international air regulations as:

- the provisions of the Chicago Convention (see the opening words of Article 11), including Articles 15 and 24 of this convention;
- other treaty obligations engaged in by those EC Member States, including those which are laid down in bilateral air agreements (see above);
- those ICAO standards which can be considered to be binding upon EC Member States,

whereas international treaty obligations incurred by EC Member States are subject to the obligation imposed upon these States to “take all appropriate

[30] See CAEP/5, report of Working Group 5.

steps to eliminate the incompatibilities" and "assist each other to this end, by adopting a common attitude where appropriate (see, Art. 307, EC Treaty).

The reason we address the subject of compliance of national law with EC law and with international aviation regulations is that the European Court of Justice (ECJ) has already addressed this question[31].

In 1988 the Swedish government established a law ('the 1988 Law') designed to impose an environmental protection tax calculated on fuel consumption and emissions of hydrocarbons and nitric oxide. The EC has a Council Directive, namely Directive 92/81/EEC, which exempts air carriers from payment of excise duties on fuel consumption within the EC.

The ECJ found that ".... there is *direct and inseverable link* between fuel consumption and the polluting substances in the 1988 Law which are emitted in the course of fuel consumption, so that the tax at issue, as regards both the part calculated by reference to the emissions of hydrocarbons and nitric oxide and the part determined by reference to fuel consumption, which relates to carbon dioxide emissions, must be regarded as levied on consumption of the fuel itself for the purposes of Directives 92/12 and 92/81." (*emphasis added*)

The legal context under which this decision was made will change as soon as said Directives are amended to remove air carriers' exemption from paying excise duties on fuel consumption within the EC, or if those Directives are cancelled.

The argument raised by the ECJ combined with the interpretation put forward by ICAO's Legal Bureau on this matter (see above) makes clear that a calculated emission charge, based on a *direct* link between the emissions and fuel consumption of the aircraft, is liable to be challenged under the same international and EC-related regulations as fuel, which is exempted from payments of taxes, charges and levies. However, the jurisprudence referred to above proceeds from a "direct and inseverable link" between fuel consumption and polluting substances such as carbon dioxide. If this link is removed, an emission-based levy could be considered independently from fuel consumption. Hence, the legal constraints identified above would no longer be applicable. A methodology that also employs other parameters (e.g. engine temperature, thrust) to calculate the emission-based charge would and/or could probably not be interpreted in the same manner.

5.4 Is it legally feasible to use the administrative infrastructure of Eurocontrol for charging and collecting an emission-based en route charge?

It is feasible to use Eurocontrol for an emission-based *en route* levy as long as there is agreement among the Member States of this organisation on imposing such an incentive, which fits within the framework of ICAO.

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[31] See Judgment of the European Court of Justice of 10 June 1999 in the case of *Braathens Sverige AB* v *Riksskatteverket*; Case C-346/97.

5.5 What international laws and regulations pertain to definition of an airspace for the application of an emission-based route charge?

The Chicago Convention/ICAO regime
Pursuant to Articles 1 and 15 of the Chicago Convention, contracting States are entitled to impose charges upon operators of aircraft within their national airspace and on their national territories. Article 12 of the Chicago Convention states that, above the high seas, ICAO rules apply to the operation of international air services.

National airspace and national territory are defined in Article 2 of the Chicago Convention. Under the Chicago Convention (Articles 2 and 12) the sea is divided into a territorial sea and high seas. National law must determine the breadth of the territorial sea, which, since the United Nations Treaty on the Law of the Sea came into force, is 12 nautical miles.

Outside territorial seas are the high seas. In the airspace over the high seas and airspace of undetermined sovereignty under the ICAO-based Regional Air Navigation Plan, the principles established by ICAO in Annexes and policy recommendations apply to the operation of international air services.

The territorial scope of the Eurocontrol system on charges
The territorial scope for establishing en route charges is determined by the Multilateral Agreement on the establishment of en route charges of 1981. This area does not coincide with the combined national airspaces of the participating Eurocontrol states, but also includes adjacent international airspace, that is, the airspace of the **Flight Information Regions** established under the auspices of ICAO and in accordance with Annex 2 of ICAO, falling within the competence of the participating states.

The EC regime
Article 299 of the EC Treaty does not define territory or airspace to which the EC Treaty is applicable.

Conclusion
To define the territorial scope of an EC regulation applicable to air transport, regard must be had to:
- a articles 1 and 2 of the Chicago Convention, defining the territory of a State so as to include the "land areas and territorial waters adjacent thereto under the sovereignty" of a contracting State to this convention (see also chapter 2);
- b the territorial scope of the EC Treaty, as defined by Article 299, with special reference to paragraph 1 of this provision;
- c applicable regulations made by ICAO, especially those contained in Chapter 2.1.2 of Annex 2 *(Rules of the Air*) and Chapter 2.1.2 of Annex 11 (*Air Traffic Services*) on the basis of which EC Member States, and other states, including but not limited to Ireland, the United Kingdom and Norway, exercise jurisdiction under the auspices of ICAO outside their national airspace for the purpose of providing air traffic services, and for which they collect charges, pursuant to Regional Air Navigation Agreements;
- d agreements made between EC Member States and Eurocontrol in the context of the Central Route Charges Office (CRCO).

5.6 Is it legally feasible to use the Eurocontrol air space for an emission-based route charge?

Once the Community has adopted a measure designed to introduce an environmental charge, in cooperation with Eurocontrol and while taking into account the framework of ICAO for that purpose, such a charge can be imposed on flights passing through the airspace covered by Eurocontrol/CRCO agreements and principles.

5.7 Is it legally feasible to include the high seas outside the 12 nautical mile zone of Member States in the charge regime?

The environmental effectiveness of an emission-based route charge in EU airspace is to a large extent determined by the size of the airspace, for two reasons:
- a larger airspace implies that a greater proportion of flights to and from the EU are subject to the incentive;
- a larger airspace is less likely to encourage changes in routes consequent upon the en route emission charge.

For this reason we investigated whether it is legally feasible to establish an EU airspace encompassing not only the national territory of the 15 EU Member States but also parts of the adjacent seas, the so-called high seas. The Flight Information Regions (FIR) of Eurocontrol include part of the high seas.

Based on the legal analysis, we conclude that in the airspace over the high seas and airspace of undetermined sovereignty under the ICAO-based Regional Air Navigation Plan, the principles established by ICAO in Annexes and policy recommendations apply to the operation of international air services. Annex D describes the conditions that should be taken into account.

5.8 Conclusions

Based on our legal feasibility study the following conclusions can be drawn:

1 International aviation law and bilateral air service agreements pose no specific obstacles to introduction of a non-discriminative emission-based charge or PSI in EU airspace. However, the incentives will need to take due account of the following:
   a the aim of the incentive should be to reduce greenhouse gas emissions;
   b the principle of cost-relatedness, laid down in many bilateral agreements, should be respected, with a charge rate proportional to the (external) costs of greenhouse gas emissions;
   c the terms of the proposed scheme should be clearly communicated to all parties;
   d the principles of transparency and non-discrimination should be respected;
   e any revenues collected should be used primarily for mitigating the climatic impact of aircraft engine emissions.

2 A key question raised in this chapter was whether it is legally feasible to use fuel consumption as a key element of the method for calculating emission charges. On this point the following conclusions can be drawn:
   a An emission calculation methodology underlying the charge or PSI that is based on a “direct and inseverable link” between fuel

consumption and polluting substances such as carbon dioxide is liable to be challenged under the same international regulations as fuel, which is exempted from taxes, charges and levies. Many of the bilateral agreements between EU Member States and third countries contain a clause to the effect that both fuel in transit and fuel supplied in the territory of the bilateral partner is also exempted from taxes or charges on fuel.

b In order to minimise the scope for challenge in an international court with respect to this latter point, we recommend the following:
   - to make clear that the economic instruments considered are (revenue-eutral) levies on greenhouse gas emissions aiming to mitigate the negative climatic impacts of aviation. The incentives are certainly *not* taxes on fuel and have no underlying fiscal aim;
   - to use the Polluters Pays Principle 16 laid down in the Rio Declaration (UNFCCC) and in Article 174 of the EC Treaty as the legal basis for imposition of a charge or PSI on greenhouse gas emissions of air transport in the EU. The UNFCCC, drawn up in Rio de Janeiro in 1992 under the auspices of the UN, has been ratified by almost all countries in the world (including the USA);
   - to use the carbon content of aviation fuel and not the amount of fuel itself to calculate the CO_2 emissions emitted by an aircraft in EU airspace. It can be argued that carbon has no “direct and inseverable link” with aviation fuel, because the amount of carbon in one litre of fuel varies slightly for every litre of fuel, depending on the crude oil used and the refinery process;
   - to include emissions of NOx in the incentive base, because NOx emissions have no direct link with fuel. This is because NOx formation depends on engine characteristics such as pressure, combustion temperature and dwell time. These factors should be reflected in the calculation methodology for the levy base.
   - with regard to the PSI: to communicate that there is no direct and inseverable link between fuel and the calculation methodology, because a unit of air transport performance (e.g. actual payload-kilometre) is included, besides emissions.

3 It is feasible to use the Eurocontrol infrastructure for an emission-based *en route* levy as long as there is agreement among the Member States of this organisation on imposing such an incentive, which fits within the framework of ICAO.

4 It is legally feasible to use the Eurocontrol airspace, once the Community has adopted a measure designed to introduce an environmental charge, in cooperation with Eurocontrol and while taking into account the framework of ICAO for that purpose; such a charge can then be imposed on flights passing through the airspace covered by Eurocontrol/CRCO agreements and principles.

6 Use of revenues (*charge option only*)

6.1 Introduction

The primary aim of the policy instruments under consideration is to provide economic incentives to mitigate the global impact of aviation and certainly not to raise revenues for governments. Although not designed for this purpose, these economic incentives may generate revenues, however. This raises questions regarding optimum use of those revenues.

We distinguished the following, not necessarily exhaustive, list of options for revenue usage[32]:

1. Allocation to general government budget:
   a. recycling to citizens in the form of a lump-sum payment;
   b. recycling by lowering taxes ('double dividend');
   c. recycling to the economy by earmarking revenues for investments in environmental public goods like maintenance of natural parks;
   d. compensating individuals and organisations faced with environmental damage.
2. Recycling to the aviation sector by earmarking for environmental investments; the following variants can be distinguished:
   a. support of R&D (cleaner technology) by airlines and manufacturers;
   b. financing of scrapping programmes (early withdrawal of older aircraft/engines);
   c. improving air traffic management control (ATC);
   d. purchasing emissions reductions from other sectors.
3. Revenue-neutral: Performance Standard Incentive.

Based on a preliminary analysis of pros and cons, it was decided to select the following options for the revenue use for further study in this chapter:

1. Allocation to the general treasury of the EU Member States.
2. Installation of a supranational fund aiming at maximisation of the environmental benefits on top of the impact of the incentives itself.
3. Revenue-neutral (Performance Standard Incentive, PSI).

6.1.1 Revenue collection

As already discussed in section 2.7 revenues generated by the economic incentives could be collected under the Route Charge System of Eurocontrol. It was established in the legal analysis (see chapter 6) that there are no international prohibitions on the use of the Eurocontrol infrastructure, and particularly its Central Route Charges Office (CRCO), as a vehicle for collecting environmental charges. As far as collection is concerned, this would be feasible for both a charge and a revenue-neutral PSI.

As already stressed in section 2.7, the emission charge would be identified and accounted separately from the current en route charge for air navigation services. Obviously in the case of the revenue-neutral PSI, no revenues would be generated. However, there will then be financial transfers from airlines with relatively polluting aircraft to those with relatively clean aircraft.

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[32] Many of the options for revenue use can be applied at different institutional scales (national, EU level, aviation sector).

Before discussing the three options for revenue use in greater detail in the following sections, we first provide, for the year 2000, an indication of the amount of revenues generated by the incentive options at different incentive levels (Table 33).

Table 33 **Revenues** of the two options at different incentive levels

Valuation, CO_2 €/tonne	Valuation, NO_x €/kg	Emission charge (€ billion)	Performance Standard Incentive (€ billion)
10	0	1.1	0
30	0	3.3	0
50	0	5.4	0
10	1.2	1.8	0
30	3.6	5.3	0
50	6.0	8.6	0

In the case of the emission charge, these figures compare with a total annual EU budget for 2000 of some € 93 billion; and with a budget for the Community's entire Fifth Framework Research Programme for the five years 1998-2002 of € 15 billion. These figures imply that, in addition to the intense political interest likely to be engendered by proposals for use of the revenues, the financial resources generated are of such a magnitude as to require specially negotiated principles and modalities for allocation and disposal.
Obviously, the Performance Standard Incentive will not raise any revenues as it is designed to be revenue-neutral.

6.1.2 Scope of this chapter

Sections 6.2 to 6.4 describe the possibilities and pros and cons of the three selected options for revenue use:
1 Allocation to general treasuries of EU Member States (section 6.2).
2 Allocation to supranational fund (section 6.3).
3 Revenue-neutrality (transfer from relatively 'dirty' to 'clean' aircraft) (section 6.4).

The *first option*, allocation of revenues after initial collection to the general treasuries of individual EU Member States, is discussed in section 6.2.1. The benefits and drawbacks of this option are then considered.

With regard to the *second option*, allocation to a supranational fund, the following issues are addressed:
- scope for establishing a supranational fund, and pros and cons thereof;
- possible criteria for use of revenues from such a fund (e.g. criteria for exemptions from EU state aid regulations);
- R&D investments and additional measures that might be financed by the fund, with the aim of maximising environmental benefits over and above the impact of the incentive itself;
- possible mechanisms for selection of investments and projects;
- evaluation of pros and cons.

Finally, *the third option*, revenue-neutrality, is discussed only briefly because the main design element of this option is definition of the performance standard, which has already been described in section 6.4.

6.1.3 Evaluation criteria

In the following sections, after considering the basic design of the three selected options for revenue use, we assess their respective pros and cons on the following criteria:

Legal issues
The options are assessed for compatibility with relevant international regulations, including the Chicago Convention, Bilateral Air Service Agreements, ICAO statements and the state aid regulations of the European Union.

Distributional equity/polluters pays principle (PPP)
Considerations of fairness play a major role in devising policies. Principles such as the User Pays and Polluter Pays are widely accepted and refer to the distributional issue. According to the OECD[33] the Polluter Pays Principle entails that “the polluter should bear the expenses of carrying out the costs of pollution prevention and control measures to encourage rational use of scarce environmental resources, decided by public authorities to ensure that the environment is in an acceptable state. In other words, the costs of these measures should be reflected in the costs of goods and services, which cause pollution in production and/or consumption. Such measures should not be accompanied by subsidies that would create significant distortions in international trade and investment”.
In this context, the Polluter Pays Principle is a non-subsidisation principle, meaning simply that governments should not as a general rule give subsidies to their industries for pollution control. It is intended to guide the allocation of costs between the government and the private sector in paying for pollution or protecting the environment. It is concerned with *who* should pay for environmental protection, not how much should be paid.

Besides this principle, some options for the allocation and use of the revenues might lead to undesired consequences from the distributional or competitiveness perspective.

Economic efficiency
This key criterion requires that revenues will be allocated to the economy in the most efficient manner without leading to additional market distortions. Revenues might even be used to improve the functioning of markets by taking away market failures.

Environmental effectiveness
This criterion relates to the question of whether revenue allocation is used to provide an *extra* incentive, on top of the incentive of the charge itself, to reduce the global environmental impact of aviation. In general, the environmental effectiveness of a charge scheme will be enhanced if revenues are used to tackle further emissions sources.

6.2 General treasuries of EU Member States

Eurocontrol might be the ideal collector and initial recipient, but since it does not have the legal competence to take spontaneous allocation and distribution decisions, the proceeds of the fund must either be:
– allocated to the EU Member States according to prior politically agreed principles included in a new form of Convention or Treaty (and thus re-

[33] *Environmental principles and concepts*, OECD (1995).

maining relatively inflexible), with control of distribution and use to be determined probably at State level, or
– turned over to some other form of holding entity.

It may, however, be considered desirable to avoid predetermined allocation of revenues to Member States. This might be in order to try to keep the whole matter of emissions by the essentially global aviation sector at the supra-State level, on principle – particularly for CO_2 with its long dwell time and global dispersion.

A more negatively-oriented line of reasoning, but of practical significance, is that it is difficult to determine an equitable basis for allocation among States. These difficulties are discussed further in the next section.

It may conveniently be noted here, however, that if the revenues from charges imposed at Community level (or internationally) are allocated to individual States, Community (or international) influence on their distribution and use is self-evidently lost.

6.2.1 Criteria for allocation to Member States

It is very common for national authorities to collect the revenues from environmental charges and decide on their actual use. Prior to this, though, a decision has to be made based on what criteria or formula the revenues should be allocated among the EU Member States without raising distributional complications. The following options for allocating revenues to individual states seem possible:
– allocation proportional to emissions occurring in national territorial airspace;
– allocation based on Flight Information Region (FIR) related to individual States (including high seas);
– allocation per capita or according to other criteria.

The first option, allocation proportional to emissions in national airspace, may imply following Eurocontrol rules for recovering the costs of air traffic control from Member States. Disbursement, i.e. allocation, of the revenues of the route charge is currently based on the en-route facility cost-base of the State concerned for the reference year and the number of service units[34] generated in the airspace of that State during the same year.

Adopting a disbursement rule similar to that of Eurocontrol, the revenues of an emission-based charge could go to the country in whose airspace the emissions occurred. This means that the charges paid on all emissions in a country's airspace - including those from flights without a stop - go to that country. The charge base would then have to be something like the amount of emissions per kilometre per aircraft type multiplied by the number of kilometres flown over the own territory of the member state and the levy level[35].

A distributional issue that remains in this allocation option is how to allocate the revenues of route charges levied on emissions occurring over the high

[34] The product of the distance factor $\mathbf{d}_i$ and the weight factor **p** is defined as the number of service units in State (**i**) for this flight (see also Annex A).

[35] See Preliminary study 1 (Dings, et. al.) for a detailed discussion of pros and cons of different possible charge bases. See Preliminary study 2 (Dings en Wit) for a detailed discussion of different approaches to establish the levy level of an environmental aviation charge.

seas. One way out of this problem is to limit the scope of the emission-based route charge to the national territories (including 12-mile zones) of the EU Member States. However, this might move airlines to avoid flying through Member State airspace by adapting the routes of some current flight stages. Generally speaking, this would extend the length of the flight and consequently increase rather than reduce emissions. If this allocation option is selected for further consideration there should be further in-depth study to devise practical caps on such potential avoidance behaviour. If this option were to include the high seas, the scope for charge avoidance would be limited to virtually zero.
Option 2, allocation based on Flight Information Region (FIR) include high seas and may therefore form a better alternative.

However, a complication of both the first and second option is that revenue allocation will be dictated by the size and geographical setting of a country (located under denser flight stages, for example, or bordering high seas). This strikes us as inequitable, since the damage costs of, say, climate change are not directly related to the magnitude of emissions in a given country's airspace.

The third option for allocation to national states considered here, viz. proportional to national population, seems more equitable and in line with other practices of the European Union. This option may be added with other common distribution rules applied by the EU.

6.2.2 Evaluation: option 1 (revenues to EU Member States)

Legal issues
Levies that generate revenues for the national treasuries of Member States will be qualified as 'taxes' under the Chicago Convention and ICAO rules. ICAO prefers charges to taxes, adopting a resolution to the effect that charges should have no underlying fiscal aims; see also Annex D. At the same time, ICAO leaves due scope for the conduct of national policy with respect to taxation, be it that, during the 33rd General Assembly of ICAO, contracting States of ICAO were urged not to take unilateral action in the above area.

Distributional issues
As outlined in the preceding section, it might be difficult to reach agreement on a criterion or formula for revenue allocation to individual Member States.

Economic efficiency
If revenues are allocated to national treasuries, decisions about their subsequent use will be made in the overall context of national government budgeting, implying that individual States decide on how these revenues are to be used. In general, therefore, the revenues can:
- be used to cut back the budget deficit;
- be used to increase government expenditure;
- be recycled to citizens;
- be used to reduce the rates of other taxes;
- be earmarked for specific spending purposes, possibly environmentally motivated.

The first and second option are not in line with the aim of the charges that are the subject of this study, for the aim is to reduce global air pollution and not to raise government revenues, nor to cut back the budget deficit or increase government expenditure. Therefore, only the pros and cons of the other options for revenue usage within government budgets will be elaborated below.

In the public finance literature the conventional view is that taxes collected from various activities should be paid into a general fund, from which government expenditures are financed. When environmental levies raise substantial revenues, the *theoretical first-best solution*, from an economic efficiency point of view, is to recycle these revenues back to citizens through lump-sum payments or through reduction of lump-sum taxes (see Musgrave and Musgrave, 1984). The modern variant to this alternative is to recycle them by cutting back the government's budget deficit. A Japanese study (EIEP, 2000) showed that from the perspective of economic efficiency a policy of reducing public debt, which reduced interest rates and shifted money to the private sector, was the best alternative for spending the income raised from an assumed CO_2 tax.

Pearce (1991) has suggested that there may be a better *practical* solution to the expenditure of governmental revenues, known as the 'double dividend'. The revenues from environmental levies could be used to lower other taxes in the economy. In practice, many of these other taxes are distortionary (i.e. interfere with the efficient functioning of markets) and a reduction in their rates can therefore be seen as a means of improving efficiency, thus yielding a second 'dividend' from the adoption of environmental taxes over and above internalisation of external costs[36].

The most frequently mentioned problem in connection with the recycling of revenues from an environmental levy to reduce distortionary taxes is that the environmental goal of creating incentives for a desired level of pollution conflicts with the fiscal goal of providing stable revenues. Stable and predictable revenue sources come in the form of broad-based taxes on activities with a low price elasticity. However, these translate into small incentives. Designing an actual environmental charge with 'double dividend' potential is therefore no simple task.
Nevertheless, most governments have made some attempt to combine introduction of environmental levies with a reduction of the rates of other distortionary taxes. The shift away from income and profit taxes toward pollution taxes in the Swedish and Dutch tax systems provide practical examples for operationalising the double dividend.

The third option for spending revenues once they have been allocated to participating national states is to earmark them, and thus the charges, for provision of specific environmental public goods. The underlying notion is that governments have a certain responsibility to provide specific environmental services, such as rivers, air sheds, land resources etc. that belong to the nation. In this interpretation it is appropriate that the government should charge those who utilise or degrade these resources and use the ensuing revenues to maintain the quality of those resources. This has been cited as a justification for expenditures on an earmarked basis for upkeep of water resources or protection of waste sites from extensive environmental degradation.

However, several economists (e.g. Opschoor and Voss, 1989) have shown that this results in *economic inefficiencies* for society as a whole, because

36 The frequently made connection between the 'double dividend' and job creation ensues from the fact that one possible distortionary effect of taxation is to reduce employment.

the ‘right prices’ are not being paid. If environmental charges are earmarked for expenditure on environmental investments, the difficulty is that the level of those investments will be dictated by the revenues[37]. There may hence be 'too much' abatement or 'too little' investment. Opschoor and Voss (1989) argue that French water pollution taxes were rather low and therefore led to too little abatement, whereas Dutch water taxes may have resulted in excessive investment, because the revenues were earmarked and too high (Opschoor and Voss, 1989).

Environmental effectiveness

A potential benefit of earmarking revenues, at State level, for additional environmental measures would be enhancement of *the environmental effectiveness* of the charge. This may imply that the level of the charge can be set lower to achieve a predefined environmental target compared with a charge in which the revenues are not used for additional environmental measures. This may increase the acceptability of the charge.

This kind of earmarking will increase overall government revenue, however, heightening the impression that one aim of the charge is to generate revenues. This may reduce public and political acceptance of a potential aviation charge.

6.3 Supranational fund

We do not know of any comparable supra-State charging system where revenue is collected from international as well as domestic activity in a certain sector of the economy and allocated:

- at the State level;
- at EU or other regional level; or
- on a sectoral basis (recycling).

The European Coal and Steel Community is a possible quasi-exception, since it is specifically sector-related and funded by a Community sectoral product levy, but it is understood to be expiring next year. Its history and institutional structure might nonetheless deserve closer attention as a potential model.

There are superficially tempting quasi-parallels in the funding and activities of ICAO itself, particularly its regional activities (and those of other UN agencies), but revenues are State-based, not sector-based.

It is, however, clear that some form of organisational/institutional identity must be established if only as a 'holding receptacle' for the fund. Since the revenues will tend not to 'turn over', as in the revenue-neutral option, but to accumulate, they have to be held somewhere.

One form of a fund-holding entity might indeed be a new EU fund, either within or outside the Community Budget. There are quasi-precedents for this, but also some difficulties, addressed in more detail in the following few sections.

6.3.1 Allocation to a European Community fund

Within the EU Budget envelope, there are established mechanisms well known to the Project Committee for the channelling of financial resources to

[37] Or alternatively the tax rates will be dictated by abatement expenditure requirements and not by estimates of environmental damage.

specific policy objectives over-arching annual budget limitations. The range includes, for example:

- 'seed-corn' funding for Trans-European Transport Networks (TEN-T) projects, with a multi-annual indicative programme (MIP) of spending (+/- € 4 billion 2000-2006) subject to modal policy constraints imposed by Council or Parliament;
- substantial research, technological development and demonstration (RTD) four-year framework programmes (FP5 has nearly € 15 billion 1998-2002), with Council-approved policy objective themes;
- Structural Funds and the Cohesion Fund, with respectively € 182 billion and € 18 billion over the 2000-2006 period, and with policy objective-related rules on financing – how, what, and where;
- the COPE Fund (proposal) for the compensation of oil pollution damage in European waters and related measures (€ 1 billion ceiling for victims). The COPE Fund derives its income from any person who, in a Member State, receives more than 150,000 tonnes of crude oil and/or heavy fuel and is therefore liable to contribute in proportion to the quantities of oil received. The COPE Fund will only be collected following an incident in European waters (thus no pre-funding). The Cope Fund is represented by the Commission.

All these are funding priorities essentially decided by the Member States within a Treaty-based single budget regime. Earmarking of EU revenue sources would not be permitted without Treaty amendment. This is perhaps rather impracticable for dealing with the proceeds of an emissions charge on a transport sector contributing less than 4% to total anthropomorphic radiative forcing[38].

Further, where the revenues and costs of an activity are related to tangible goods whose physical movement can be established, EU intervention (e.g. VAT on e-commerce) is relatively straightforward. It is a more difficult situation when dealing with amorphous emissions that occur over oceans and States, disperse with varying dwell times and affect different States differently.

For these reasons the study team has tended to rather move away from the concept of a Community Fund administered by the Commission. Control of revenues raised by charges on economic sectors (or, more usually, taxes) has been understandably guarded by Member States under the principle of Subsidiarity. If such a fund were within the Community budget, it would therefore be essentially pre-allocated to 'the general Treasury' (albeit at Union level) and other earmarked distribution possibilities would be lost.

6.3.2 Allocation to an autonomous fund

Perhaps ideally, in order to meet the objectives of the charge effectively, the proceeds of charges should be allocated for distribution to a supra-State body working with earmarked funds within guidelines jointly specified by States, but retaining technical authority and expertise in support of at least quasi-independent status.

There are precedents for such organisations within the framework of the EU, but outside the budget limitations of the Commission and the direct political control of the Council and Parliament, in the form of banking institutions:

[38] IPCC report, Aviation and the global atmosphere, 1999.

- European Investment Fund (EIF), a joint venture between the EU (effectively the Commission), the European Investment Bank (EIB, see below), and public as well as private financial institutions in the Member States. It is not a lending bank, nor, despite its name, an aid funding institution, but a guarantor bank aimed at TENs projects and small and medium sized enterprise (SME) development.
- European Bank for Reconstruction and Development (EBRD), established in 1991 with as members the EU (the Commission), the EIB (see below), Member States of the IMF and other States. It acts as a merchant bank oriented toward encouraging the transition of Eastern Europe and the Former Soviet Union to the market economy under environmentally sound and sustainable conditions; and incidentally acts as the administrator of the Nuclear Safety Account (NSA) and the Chernobyl Shelter Fund (CSF).
- European Investment Bank (EIB), created by the Treaty of Rome. It is the EU's financial institution, lending to airlines and airports, among others, on a non-profit basis in furtherance of Community policies, but with its own financial autonomy. Its lending is largely funded by its own borrowings on the money market. Loan decisions (e.g. on TEN-T projects) are subject to at least summary scrutiny by the Commission services.
- Global Environment Facility (GEF), an environmental fund implemented by three agencies: UNDP, UNEP and the World Bank. The strategy of GEF incorporates guidance from two conventions for which GEF serves as financial mechanism: the Convention on Biological Diversity and the UN Framework Convention on Climate Change. It also establishes operational guidance for international waters and ozone activities, the latter consistent with the Montreal Protocol on Substances that Deplete the Ozone Layer and its amendments. Any eligible individual or group may propose a project, which must meet two key criteria: It must reflect national or regional priorities and have the support of the country or countries involved, and it must improve the global environment or advance the prospect of reducing risks to it. Country eligibility to receive funding is determined in two ways. Developing countries that have ratified the relevant treaty are eligible to propose biodiversity and climate change projects. Other countries, primarily those with economies in transition, are eligible if the country is a party to the appropriate treaty and is eligible to borrow from the World Bank or receive technical assistance grants from UNDP.

These examples indicate that funding institutions can operate autonomously at the EU level or global level, not, so far as is known, with revenues from sectoral charges, but certainly with funds raised independently of the Community budget and earmarked for specific policy objectives. While the EBRD and EIB are banks, and can be creative in their use of resources, the administration of particular environmentally-related funds by the EBRD might serve as promising models for an aviation emissions fund.

Such institutions could perhaps be considered as potential vehicles (administrators, fund-holders and distributors) of a European aviation emissions fund themselves. Alternatively, their articles of association might serve as a model for a supra-State fund-holder model with technical and financial autonomy within policy guidelines.

6.3.3 Possible measures to be financed by a fund

Before we consider what measures might be financed by the fund, it must first be discussed whether the measures should be limited in scope to mitigation of greenhouse gas emissions *and/or* the aviation sector. Or should the fund also be open for mitigation of other environmental issues and/or other economic sectors?

Working group 3 of CAEP (2001) gives guidance on this question by defining revenues from a charge as: "Revenue from levies being used to defray costs within the same economic sector either through direct or indirect investment. For example, revenue collected through a charge could be invested in measures within the aviation sector to further reduce CO_2-emissions. In order to facilitate this a system could be designed where suitable projects and associated costs are identified on a consistent basis, prior to the collection of the revenues".

An important question is then to define what 'suitable' projects are. Economic efficiency will increase if a broader definition is applied. However, legal or political objections may arise.

Indicative examples, at random, of the R&D approach address the following research areas, which range from relatively small programmes to meet known specific needs, through the expansion and acceleration of ongoing work in wider sectors, to the strategic boundaries of long-term development:
- development of new, cleaner and more efficient aircraft and engines;
- R&D to improve air traffic management control (ATC) in order to reduce flight time and consequently fuel use;
- development of new materials that improve aircraft efficiency;
- supporting the breakthrough of renewable aircraft fuels;
- development of an updated international model for the modelling of the costs of aircraft noise and emission certification procedures for use in aviation environmental cost/benefit analysis procedures;
- definition and demonstration of validation techniques for the harmonisation of environmental stringency requirements and certification methodology between US Federal aviation regulations and European joint airworthiness requirements (FAR's and JAR's);
- further work on the calibration and implementation phases of advanced surface movement guidance and control systems (A-SMGCS) at airports, to reduce taxiing and holding time emissions and noise;
- a major global research programme to address all aspects of the climatic effects of contrail formation.

It may be noted that all the above 'wildcat' examples meet the test of not only being available but also having potential practical applicability on a global scale. Some indeed require a global effort. It must be restressed, however, that none of these suggested examples should be left contingent on availability of the proposed aviation environmental emissions fund. The list is not exhaustive, it is intended to be catalytic, for discussion among the Commission services, and with Member States, as well as with stakeholders.

6.3.4 Mechanisms for selection of projects funding

It is in considering the operation of a fund administered at the supranational level (EU or autonomous body) that the question of selection of fund recipients arises; whether dealing with aviation- or environment-related research or environmental investment. There are at least three basic decision mechanisms, but this is not necessarily an exhaustive or a mutually exclusive list:

- Auction, in which bids for infrastructure investment or research grants are expressed in 'units' of environmental benefit such as tonnes of CO_2 saved, or persons removed from a noise contour. The main problems are that the bidding currencies are incompatible, and that the results can not be effectively audited. In any case, research can by definition never promise achievement[39].
- Representative voting, in which a Member State representative governing body (e.g. the Commission, or a Bank Board of Directors) or an hoc Committee (e.g. TEN-T Finance Committee), votes on a list of projects which has been filtered by expert assessors for quantitative and qualitative compliance with policy guidelines within a regulatory framework. This is how development banks work, as do some aspects of Commission aid. There is inevitable political and territorial competition in the process, and a vote-weighting system must be devised. In practice, whatever reaches the voting stage shortlist is agreed, so the selection is effectively made by administrators and advisors.
- Anonymous bidding, whereby periodic calls are made by the fund administrators for bids addressing stated policy aims, (environmental) objectives, and/or defined tasks to meet those aims and objectives within the policy framework. Construction of that framework itself requires some sort of drafting/filtering and representative voting process, but then so does the establishment of the charging system and fund in the first place. Selection within the framework can be by co-opted expert evaluators, scoring on a numeric basis so that the merits of a noise research project can be compared with those of emission-reducing investment. Alternatively, to avoid subjective imperfection in scoring, a call can be associated with a given *tranche* of money allocated (by vote) to a particular task or group of tasks (as in EU FP evaluation). Team scoring can be either by averaging or by consensus rules.

A further possibility, which does not readily fit into any of the above categories, might be for the fund to be devoted to meeting (at least part of) the operating expenses of an independent international environmental research institute, possibly specialising in emissions or climate.

6.3.5 Evaluation: option 2 (revenues to a supranational fund)

Legal issues: ICAO rules

Existing ICAO policies provide only limited insight into the role that externalities and use of revenues might play in the context of emission levies. The ICAO Council's 9 December 1996 interim resolution on environmental charges and taxes states that:

> *"Levies should be applied in the first instance to mitigating the environmental impact of aircraft engine emissions."*

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[39] An example of this type of mechanism for selecting projects for funding is the 'Descending Clock auction' developed for the new UK emission trading scheme under the climate change programme. Under this auction system, to start in 2002, the UK will allocate 'incentive money' (30 million pounds a year) to participants.

Furthermore, in September 2001, at the 33rd Assembly of ICAO, Appendix I of Resolution A33-7 refers to Principle 16 of the Rio Declaration (1992) which states:

> *"National authorities should endeavour to promote the internalisation of environmental costs and the use of economic instruments, taking into account the approach that the polluter should, in principle, bear the cost of pollution, with due regard to the public interest and without distorting international trade and investment."*

In addition, ICAO has addressed the issue of pre-funding of certain projects through charges, a practice that some airports had introduced in recent years. Under the principle of cost-relatedness:

> *"….Charges should not be levied for any facilities and services until they had been implemented, and that reserves being built from an excess of revenues over expenses could contain an element of pre-funding"*

However, the ICAO Secretariat went on to state that:

> *"….in very specific circumstances pre-funding through charges could perhaps be justified if strict safeguards against abuses were in place."*

The Air Navigation Conference recommended that the ICAO Council adopt a recommendation[40] along the above lines, whereby a number of conditions were mentioned. These conditions included:

- retention of the principle of cost-relatedness;
- transparency of economic regulation of user charges and the provision of services;
- transparent accounting principles, and provision of information to users, who should agree with pre-funding "to the greatest extent possible";
- limitation of pre-funding through User Charges in time, with due regard for efficiency of the arrangements with respect to charges.

We note that a certain flexibility exists with respect to the acceptance by states of the interpretation of the principle of cost-relatedness. However, if financial resources of a supranational fund, constituted by the revenues of an emission-based aviation charge, are used for other purposes than mitigation of aircraft engine emissions, the charge will be qualified as a tax. Imposition of taxes may meet with obstacles, as laid down in ICAO-based resolutions.

In conclusion, there is no rule of international air law which explicitly forbids the inclusion of pre-funding of ATS-related activities under the principle of cost-relatedness. The question is a matter of *interpretation* of applicable law. Perhaps even more importantly, it is a matter of *designing* the pre-funding device in accordance with applicable principles of international law. Last but not least, the device must be *negotiated* with all parties concerned.

Legal issues: trade issues and the Community state aid regulations

A crucial design question with regard to trade issues is how the revenues are allocated to the aviation industry. This raises two legal issues:

1 Potential illegal distortions of competition between the aviation industries of Member States versus non-member states.

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40 See, ANS Conference; 5.2.5 – 5.2.8.

2 Support, in the form of investment subsidies, say, to encourage development of cleaner engines, is discriminatory towards other sectors and might be in conflict with state aid regulations.

With regard to the first of these issues, it seems to us unfeasible to redistribute revenues only to the aviation industry of Member States via R&D mechanisms, while non-EU airline companies flying in EU airspace also contribute by paying the charge. Consequently, any mechanism for redistributing charge revenues should probably also allow the non-EU aviation industry to receive support for, say, new technology development or the associated introduction costs.

With regard to the second legal issue, recycling of revenues to one sector only – here the aviation sector – would, generally speaking, be regarded as state aid and thus be in conflict with existing state aid regulations of the EU (see articles 87 and 88 of the EU Treaty). However, conditional exemptions exist with regard to aid for research and development (OJ C 45, 17.02.1996) and aid for environmental protection (OJ C 72, 10.3.1994).
A detailed review of all the conditions to which the exemptions are subject would not be possible within this study. To provide some guidance to the reader, however, there follows a summary of the main requirements regarding the purpose of authorisable aid and the maximum admissible intensities[41]:

1 Aid for research and development:
   a aid to fundamental research[42] is captured by Article 87 in exceptional cases only;
   b as a general rule, aid up to 50% gross of investments can be followed for industrial research.
2 Aid for environmental protection:
   a aid to investments will be allowed if it helps with the adaptation of existing plant (at least two years old) to new environmental standards, or with the improvement of new or existing plant to exceed any standards in force;
   b the maximum aid intensity is 15% gross of the eligible costs in the first case and 30% gross in the second case;
   c etc.

Economic efficiency
It is generally considered to be both fair and economically efficient that every economic activity pays its full costs, including those costs that are currently external. A crucial question is then how recycling of revenues, through a fund, to the aviation sector is to be regarded.
In general terms, earmarking charge revenues for specific R&D within the aviation sector has a number of disadvantages. First, it allocates the revenues in advance, creating obstacles for re-evaluation, based on economic and environmental criteria, of a targeted expenditure programme financed by the recycled revenues. The result is inefficient spending of the revenues. In addition, earmarking revenues within the aviation sector may create inflexibility, as programmes may last longer than optimal because of obstructions to reform created by vested interests.

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[41] Competition law in the Communities, Volume IIB; Explanation of the rules applicable to State aid, Brussels 1997.

[42] The Commission qualifies fundamental research as follows: the work should not be linked to any industrial or commercial objectives of a particular enterprise, and a wide dissemination of the results of the research must be guaranteed.

Another possible disadvantage of earmarking revenues within the aviation sector is that the revenues might support only a limited number of emission reduction measures (such as technologies, operational changes, etc.; see section 3.3 for a full overview of these measures). This may in turn reduce economic efficiency, by limiting development of other, more efficient alternatives.
With regard to manufacturers, any R&D fund or investment programme should, from the efficiency point of view, be open equally to all manufacturers in the world as long as they meet the conditions for receiving support. An important argument for using charge revenues (in part) to provide extra incentives to manufacturers to develop improved, environmentally sound aircraft, might be the limited size of the EU market. This is because the relatively limited size of the EU airspace within which aircraft are subject to the charge may not be large enough to justify a substantial manufacturers' response, given the substantial economic risks involved in developing improved engines and aircraft. Support could allow such economic barriers to be overcome.

Environmental effectiveness
Earmarking the revenues for additional environmental measures within the aviation sector would probably increase *the environmental effectiveness* of the charge. However, any gains in effectiveness might be offset to some extent by the fact that recycling the revenues to the aviation sector may reduce the price of air transport and thus increase demand.

One possible option often cited for recycling revenues is to use them to benefit aircraft operations by improving air traffic management control (ATC). This option may run contrary to the cost-relatedness principle (see below), but it may also be very effective in reducing CO_2 emissions from aviation.
The underlying idea is that this approach can reduce fuel burn and emissions by facilitating more efficient operations and flight profiles outside the landing and take-off cycle, in particular by reducing flight detours. IPCC (1999) estimate that ATC improvements may lead to emission reductions ranging from 6 to 12% if all necessary institutional and regulatory arrangements are fully implemented in the coming 20 years.
However, using revenues for improving ATC may not solve the current problems if these are rooted mainly in institutional, regulatory and political issues rather than a lack of financial resources. Furthermore, it should be stressed that using revenues from an emission-based charge would probably be in conflict with the cost-relatedness principle of ICAO.

Acceptability
Revenue recycling to the aviation sector for specific purposes may also improve the acceptability of an emission-based route charge because the revenues remain within the sector itself.

6.4 Revenue-neutral option

In the revenue-neutral case of the Performance Standard Incentive, dealing with both receipts and payments is a 'clearing house' or 'current account' function. Charges are collected from relatively polluting operators (debits) and payments made to relatively clean operators (credits), on the basis of unit charges calculated to keep the account at break-even (zero) at the end of each accounting period. Provided the forecast of operations proves to be reasonably accurate, the basis of payments and receipts is pre-determined on a purely technical basis. A revenue-neutral incentive is consequently free of distribution problems.

In addition, Eurocontrol has indicated (section 2.5) that, given the installation of a proper treasury mechanism, they could operate a revenue-neutral system.

6.4.1 Evaluation: option 3 (revenue-neutral)

Legal issues

Revenue-neutral incentives (Performance Standard Incentive) in the form of a differentiated route levy are fairly novel in air transport. These incentives may be captured under the generic term 'user charges'. It could be argued that they qualify as 'charges' for those operators having to pay such levies, because the revenues are used to encourage the use of environmental friendly aircraft by other operators. This implies that, if environmental costs may be internalised, these costs are for the provision of facilities and services for air transport.

Assuming that a Performance Standard Incentive qualifies as a charge, the legal conditions would apply as mentioned in the legal chapter of this report. It seems important to mention one issue in particular here, however. Operators of aircraft on which a charge is imposed because they operate aircraft that are less environmentally efficient in flight than the average performance standard might argue that such a charge contravenes the letter if not the spirit of Article 15 of the Chicago Convention, dictating that user charges be imposed in a non-discriminatory fashion. However, already existing differentiated levies (e.g. peak/off-peak air navigation charges) are accepted and appear not to contravene Article 15 of the Chicago Convention as long as there is no discrimination according to the nationality of the aircraft operators.

Distributional issues

The most important advantage of this option is that a potentially difficult discussion and choice regarding redistribution of revenues among countries can be avoided.
A second major advantage for the aviation sector is that a revenue-neutral incentive will only increase the financial burden of the sector somewhat through the extra abatement costs of emission reduction measures. However, the question then arises whether it is fair for aviation not to pay fully for the environmental damage for which it is responsible.
Another advantage of a revenue-neutral incentive is that it does not alter the sector's competitiveness (although individual firms may be affected) and that is why support for this option can be found, in general. In addition, the sector may be willing to accept higher, more environmentally effective, incentive levels (read: larger differentiation between more and less environmentally efficient aircraft).
An important disadvantage of the Performance Standard Incentive, is that the Polluter Pays Principle is not fully followed, as revenues are recycled to the aviation sector.

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Abbreviations used

€, EUR	euro
€ct	euro cent
€M	million euro
AERO	Aviation Emissions and analysis of Reduction Options: model developed by Dutch CAA
anthropogenic	caused or produced by humans
ART	Adjusted Revenue Tonnes carried Kilometres (abbreviation only used in this study), 0.16*passengers + tonnes freight carried by an aircraft
ARTK	Adjusted Revenue Tonne Kilometres (abbreviation only used in this study). Analogous to RTK, but passengers are taken as 160 kg instead of 100 to account for seats, galleys, catering, crew etc. required per passenger. This correction is necessary because otherwise freight transport would benefit and passenger transport would suffer in a PSI variant based on emissions per ARTK. Formula: ARTK 0.16*(passenger kilometres) + (cargo tonne kilometres)
ATC	Air Traffic Control
block time	the time elapsing from start of taxi out, at origin, to end of taxi in, at destination
CAA	Civil Aviation Authority
CAEP	Committee on Aviation Environmental Protection: environmental committee of ICAO
CO_2	carbon dioxide, the principal greenhouse gas
Dp/F00	the ICAO regulatory parameter for gaseous emissions, expressed as the mass of the pollutant emitted during the landing/take-off (LTO) cycle divided by the rated thrust (maximum take-off power) of the engine
efficiency	in economic theory and in this report, the pursuit of optimum pricing based on marginal costs; cf. 'distribution' and 'fairness'
Emission Index	the mass of material or number of particles emitted per burnt mass of fuel (for NO_X in g of equivalent NO_2 per kg of fuel; for hydrocarbons in g of CH_4 per kg of fuel)
energy efficiency	ratio of energy output of a conversion process or of a system to its energy input; also known as first-law efficiency.
environmental cost	financial value assigned to negative environmental effects, based either on the costs of losses or on the costs of prevention
FAA	United States Federal Aviation Authority
FESG	Forecasting and Economic Support Group of CAEP
greenhouse gas	a gas that absorbs radiation at specific (infrared) wavelengths of the spectrum emitted by the Earth's surface and by clouds. At altitudes cooler than surface temperature, these gases emit infrared radiation. The net effect is a local trapping of part of the absorbed energy and a tendency to warm the planet's surface. Water vapor (H_2O), carbon dioxide

	(CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the principal greenhouse gases in the Earth's atmosphere.
Green Paper	in this report, the European Commission's Green Paper Towards Fair and Efficient Pricing in Transport, 1995, a first step towards a common framework for a European transport pricing policy; see also 'White Paper'
H_2O	water (vapour)
HC	hydrocarbons; in this report, all hydrocarbons
ICA	intercontinental: aviation term
IPCC	Intergovernmental Panel on Climate Change: worldwide scientific panel established to coordinate international climate change research and publication of results
kerosene	hydrocarbon fuel for jet aircraft
km	kilometre(s)
Landing/Take-Off cycle	a reference cycle for the calculation and reporting of emissions, composed of four power settings and related operating times for subsonic aircraft engines. Take-Off: 100% power / 0.7 minutes; Climb: 85%/2.2; Approach: 30%/4.0; Taxi/Ground Idle: 7%/26.0
LTO	Landing/Take-Off cycle
Mach number	aircraft speed divided by the local speed of sound
Maximum Payload	The difference between the maximum design zero fuel weight (MZFW) and operational empty weight (OEW)
Maximum Useful Load	The difference between the maximum design take-off weight (MTOW) and operational empty weight (OEW). Useful load is the sum of payload and usable fuel.
MBO	market-based option (levies or trading regimes) for limiting the carbon dioxide emissions of the aviation sector
MEW	Manufacturer's Empty Weight The weight of structure, power plant, systems, furnishings and other items of equipment that are an integral part of particular aircraft configuration, including the fluids contained in closed systems. The weights of all operator's items are excluded.
MIT	Massachusetts Institute of Technology
MLW	Maximum Landing Weight, the maximum weight at which the aircraft may land.
MTOW	Maximum Take-Off Weight, the maximum weight at the start of take-off-run.
MTW	Maximum Taxi Weight, The maximum weight for ground manoeuvre (including the weight of run-up-and taxi fuel).
MZFW	Maximum Zero Fuel Weight, The total maximum of operational empty weight (OEW) and payload; it is also the maximum operational weight without usable fuel.
NO_X	generic term for oxides of nitrogen (NO, NO2, NO3), which contribute to acid rain, eutrophication and tropospheric ozone formation and indirectly to global warming and ozone layer changes

OEW	Operational Empty Weight, sum of manufacturers empty weight and operator's items
Operator's items	These items include the following: unusable fuel, oil for engines, IDG and APU, water for galley and toilets, chemical fluid for waste tanks, aircraft document and tool kits, passengers seats and life vests, galley structure and fixed equipment, catering, emergency equipment, crew and their baggage
P/L	Payload
passenger-km	passenger-kilometre, unit of passenger transport provision: one person moved one kilometre
Payload	Weight of passengers, cargo and baggage (These may be revenue and/or non-revenue).
pax	aviation term for 'passengers'
performance standard	environmental efficiency of a certain flight. In this report, emissions per ARTK are considered the most accurate definition of a performance standard, and emissions per MZFW.km as a second-best option.
pkm	see 'passenger-km'
pressure ratio	the ratio of the mean total pressure exiting the compressor to the mean total pressure of the inlet when the engine is developing take-off thrust rating in ISA (International Standard Atmosphere) sea level static conditions
PSI	Performance Standard Incentive, term used in this report to indicate a revenue-neutral incentive system that rewards flights that perform better than a certain performance standard, and punishes flights that perform worse than this performance standard
RTK	Revenue Tonne Kilometres, usually calculated as 0.1*(passenger kilometres) + (cargo tonne kilometres)
SFC	specific fuel consumption
Spec. fuel consumption	the fuel flow rate (mass per time) per thrust (force) developed by an engine
tkm	see 'tonne-km'
tonne-km	tonne-kilometre, unit of freight transport provision: one tonne moved over one kilometre

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Economic incentives to mitigate greenhouse gas emissions from air transport in Europe

Annexes

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A Route Charge System of EUROCONTROL

A.1 EUROCONTROL Route Charge System

In 1969, the EUROCONTROL Member States adopted the basic principles for a harmonised regional en-route charges system, involving a single charge per flight, which came into operation in 1971. The EUROCONTROL Central Route Charges Office (CRCO) was set up to operate this system on behalf of the States.
Under the EUROCONTROL International Convention relating to Co-operation for the Safety of Air Navigation of 1960, as amended in 1981, and in 1997 (subject to ratification), the Member States consider that the operation of **a common route charges system**, with due regard to the guidelines recommended by the International Civil Aviation Organization (ICAO), in particular concerning equity and transparency, contributes to the funding of the uniform European air traffic management system and facilitates consultation with users. Accordingly, the Member States have agreed to implement a common policy for the establishment and calculation of charges levied on aircraft operators of en-route air navigation facilities and services, hereinafter called "**route charges**". This common policy builds on the provisions of the Multilateral Agreement relating to Route Charges, which has been in force since 1986. The EUROCONTROL Route Charges System is open to all European States wishing to participate and in particular those States which are members of ECAC[43].

The CRCO offers Member States, additional to route charges, a calculation, billing and collection service for **terminal charges** and the same mechanisms for air navigation charges on a bilateral basis to *non*-Member States.

A.2 Mission and tasks of CRCO

Mission
The mission of the Central Route Charges Office (CRCO) is to provide its stakeholders with an efficient cost-recovery system that funds air navigation facilities and services and supports ATM developments.
The CRCO strategy to fulfil this mission is "Sustainable Growth" and the primary objectives flowing from it are as follows:
- reduction of the administrative unit rate through cost control and flexibility in resource allocation;
- integration of CRCO developments within the Agency strategy to foster secure and equitable funding of the ATM system in Europe;
- raising the level of quality to improve internal performance and services to the customers.

Tasks
The tasks of the CRCO include:
- establishment and collection of route charges and disbursement to the Member States of charges collected;

[43] ECAC is the European Civil Aviation Conference, an inter-governmental organisation established in 1955 at the initiative of the Council of Europe and with the active support of the International Civil Aviation Organization (ICAO). The ECAC Objective is the promotion of the safe and orderly development of civil aviation on routes within, to and from Europe.

- participation in the development of the Route Charges System;
- provision of resources or technical assistance in connection with air navigation charges not covered by the Multilateral Agreement for Member or non-Member States.

A.3 Calculation method for current route charges

The EUROCONTROL Route Charges System is a harmonised regional system whereby route charges:
- are established according to a common formula which takes account of the costs incurred by Member States in respect of air traffic facilities and services, and
- are collected by EUROCONTROL as a single charge per flight.

The CRCO operates the EUROCONTROL Route Charges System. It issues one bill per flight or series of flights, irrespective of the number of Member States overflown. The bill is settled by a single payment, in one currency - the euro, to one body - the EUROCONTROL CRCO

Calculation method charges
Member States provide air traffic control (ATC) facilities and services to ensure the safe, efficient and expeditious flow of air traffic through their airspace. They recover the costs of providing these facilities and services by means of route charges levied on users of their airspace.

The route charge is levied for each flight performed under Instrument Flight Rules (IFR) in the Flight Information Regions (FIRs) falling within the competence of the Member States.

The *total charge per flight* collected by EUROCONTROL (**R**) equals the sum of the charges ($\mathbf{r}_i$) generated in the FIRs of the individual States (**i**) concerned. The individual charge ($\mathbf{r}_i$) is equal to the product of:
- the distance factor ($\mathbf{d}_i$) within the airspace of a Member State;
- the weight factor (**p**) for the aircraft concerned;
- and the unit charge rate ($\mathbf{t}_i$).

The **distance factor** ($\mathbf{d}_i$) is equal to one hundredth of the great circle distance, expressed in kilometres, between points of entry into and exit from the airspace of State (**i**) (or the airports of take-off and landing, if applicable) as described in the last filed flight plan. This flight plan incorporates any changes made by the operator to the flight plan initially filed as well as any changes approved by the operator resulting from air traffic flow management measures.
The distance to be taken into account is reduced by a notional twenty kilometres for each take-off and for each landing on the territory of State (**i**).

The **weight factor** (**p**) is based on the maximum certified take-off weight (MTOW) of the aircraft. The weight factor increases with MTOW, but less than proportionately: weight factor **p** equals the square root of the quotient obtained by dividing MTOW expressed in metric tons by fifty.
Where the maximum take-off weight authorised of the aircraft is not known to the CRCO, the weight factor is calculated by taking the weight of the heaviest aircraft of the same type known to exist.

The **unit rate** ($\mathbf{t}_i$) for flights in the FIRs of State (**i**) is established by each State in advance of the year in which it will be applied. Essentially, each

State establishes its forecast cost-base, applying the common principles[44] for the year in which the charges are collected. This cost-base comprises operating costs plus depreciation costs and cost of capital, as well as the State's share of EUROCONTROL's costs (excluding CRCO costs).
A unit rate is then established for each State. It is expressed in euro and consists of two parts:

- the **national unit rate**, obtained by dividing the en-route facility cost-base of the State concerned for the reference year by the number of service units[45] generated in the airspace of that State during the same year;
- the **administrative unit rate**, the purpose of which is to recover the costs of collecting route charges (CRCO costs). It is obtained by dividing these costs by the number of service units generated in the EUROCONTROL charging area as a whole. The component of the unit rate representing the CRCO costs therefore is identical in all States.

These figures are presented by the States' representatives in June (preliminary figures) and November (final figures). The unit rates are then determined by the (enlarged) Commission of Transport Ministers. The unit rates are applicable as from 1 January of each year[46].
As it is the objective to cover the costs of air navigation services, under- or over recovery of costs in the latest year will be considered in the calculation of the following year in order to minimise divergence of charge revenues from costs.

A.4 How works the current data collection and billing procedure?

The national Route Charge Offices of the Member States supply the basic data required for calculating the route charges and are responsible for the accuracy of these data.
In order to limit the volume of data, only one message per flight is transmitted to the CRCO irrespective of the number of Member States overflown. Thus, the State responsible for collecting and sending the flight data is the State on whose territory the aerodrome of departure is situated, or via whose airspace the aircraft enters the EUROCONTROL charging area.

The following information is available at the CRCO for all IFR flights performed within the airspace of EUROCONTROL Member States (including overflights):

- date of flight/actual time of departure or time of entry into EUROCONTROL airspace;

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[44] The common principles adopted by the Member States for the calculation of costs are enshrined in the "Principles for Establishing the Cost-Base for Route Facility Charges and the Calculation of the Unit Rates", which are available from EUROCONTROL on request. The principles are based on those described in the "Statements by the Council to Contracting States on Charges for Route Air Navigation Facilities" as contained in ICAO Document 9082/5 and in the "Manual on Air Navigation Services Economics" as contained in ICAO Document 9161/3, subject to any modification made in order to take account of other methods specific to the EUROCONTROL Route Charges System.

[45] The product of the distance factor $\mathbf{d}_i$ and the weight factor **p** is defined as the number of service units in State (i) for this flight.

[46] To reduce the effects of exchange rate fluctuations on the System, the unit rates are adjusted every month in line with the exchange rate of the euro against the national currencies concerned. However, States experiencing high inflation can establish their national costs in euro without any subsequent monthly adjustment of their unit rate.

- last filed flight plan;
- great circle distance flown in EUROCONTROL airspace;
- airport of departure/airport of destination;
- aircraft type (and thus MTOW-average per user and aircraft type);
- aircraft call sign (aircraft registration, flight number or military call sign).

Flight messages are sent within 10 days after the day of flight and according to a pre-established transmission calendar.

The EUROCONTROL Central Flow Management Unit (CFMU) provides the CRCO with the route description filed by the aircraft operator, based on the last filed flight plan. This is to calculate the distances flown in each State's airspace.

Based on the information received by the CRCO, bills are send to the operators of airlines every month. In addition, users may receive credit notes and bills for interest on late payment, as well as Value Added Tax (VAT) invoices on behalf of those States where route charges are subject to VAT.

A.5 How is the disbursement of revenues of current route charges organised?

Route charges income is disbursed weekly to the States. Interest earned on short-term investment of funds, as well as interest on late payment, is also paid to the States. Payment can also be made to third-parties on behalf of States, at their instructions.

B Emission calculation methods

B.1 Introduction

In this Annex we will describe the pros and cons of several options to calculate emissions of CO_2 and NO_X. We can distinguish methods to calculate emissions *ex ante* and *ex post*.
With *ex ante* calculation we mean that the emission level of a specific flight is determined *before* the flight has taken place, dependent on parameters like calculated distance and aircraft characteristics.
With *ex post* calculation we mean that the emission level of a certain flight is determined *after* the flight has taken place (ex post), dependent on flight parameters like actual fuel use, or measured settings.

From an environmental effectiveness point of view, it can be said *that ex post* calculation of emissions is to be preferred above *ex ante* calculation. *Ex post* calculation leaves the operators a wider range of options to reduce emissions. For example, if emissions of a certain flight are *ex post* calculated, incentives exist to optimise cruise speed for minimum fuel consumption during that certain flight, whereas these incentives do not exist if emissions are *ex ante* calculated.

We start with rough (section B.2.1) and more refined (section B.2.2) options to *ex ante* calculate CO_2 emissions, then (section B.2.3) options to *ex post* calculate CO_2 emissions. Finally, in section B.3 and B.4 NO_X emissions calculated methods are discussed.

B.2 *Ex ante* calculation of CO_2 emissions

The CO_2 emission of a certain aircraft at a certain flight is dependent on a wide variety of technical and operational variables. There is currently no official cycle to calculate CO_2 emissions from aircraft. Work on this issue is being done in CAEP; preliminary results are presented in the interim reports from Working Groups 3 and 5.
We distinguish the methodologies to calculate CO_2 emissions into two groups:

- the first group considers options to calculate the emissions ‘from a distance’ i.e. without any additional help from the aviation industry. Only publicly available and easily accessible data can be used, which means that results will not be aircraft-specific. In case the engine used is included in the ICAO database, engine/airframe type specific emissions can be calculated; in the case of smaller and turboprop engines, only airframe-specific emissions can be calculated;
- the second group considers options to calculate the emissions more closely with the help of more specific data of the aircraft. In order to do this, information is required that is currently not publicly available.

B.2.1 Rough CO_2 estimates – only use publicly available data

In this paragraph, we describe two methods for a first-order estimate of CO_2 emissions that arise from a certain flight. The first-order estimates could be used as a 'worst case' starting point for incentive calculation. Options 1 and 2 could be done with data currently available at EUROCONTROL, as they do not require aircraft registration numbers for every flight. Also they do not require aircraft-specific calculations, making it possible that the administrative authority calculate the emission values to be used.

It is important to have such first order estimates as there are many reasons to doubt whether more precise data will be widely available for each aircraft:

- as already said, aircraft registration data for individual flights are not available at EUROCONTROL, and as a result engine data are neither;
- public information on aircraft engine emissions is limited to the ICAO engine exhaust emissions data base, which does not include smaller (< 26.7 kN) and turboprop engine data;
- there is also very limited publicly available data on airframe characteristics.

Option 1: emissions based on great circle distance + MTOW
The simplest approach is to make an estimate of the emissions on the basis of the great circle distance and the MTOW of the aircraft considered. A simple formula, to be developed by a specialised institute, describing the emissions as a function of these two parameters would be sufficient:

maximum emissions = F (GCD [km], MTOW [t])

The result is a very rough estimate that is independent of airframe and engine type, and that could possibly be used as a baseline maximum estimate if no more specific data are available. This is the same system as many airports use today with regard to noise differentiation of landing charges: the baseline charge is based on maximum noise emissions of an aircraft with a certain MTOW, and airlines can deliver more specific data if the actual emissions are lower than this maximum.

Option 2: emission based on great circle distance + airframe type
In this option, the administrative authority includes the airframe type in the first CO_2 calculations, in order to make a somewhat more precise first estimate of the emissions.

maximum emissions = F (GCD [km], airframe [type], MTOW [t])

An advantage is that the maximum estimate comes a bit closer to a realistic maximum for the specific airframe type. Still, no engine data are required. However, it would require a lot of effort to make available the data for all important airframe types.

Combining options 1 and 2
Also a combination of options 1 and 2 could be used to serve as a first estimate without requiring aircraft registration data. For aircraft on which much information on specific emissions is available in current models, such as B747-400 and B737-400, the second approach could be used, while for aircraft on which information is very limited, the first option could be followed. This approach seems to combine the advantages of simplicity of option 1 and the advantage of somewhat higher accuracy of option 2, without causing administrative difficulties with respect to data requirements.

Option 3: emission based on great circle distance + airframe type + engine type
In case for every flight airframe *and engine* type would be available, the level of detail could drastically increased. airframes can generally be fitted with two or three different types of engines, but sometimes also with five.

maximum emissions = F (GCD [km], airframe [type], MTOW [t], engine emissions)

At first sight, this option could serve as a definitive incentive base to calculate emissions for each individual flight without the need for additional industry data, as all relevant data seem to be available. However, things are not that simple:
- first, the methodologies to calculate emissions on the basis of the data given above are not certificated;
- second, within each aircraft type, numerous variants exist, often built-to-order, with subtle differences in emissions;
- third, for a large category of engines no emission data are available;
- and, if all these data obstacles were removed, the administrative body faces an enormous amount of work as over 1,000 combinations have to be modelled.

Therefore, it is doubtful whether also this most refined 'public data' variant would be acceptable and feasible as a definitive basis for the environmental incentives.
Of course, a somewhat more basic model, which contains several dozens or possibly several hundreds of different engine/airframe combinations could serve as a good first estimate of (maximum) emissions.

B.2.2 Refined CO_2 estimates – aircraft manual data required

If In this paragraph we describe options to calculate CO_2 emissions in a more refined way, at the level of an individual aircraft.
Such a more refined CO_2 emission calculation would consist of three steps.

First, there should be an agreed *methodology to calculate emissions* of the specific aircraft type considered. At this moment, the only option is do derive the emission calculation from the fuel consumption tables that manufacturers have to deliver to airlines for aircraft airworthiness certification. The data are given in the **aircraft performance manuals**, or sometimes delivered as a computer tool.
In principle, the manuals are property of the airlines. Two principal possibilities exist to make the emission data available to the authorities:
- legislative measures. It could be stated in legislation that aircraft manufacturers and/or operators supply a copy of every active aircraft's manual to the authorities;
- voluntary participation. In this case, a situation has to be created in which it is attractive for the aircraft manufacturers and/or operators to deliver the relevant parts of the aircraft manuals to the authorities, or to make specific emission calculations with these models and have the calculations checked by the authorities.

Second, a *standard cycle* has to be defined along which the fuel data have to be taken from the tables. Three principal approaches exist:
- 'worst case' approach: the emission calculation is based on a flight cycle that leads to *minimum trip time* or to *maximum performance* (i.e. steepest climb and descent angles and highest cruise speeds. These two will often lead to the same fuel consumption, and if not, the one with the highest fuel could be taken;
- 'best case' approach: the emission calculation is based on a flight cycle that leads to *minimum fuel consumption*;
- average case approach: the emission calculation is based on some kind of average of the three approaches mentioned.

The choice of optimal approach is dependent on the final system design.
If airlines are given the opportunity to also deliver emission figures on an *ex post* basis, based on *actual* flight data (see next chapter), then it could be wise to use one of the 'worst case' approaches. This leaves all opportunities open for airlines to increase their efficiency relative to this 'worst case' standard.
If, however, airlines are not given this opportunity, then it is very important to reflect as much as possible realistic flight patterns, and the choice would then preferably be the third approach.

Third, an emission calculation has to be carried out along the flight cycle defined. This could be done by the aircraft manufacturer, the operator, or the administrative authority. For reasons of efficiency it seems preferable that either the manufacturer or the airline perform the calculation, and the administrative authority check the data.

An important question with this methodology is the amount of different calculations that has to be made. If the amount of different calculations is limited to the number of aircraft configurations, the number of calculations required would probably be somewhere around 1,000. Currently the market leaders, Boeing and Airbus, together deliver about 350 configurations (variations in airframe type, engine type, and tolerated weight and payload/range characteristic). Including configurations that are still in the fleet but not on sale any more, and aircraft from other manufacturers, the number of different configurations could easily be over 1,000.

B.2.3 *Ex post* calculation of CO_2 emission

Ex post (i.e. after the flight) calculation of CO_2 emission has two advantages compared with *ex ante* (before the flight) calculation.
- the aircraft operator is left more options to reduce emissions, namely by choosing a flight cycle that is closer to minimum fuel consumption than to maximum performance or minimum time. First estimates with the APD model indicate that the difference between the 'minimum fuel' and 'maximum performance' operations in terms of CO_2 emission could be somewhat around 15-25%. Keeping the flexibility is desirable in order to achieve cost effective emission reduction;
- with ex ante calculation, there is always a risk that manufacturers and airlines optimise their aircraft around the predefined emission calculation points. This might lead to sub-optimisation in the longer term: the aircraft is better at the certified points, but worse during actual flights. With ex post calculation, only real emissions count.

It has, of course, also some disadvantages:
- it is clear that administrative efforts to gather ex post data are much larger. For example, if emissions are calculated ex post, aircraft classifications are not very useful any more. Besides, many more data checks have to be made;
- airlines could become the victim of unnecessarily high emissions due to ATM problems (congestion, suboptimal routing, flight level changes etc.). This disadvantage could be overcome by falling back in these cases to the ex ante calculated option as described in the previous paragraph. Airlines who do better than this standard value are rewarded; airlines who do worse face no consequences. In this case the ex ante calculation should be based on a worst case approach.

Link CO_2 to fuel consumption only
CO_2 could be directly linked to fuel consumption at specific flights, by multiplying the amount of fuel by certain fixed factor like 3.16. Currently registration of trip fuel is required by law to be registered by the flight instruments, by the flight data recorder ('black box') and in the mass and balance documentation that has to be prepared before and after each flight.

As trip fuel data are considered competition-sensitive information, it would be preferable to gather the actual fuel data on a voluntary basis, and to have the airlines decide whether or not to deliver the data to the authority. Incentives could be given to deliver the *actual* data by basing the *calculated* emission estimate on a 'worst case' flight (see section B.2.2).

First, we describe some technical options to calculate NO_X emissions, after that, we will describe a practical way to deal with it.

B.3 Technical options to calculate NO_X

Currently there is work going on to develop new methodologies to assess cruise emissions with emission data derived from engine tests conducted at sea level static (SLS) conditions [CAEP, 2001]. The main reason for this is the fact that altitude simulation test facilities are extremely expensive to operate and are few in number. These test facilities, which have the capability of controlled simulation of flight conditions (Mach Number, altitude pressure, temperature and humidity) and of recording all essential engine performance data, have allowed limited amount of emissions testing to be carried out over the last 25 years. These data (performance and emissions) are considered to be the 'gold' standard against which all other measurements and predictions are judged [CAEP, 2001].
Over the years, several methods to assess cruise emissions from emission data derived from engine tests conducted at SLS conditions have been developed, based on experience of combustor and engine testing. Two basic emissions prediction approaches have been used [CAEP, 2001; IPCC, 1999]:
- rigorous performance based methods, which use known engine performance changes between two operating conditions to correct emissions indices from one condition to another; and
- fuel flow prediction methods, which correlate LTO certification emissions indices with fuel flow and try to take account of engine inlet temperature and pressure effects.

Rigorous performance based methods
From the engine certification process, engine manufacturers have all the necessary engine performance data that are needed to carry out the rigorous performance based predictions. These data comprise power setting, combustor design, chemical kinetic rates, residence times in the reaction zone, and flight conditions.
Once a model of a specific engine design is developed, combustor inlet pressure and temperature are the main parameters that determine the emission of NO_X. Using input values for these parameters, NO_X emissions at in-flight conditions appear to be accurately predicted by these models. The best results using these procedures indicate an uncertainty of ± 3%.
A disadvantage of the rigorous performance based procedures P3-T3 method (also referred to as the P3-T3 method, after the main input parameters) is that it requires detailed data of the engine internal gas path. These data are sensitive from a manufacturer's point of view. Therefore, effort has

been put into developing methods that use publicly accessible data to predict emissions during cruise conditions [IPCC, 1999].

Fuel flow correlation prediction methods
Fuel flow correlation prediction methods aim to predict emissions during the cruise phase of flight from emission certification data and the fuel flow at cruise. Generally, fuel flow correlation prediction methods give results that appear poorer than those achieved with the rigorous performance based method.

B.4 Dealing with NO_X in the incentive base

The previous paragraph shows that a precise NO_X calculation is highly complex. A point of discussion is whether the fuel flow method is considered an acceptable basis for incentive calculation. It could be argued that if no engine specific emission model is available, it is better to use the fuel flow method for ex ante calculation than to do nothing. It does seem enormously labour- or capital-intensive to make P3-T3 NO_X estimates for each flight.

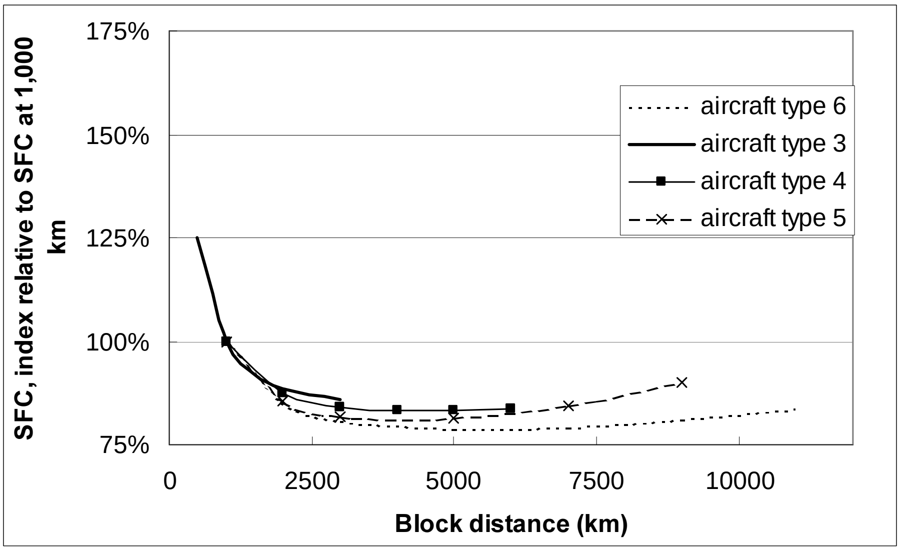
A practical way to deal with it could be as follows:
- the administrative authority establishes a baseline maximum emission of NO_X for each certain flight, equivalent to the CO_2 baselines as described in B.2.1;
- aircraft operators or manufacturers could deliver more accurate profiles based on the 'worst case' fuel estimates of B.2.2, and they may choose whether to apply the fuel flow method or the P3-T3 method (as a result, they might chose the method that leads to the lowest results);
- if the airlines realise a lower fuel consumption than this baseline, than they may receive a proportional reduction of NO_X emission, unless they can prove that the NO_X reduction is more than proportional to the CO_2 reduction.

A result, some airlines might develop advanced P3-T3 NO_X calculation models for their aircraft, have them certified, and send the values to the administrative authority. Others may not do this and will be satisfied with the standard figures.

C Correction PSI for stage distance

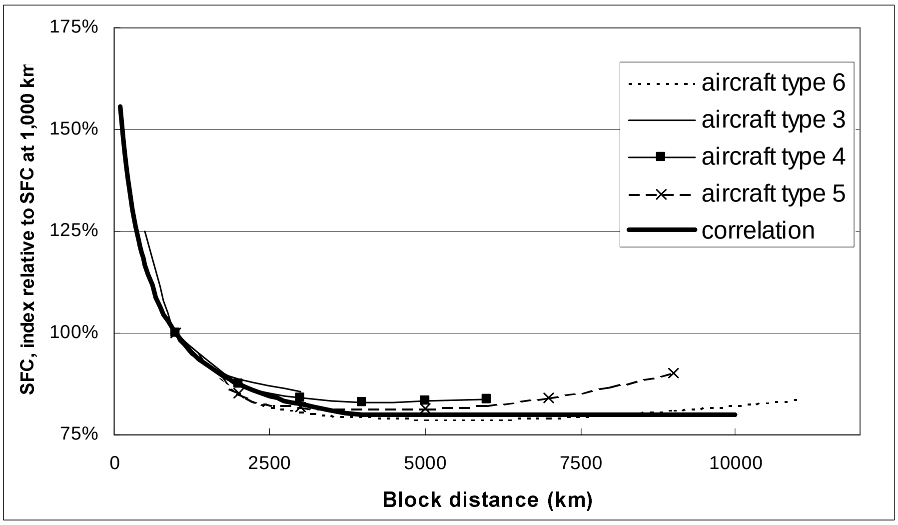
In section 2.4.4 of the body of this study, we acknowledge that although a linear relationship between performance standard and distance (such as ARTK or MZFW.km) is both simple and transparent, it puts short-haul flights at a relative disadvantage due to their operationally intrinsic lower environmental efficiency. We have therefore also investigated a PSI variant in which the performance parameter is corrected for this.
First, we made an in-depth analysis with the APD model, of the relationship between fuel consumption and stage length for four sample aircraft types. This relationship is shown in Figure 15.

Figure 15 Specific fuel consumption (SFC) of four sample aircraft types used in this study, related to the distance flown (SFC at 1,000 km = 100)



It can be seen that specific fuel consumption is the lowest at stage lengths of about 4,000 to 5,000 km. On shorter stages than this optimum, the extra fuel consumption due to take-off and climb increases the SFC; while on longer stages, the weight of the extra fuel that must be carried has a negative impact on SFC.
In order to make a proper proxy of a distance correction, the figures for the four sample aircraft types were then interpolated with an exponential function, as shown in Figure 16 below.

Figure 16 Correlation between distance and specific fuel consumption, based on four sample aircraft types



The bold line in the figure above is characterised by the formula:

$$SFC_{\text{relative to distance = 1,000 km}} = 13{,}02 * \exp^{(31/(\text{distance}+390))} - 12{,}3$$

It was decided not to take his variant into account in the calculations, as its smoothing of the SFC/distance relationship for the shortest and the longest stage lengths is not felt to be justified by the additional complexity introduced to a transparent, explicable and justifiable method of PSI calculation. Thus only the linear variant has been elaborated in the economic and environmental assessment in the body of this study.

D Legal analysis

The legal analysis addresses the legal obstacles and conditions that are relevant to implementing economic incentives designed to mitigate the global environmental impact of European aviation. The legal analysis focuses on international provisions, including the Chicago Convention, bilateral air services agreements, the legal framework of the European Union and the regulatory regime of EUROCONTROL.

D.1 Substantive scope of charges

D.1.1 The Chicago Convention

The Chicago Convention provides the framework for the operation of international air services. The fifteen EU Member States are parties to this Convention. Its provisions are binding upon these Member States. World wide, 188 states are a party to the Chicago Convention.
In the following we shall consider the environmental charges as a user charge under international air law.
User charges are charges imposed upon the users of services, that is, operators of aircraft including airlines, related to the safe and efficient operation of air services. Charges are levied on operators of aircraft in three phases of flight: airport control, approach control and *en route*.
This study focuses on (*en*) *route* charges, a term which is based, inter alia, on the EUROCONTROL Multilateral Agreement relating to Route Charges of 1981. The EUROCONTROL Contracting States have adopted the basic principles for a harmonised regional en route charges system, involving a single charge per flight for the use of en route air navigation and facilities. Arrangements made by EUROCONTROL with respect to the imposition of route charges comply with Article 15 of the Chicago Convention.

D.1.2 User Charges in the context of the Chicago Convention

We refer to Article 15 of the Chicago Convention. Article 15 of the Chicago Convention deals with “Airport and similar charges” encompassing both airport charges and en route charges. The terms “User Charges” and “Route charges” are not used in Article 15 of the Chicago Convention. However, this provision refers to “charges … for the *use* of airport and air navigation facilities …” (*italics supplied*) which charges are related to the user charges mentioned above. This provision sets a global regime for the establishment of route charges, because it speaks of “charges that may be imposed …. for the use of … air navigation facilities …” on “international air services”.
The last sentence of Article 15 of the Chicago Convention, regulating charges for transit flights, confirms the point of view that this provision is also concerned with *route* charges. Said last sentence will be further discussed under 3, below: “Permissibility of charges for transit passage”.
Three conditions must be taken into account by contracting States when imposing user charges under said Article 15.

1 Non-discrimination

Levies must be imposed without regard to the nationality of the aircraft, which means in practice: without regard to the nationality of the operator of the aircraft, that is, the airline. Reference is made to the discussion on the distinction between *national treatment* and *non-discrimination*, made below.

Levies must be imposed without regard to the nationality of the aircraft, which means in practice: without regard to the nationality of the operator of the aircraft, that is, the airline. If a certain measure is presented in a non-discriminatory fashion, it may produce, however, discriminatory effects *in practice* because certain categories of airlines are discriminated against as a consequence of the imposition of the measure. The legislator must take this into account when drawing up environmental measures.

In the context of the non-discrimination principle as formulated in Article 15 of the Chicago Convention, we interpret the term "uniform conditions" as an application of the "national treatment" principle. As to charges, this means that charges, which are imposed to operators of national aircraft must be based on the same or similar standards as charges which are imposed to operators of foreign aircraft. Contracting states must provide such “national treatment” to operators of aircraft engaged in both the operation of scheduled and in non-scheduled international air services.

The danger of discriminatory effects will be mitigated by the use of *objective* principles in the course of the establishment of the charge, especially the principle of cost-relatedness. The requirement pertaining to the application of objective standards with respect to the establishment of charges will be examined in the next sub-section.

2 Restriction of user charges for use of services and facilities

It could be argued that "… charges may be imposed … for the *use* of .. air navigation facilities …" only (*emphasis added*) implies a strict application of the principle of cost-relatedness, excluding the inclusion of costs which are unrelated the “use of air navigation facilities”.

To uphold such an argument would affect the ongoing discussions on the internalisation of external costs. We are of the opinion that a strict, or formal interpretation of the world "use" in Art. 15 of the Chicago cannot be maintained. We refer, for instance, to ICAO Council Resolution *on Environmental Charges and Taxes*, which seems to reconcile the above provision of Article 15 of the Chicago Convention and its related principle, that charges must be cost related, with the principle of internalisation of external environmental costs (see also, below)[47].

3 Permissibility of charges for transit passage:

Subject to the provisions of Article 15 of the Chicago Convention and applicable ICAO and bilateral regulations, states are entitled to impose charges for flights in transit.

The last sentence of Article 15 reads:

> "No fees, dues or other charges shall be imposed by any contracting State in respect *solely* of the right of transit over or entry into or exit from its territory of any aircraft of a contracting State or persons or property thereon." (*emphasis added*)

One could argue that the word "solely" has legal relevance. For instance, if a country would impose a charge only for the use of the airspace, as opposed for the use of air navigation facilities, the state of the operator of the overflying aircraft might contest the imposition of the overflight – or transit – charge

[47] See, Assembly Resolution A 32-8 (1998), under 3: "Reaffirms that ICAO is seeking to identify a rational common basis on which States wishing to introduce environmental levies on air transport could do so."

on the basis of Article 15 of the Chicago Convention. In addition, the state of the operator of the overflying aircraft could argue that the "transit charge" is not cost-related, as the overflown state does not incur costs by the sole use of its airspace by operators of foreign aircraft.

However, practice reveals that states, especially states having large airspaces, are tempted to charge operators of foreign aircraft what could be termed as a "transit fee", that is, a fee which is unrelated to the costs of the services and facilities provided by the overflown state. We note that states with large airspaces, which asset is often combined with a geographically speaking attractive location, are not a party to the International Air Services Transit Agreement of 1944, providing for the "privileges" of free transit flights, and cost related charges. All 15 EC Member States are a party to this Agreement, which has 115 contracting states. However, countries like Russia, the US, Rumania and Indonesia are not.

The following two examples demonstrate that certain countries, including Russia and the US, are not always respecting the above mentioned rule, laid down in both the last sentence of Article 15 of the Chicago Convention – to which they are bound as contracting states – and sections 1(1) and 4(2) of the above International Air Services Transit Agreement of 1944.

For instance, the EC Commission has been engaged in discussions with the Russian authorities concerning the imposition of charges by the Russian authorities to the amount of US$ 200 million per year. In that dispute, the Commission put forward that the system of royalty payments, used to subsidize the Russian carrier Aeroflot, should be replaced with a more transparent, non-discriminatory mechanism, at least partly based on the costs of air navigation facilities.

In the US, the United States Court of Appeals for the District of Colombia[48] set aside once again the overflight fees promulgated by the Federal Aviation Administration (FAA) in the summer of 2000 with respect to flights that use the air navigation facilities of the FAA but do not take of or land in the United States. The said court of appeals found that the charges imposed by the FAA were not cost-related.

Consequently, the mentioned countries charged operators of foreign aircraft with "transit fees" unrelated to the costs of the services and facilities provided by the mentioned countries. However, this is not to argue that the inclusion of an environmental component in a route charge amounts to the imposition of a "transit fee" which is forbidden by the last sentence of Article 15 of the Chicago Convention. We confirm here our conclusion set out in 2, above, *2 Restriction of user charges for use*, that external costs to society, if they can be identified, can form part of the cost basis in the establishment of charges. If one would say that an environmental levy is not solely for transit over or entry into or exit from the airspace of a state, then it stands to reason that an environmental levy is permissible, as long as it can be identified, and be considered as a permissible internalisation of costs which are, strictly speaking, external to services and facilities used by operators of aircraft engaged in international air services.

In brief, the main mandatory provision of Article 15 of the Chicago Convention is application of the *non-discrimination* principle.

Exemption of aircraft fuel from taxation

In this context, Article 24 of the Chicago Convention is relevant, which reads (in so far as relevant):

> "Aircraft on a flight to, from, or across the territory of another contracting State shall be admitted temporarily free of duty, subject to

[48] Decision of 13 July 2001, case No. 00-1334 and others.

> the customs regulations of the State. Fuel, lubricating oils, spare parts, regular equipment and aircraft stores on board an aircraft of a contracting State, on arrival in the territory of another contracting State and retained on board on leaving the territory of that State shall be exempt from customs duty, inspection fees or similar national or local duties and charges."

It follows that fuel, which is kept on board and consumed on international air services, is not taxable. "Taxable" includes the imposition of taxes, charges and levies.

However, the question arises whether this exemption from taxation can be extended from fuel to emissions. It could be argued that, if fuel is exempted, then emissions are or should be exempted as well since fuel and the gasses, which are produced through combustion of fuel, are the same.

The ICAO Legal Bureau has suggested that Article 24 "might be interpreted to extend to an en route emission based tax because of the close link between emissions and fuel". [49] It seems to us that ICAO takes a prudent stance as to the permissibility of the imposition of a fuel-related environmental charge, so that there may be room for other, that is, more flexible interpretations of the legal restrictions upon imposition of such a charge. If the argument of the ICAO Legal Bureau can be upheld, and applied to the exemption laid down in bilateral air agreements, emissions produced by fuel, which was taken on the aircraft on the territory of another state, would also be exempted. In practice, proceeding from the correctness of the opinion given by the Legal Bureau of ICAO, emissions coming from both fuel in transit and kept on board the aircraft, and from fuel bunkered on foreign territory, would be subject to the exemption from taxation. The European Court of Justice arrived at the same conclusion (see, below).

Although the provisions of the Chicago Convention are formulated in a general fashion, we conclude that the terms of Article 15 and 24 are sufficiently precise to be applied in practice. This is especially true for the non-discrimination and the fuel tax exemption principles. The standards related to the cost-relatedness of user charges must be further explained by contracting states, and implemented in their national legislations. Therefore, the substantive provisions of Article 15 and 24 are binding on the contracting states of the Chicago Convention.

D.1.3 ICAO (International Civil Aviation Organization)

Tax or charge

ICAO prefers charges over taxes. This standpoint is in line with ICAO's recommendation that charges should be related to costs, [50] which recommendation may be seen as an implementation of Article 15 of the Chicago Convention. It follows that charges should be designed to constitute a remedy of the cause of the – environmental – damage.

ICAO has always made a distinction between taxes and charges. It advised its member states to consider that there should be no fiscal aims behind the charges. If at all, ICAO prefers charges over taxes but is aware that its Contracting States wish to have a certain freedom of action in this respect. In WP/283 of the 33rd General Assembly of ICAO, which was held in September 2001, The General assembly recognised that"…. ICAO policies make a conceptual distinction between a charge and a tax, in that 'a charge is a levy

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[49] See CAEP/5, report of Working Group 5.

[50] See, ICAO Doc 9579 (1991).

that is designed and applied specifically to de fray the costs of providing facilities and services for civil aviation, and a tax is a levy that is designed to raise national or local government revenues which are generally not applied to civil aviation in their entity or on a cost-specific basis."

The introduction of an environmental charge

At present, the principal documents relevant to user charges are:

- ICAO Documents 9082/6: ICAO's policies on Charges for Airports and Air Navigation Services, containing, inter alia, the ICAO Resolution *on Environmental Charges and Taxes* of 1998;[51]
- ICAO Document 9161/3: Manual on Air Navigation Services Economics

During the 33rd General Assembly of ICAO, this body also recognised "the continuing validity of Council's Resolution of 9 December 1996 regarding emission-related levies," urging contracting states to follow the current guidance contained therein. At the same time, states were "urged" to refrain from taking unilateral actions designed to introduce emission-related levies inconsistent with the current guidance. This ICAO resolution was re-affirmed in the resolution of the General Assembly of 1998.

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[51] The relevant parts of this Resolution read: (ICAO):

"1 Notes that the use of levies to reflect the environmental costs associated with air transport is considered desirable by a number of States, while other States do not consider it appropriate in the present circumstances;

2 Considers that the development of an internationally agreed environmental charge or tax on air transport that all States would be expected to impose would appear not to be practicable at this time, given the differing views of States and the significant organizational and practical implementation problems that would be likely to arise;

3 Reaffirms that ICAO is seeking to identify a rational common basis on which States wishing to introduce environmental levies on air transport could do so;

4 Strongly recommends that any environmental levies on air transport which States may introduce should be in the form of charges rather than taxes and that the funds collected should be applied in the first instance to mitigating the environmental impact of aircraft engine emissions, for example to:

a addressing the specific damage caused by these emissions, if that can be identified;

b funding scientific research into their environmental impact; or

c funding research aimed at reducing their environmental impact, through developments in technology and new approaches to aircraft operations;

5 *Urges* States that are considering the introduction of emission-related charges to take into account the non-discrimination principle in Article 15 of the *Convention on International Civil Aviation* and the work in progress within ICAO and, in the meantime, to be guided by the general principles in the *Statements by the Council to Contracting States on Charges for Airports and Air Navigation Services* (Doc 9082/4) and the following principles adapted from those agreed by the 31st Session of the ICAO Assembly:

a there should be no fiscal aims behind the charges;

b the charges should be related to costs; and

c the charges should not discriminate against air transport compared with other modes of transport."

The ICAO Resolution *on Environmental Charges and Taxes* of 1998 represents the legal state of affairs[52].

At the same time, ICAO realises that its contracting States may have different views on this matter. For the time being, diverging views will have to be dealt with in a bilateral context, or in a regional, that is, for instance, intra-EC or intra-Eurocontrol context (see, below), taking into account the developments, which are taking place within ICAO with respect to the introduction of an environmental charge.

Hence, ICAO is aware that its Contracting States wish to have a certain freedom of action in this respect. It seems to us that ICAO policy recommendations leaves room for the imposition of "levies" including an environmental component, which must be understood to cover both taxes and charges.

Meanwhile, ICAO and its Committee on Aviation Environmental Protection (CAEP) are involved with an examination of the conditions the costs of environmental damage can be passed to the users[53].

The legal force of ICAO measures

ICAO itself recognises the lack of legal force in relations to its Statements. In paragraph 1.10 of the ICAO *Manual on Air Navigation Services Economics* (9161/3) it is noted that the ICAO Council Statements differ in status from the Chicago Convention in that Contracting states are not bound to the Statement's provisions and recommendations. The paragraph also notes however that, since recommendations have been developed by major international conferences, there is at least a strong moral obligation for states to ensure that their air navigation services cost recovery practices conform to

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[52] The relevant parts of this Resolution read: (ICAO):

"1 Notes that the use of levies to reflect the environmental costs associated with air transport is considered desirable by a number of States, while other States do not consider it appropriate in the present circumstances;

2 Considers that the development of an internationally agreed environmental charge or tax on air transport that all States would be expected to impose would appear not to be practicable at this time, given the differing views of States and the significant organizational and practical implementation problems that would be likely to arise;

3 Reaffirms that ICAO is seeking to identify a rational common basis on which States wishing to introduce environmental levies on air transport could do so;

4 Strongly recommends that any environmental levies on air transport which States may introduce should be in the form of charges rather than taxes and that the funds collected should be applied in the first instance to mitigating the environmental impact of aircraft engine emissions, for example to:

a addressing the specific damage caused by these emissions, if that can be identified;

b funding scientific research into their environmental impact; or

c funding research aimed at reducing their environmental impact, through developments in technology and new approaches to aircraft operations;

5 *Urges* States that are considering the introduction of emission-related charges to take into account the non-discrimination principle in Article 15 of the *Convention on International Civil Aviation* and the work in progress within ICAO and, in the meantime, to be guided by the general principles in the *Statements by the Council to Contracting States on Charges for Airports and Air Navigation Services* (Doc 9082/4) and the following principles adapted from those agreed by the 31st Session of the ICAO Assembly:

a there should be no fiscal aims behind the charges;

b the charges should be related to costs; and

c the charges should not discriminate against air transport compared with other modes of transport."

[53] See, Proceedings of the CAEP meeting held from 1 to 17 January 2001 in Montreal, CAEP/5-WP 86, and CAEP/5-IP/22.

the policies and philosophies set out in the statements. This appears to be the general practice amongst Contracting States.
Consequently, Statements made by the ICAO Council, and Resolutions adopted by the General Assembly, may, on the first face, not be considered as mandatory provisions under public international law as they do not enjoy "treaty status". However, the following factors may affect and enhance the binding force of Statements made by and Resolutions adopted under ICAO:

- whether those instruments are also embodied in ICAO Annexes;
- the number of states which agreed to the adoption of these instruments;
- the confirmation of the validity of these instruments in following meetings of the Council and the general Assembly;
- the formulation of the legal instruments in terms of specification of the imposition of the obligations as well as the use of such terms as "urging" and strongly recommending rather than, for instance, "inviting" or "requesting";
- last but certainly not least, State practice with respect to the application and implementation of these instruments.

However, we make again the observation that the General Assembly meeting of ICAO held in September 2001 at several instances "urged" contracting states to refrain from unilateral actions (see, above).

Legal force of recommendations made under Article 15 of the Chicago Convention
As to the binding force of recommendations in the context of the establishment of User Charges, we note that, Article 15 of the Chicago Convention mentions that the ICAO Council may make recommendations on the establishment of charges "for the consideration" of contracting States. It follows that such recommendations made by the ICAO Council may be taken into account by contracting states of ICAO, but those states are not bound by the contents of these recommendations.

Enforcement powers of ICAO
ICAO does not have enforcement powers. If a contracting state of ICAO does not comply with the provisions of the Chicago Convention or of ICAO legal instruments, it is up to another or other contracting state(s) to take action against that not-complying state. The "hushkit" case between the US and EC Member states forms an example of procedure.

D.1.4 Bilateral air agreements

Substantive scope
The restrictions under bilateral air agreements go one step further than those imposed by Article 24 of the Chicago Convention. Fuel taken on the aircraft engaged in the operation of international air services falling under the scope of the international air agreement is *also* exempted. If both states agree, this exemption can be lifted. To proceed from here towards lifting the exemption may be a complex procedure because the other party may either refuse the proposal to lift the exemption or ask for concessions. EC Member States are engaged into some 1100 bilateral treaty relationships with third states.

Again, the term "User Charges" as used in clauses of bilateral air agreements may apply to both airport charges and *en route* charges. In older bilateral agreements (concluded in the 1950s, 1960s, and 1970s), one may find that the term "User Charges" only includes airport charges. In the more

recent bilateral air agreements concluded in the 1990s, especially those falling under the term “Open Skies” agreements, “User Charges” may explicitly refer to the inclusion of an environmental component. Nine EC Member States concluded “Open Skies” agreements with the US in the 1990s. Eight Open Skies agreements are currently under review by the ECJ; however, the clause on User Charges is not subject of this litigation.
In the context of the inclusion of an environmental charge in User Charges, regard must be had to bilateral clauses[54] in relation to:

– the non-discrimination principle, confirming the applicability of the Chicago Convention;
– the principle of cost-relatedness laid down in bilateral air agreements;[55]
– the principle of equitable apportionment of the charge among categories of users[56].

Having examined the above “Open Skies” agreements, we arrive at the conclusion that the environmental component may be included in the “airport” element rather than in the “en route” element of the User Charge. Reference is made to the term “airport environmental” in the quotation made under footnote 8.
In our view, this does not necessarily preclude states from including an environmental component in the en route charge, as long as such states:

– respect the mandatory provisions explained above, as well as
– the instruments promulgated by ICAO on the subject, as discussed in the previous paragraph, and while taking into account
– the explanations given by the ECJ (see, below) and the ICAO Legal Bureau (see, above) pertaining to the exemption of fuel from taxation.

More specifically, it seems appropriate that a state in whose territory such a component will be included in the User Charge:

– makes precise calculations of the costs of the environmental damage,[57] *and*:
– provides explanations to users how these costs are included in the User Charges, *and*:
– engages into consultations on such new methods of calculations of User Charges with foreign states if foreign states ask for clarification on the establishment of the User Charges,

in order to meet the mandatory conditions pertaining to transparency of the establishment of the charge and provisions of information thereon.

We note that some, but not all, bilateral air agreements state that the costs of “airport environmental services” may be recovered under user charges. The costs incurred by the provision of “airport environmental services” may be allowed to be included in airport charges, and, under a broad interpretation, in terminal charges, but not in *en route* charges.[58]

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[54] See, the provision on “User Charges” which is taken from an Open Skies agreement:
“User charges imposed on the airlines of the other Contracting Party may reflect, but shall not exceed, an equitable portion of the full cost to the competent charging authorities or bodies of providing the appropriate airport, air navigation, *airport environmental*, and aviation security facilities and services, and, in the case of airports, may provide a reasonable return on assets, after depreciation.” (*emphasis added*).

[55] See, note 14: "User charges … may reflect, but shall not exceed, an equitable portion of the full cost ... of facilities and services …".

[56] This condition is included in some but not in all bilateral air agreements.

[57] See also, Principle 16 of the Rio Declaration, cited above, speaking of *internalisation of costs*.

[58] See, the words "airport environmental" in note 14.

In cases where bilateral air agreements do not provide for the inclusion of an environmental component in the User Charge, whether in the *en route*, terminal, or airport charge, it would seem recommendable if not mandatory that a state in whose territory such a component will be included in the User Charge:

– makes precise calculations of the costs of the environmental damage,[59] *and*:
– provides explanations to users how these costs are included in the User Charges, *and*:
– engages into consultations on such new methods of calculations of User Charges with foreign states if foreign states ask for clarification on the establishment of the User Charges,

in order to meet the mandatory conditions pertaining to transparency of the establishment of the charge.

The view of the ECJ on the exemption of fuel from taxation
In 1988, the Swedish government had established a law - henceforth: the 1988 Law - designed to impose an environmental protection tax calculated on fuel consumption and emission of hydrocarbons and nitric oxide. The EC has a Council Directive, namely, Directive 92/81/EEC, which exempts air carriers from payment on excise duties on fuel consumption within the EC.

The European Court of Justice was confronted with the question, whether a charge on en-route emissions is similar enough to a tax on fuel, in which case such an environmental charge would be invalidated as violating the current exemption on taxing fuel under Community law.

The ECJ found that "…. there is *direct and inseverable link* between fuel consumption and the polluting substances in the 1988 Law which are emitted in the course of fuel consumption, so that the tax at issue, as regards both the part calculated by reference to the emissions of hydrocarbons and nitric oxide and the part determined by reference to fuel consumption, which relates to carbon dioxide emissions, must be regarded as levied on consumption of the fuel itself for the purposes of Directives 92/12 and 92/81."[60]
(*emphasis added*)

The Advocate General Fennelly in this case that the Swedish tax was indeed caught by the exemption envisaged by Directive 92/81, but that taxation should be allowed if “it is shown that those calculations ensure that the tax genuinely and significantly advance an environmental object of encouraging the sue of less polluting aircraft.”[61] In our view, the Advocate General did not make quite clear why the exception – that is, allowance of the tax in cases of environmental benefits – to the exemption – of aircraft fuel from taxation – is justified. We have not found a legal basis for this argument – defending the exception to the exemption – in any of the above Council Directives.

The legal context under which this decision was given will change as soon as the said Directives are amended in such a way that the exemption for air carriers from payment of excise duties on fuel consumption within the EC is lifted, or if those Directives are cancelled.
The argument raised by the ECJ combined with the interpretation put forward by ICAO's Legal Bureau on this matter, makes clear that a calculated

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59 See also, Principle 16 of the Rio Declaration, cited above, speaking of *internalisation of costs*.
60 Case C-346/97; decision of 12 November 1998.
61 Delivered on 12 November 1998.

emission charge, based on a *direct* link between the emissions and fuel consumption of the aircraft, is liable to be challenged under the same international and EC related regulations as fuel, that is exempted from payments of taxes, charges and levies. However, the judicial decisions referred to above proceed from a “direct and substantive link” between fuel consumption and polluting substances such as carbon dioxide. If this link is lifted, an emission-based levy could be considered independently from fuel consumption. Hence, the legal constraints identified above would be inapplicable. A methodology which uses also other parameters (e.g. temperature of the engine, thrust) to calculate the emission based charge would and/or could probably not be interpreted in the same manner.

D.1.5 Eurocontrol

In the context of EUROCONTROL, the imposition of charges is organised under the Multilateral Agreement on *en route* charges of 1981, or on the basis of bilateral agreements between a state and EUROCONTROL. The Multilateral Agreement is implemented and supplemented by Principles, which are from time to time drawn up by EUROCONTROL. With respect to the establishment of charges, EUROCONTROL follows ICAO law and policy, which has been briefly discussed above.

The last version of these Principles, that is, *Principles for Establishing the Cost-Base for Route Facility Charges and the Calculation of the Unit Rates* – henceforth: - the *EUROCONTROL Principles* - has been established in 1999. This version does not refer to an environmental component of the *en route* charge, or to the application of an environmental charge.

The above organisations and committees, that is, ICAO, CAEP, and EUROCONTROL, as well as the Community, are investigating the feasibility of an environmental charge.

The adoption of an environmental charge by or under the auspices of EUROCONTROL is legally feasible as long as:

– an agreement has been reached on the inclusion of an emission based charge by states who are committed to apply the EUROCONTROL Principles – as stated above, either on a multilateral or on a bilateral basis - including agreement pertaining to the collection and distribution of the revenues; *and*
– such an agreement is acceptable for third states, that is, non-EUROCONTROL states, in light of prevailing treaty obligations and other legal considerations (see, above, under question 1) as their airlines will also be subject to payment of such an environmental charge in light of the territorial application of a measure designed to introduce such a charge.

The worldwide framework

The application of GATS to the operation of air transport services is limited to a limited number of ancillary air transport services, which fall outside the scope of this study. However, there may be frictions between the objectives of free trade as endorsed by WTO and the objective to protect the environment as promoted by the UN, its specialised organisations and the EC.

D.2 Territorial scope

The Chicago Convention

Pursuant to Articles 1 and 15 of the Chicago Convention, contracting States are entitled to impose charges upon operators of aircraft within their national airspace and on their national territories. Article 12 of the Chicago Convention states that, above the high seas, rules of ICAO apply to the operation of international air services.

National airspace and national territory are defined in Article 2 of the Chicago Convention. Under the Chicago Convention (Articles 2 and 12), the sea is divided into a territorial sea and high seas. National law must determine the breadth of the territorial sea, which is, since the entry into force of the United Nations Treaty on the Law of the Sea 12 nautical miles. Outside the territorial sea, there are the high seas.

ICAO regulations

In the airspace over the high seas and airspace of undetermined sovereignty under the ICAO based *Regional Air Navigation Plan*, the principles established by ICAO in Annexes and policy recommendations apply to the operation of international air services.

Chapter 2 of Annex 11 of the Chicago Convention provides that contracting states shall determine, for the territories over which they have jurisdiction, those portions of airspace in which air traffic services will be provided. By mutual agreement a state may transfer to another state – or to an international operating agency falling under the terms of Chapter XVI of the Chicago Convention – the task to establish and provide air traffic services in flight information regions, control zones or control areas over the territories of the former.

Pursuant to Articles 12 and 38 of the Chicago Convention, and "Regional Air Navigation Agreements" under Annexes 2 and 12 (see, above), a contracting State of ICAO may accept the responsibility of providing air traffic services outside national airspace. Charges are established in accordance with principles established by EUROCONTROL/CRCO, which are designed to comply with ICAO principles.

The EUROCONTROL regime

The territorial scope for the establishment of *en route* charges is determined by the Multilateral Agreement on the establishment of *en route* charges of 1981. This area does not coincide with the combined national airspaces of the participating EUROCONTROL states, but also includes adjacent international airspace, that is, the airspace of the Flight Information Regions, established under the auspices of ICAO and in accordance with Annex 2 of ICAO, falling within the competence of the participating states.

Using the “extended” jurisdiction for the provision of air traffic services under "Regional Air Navigation Agreements" of ICAO, EUROCONTROL provides and draws up principles for the establishment, billing and collection of charges imposed on users using said services. These principles are in accordance with ICAO principles, which were discussed in chapter two.

The measures regarding the imposition of charges by or under the auspices of EUROCONTROL are applied to the national territory of EUROCONTROL's Member States, the territorial seas adjacent thereto and parts of the high seas, which are covered by the "Regional Air Navigation Agreements" concluded between ICAO Member States and ICAO, including the airspace above these areas.

D.3 Responsibility for the imposition of environmental user charges

D.3.1 The Chicago Convention

Article 15 states that a contracting State of the Chicago Convention is internationally, that is, vis a vis all other contracting States of this convention, responsible for the establishment and imposition of the User Charge. International responsibility pertaining to the imposition of so-called "User Charges" follows from the formulation of the opening sentence of the second paragraph of Article 15 of the Chicago Convention, which reads:

> "Any charges that may be imposed or permitted to be imposed by a contracting State for the use of such airports and air navigation facilities by the aircraft of any other contracting state…"

D.3.2 Bilateral air agreements

As will be explained below, states regulate User charges in bilateral air agreements. One of the most well known bilateral air agreements is the so-called Bermuda 2 agreement, concluded in 1977 between the US and the UK. In an arbitration case between the US and the UK on the matter of User Charges – imposed by a privatised British Airport Authority upon private US airlines such as Pan Am, Flying Tigers and TWA, the court ruled the following:

> "The Treaty, Bermuda 2, governs the conduct of air services, a matter which is by its nature a State prerogative; furthermore, it was intended as a comprehensive code for the operation of such services, with the result that it must be seen as a whole, from which component parts, such as Article 10 [on User Charges] cannot be severed. It is true that the Treaty contains references to designated airlines but it does not thereby confer independent rights on such airlines or alter the fact that the rights that it enshrines are those of the Contracting Parties."

Consequently, in the final analysis, states bear responsibility for the correct imposition of user charges imposed in their territory vis a vis states whose airlines operate from and into their territories. Obviously, we acknowledge that law and practice dictate that reliance on state responsibility is a matter of last resort – explaining the words "in the final analysis" in the previous sentence: following "local remedies" rules imposed by public international law, national means of dispute settlement between the parties involved – including airlines and operators of airports and air navigations facilities – must be exploited before contracting states in bilateral agreements proceed to dispute settlement under such agreements.

Meanwhile, it seems to us that a more flexible approach, that is, an approach according to which other parties than states can challenge the level of charges, may be adopted. This more flexible approach is confirmed by the above mentioned case decided upon by the US Court of Appeals for the District of Columbia, in which the charges imposed by the state, that is, the US FAA, were put to trial by a number of foreign airlines rather than by the states whose flag these airlines were flying.

As stated above, this is not to say that the mentioned US case signifies a deviation from the basic rule in international air transport, that states are ultimately responsible for all matters on which they contracted internationally, including the matter of user charges, laid down in Article 15 of the Chicago Convention and in (standard) clauses in bilateral air agreements. Before taking recourse to heavy, because politically sensitive legal proceedings between states, all parties have an interest in finding solutions by other means. The US case between the FAA and foreign airlines, as well the Commission's intervention on behalf of EC Member state vis a vis Russia, confirm this point.

If the Chicago Convention prescribes that User Charges fall under international state responsibility, this convention, as well as the Annexes thereto, acknowledges that certain tasks, including the establishment of user charges, may be delegated to other international organisations. Under Chapter XVI of the Chicago Convention, such international organisations are termed "joint operating agencies", such as EUROCONTROL. However in the final analysis a state remains entitled to rely on multilateral and bilateral provisions regarding the establishment of user charges in its international aviation relations. Consequently, the state in whose territory the charge is applied remains responsible towards other states, including their airlines, with respect to the establishment and imposition of the charge.

D.3.3 ICAO regulations

A contracting state to ICAO may accept responsibility for the provision of air traffic services (hereafter: ATS) in portions of the high seas (or in aerospace of undetermined sovereignty). The provision of those services shall be based on the regional air navigation agreements, that is, agreements approved by the Council of ICAO on the advice of the Regional Air Navigation Meetings. An ICAO state having accepted such a responsibility to provide ATS in portions of the airspace over the high seas shall thereafter arrange for the services to be established and provide in accordance with Annex 11 of ICAO.[62]

See also, Article 12 of the Chicago Convention which reads:

> "Over the high seas, the rules in force shall be those established under this [Chicago] Convention."

If an ICAO state exercises such responsibility over portions of the high seas, it must apply uniform charges for the provision of the said services. Reference is made to Article 15 of the Chicago Convention.

D.3.4 The EUROCONTROL Regime

Furthermore, Article 1 of the EUROCONTROL Multilateral Agreement relating to route charges (hereafter also referred to as: 'The EUROCONTROL Multilateral Agreement'), specifies that EUROCONTROL states have agreed to adopt a common policy for charges in the airspace of the Flight Information Region (hereafter: FIR) falling under their competence. Those FIRs are part of an annex, which is attached to the EUROCONTROL Multilateral Agreement. If by an agreement with ICAO, a State has accepted the responsibility for providing air traffic services in a FIR over the high seas, this

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62 See, ICAO Annex 11, Standard 2.1.2.

could be a region falling within its competence under the EUROCONTROL Multilateral Agreement, provided EUROCONTROL is notified. Moreover, such acceptance is potentially subject to the unanimous agreement of the other states - see, article 1(4) of the EUROCONTROL Multilateral Agreement.

The EUROCONTROL Multilateral Agreement would however not constitute the legal basis for the imposition of charges over the high seas, as it is (merely) the legal basis for the creation of the joint system for the calculation, billing and recovery of the Member States route charges.

D.4 Polluter pays principle

The imposition of an environmental charge upon the user, that is, the operator of an aircraft, is based on the principle that the polluter must compensate the damages, which he incurs. This principle is laid down in treaty texts, including but not limited to the Rio Declaration:

> "National authorities should endeavour to promote the internalisation of environmental costs and the use of economic instruments, taking into account the approach that the polluter should, in principle, bear the cost of pollution."[63]

and Article 174 of the EC Treaty:

> "Action by the Community shall be based on the principles … that the polluter should pay."

It seems to us that the PPP may conflict with international air law provisions, exempting the operators of aircraft from payment of fuel used while operating such aircraft on international services, under the above conditions. Such a conflict must be examined under international law, including the rule that the special law (exempting fuel from taxation) may have precedence over the general law (PPP).

D.5 The implementaion of an environmental user charge into Community Law

D.5.1 Substantive scope

Community law on aviation user charges

Aviation user charges are not yet regulated under Community law. In 1997, the Commission has submitted a proposal for a Directive on airport charges to the Council[64], but this proposal has not yet been adopted. En route charges may be regulated as a part of the economic regulation under the Single European Sky project, launched by the Commission in 2000.[65] The draft proposals with respect to economic regulation under the Single Euro-

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63 See, Principle 16 of the Framework Convention on Climate Change (Rio de Janeiro, 1992), drawn up under the auspices of the UN Conference on Environment and Development, and the cited considerations of the ICAO Resolution, 1996.

64 OJ C 257/2 (1997).

65 Communication from the Commission to the Council and the European Parliament on the implementation of the Single European Sky, including proposals for economic regulation thereof, COM (2001)xxx, dated October 2001.

pean Sky project are based on the above regimes, taking into account the input, which EUROCONTROL has given in this area.
The imposition of airport charges at Community airports has been subject to judicial review under the general rules of the EC Treaty, especially those pertaining to prohibiting there abuse of a dominant position (see, below).

Relationship with taxation
The present subject pertaining to the environmental charge has been linked to *taxation*, more precisely, to excise duties, which are regulated under Community law. Council Directive 92/12/EEC[66] has as its objective to lay down "the arrangements for products subject to excise duties and other indirect taxes which are levied directly or indirectly on the consumption of such products, except for value added tax and taxes established by the Community." Pursuant to Article 3(2) of this Directive, a special regime has been created for the establishment of indirect taxes, including excise duties, on specified products, such as mineral oils. That special regime has been drawn up by Council Directive 92/81/EEC on the harmonisation of the structures of excise duties on mineral oils,[67] as well as Council Directive 92/82 on the approximation of the rates of excise duties on mineral oils.[68]
Under Article 8(1)(b) of Directive 92/81/EEC, Member States are required to exempt from the harmonised excise duty, inter alia, "mineral oils supplied for use as fuels for the purpose of air navigation other than private pleasure flying"

International law aspects of the introduction of an environmental user charge into Community law
We take the point of view that an environmental charge will be applied to *all* carriers – as opposed to Community air carriers only – because this is what the Commission suggested in its Proposal for a Regulation of the European Parliament and the Council *on the provision of Air Navigation Services in the Single European Sky* (EC COM(2001) 0123). It follows that, in so far Community law and policy would go beyond and infringe the Chicago/ICAO/bilateral provisions as laid down in the concerned legal instruments, would require re-negotiation and amendment of those legal instruments.

Pursuant to Art. 307 EC Treaty, EC Member states are obliged to bring their "Chicago/ICAO" obligations in line with Community law. However, this is not an easy task, neither from a policy, nor from an economic and legal point of view. The adherence to said "Chicago/ICAO" provisions on User Charges are confirmed in bilateral agreements concluded by EC Member States. We estimate that EC Member states have concluded about 1,100 bilateral air agreements with non-EC Member States.

D.5.2 The territorial scope

Article 299 of the EC Treaty states the territories, countries and departments to which the Treaty applies, and, in specified cases, to what extent. However, although this provision uses the term "territory" it does not define it – which definition must be deemed to be subject to national law of the Member States. The term "airspace" is not used in the EC Treaty, and hence not defined by it.

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[66] OJ L76/1 (1992).
[67] OJ L 316/12 (1992).
[68] OJ L 316/19 (1992).

EC Regulation 2408/92 *on market access* refers in several articles to "territory"[69] but this Regulation (2408/92) does not define the term.

To define the territorial scope of an EC regulation applicable to air transport, regard must be had to:

a Articles 1 and 2 of the Chicago Convention, defining the territory of a State so as to include the "land areas and territorial waters adjacent thereto under the sovereignty" of a contracting State to this convention (see also chapter two);

b the territorial scope of the EC Treaty, as defined by Article 299, with special reference to paragraph 1 of this provision;

c applicable regulations made by ICAO, especially those contained in Chapter 2.1.2 of Annex 2 *(Rules of the Air*) and Chapter 2.1.2 of Annex 11 (*Air Traffic Services*) on the basis of which EC Member States, and other states, including but not limited to Ireland, the United Kingdom and Norway, exercise jurisdiction under the auspices of ICAO outside their national airspace for the purpose of providing air traffic services, and for which they collect charges, pursuant to Regional Air Navigation Agreements;

d agreements made between EC Member States and EUROCONTROL in the context of the Central Route Charges Office (CRCO);

e arrangements made between the Community with Norway, Iceland and Liechtenstein under the EEA treaty, between the Community and Switzerland under applicable bilateral air transport agreements, and between the Community and Central European countries.

In short: a number of conditions must be met when an EC Member State wishes to impose en route charges, including and environmental component:

- The EC Member State must have an agreement with ICAO for the provisions of ATS on that portion of the high seas.
- The EC Member State must take into account ICAO Standards - especially those of Annex 11 -, other rules established by ICAO under the Chicago Convention (see, Article 12) -, and the provisions of the agreement between the Member state and ICAO on the exercise of responsibility with respect to the provision of ATS by that Member State in the agreed portion of the high seas, including but not limited to the 24th edition of 1988 of the ICAO Regional Air Navigation Plan, European Region Doc no. 7754, as amended on 16 December 1999.
- The EC Member State must take into account the provisions of the EUROCONTROL Multilateral Agreement on route charges (see, above).

Extension of the territorial scope of an EC regulation

The scope of the EC regulation may be extended to:

1 Countries participating in the EEA treaty, that is, Norway, Iceland and Liechtenstein.

2 Switzerland, on the basis of the bilateral agreements between this country and the EC.

3 Central European countries, on the basis of the proposed multilateral ECAA agreement.

If the above conditions imposed by a number of sources of international air law are respected, we feel that there is no obstacle for the introduction of such a charge outside the national territories and airspace, that is the high seas, of the EC Member States.

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[69] See, for instance, Articles 3(4) and 4(1) of Regulation 2408/92.

Relationship with the implementation of the Single European Sky
As to the implementation of en environmental aviation charge in the legal framework of the Community, reference is made to the Proposal made by the Commission in October 2001 for a Regulation of the European parliament and of the Council *on the provision of Air Navigation Services in the Single European Sky*. It seems to us that this regulation is the most related regulation promulgated by the Community on this area. Its legal basis can be found in Article 80(2) of the EC Treaty (see also, above).

Part III of this Proposal for a Regulation includes provisions for "Charging Regimes". Here are the main principles, which are laid down in said Part III:
- The charging regime shall be consistent with Article 15 of the Chicago Convention;
- The charging regime shall be cost-based;
- "The costs to be taken into account shall be those assessed in relation to facilities and services, provided for and implemented under the 24th edition of 1988 of the ICAO Regional Air Navigation Plan, European Region Doc no. 7754, as amended on 16 December 1999."
- "Costs that are external to the operation of facilities and services to airspace users, such as environmental costs, may be a component of user charges."
- "Charges have to be established in accordance with the principles of non-discrimination, cost-relatedness and transparency."

The legal basis for the imposition of an environmental charge
The Commission suggests the Polluter Pays principle (PPP) (see, above under D) as the legal basis for the introduction of an environmental component into the charges, which airlines must pay so as to encourage cleaner aircraft and achieve greater efficiency in the charging structure.[70] Moreover, the establishment of an environmental charge can be seen as a component of the constitution of an internal market for air transport services. In our opinion, a Community regulation designed to introduce an environmental aviation charge should be based on the functioning of the internal market, especially the common air transport policy, as defined in Article 71 read in conjunction with Article 80(2) EC Treaty. In our opinion, an environmental aviation charge must be imposed in the context of the above Single Sky programme and regulation.

D.5.3 The relationship between the Community and EUROCONTROL

The relationship between the EC and EUROCONTROL has not been addressed in this question. Therefore, we will make just a few brief remarks on this subject.
- The EC may want to use EUROCONTROL's (and CRCO's)[71] expertise in the field of the establishment of charges. One way to do so is that EUROCONTROL draws up the principles for the *en route* and, or including, the environmental charge which will be given legal force in the Community through the adoption of an EC measure – a Regulation or Directive – in which the EUROCONTROL -based charge is embodied or

70 See, for instance, COM(1998) 466 def. At 25, 26. See also, Communication from the Commission to the Council, the European Parliament, the Economic and Social Committee and the Committee of the Regions dated 30 November 1999 at 13, 14.

71 The Central Route Charges Office (CRCO) provides Member states of EUROCONTROL a calculation, billing and collection service for air navigation charges.

to which such a charge is attached. There are examples in which this procedure has been followed.

– Under EUROCONTROL's Revised Convention of 1997 – henceforth: the *Revised Convention* -, the EC is entitled to accede to EUROCONTROL as a single party. When a number of conditions are fulfilled – that is, the Revised Convention has come into force and the EC has acceded to EUROCONTROL – the Community will have a dominant voice in this organisation so that it will be in a position to pursue its policy objectives through and within EUROCONTROL. The Revised Convention provides for the adoption of binding rules through majority voting. States who have signed and ratified the Revised Convention agree, inter alia:
    - to implement a "common policy for the establishment and calculation of charges levied on users of en route air navigation facilities and services",[72]
    - to establish, bill and collect the route charges on behalf of them, and to participate in the common route charge system as provided for in Annex IV to the Revised Convention[73].

Once the Community has adopted a measure designed to introduce an environmental charge, in co-operation with EUROCONTROL and while taking into account the framework of ICAO for that purpose, such a charge can be imposed on flights passing through the airspace covered by EUROCONTROL/CRCO agreements and principles.

The question on the status of EUROCONTROL in relation to the EC is also subject to discussion. The outcome of such a discussion might have an impact on the present study. However, we feel that it is premature to take this development into account.

D.5.4 Permissibility of exemption of flights into remote areas of the 'EUROCONTROL area'

Permissibility of exemption of flights into remote areas of the "EUROCONTROL area"

This section refers to a situation in which users of airports in peripheral or development regions located in the territories of Member States or in the territory of an EUROCONTROL Member State, as well as users of air navigation facilities and services provided in those areas do not have to pay an environmental charge when using such airports or facilities. Thus, the concerned airport and en route charges do not include an environmental component. Such a measure would be in accordance with EC law and policy with respect to the exemption of peripheral or development regions in territories of Member states from the free market principle. Reference is made to the rights if Member states to impose "public service obligations" with respect to services to the mentioned areas pursuant to Article 4 of EEC Regulation 2408/92.

It seems to us that Article 15 of the Chicago Convention forbidding discrimination on the basis of the nationality of the aircraft does not necessarily apply here, as we proceed from the point of view that said exemption shall be applied to all operators of aircraft, irrespective of their nationality. In other words, all that Article 15 requires is that "uniform conditions" be applied to users, without distinction as to nationality, and categories of users, that is,

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[72] See, Art. 1(i).

[73] See, Art. 1(q).

operators of (civil) aircraft engaged in scheduled and non-scheduled services. We confirm that contracting States are internationally responsible for the establishment and imposition of User Charges.

Another provision of the Chicago Convention, namely, Article 28, imposes the obligation upon contracting States of the Chicago Convention, to provide airports and air navigation facilities for the facilitation of international air services, confirming international state responsibility in this respect. Airport and air navigation facilities and services must be provided in accordance with ICAO Standards. There are no ICAO Standards laid down in Annexes to the Chicago Convention regarding the imposition of environmental charges.

However, the following points could be taken into account when considering a measure as envisaged above.

Cost-relatedness
We have stated above that, in principle, charges must be cost related. We add the words “in principle” as we are ware of the fact that practice with respect to the implementation of this principle may vary from state to state. Since ICAO does not have enforcement powers, states can question the cost-relatedness of charges applied in the territory of a state with whom have engaged into bilateral air agreements, pursuant to the provisions of the bilateral air agreement. International policy, economic and commercial arguments will dictate whether such a challenge is or is not opportune.

This said, we proceed from the principle, that charges must be cost related, because:
- this is the global law derived from ICAO Recommendations and bilateral air agreements as it stands now;
- the EC draft Directive on Airport Charges[74] refers to this ICAO based principle;

so that it seems that the principle of cost-relatedness is valid in a global and in an EC context.

In addition to this, it has to be accepted, and it has been accepted under, for instance, the Rio Declaration (see, above), that the costs of environmental damages must be internalised so that they constitute an element of the cost-relatedness of the charge.

As to the application of conditions, principles and recommendations based on the Chicago convention, the International Air Services Transit Agreement of 1944, bilateral air agreements and the ICAO framework (see, above) we note that those measures only apply to the operation of *international* air services. States are free to draw up measures, which apply to the operation of domestic services only.

[74] OJ C 257/2 (1997).

As to the multilateral basis, regard can be had to:

Application of Article 69 of the Chicago Convention[75]
The state in whose territory the remote airport or the remote air navigation facilities are located and who wants to exempt said providers from charging environmental costs to users might want to consult with the ICAO Council with respect to the efficient and economical operation of the international air services which are operated by airlines using said remote facilities.

The ICAO Council might then recommend that the remote facilities in question should be exempted from imposition of environmental charges because that would be inefficient or uneconomical. However, we wonder whether Article 69 have been written to address the situation, which has to be examined under this question. This provision has hardly been used in practice – if at all – so that it is difficult to give an interpretation of its scope, let alone a broad interpretation

D.6 Special subject: incentive base

Calculated emission charge base
In order to design a charge base it is essential to determine the volume on which the charge is to be levied. A relevant question from a legal point of view is: what are the legal conditions for the method that may be used to calculate the emissions from aircraft? The following conclusions can be drawn:

1. A calculated emission levy, is liable to be challenged under the same international regulations as fuel, which is exempted from taxes, charges and levies. Many of the bilateral agreements between the EU Member States and third countries contain a clause to the effect that both fuel in transit and fuel supplied in the territory of the bilateral partner is also exempted from taxes or charges on fuel;
2. In order to minimize the possibility to be challenged in international court with respect to this latter point, we recommend the following:
   a. to make clear that the economic instruments considered are (revenue neutral) levies on greenhouse gas emissions aiming at the mitigation of the negative climatic impacts of aviation. The incentives are certainly *no* taxes on fuel and have no fiscal aim behind them;
   b. to use the Polluters Pays Principle 16 laid down in the Rio Declaration (UNFCCC) and in Article 174 of the EC Treaty as the legal basis for the imposition of a charge or PSI on greenhouse gas emissions of air transport in the EU. The UNFCCC, which was drawn up in Rio de Janeiro in 1992 under the auspices of the UN, has been ratified by almost all countries in the world (including the USA);
   c. to use the carbon content of aviation fuel and not the amount of fuel itself in order to calculate the amount of CO_2 emissions emitted by an aircraft in EU airspace. It can be argued that, carbon has no “direct and inseverable link” with aviation fuel because the amount of

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[75] Art. 69 of the Chicago Convention reads:
"If the Council is of the opinion that the airports or other air navigation facilities, including radio and meteorological services, of a contracting State are not reasonably adequate for the safe, regular, efficient, and economical operation of international air services, present or contemplated, the Council shall consult with the State directly concerned, and other States affected, with a view to finding means by which the situation may be remedied, and may make recommendations for that purpose. No contracting State shall be guilty of an infraction of this Convention if it fails to carry out these recommendations."

carbon in one litre fuel varies slightly for every litre of fuel, depending on the crude oil used and the refinery process;

d With regard to the emission charge: to include emissions of NOx in the incentive base because NOx emissions have no direct link with fuel. This is because NOx formation depends on engine characteristics such as pressure, combustion temperature and dwell time. These factors should be reflected in the calculation methodology for the levy base.

e With regard to the PSI: to communicate that there is no direct and inseverable link between fuel and the calculation methodology because a unit of air transport performance (e.g. actual payload-kilometre) is included besides emissions.

D.7 ANNEX: Community law aspects of the introduction of an environmental user charge into Community law

If EC Member States proceed to the adoption of a measure designed to exempt certain domestic services from the inclusion of an environmental component, EC law and policy applies, regard must be had to:

- the fiscal neutrality of the proposed measures, that is, the operation of domestic services may not enjoy a preferential treatment as a consequence of fiscal privileges;
- the prohibition of infringe of the free movement of services;
- the prohibition of the grant of state aid;
- the prohibition of distortion of competition;
- the existing and proposed EC policy pertaining to the imposition of environmental charges.

Obviously, the above EC based rules and policy measures may allow for exemptions, which may be established by law. For instance, the right of EC Member States to impose *Public Service Obligations* in accordance with Regulation 2408/92 is such an exemption.

If the suggested measure has an international dimension, for instance, in that the measure concerns, the operation of an international air service, the Community must consult, and, if necessary negotiate with, non-EC states on the exemption (applying to imposition of environmental charges in remote areas) either on a bilateral basis or on a multilateral basis, or both.

Airport (user) charges have been examined under general Community law, with special reference to rules applying to undertakings in the context of the EC competition regime.[76]

It seems to us that the most relevant findings in these decisions are related to the following:

- Airports are “undertakings” under the completion rules of the EC Treaty, by defining an undertaking as an “entity engaged in an economic activity, regardless of the legal status of the entity and the way in which it is financed”[77].

[76] See, for instance, *Commission* v. *Portuguese Republic*, Judgment of 26 June 2001, Case C-70/99; ECR 4845 (2001).

[77] See, in particular, case C-41/90 *Höfner and Elser* v. *Macroton*, ECR I-1979 1991), par. 21 and Case C-159 and 160/91 *Christian Poucet* v. *Assurabnces Générales de France and Caisse Mutuelle Régionale du Languedoc-Roussillon*, ECR I-637 (1993), par. 17.

– The "relevant market" is "the market in services linked to access to airport infrastructures for which a fee is payable"[78].
– An undertaking may hold a "dominant position" if that undertaking benefits from a legal monopoly in a substantial part of the common market[79].
– Application of the principle of *non-discrimination*, in cases where dissimilar conditions are applied to equivalent landing and take off services[80].
– Application of the principle on *proportionality* to the differentiation of airport charges imposed or permitted to be imposed by an EC Member state[81].

Otherwise, we limit our remarks with respect to taxation from a Community to a couple general remarks:

– Apart from the establishment of harmonisation measures in the field of the Value Added Tax, Member states have retained their competencies with respect to taxation, so that each Member State is free to set up its own tax system, and to determine the level of these taxes, up to the moment at which harmonisation is accomplished, subject to:
– The freedom of Member States to set up own tax systems is subject to the application of the fundamental principles of Community law, including but not limited to prohibitions with respect to:
    - discriminatory practices;
    - unlawful state aids;
    - infringing the free movement of persons, goods and services.

Finally, in a case unrelated to air transport but related to road transport, the ECJ ruled that users on Austrian toll ways must be treated in a non-discriminatory fashion, and that charges, that is, tolls, imposed for the use of the infrastructure, that is, high ways, must be related to the costs of infrastructure. The decision was based on an interpretation of Directive 93/89/EEC.[82]

[78] See, Commission Decision of 10 February 1999 relating to a Proceeding pursuant to Article 90 of the Treaty (Case No IV/35.703 – Portuguese airports, OJ L69/31-39 1999), as well as the "Port of Genoa" case, Case C-18/93, *Corsica ferries Italia/Corpo deil piloti del porti di Genova*, ECR I-1783 (1994).

[79] See, the first case cited in footnote 20, above, under paragraph 28.

[80] See, the first case mentioned in footnote 21 (Portuguese airports), par. 35, and case C-447/99 *EC Commission* v. *Italy*, ECR … (2001).

[81] See, the above decision of the ECJ of 21 March 2001 in the case of the *Portuguese Republic* v. *the Commission*, and, more specifically, the cases decided by the ECJ in Commission versus Portuguese Republic, decision of 26 June 2001 (case C-70/99) as well as Commission versus Italian Republic, decision of 4 July 2001 (case C-447/99)

[82] Judgement of the ECJ of 26 September 2000, in the case of the *EC Commission* v. *Austria*, Case C-205/98, ECR I-7367 (2000).

E APD model description

E.1 Introduction

In this annex we give a description of the Aircraft Performance and DOC Model (APD Model) used in this project to estimate block fuel, block time and block DOC (Direct Operating Costs) for a given aircraft/engine combination. Further it calculates block emissions for CO_2 and NO_X. The model has been developed and reviewed for the ESCAPE study ((Peeters, P. M., 2000)). Basically the model calculates from mathematical descriptions of the aircraft, engine, payload and flight path the total block fuel and block time and from these block DOC and block emissions. The algorithms used are based on aircraft performance theory and economics as commonly used in the industry (see (Padilla, C. E., 1996; Raymer, D. P., 1992; Roskam, J., dr., 1990; Torenbeek, E., 1982)).

Following aircraft/engine combinations have been used for this study in APD:
- Aircraft type 2: a short range medium size (SRSS) aircraft within the seat-capacity range of 80-179 seats and up to 4,000 km range[83] (representative aircraft is the Boeing 737-400/CFM56-3B-2 a/c-engine combination);
- Aircraft type 4: a medium range medium size (SRMS) aircraft within the seat-capacity range of 180-299 seats and 4,000-8,000 km range (representative aircraft is the Boeing 767-200/CF6-80A3 a/c-engine combination);
- Aircraft type 5: a long range medium size (LRMS) aircraft within the seat-capacity range of 180-299 seats and over 8,000 km range[84] (representative aircraft is the Boeing 767-300ER/PW4060 a/c-engine combination);
- Aircraft type 7: a long range large size (LRLS) aircraft within the seat-capacity range of 300-500 seats and over 8,000 km range (representative aircraft is the Boeing 747-400/CF6-80C2B1F a/c-engine combination).

The data for these aircraft have been gathered from many sources during earlier work of PA. Part of this is company confidential. The results have been compared to AERO model results, and to actual fuel consumption data that are used for validation of the NLR FLEM-model, which is the technical basis for the AERO model (see section E.7, validation).

E.2 General overview

The Aircraft Performance & DOC model has been programmed with Mathconnex, by connecting Mathcad 8 modules to each other. The Mathcad modules describe parts of the model like the calculation of DOC, the fuel and emissions for taxiing and take off and the fuel, emissions, weight and time for cruise.

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[83] In this report we call this ‘short range’ because the range capacity of the representative aircraft type is less than 4,000 km.

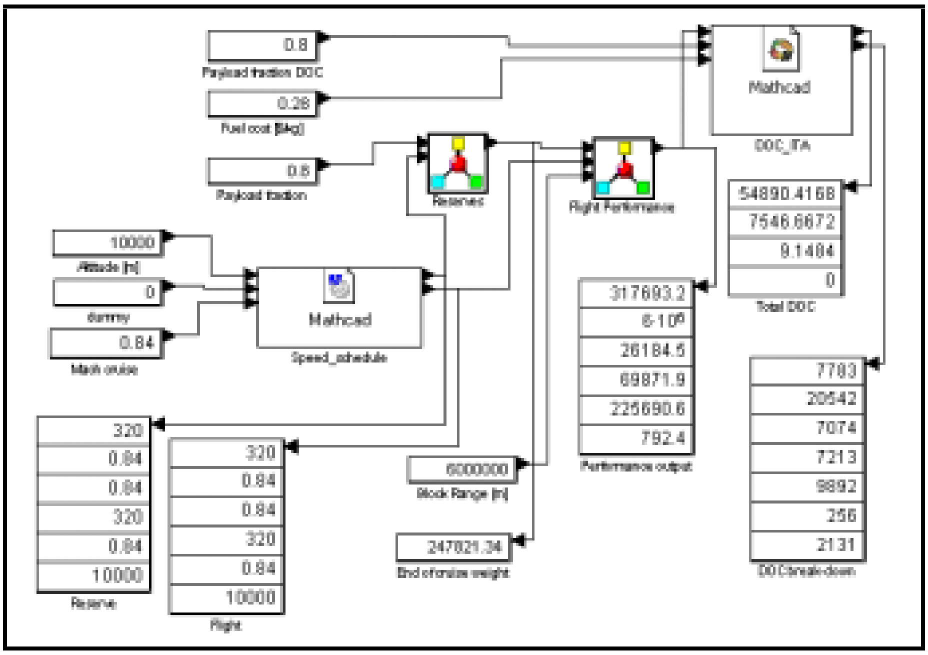
[84] The representative aircraft type only slightly passes the 8,000 km range limit set for this category.

APD first asks for a payload fraction of the maximum payload, a block range and the speed- and altitude-schedules for the flight and the reserves. Also the starting value for the price of fuel has to be given to the model. With all this information the following main steps are carried out:

- Find the amount of reserve fuel and the aircraft weight at the end of the cruise;
- Find the required amount of block fuel and block time for the flight over the given block range and with the given speed schedule;
- Calculate the DOC from the given block range and payload and calculated block time and block fuel for a given set of values for the so-called 'fuel plus carbon price'. The 'fuel plus carbon price' is the effective price of fuel and includes a possible charge on CO_2 emissions.

The general layout of the Mathconnex model for the short haul baseline 2010 aircraft is given in Figure 17. The input for the sheet is given in the tables at the left end of the diagram. The meaning of them is given by the label below each input table. The three figures give the collapsed models for Reserve fuel, Flight Performance and DOC. These will be described in more detail in section E.3 to E.6. The table 'inspector1' gives the results of the DOC calculations. The first row represents the fuel plus carbon price in $/kg, the second one the DOC in $/RTK (revenue ton kilometre).

Figure 17 General lay out of the Mathconnex program APD (example for the type 7 long haul large size aircraft)



E.3 Aircraft performance

General set-up

To find the block performance for the evaluation flight the whole flight path is determined, using normal flight mechanics and performance formulas. All stages in the flight path contribute to the block fuel and block time. Block range is found only for the flight path from above 3,000 ft: the standard ICAO LTO cycle does not count for block distance.

The flight path consists of the following stages (and programme modules):
- taxi and ground manoeuvring;
- take off;
- climb out to 3,000 ft;
- climb to cruise;
- cruise;
- descent to 3,000 ft;
- approach;
- landing.

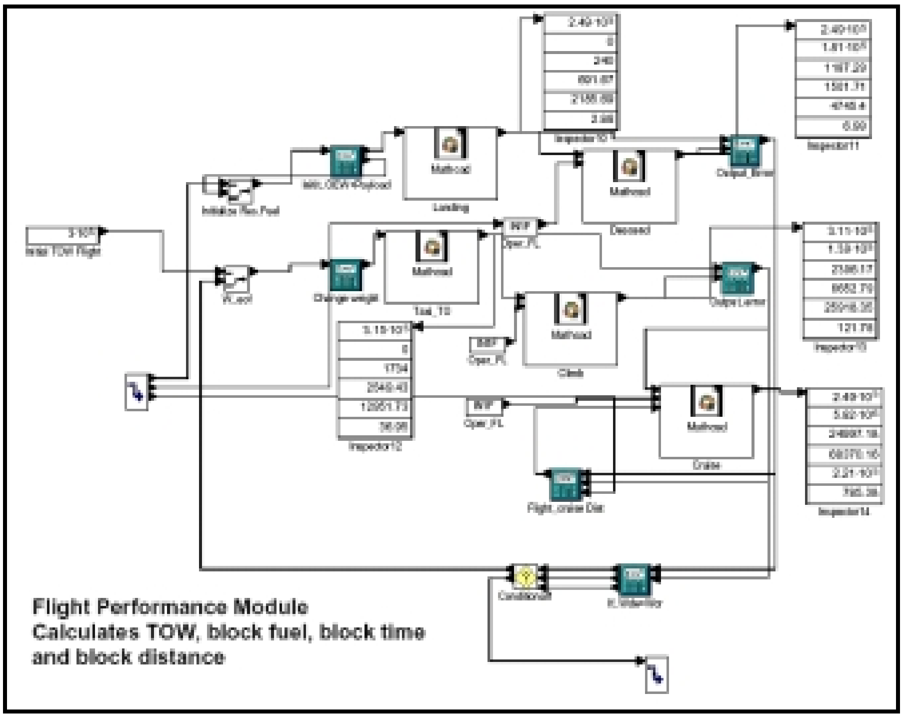
This kind of performance calculations is quite complex. First, one needs the take off weight to calculate the fuel weight, while the fuel weight is part of the take off weight. Second, one needs the cruise distance to calculate cruise time and fuel, but this is unknown as the climb and descent distances depend on the fuel weight for the whole flight, thus also on the fuel weight during cruise. These problems are solved by calculating landing and descent backwards and iterating using an initial value of the take off weight as is shown in Figure 18.

In Figure 18 in the high left corner the weight at touch down (that is the OEW plus the payload plus the reserve fuel) is given to an initialising routine and then to the Approach and Landing module. This directly calculates the weight and time and fuel used at the end of descent at 3,000 ft. Then the descent module backwards calculates fuel, emissions, distance, time and weight from 3,000 ft up to the cruise altitude.

At the same time the Taxi_TO module calculated the weight, fuel and time from engine start-up to 3,000 ft based on an initial TO weight (at the first loop) or as given by the result of the preceding loop, and passes these values to the climb module. This adds in a stepwise calculation the fuel, emissions, time and distance covered for the climb to cruising altitude and speed and passes the values to the cruise module. As now intermediate values for descent and climb distance are known the cruising distance is defined by subtracting them from the given block range.

With all this information the cruise fuel, emissions and time are determined resulting in an end-of-cruise-weight. Of course this weight must be the same as the start of descent weight. This is checked in the 'If_Wde=Wcr' routine. If the two weights differ more than 0.1% a new take off weight is found by adding the end-of-cruise *fuel* weight to the start-of-descent-aircraft-weight and the whole calculation is repeated. Normally three or four iterations suffice to fulfil the requirement. The final take off weight and block fuel and time are returned to the main program.

Figure 18 Mathconnex overview for the flight performance iterations



In the following subparagraphs we will give some detailed information on the modules used.

Ground manoeuvres, take off and climb to 3,000 ft

A standard time for ground manoeuvres is set at 26 minutes with 7% of MTO thrust rating (the ICAO LTO definition of idle). The fuel flow for this has been assumed to be also 7% of the MTO fuel flow.

For the takeoff run and climb-out to 35 ft an allowance of 0.7 minute at take-off power setting is taken as a standard. The corresponding fuel flow depends on the engine properties and has been selected for a mean speed of mach 0.2.

Between 35 ft and 3,000 ft ICAO prescribes 2.2 minutes climb out at 85% MTO rating. The climb speed for this thrust setting at the mean altitude of 1500 ft is calculated to check if 2.2 minutes is not too short. The aircraft speed for this calculation is chosen 20% above the stall speed.

The time and fuel used are added to the block time and block fuel. No credit is given to the block distance up to 3,000 ft.

Climb

Climb is executed with maximum climb power as is specified for the specific engine in the engine input file. The speed schedule for climb from 3,000 ft to the specified cruising altitude depends on the following assumptions:

- maximum of 250 knots true air speed (TAS) below 10,000 ft;
- constant CAS climb at the specified speed until the specified climb mach number has been reached;
- constant mach climb until the cruising altitude has been reached.

The aircraft weight starts at the weight given by the taxi, take off and climb to 3,000 ft module. Then the climb is divided into 25 altitude sectors. For every sector the rate of climb (*ROC*) is found from the known starting weight, aircraft speed, available thrust at the mean sector altitude.

$$ROC = V \cdot \frac{T_{cl} - \frac{1}{2} \cdot C_D \cdot \rho \cdot V^2 \cdot S}{m_a \cdot g \cdot (1 + f_{acc})}$$

In this equation V is the true air speed, T_{cl} the climb thrust for the speed and mean sector altitude, C_D the drag coefficient, Δ the air density at the mean sector altitude, m_a the aircraft mass, S the reference wing area and f_{acc} a factor for the acceleration needed for climb at constant CAS or constant mach (see Padilla, 1994).
From the rate of climb it is simple to find the sector time. From the sector time and the fuel flow at the mean sector altitude and speed, the total fuel weight used for the sector can be found. Subtracting this value from the starting aircraft weight gives the starting aircraft weight for the next sector. With the aircraft speed and sector time known also sector the distance can be found.
At the end all sector fuel usage, sector times and sector distances are added to the block fuel, block time and block distance and given to the next module of APD.
The rule for maximum depressurisation rate of the cabin to be lower as the equivalent of 300 ft/minute is calculated, but has no influence on the thrust setting. Normally this value is not exceeded much and therefore it has been neglected in calculations.

Cruise
The required cruise distance depends on the climb and descent distances calculated and the given block range. The module divides the cruise into 25 to 50 sectors (depending on the total block distance required), all with constant length, for which successively the sector time and fuel consumption are calculated using standard equations for lift and drag coefficients and defining the fuel flow by interpolating into the engine table for the appropriate cruising altitude, mach number and required thrust. The cruise speed and cruise altitude have to be specified in advance. The speed is not automatically optimised for lowest fuel consumption or lowest DOC. By manual iteration an optimum altitude and cruise speed may be found (i.e. lowest fuel consumption or lowest DOC).
The thrust setting is limited by the maximum cruise thrust specified. If thrust required is higher than the thrust available this can be seen from the output files. In that case the aircraft speed, cruising altitude or payload has to be reduced. Fuel flow is three-dimensionally interpolated (using a least-square cube method) directly from engine fuel flow tables as a function of altitude, thrust and speed.
The required thrust per sector is found by first calculating the lift coefficient from aircraft weight at start of the sector and aircraft speed and altitude. The lift coefficient and the cruising mach number give the drag coefficient and with this the total drag is determined. In stationary straight flight the thrust must equal the drag, which gives the thrust required.
When this is known, the fuel flow can be interpolated from the engine table. The airspeed gives the sector flying time and then the fuel used can be found as well as the weight and the aircraft weight for the next sector is defined.
After all sectors have been run through, summing the fuel per sector, the sector time and the sector distance give the block fuel, block time and block distance for cruise.

Descent and landing

The descent is limited by the maximum cabin rate of descent of 300 ft/min. Therefore first the minimum descent time between cruising altitude and 3,000 ft is calculated from the maximum cabin pressure difference following from the cruising altitude and the maximum cabin altitude (as a measure of cabin pressure). From this minimum descent time the maximum aircraft rate of descent (ROD_m) is found.

The descent is divided into 25 sectors of equal altitude difference. The whole calculation is done backwards (from 3,000 ft up to the cruising altitude). For the first sector the aircraft weight is taken from the approach and landing module. For this weight and the mean sector altitude the speed is determined from the speed schedule (constant CAS until the descent mach number is reached at some altitude; below 10,000 ft the maximum aircraft speed is limited to 250 kTAS). Then the thrust required for the maximum aircraft ROD_m is calculated from following equation:

$$T_{req} = \frac{1}{2} \cdot \frac{\left(-2 \cdot ROD_m \cdot m_a \cdot g + C_D \cdot \rho \cdot V^3 \cdot S\right)}{V}$$

In this equation V is the true air speed, ROD_m the maximum rate of descent, C_D the drag coefficient, Δ the air density at the mean sector altitude, m_a the aircraft mass and S the reference wing area. If the required thrust is less then zero[85] the thrust is set to zero and the *ROD* belonging to this zero thrust is calculated. The final *ROD* is of course the minimum of ROD_m and *ROD*.

As is the case for climb, below 10,000 ft the maximum descent speed is limited to 250 kIAS. At the end all sector fuel usage, sector times and sector distances are added to the block fuel, block time and block distance and given to the next module of APD.

Approach and landing

Approach and landing time has been fixed by the ICAO LTO value of 4 minutes. The engine will be used at 30% MTO rating. The approach speed has been specified in the airframe input file (based on Jane's, 1998/1999). The fuel flow is found by interpolating into the engine tables given in the engine input file for the approach speed and the intermediate altitude (1500 ft). The amount of fuel used follows from the approach and landing time multiplied with the fuel flow.

The weight of fuel and the approach time are added to the block fuel and block time. No credit is given to the distance covered as is recommended by ICAO.

E.4 Emissions

Introduction

Modules for the calculation of the emissions for CO_2 and NO_x have been added to APD to make it fit for use for this study. The emissions of carbon dioxide are directly related on the amount of block fuel burnt. Therefore these are found at the end of the calculation. The nitrogen oxide emissions depend on the outside temperature and the fuel flow and therefore have top be evaluated for every sector of the flight individually.

[85] Actually the minimum thrust should be the idle thrust at the specific altitude and speed, which could actually become negative as well as being positive. As idle figures are difficult to find for engines, we have simplified flight idle to be the same as zero thrust.

CO_2

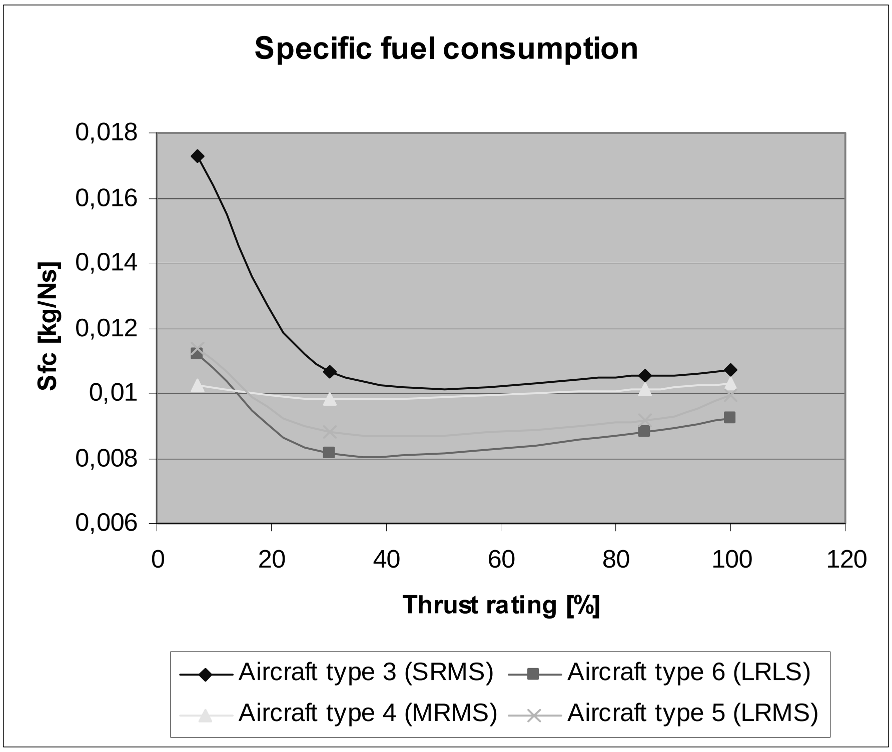
The calculation of carbon dioxide emissions is straightforward, as it is directly proportional to the amount of fuel burnt, minus a small (negligible) amount of about 2% going to the formation of carbon monoxide and C_xH_y. Most of the CO eventually ends as CO_2. Following form has been used for the total emission per flight of CO_2:

$$E_{CO_2} = 3.16 \cdot W_f \quad [kg]$$

In this form E_{CO_2} is the total emission of a flight and W_f is the block fuel used during this flight.

In Figure 19 we give the specific fuel consumption for the four example engines for ISA/SL, based on the ICAO database. It is clear from this figure the two biggest engines have the best s.f.c., which is to be expected.

Figure 19 LTO specific fuel consumption for the four example aircraft



NO_x

The calculation of the emission of nitrogen oxide has been based on the fuel flow method as given by Döpelheuer ([Döpelheuer, 1998 #218]). He gives the following form for the emissions factor of NO_x:

$$EINO_{x_{flight}} = EINO_{x_{ref}} \cdot \delta_t^{\,a} \cdot \theta_t^{\,b} \quad [gramme / kg]$$

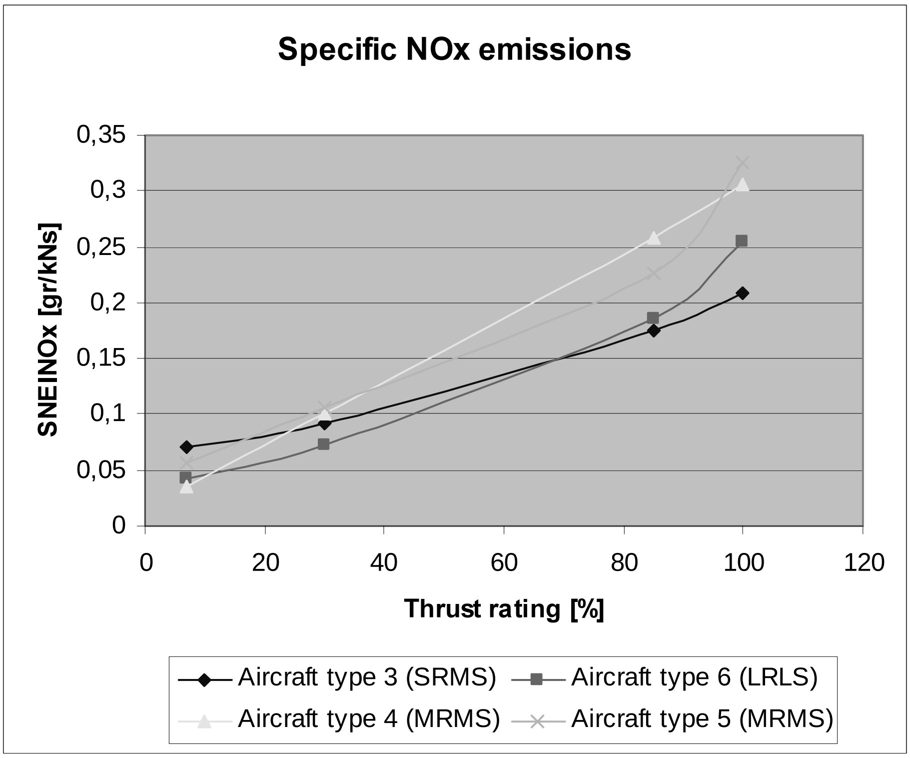
In this form $EINO_{x_{flight}}$ has to be based on corrected fuel flow. Using Figure 2 of the Döpelheuer paper ([Döpelheuer, 1998 #218]) we have fitted the factors for the real fuel flow and $EINO_{x_{flight}}$ giving the following form:

$$EINO_{x_{flight}} = EINO_{x_{ref}} \cdot \delta_t^{-0.65} \cdot \theta_t^{\ 3}\ [gramme/kg]$$

The $EINO_{x_{ref}}$ is the value for SL/ISA given by the ICAO engine data bank [ICAO, 2001 #264], modified to represent the emission index as function of the fuel flow. δ_t is the total pressure ratio and θ_t the total temperature ratio.

The ICAO data bank gives values of fuel flow and emission index for the four LTO cycle points: taxi (7% max take off thrust) approach (30%), climb out (85%) and take off (100%). Figure 20 gives the specific NO_x emissions for these engines. It appears the engines for the 767-200 and 767-300ER have higher specific emissions than the two other engines.

Figure 20 Specific LTO NO_x emissions for the four example aircraft engines



For the four example aircraft these data are given in Table 34.

Table 34 Fuel flow and emission data for the four engines (source: [ICAO, 2001 #264])

Aircraft	Aircraft type 2		Aircraft type 4		Aircraft type 5		Aircraft type 7	
Engine	CFM56-3B-2		CF6-80A		PW4060		CF6-80C2B 1F	
	Fuel flow [kg/sec]	EINOX [g/kg]	Fuel flow [kg/sec]	EINOX [g/kg]	Fuel flow [kg/sec]	EINOX [g/kg]	Fuel flow [kg/sec]	EINOX [g/kg]
Taxi	0.119	4.1	0.15	3.4	0.213	4.9	0.199	3.78
AP	0.314	8.7	0.615	10.3	0.703	12	0.621	9
CO	0.878	16.7	1.795	25.6	2.085	24.7	1.901	21.07
TO	1.056	19.4	2.145	29.8	2.647	32.8	2.341	27.73
Rated Output [kN]		98.3	208.8		266.9		254.3	

A quadratic curve has been fitted for all four engines:

$$EINO_{x_{ref}} = A_0 \cdot FF^2 + A_1 \cdot FF + A_2$$

In this form *FF* is the uncorrected fuel flow in [kg/s]; the constants A_0, A_1 and A_2 are given in Table 35.

Table 35 Polynomial constants for the four engines and the statistical fit

	A_0	A_1	A_2	R^2
Aircraft type 2/CFM56-3B-2	-6.0386	22.881	1.702	0.9967
Aircraft type 4/CF6-80A	-0.9417	15.353	1.1523	1.0000
Aircraft type 5/PW4060	0.2237	10.272	3.4314	0.9921
Aircraft type 7/CF6-80C2B 1F	0.8802	8.4886	2.5579	0.9949

E.5 Reserves

The authorities (and common sense) require the aircraft operator to fill the aircraft not only with the predicted amount of fuel, but also with some amount of reserves. Torenbeek (1982) gives several policies for reserves. We have chosen for two different policies for short haul and long haul.
The short haul procedure is based on the Air Transport Association recommendation ATA ’67 and consists of:
– hold for 30 minutes[86] at normal cruise altitude and 99% of the maximum range cruise speed[87];
– exercise a missed approach and climb out at the destination;
– fly to and land at alternate airport at 200 NM distance.

For the long haul flight (a/c/ type 7) the ATA ’67 policy without a specified alternate has been followed which is:
– continue the basic cruise flight for two hours.

The short haul reserves require the calculation of a whole flight for the block range of 200 NM at the end-of-flight aircraft weight and at a lower cruising altitude if requested by the user of the model. This reserve strategy has been used for the a/c types 2, 4 and 5. The reserves are calculated in advance of the flight, to find the basic end-of-flight weight (OEW plus payload plus reserve fuel). The basic reserves weight is OEW plus payload.

E.6 DOC

The DOC module calculates the Direct Operating Costs for a given block time, block fuel and fuel plus carbon price per kilogram. The block time and block fuel are calculated by the aircraft performance part of the APD model as has been described in the previous paragraphs. The module has been based on the method given by Roskam (1989, Part VIII). Input on the payload and the block range allows for finding the DOC per revenue ton-kilometre (RTK) or passenger-kilometre.

86 Actually ATA ’67 recommends one hour, but this seemed overdone for a 600 N.M. flight as is the evaluation flight.

87 APD uses the given cruise mach number.

Further input is given in the DOC input sheet (Excel) containing the following data:

- fraction of oil in total fuel plus carbon price;
- landing fee in \$/kg MTOW;
- labour cost for pilot, co-pilot, cabin attendant and maintenance personnel per block hour;
- airframe market price including avionics and spares;
- engine market price including spares;
- fractions of total DOC for finance and insurance;
- depreciation period and fraction for airframe and engine;
- number of flight crew and cabin attendants;
- annual utilisation in block hours;
- time between overhaul for the engines;
- airframe empty weight (excluding engines).

The total DOC is the sum of the direct flying cost (crew and fuel) and the cost for maintenance, depreciation, landing fees, insurance and finance. The values for above mentioned input file are described if they are design specific in the chapters on the designs. The general values from the literature have been adjusted to fine-tune the results (see section E.7, validation). In the following subparagraphs we describe the way in which the cost items are calculated.

Direct flying cost
The cost for crew is simply the sum of the number of a specified crew type multiplied with the labour cost per block hour for it and the block time. This labour cost consists of the salary, taxes, education, training and bonuses for a mean crew member divided by the normal number of block hours produced by the crew member. Fuel cost is found by multiplying the amount of block fuel with the given price for fuel per kg and the factor for oil cost.

Maintenance
The maintenance costs has been calculated with the method given by Roskam (1989, part VIII), which distinguish between labour cost and material cost for both airframe and engine. The maintenance man-hour per block hour for the airframe is given by (Eq. 6-1) and for the engine by (Eq. 6-2).

(Eq. 6-1)

$$MHR_{af.bl} = 3.0 + 0.1467 \cdot \frac{w_{af}}{1000}$$

(Eq. 6-2)

$$MHR_{eng.bl} = \left(0.718 + \frac{0.0698}{g} \cdot \frac{T_{TO}}{1000}\right) \cdot \left(\frac{1100}{t_{BEO}} + 0.1\right)$$

In these functions w_{af} is the airframe weight in kg T_{TO} the maximum take off thrust per engine in N and t_{BEO} the time between overhaul in flight hours for the engines.
Maintenance material cost is calculated in \$/block hour for airframe (Eq. 6-3) and engine (Eq. 6-4).

(Eq. 6-3)

$$C_{mat.af.bl} = 30 + 0.79 \cdot 10^{-5} \cdot Pr_{af} \qquad \left[\frac{\$}{hr}\right]$$

(Eq. 6-4)

$$C_{mat.eng.bl} = \left(5.43 \cdot 10^{-5} \cdot Pr_{eng} \cdot ESPPF - 0.47\right) \cdot \frac{1}{0.021 \cdot \frac{t_{BEO}}{100} + 0.769}$$

$$\left[\frac{\$}{hr}\right]$$

The variables Pr_{af} and Pr_{eng} give the airframe respectively the engine market prise in \$. *ESPPF* is an engine spare part price policy factor, (usually *ESPPF* = 1.5 according to Roskam (1989, Part VIII).
The total DOC for maintenance now comes to:

(Eq. 6-5)

$$DOC_{maint} = 0.53 \cdot T_{block} \cdot \left[Pc_{maint} \cdot \left(MHR_{af.bl} + 1.3 \cdot n_{eng} \cdot MHR_{eng.bl}\right) + \left(C_{mat.af.bl} + 1.3 \cdot n_{eng} \cdot C_{mat.eng.bl}\right)\right]$$

The factor 0.53 replaces the factor 1.03 originally given by Roskam. This much lower factor has been implemented because the maintenance cost for the current fleet is largely overestimated by the original equation. The reason for this is, among others, the strong development during the last three decades in maintenance practice in the industry. Further T_{block} gives the block time, n_{eng} the number of engines. The other variables are given in (Eq. 6-1) through (Eq. 6-4).

Depreciation
The DOC for depreciation is broken down into airframe and engine depreciation, because of variations in the depreciation period and residual value (given by a depreciation factor). The equation has been derived from Roskam (1989, Part VIII):

(Eq. 6-6)

$$DOC_{dep} = T_{block} \cdot \left(DF_{af} \cdot \frac{Pr_{af}}{DP_{af} \cdot U_{ann.bl}} + DF_{eng} \cdot \frac{Pr_{eng}}{DP_{eng} \cdot U_{ann.bl}}\right)$$

In (Eq. 6-6) T_{block} gives the block time, *DF* the depreciation factor (the fraction of the original market price that is written off), *DP* the depreciation time in years, *Pr* the market price and $U_{ann.bl}$ the annual utilisation of the aircraft in block hours.

Landing fee, charges and ground handling cost
Roskam (1989, Part VIII) identifies not only the DOC of landing fees, but also for navigation and other taxes. Jesse (2000) states the However, the AVMARK data probably includes ground handling cost, as is usual in European DOC breakdowns. As we fitted the charges to the AVMARK data we have to include following items into this part of the DOC:

- landing fee;
- navigation charges;
- ground handling and services.

For the short haul market the European rules have been followed and fitted to the AVMARK data (see section E.7.4). The short haul equation is:

(Eq. 6-7)
$$DOC_{ch\_SH} = C_{fit_{SH}} \cdot \left(Pc_{lf} \cdot MTOW + P_{gh} + P_{nav\_EU}\right)$$

with

$Pc_{lf\_EU} = \frac{\$0.009}{kg}$ (European landing fee)

$P_{gh} = \$182 + \$6.6 * n_{seat}$ (ground handling)

$P_{nav\_EU} = \$1.6 \cdot \frac{R_{block}}{NM} \cdot \sqrt{\frac{MTOW}{50000 \cdot kg}}$ (European navigation)

For long haul we have assumed a mix of European and International (US) tariffs for landing fee and half the navigational cost:

(Eq. 6-8)
$$DOC_{ch\_LH} = C_{fit_{LH}} \cdot \left(Pc_{lf\_EU} \cdot \frac{MTOW}{2} + Pc_{lf\_Int} \cdot \frac{MLW}{2} + P_{gh} + P_{nav\_Int}\right)$$

with

$Pc_{lf\_Int} = \frac{\$0.00267}{kg}$ (International landing fee)

$P_{gh} = \$182 + \$6.6 * n_{seat}$ (ground handling)

$P_{nav\_Int} = \$0.8 \cdot \frac{R_{block}}{NM} \cdot \sqrt{\frac{MTOW}{50000 \cdot kg}}$ (International navigation)

Insurance and finance
The cost for finance and insurance is given as a fraction of the sum of fuel, crew, maintenance and depreciation cost. See section E.7 for the values used in these factors.

Final DOC
Final DOC is the sum of the in the previous subparagraphs mentioned costs. The DOC is calculated as the whole cost for the evaluation flight, the cost per block hour, per block kilometre, per RTK and per passenger kilometre.

Adjusting to ITA data
As the ITA DOC data differed quite large with those generated with APD based on AVMARK data we have tuned the data of APD to those of ITA in the following way:
The DOC calculations have been adjusted to the method of ITA on the following subjects:
- number of flight attendants (slightly lower number);
- cockpit crew cost (much lower levels);
- cabin attendant cost (less than half the cost);
- maintenance: tBEO=, age of aircraft (heavily factored down);
- depreciation time aircraft (full life of 30 years, no residual value);
- depreciation time engines (full life of 30 years, no residual value);
- charges (for landing, navigation and ground handling) adjusted.

In section E.7 the detailed adjustions per a/c type and the resulting validation of the APD model has been given.

E.7 Validation

The APD model aircraft performance results have been validated with the help of performance data published by the National Aerospace Laboratory NLR for their FLEM model (Flights and Emissions Model) (Ten Have and Witte, 1997), which is a module in the AERO model. To validate the a/c types 4 and 5 unpublished data from NLR on FLEM calculations have been used. These were also used to validate the NO_x emissions.

E.7.1 Validation of block time and fuel for type 2 and 7 aircraft

The total block time and block fuel for flights of 250, 500, 1,000, 2,000 and 3,000 km (short haul) and 1,500 km, 2,000 km, 3,000 km, 6,000 km and 11,434 km (long haul) are available from the NLR FLEM reference. Because FLEM gives credit for distance covered to the LTO phase of the flight (of 30 km) and APD does not do so, the evaluation performance results of APD have been calculated for the given block distance less this 30 km. In Table 36 we compare these results from FLEM with the results from APD.

Table 36 Validation of the APD results with results by the FLEM model from NLR

Block Distance	Block time		Block fuel	
[km]	Index FLEM=100		Index FLEM=100	
	TYPE 2	TYPE 7	TYPE 2	TYPE 7
250	99	-	102	-
500	99	-	103	-
1,000	100	-	102	-
1,500	-	100	-	102
2,000	100	100	99	100
3,000	100	100	99	98
6,000	-	99	-	97
11,434	-	99	-	95

The block time is predicted within 1% deviation for both short haul and long haul market transports. APD over-predicts the block fuel with 2-3% for the short haul aircraft at short range and underestimates it at the medium ranges. The long haul aircraft shows deviations of up to 5% lower fuel consumption than predicted by FLEM. However the validation of the FLEM data on actual KLM flight data as shown by Ten Have and Witte (1997) shows FLEM to be about 3% too high on fuel consumption prediction for a 6,000 km block range. At this point, which is near the long range evaluation flight over 7,000 km, it seems the APD results approximate actual flight data somewhat better than FLEM does.

E.7.2 Validation of fuel consumption for a/c type 2, 4, 5 and 7

The following has been based on unpublished data from NLR from 1997.

The Aircraft type 2 (SRMS)
Cruise alt 10,970 m for London, 10,670 m for Barcelona and 10,060 m for Athens. Cruise speed 0.745. Load factor such as to reach the same TOW as for FLEM. Distance for APD less 30 km for LTO (as FLEM uses the full distance flown).

Resulting fit for block fuel [kg]:

Route	APD/FLEM	APD/KLM
Amsterdam-London	1.0460	1.0116
Amsterdam-Barcelona	1.0128	1.0018
Amsterdam-Athens	1.0144	1.0481

Aircraft type 5 (LRMS)
Cruise alt 11280 m for London, 10970 m for Barcelona and 10670 m for Athens. Cruise speed 0.8. Load factor such as to reach the same TOW as for FLEM. Distance for APD less 30 km for LTO (as FLEM uses the full distance flown).

Resulting fit for block fuel [kg]:

Route	APD/FLEM	APD/MA
Amsterdam-London	0.9760	1.1718
Amsterdam-Barcelona	0.9799	1.0605
Amsterdam-Athens	1.0078	1.0160

Aircraft type 7 (LRLS)
Cruise alt 11890 m for Barcelona and Rome and 11580 m for Athens. Cruise speed 0.84. Load factor such as to reach the same TOW as for FLEM. Distance for APD less 30 km for LTO (as FLEM uses the full distance flown).

Resulting fit for block fuel [kg]:

Route	APD/FLEM	APD/KLM
Amsterdam-Barcelona	1.0591	1.0229
Amsterdam-Rome	1.0569	1.0519
Amsterdam-Athens	1.0416	1.0384

Differences between FLEM and APD for the A/C type category 3 (SRMS) and Aircraft type 5 (LRMS) are relatively small (less than 5% and a mean of about 2%). The Aircraft type 7 (LRLS) gives 4-6% higher fuel than FLEM does. If we take [ten Have, 1997 #199] as base for comparing FLEM and APD compare much better (see [Peeters, 2001 #241]).

E.7.3 Validation of NO_X emission calculations

Table 37 gives the resulting comparison for NO_X emissions as calculated by FLEM and APD. The data have been gathered using 66.7% load factor with following long-range speed schedule and cruising altitude:

- Aircraft type 2: 66.7% l.f., mach 0.745, 10,000 m;
- Aircraft type 5: 70.0% l.f., mach 0.80, 11,000 m;
- Aircraft type 7: 66,7% l.f., mach 0.84, 11,000 m.

Table 37 Comparison of NO_X emission results of FLEM and APD

Distance [km]		NO_x [g/kg CO_2]		
		Aircraft type 2	Aircraft type 5	Aircraft type 7
500/500/500	APD/FLEM	1.133	-	-
1000/1200/1500	APD/FLEM	1.189	1.264	1.029
2000/2000/2000	APD/FLEM	1.203	1.285	1.048
3000/3000/3000	APD/FLEM	1.214	1.303	1.077

From Table 37 it appears that APD estimates NO_x emissions higher than FLEM does. The values for the Aircraft type 7 give the best fit with the FLEM data. The data of FLEM have been derived using a different, more sophisticated method, for example incorporating the effects of air humidity.

E.7.4 DOC representing AVMARK data

The DOC model has firstly been validated against general data from AVMARK (AVMARK, 1999). The mean value of the DOC model has been weighted for the traffic volume for short and long haul. Assuming Internal European flights from all European airports to be short haul and intercontinental flights to be long haul. The long haul should be valued two times the short haul (Peeters et al., 1999).
Because the results for several of the parts of DOC did have a deviation from the figures given by AVMARK it was decided to incorporate the following modifications from the original figures given by Torenbeek (1982), Roskam (1989, part VIII) and Jesse (2000):

- Insurance cost 1% (was 2%);
- Fitting factor European (short haul) charges: $C_{fit\_EU} = 0.8115$;
- Fitting factor International (long haul) charges: $C_{fit\_Int} = 0.9625$;
- Finance cost 5% (was 7%);
- Depreciation period airframe 15 years (was 10 years);
- Flight crew 32% higher costs;
- Cabin crew 106% higher costs;
- Maintenance factored with 0.52.

The basic data are given for the late seventies/early eighties, which explains the sometimes large deviations. The crew costs are based on data given by Roskam (1990, Part VIII) for crew salaries. The main assumption is: the salaries are linearly proportional to the total cost per block hour for the airline.
After all this fine tuning of the model and parameters the final validation shows a good resemblance between AVMARK and the weighted mean (Table 38).

Table 38 Validation of the DOC model

Cost item	AVMARK (mean European market)	AIRCRAFT TYPE 2 at 1,000 km	AIRCRAFT TYPE 7 at 7,000 km	Weighted Mean for the two example planes
Flight deck crew:	4.5	6.1	3.7	4.5
Cabin crew	4.0	6.0	3.0	4.0
Fuel&oil	5.7 (22%/17%)	6.8	5.1	5.7 (22%/17%)
Maintenance&Overhaul	5.6	7.5	4.6	5.6
Charges	6.3	13.0	2.9	6.3
Insurance	0.3	0.4	0.2	0.3
Finance	0	0 (1.9)	0 (1.0)	0 (1.3)
Depreciation (plus rentals)	(6.4)	0 (9.8)	0 (5.4)	0 (6.9)
TOTAL	26.4 (32.8)	39.8 (51.5)	19.6 (26.0)	26.3 (34.5)

E.7.5 DOC validation to ITA data

Aircraft type 2 (SRMS)
The DOC calculations have been adapted to the ITA figures ([Thwaites, 2001 #265] in the following way:

- labour cost of captain reduced from $331/flighthour to $210/fthr (to match total crew cost);
- labour cost of copilot reduced from $216/fthr to $137/fthr (to keep the original APD ratio between captain and pilot);
- labour cost of cabin attendant reduced from $108/fthr to $50/fthr (the ITA value);
- airframe and engine market prices (plus spares etc) reduced with the factor 0.9 (given by ITA due to the 'intermediate' age of the fleet of this aircraft) to $34.02 million and $2.79 million per engine;
- the depreciation period of the airframe has been adjusted to the ITA strategy from 15 years to the full airframe life of 30 years;
- the depreciation period of the engines have been adjusted to the ITA strategy from 7 years to the full engine life of 30 years (best fit for ITA figures, but seems a bit unlikely high);
- depreciation factors of airframe and engine set to 1.0 (was 0.85) because with full life there will be no residual value;
- the number of cabin attendants has been adjusted to the ITA equation (being the lower integer of (nr seats+12)/32): 4 in stead of 5;
- the time between engine overhaul has been increased to 12000 hours (was 3700 hr), because of information on the web-site of CFM International about 16000 hrs for the first removal and 10000 hours after the first overhaul, conservatively rounded to 12000 ([CFM International, 2001 #266]);
- the Engine Spare part Price Policy Factor has been adjusted from 1.5 to 1.2. To fit the results to the ITA values the engine and airframe maintenance costs have been fitted with a factor 0.63;
- the total of landing fee, ground handling costs and navigation charges has been fitted to ITA with a factor 1.06.

De resulting differences are given in Table 39.

Table 39 Comparison between ITA and APD data for Aircraft type 2 (SRMS) (factors APD/ITA)

Block Dist. [km]	500	2000
Fuel cost	1.54	1.14
Crew	1.07	1.00
Maintenance	1.05	1.00
Aircraft	0.78	0.99
Charges	0.99	0.99
Total DOC	1.03	1.03
Fuel fraction [%]	1.49	1.11

Aircraft type 4 (MRMS)

The DOC calculations have been adapted to the ITA figures ([Thwaites, 2001 #265] in the following way:

- labour cost of captain reduced from $ 584/flighthour to $ 222/fthr (to approximately match total crew cost);
- labour cost of copilot reduced from $ 312/fthr to $ 119/fthr (to keep the original APD ratio between captain and pilot);
- labour cost of cabin attendant reduced from $ 108/fthr to $ 50/fthr (the ITA value);
- the depreciation period of the airframe has been adjusted to the ITA strategy from 15 years to the full airframe life of 30 years;
- the depreciation period of the engines have been adjusted to the ITA strategy from 7 years to the full engine life of 30 years (best fit for ITA figures, but seems a bit unlikely high);
- depreciation factors of airframe and engine set to 1.0 (was 0.85) because with full life there will be no residual value;
- airframe and engine market prices (plus spares etc) reduced with the factor 0.88 to fit the resulting aircraft cost to those of ITA for a 2000 kilometre range. The result is $ 53.34 million for the airframe and $ 4.536 million per engine;
- the number of cabin attendants has been adjusted to the ITA equation (being the lower integer of (number of seats+12)/32): 7 in stead of the APD value of 8;
- the engine TBO has been increased to 12,000 hours. The Engine Spare part Price Policy Factor has been adjusted from 1.5 to 1.2. To fit the results to the ITA values the engine and airframe maintenance costs have been fitted with a factor 1,06. This factor is now higher than 1.0 because ITA reckons the 767-200 to older aircraft and therefore increases the maintenance cost with a factor 1.6 ([Thwaites, 2001 #265]). The real fitting factor therefore is 0.66;
- the total of landing fee, ground handling costs and navigation charges has been fitted to ITA with a factor 1.004.

The resulting differences are given in Table 40.

Table 40 Comparison between ITA and APD data for Aircraft type 4 (MRMS) (factors APD/ITA)

Block distance [km]	500	2000
Fuel cost	1.48	1.07
Crew	1.17	1.08
Maintenance	0.99	1.00
Aircraft	0.83	1.04
Charges	1.00	1.00
Total DOC	1.04	1.03
Fuelfraction [%]	1.43	1.03

Aircraft type 5 (LRMS)

The DOC calculations have been adapted to the ITA figures [Thwaites, 2001 #265] in the following way:

- labour cost of captain reduced from $685/flighthour to $295/fthr (to approximately match total crew cost);
- labour cost of copilot reduced from $351/fthr to $151/fthr (to keep the original APD ratio between captain and pilot);
- labour cost of cabin attendant reduced from $108/fthr to $50/fthr (the ITA value);
- the depreciation period of the airframe has been adjusted to the ITA strategy from 15 years to the full airframe life of 30 years;
- the depreciation period of the engines have been adjusted to the ITA strategy from 7 years to the full engine life of 30 years (best fit for ITA figures, but seems a bit unlikely high);
- depreciation factors of airframe and engine set to 1.0 (was 0.85) because with full life there will be no residual value;
- airframe and engine market prices (plus spares etc) reduced with a factor 0.7 as given by ITA for 'new aircraft' (a fleet consisting of aircraft build after 1990, [Thwaites, 2001 #265]. The result is $60.648 million for the airframe and $4.676 million per engine;
- the number of cabin attendants has been adjusted to the ITA equation (being the lower integer of (nr seats+12)/32): 8 (in stead of the APD value of 9);
- the engine TBO has been increased as with the CFM tot 12000 hours (a United Airlines press release (see www.airward.com/eaamarin/ualtour.htm) gives 14,000 hours for the larger PW4085 engine. The Engine Spare part Price Policy Factor has been adjusted from 1.5 to 1.2. To fit the results to the ITA values the engine and airframe maintenance costs have been fitted with a factor 0.72;
- the total of landing fee, ground handling costs and navigation charges has been fitted to ITA with a factor 1.02.

The resulting differences are given in Table 41.

Table 41 Comparison between ITA and APD data for Aircraft type 5 (LRMS)

Block distance [km]	500	2000	6000
Fuel cost	1.46	1.00	0.97
Crew	1.14	1.06	1.03
Maintenance	1.09	1.03	1.00
Aircraft	0.68	0.86	0.97
Charges	1.00	1.00	1.00
Total DOC	1.02	0.99	0.99
Fuelfraction [%]	1.43	1.01	0.98

Aircraft type 7 (LRLS)

The DOC calculations have been adapted to the ITA figures [Thwaites, 2001 #265] in the following way:

- labour cost of captain reduced from $992/flighthour to $286/fthr (to match total crew cost);
- labour cost of copilot reduced from $467/fthr to $134/fthr (to keep the original APD ratio between captain and pilot);
- labour cost of flight-engineer removed (two pilot cockpit);

- labour cost of cabin attendant reduced from $108/fthr to $50/fthr (the ITA value);
- airframe and engine market prices (plus spares etc) reduced with the factor 0.7 (given by ITA due to the 'new' age category of the fleet) to $103.88 million and $3.78 million per engine;
- the depreciation period of the airframe has been adjusted to the ITA strategy from 15 years to the full airframe life of 30 years;
- the depreciation period of the engines have been adjusted to the ITA strategy from 7 years to the full engine life of 30 years (best fit for ITA figures, but seems a bit unlikely high);
- depreciation factors of airframe and engine set to 1.0 (was 0.85) because with full life there will be no residual value;
- the number of cabin attendants has been adjusted to the ITA equation (being the lower integer of (no seats+12)/32): 13 instead of 15;
- the time between engine overhaul has been increased to 15000 hours (was 3700 hr), because less cycles for a long range aircraft will generally increase this value (compared to the other models described above);
- the Engine Spare part Price Policy Factor has been adjusted from 1.5 to 1.2;
- to fit the results to the ITA values the engine and airframe maintenance costs have been fitted with a factor 0.80;
- the total of landing fee, ground handling costs and navigation charges has been fitted to ITA with a factor 1.075.

The resulting differences are given in Table 42.

Table 42 Comparison between ITA and APD data (factors APD/ITA) for Aircraft type 7 (LRLS)

BL. DIST. [KM]	500	2000	6000	10000
Fuel cost	1.48	1.00	0.94	0.98
Crew	1.11	1.03	1.00	0.99
Maintenance	1.09	1.03	1.00	1.00
Aircraft	0.70	0.88	1.00	1.04
Charges	1.00	1.00	1.00	1.00
Total DOC	1.03	0.99	0.98	1.00
Fuelfract. [%]	1.44	1.025	0.96	0.99

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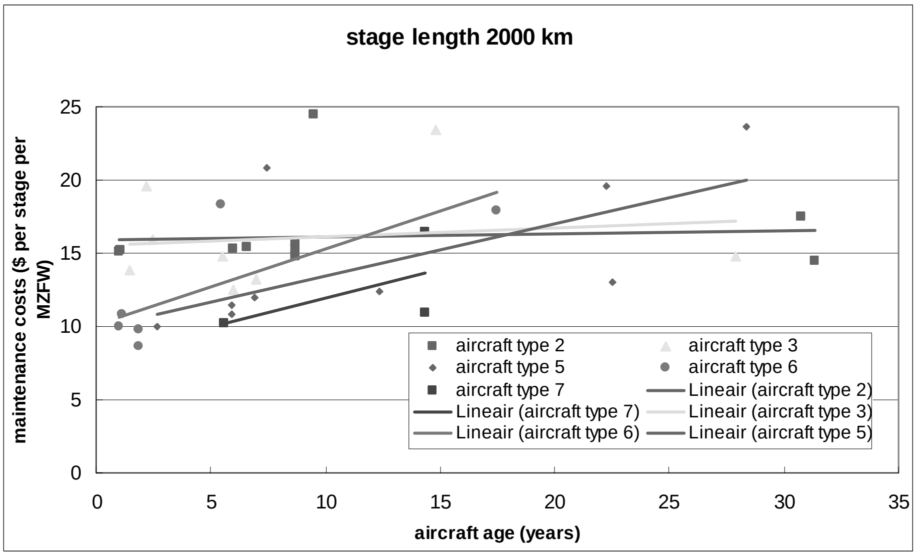
F Supply-side measures in greater detail

F.1 Accelerated fleet renewal

The main cost components that play a role in aircraft replacement are depreciation costs (decreasing with aircraft age), fuel costs and maintenance costs (both increasing with aircraft age). In this annex we develop insight into these costs by establishing proxies as a function of aircraft lifetime. We start with maintenance costs, based on the database supplied by ITA.

Figure 21 Relationships between aircraft age and maintenance costs (source: data of 639 aircraft types supplied by ITA)

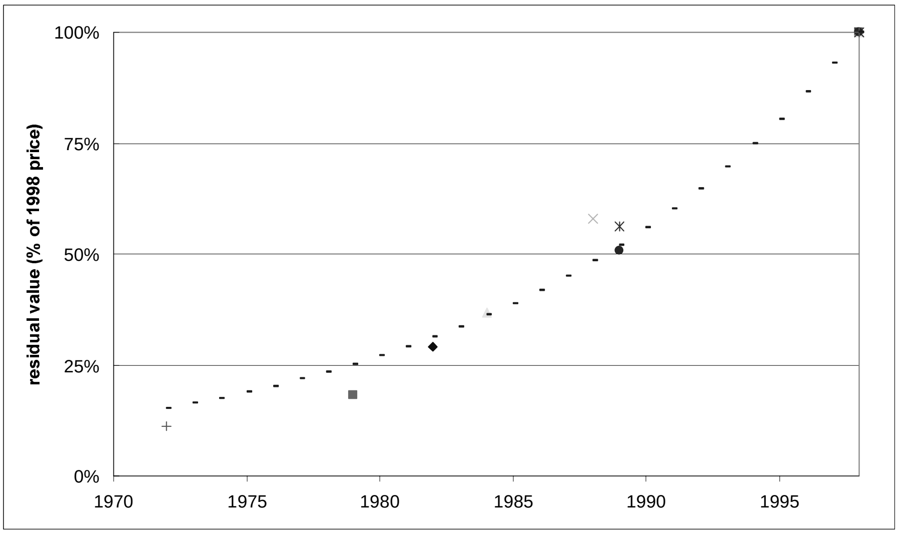


It can be seen that aircraft maintenance costs generally increase with time. The causes are twofold:

- first, older aircraft are technologically less advanced and hence need more maintenance
- second, the older a specific aircraft gets, the more maintenance it needs.

With respect to fixed aircraft depreciation costs, we used estimates for market values of 7 different aircraft types in old and new versions. See Figure 22. The average decline in market value is about 7% per year. Additionally we included an 8% interest rate.

Figure 22 Estimates of market value in 1998 as a percentage of the new price in 1998 of 7 different aircraft types



With respect to fuel costs, historical trends indicate that new aircraft on average use about one-third less fuel than 25 year old aircraft (IPCC 1999, Lee 2000). Historical improvements in fuel consumption have amounted to about 1.7% per year.

F.2 Wingtip devices

The aerodynamic design of wings has an important effect on the total drag during cruise and therefore on an aircraft's emissions, but also on performance characteristics like payload-range capability and take-off and climb-out. Wing-design is one of the most complicated and challenging parts of the development of aircraft.
Most designers try to come with a well balanced wing design and normally do not choose for additional features. The final design is always the result of a compromise between the cost of building the wing and the cost (fuel and maintenance) of operating the wing. Therefore changes in fuel cost have an effect on the optimal wing-design.
Many 'new' aircraft models are further developments of existing models and are no always fitted with a fully new wing. Ways to improve aerodynamic performance of a wing are:
– extending wing span;
– adding a wingtip device.
Adding wingspan on a retrofit basis is normally very difficult.

Effect of wingtip devices and winglets on induced drag

Wing tip devices reduce the overall induced drag of an aircraft. The induced drag is given by:

$$C_{D_i} = \frac{C_L^{2}}{AR \quad e}$$

Well-designed winglets have in general the effect of increasing the wingspan with double the winglets height added to the wingspan (Raymer, D. P., 1992), p.65. For blended winglets as introduced to the Boeing 737NG-family this may even larger. further the winglets add themselves to the span with about 5 ft of 4%, thus increasing AR. With 6-7 ft high blended winglets the total effect should come to (112.5+5+4*6)/112.5 = 1.26 or a 26% effective increase of AR. We chose a conservative 20%. The total drag at cruise consist not only of induced drag but also of parasite drag and mach-drag, normally together more than the induced drag.

As given in (Faye, R., Laprete, R. and Winter, M., 2001) the ‘raked wingtip device’ of the 767-400ER has an even larger effect on total average cruise drag of 5.5%, compared to 3.7% for the Boeing 737-800.

The market for retrofitting existing wings with winglets already exists (see (Inman, J., 2001)). Currently two programmes are underway: Quiet Wing System’s (formerly DuganAir) B727 retrofit (using ‘blended winglets’ developed by Winglet Systems, CT), and Aviation Partner’s (AP) winglet for the B737-NG series. The latter programme is a development from AP’s earlier winglet retrofit programme for Gulfstream IIs which was followed by the Boeing BBJ business jet. The Boeing 727 project led to some structural difficulties in the wing. These were solved by readjusting some of the flaps and ailerons instead of a costly redesign of the main upper wing spar.

Effects of winglets depend on aircraft type and the winglet geometry itself. Typically a Boeing 737 will save op to 7% on fuel (Aviation Partners, 2001). Larger aircraft may save even more.

Extra weight for the winglets on the next-generation 737 (models 600/700/800/900) is 262 lbs plus extra strengthening of the wing with 216 lbs. Currently the next-generation 737’s are produced with the strengthened wing structure as a standard, to accommodate later retrofit much more cheaply. The 737-800 is delivered with winglets as a standard feature.

Winglets increase aircraft payload-range capabilities, noise (due to the ability to attain the same climb angle with less power) and the aircraft’s “sex-appeal” (Inman, J., 2001). Hapag Lloyd is retrofitting its 26 B737’s with winglets after certification by the FAA. The new Airbus A380 has a restricted wingspan (because of the ICAO 80x80 ‘box’ limit on airports). It therefore seems reasonable this wing will be fitted with winglets from the start, to get some percents of fuel efficiency and range extra (Inman, J., 2001).

The retrofit of winglets on the Boeing 737-800 has not only a beneficial effect on fuel efficiency but also on ((Boeing, 2000, 2001)):

- lower operating costs due to block fuel burn by 3.5 to 4.0 percent on missions greater than 1,000 nautical miles;
- reduce engine maintenance cost;
- increase range up to 130 nautical miles;
- improved payload capability by up to three tonnes;
- reduce community noise by 0.5 to 0.7 EPNdB;
- lower emissions due to lower cruise thrust.

The costs of retrofitting with winglets depend on the shape and dimensions of the winglet and the amount of modification to the wing structure required. Typically the retrofit can be done within two weeks ((Aviation Partners, 2001; Boeing, 2000)). Following costs indications were found:

- Gulfstream II in 1991 $520,000 (Aviation Partners, 2001)
- Gulfstream GII for $475,000 (Aviation Partners, 2000)

For the four example aircraft following assumptions have been made:

Table 43 Assumptions made in the evaluation of winglets

	Unit	A/c type 2	A/c type 4	A/c type 5	A/c type 7
Retrofit cost[88]	10^3 $	900	1230	1400	
Extra weight[89]	kg	250	560	615	
AR increase[90]	%	20	20	20	
Engine maintenance cost	%	-1	-1	-1	

1 Taken as 2.3% of the new airframe price.

1 0.76% of empty weight

1 AR = Aspect Ratio (see box)

The winglets were evaluated with the assumptions mentioned above on aircraft types 3, 4, and 5. The results are shown in Table 8. The effect on total block fuel consumption for Aircraft Type 3 compares conservatively to the figures given by Boeing (figure 6 of (Faye, R., Laprete, R. and Winter, M., 2001)).

Table 44 Impacts of application of winglets or advanced wingtip devices on DOC of certain aircraft

aircraft type	stage length	impact on emissions		impact on DOC		
		CO_2	NO_X	baseline	CO_2 only, € 30 per tonne	CO_2 & NO_X, € 30 & 3.6 per tonne & kg
aircraft type 3	500	-2.3%	-3.1%	+0.2%	0.1%	0.0%
	2000	-3.9%	-5.7%	-0.2%	-0.5%	-0.6%
aircraft type 4	500	-2.3%	-3.1%	+0.3%	+0.1%	0.0%
	2000	-4.3%	-6.9%	-0.3%	-0.6%	-0.8%
aircraft type 5	500	-2.3%	-3.7%	+0.2%	0.0%	-0.1%
	2000	-4.6%	-7.6%	-0.5%	-0.8%	-1.1%
	6000	-6.4%	-11.1%	-1.8%	-2.2%	-2.7%

It can be seen that the environmental impact of winglets is particularly high at longer distances, and in particular for NO_X emissions. This can be explained from the lower engine loads that can be applied, which reduce NO_X emission indices. Emission reductions vary from 2%, for CO_2 at short distances, to 11% for NO_X at long distances.

88 This has been taken as 2.3% of the new airframe price.

89 This value is 0.76% of empty weight.

90 Rule of thumb.

The extra DOC advantage generated by incentive on only CO_2 is 0.1 to 0.4%, whereas and additional incentive on NO_X generates an additional incentive of 0.1 to 0.5% of DOC. These results should be corrected for the percentage of km flown within EU airspace.

It can be seen that under the current cost and environmental estimates, at longer distances application of winglets is already attractive under current market circumstances. This could explain the current developments in this field. Boeing offers his new 737-800 with and without blended winglets. The aircraft are for example sold without blended winglets to a low-budget-short range airliner as Ryanair (Boeing, 2002), but has sold a 737's with winglets to Kenia Airlines (1 on 11-9-2001), to Qantas (15 on 14-2-2002), to American Trans Air (20 on 4-5-2000 with ATA planning to lease an additional 17), to Pegasus Airlines (1 on 29-1-2002 because they want to use it on longer routes), to Hainan airlines (3 on 11-1-2002) and to air Europe (1 on 3-1-2002; AE planned to retrofit all her other 737-800's with blended winglets, because they fly normally long distances with them between Spain and the Canary Islands). Dates in the above list refer to the news release date of www.boeing.com/news/releases website.

The environmental incentives could speed up the process and give just an additional push for a number of aircraft in the fleet, particularly on those that fly shorter distances. Of course there are arguments against introduction of winglets like:
- class of airport box dimensions: if an aircraft just fits some class of box dimensions on airports, it may be undesirable to extend the wingspan with a winglet; sometime it may be possible to reduce the current wingspan and add a winglet or wingtip device to the wing, remaining in the same box;
- if an aircraft has already wingtip devices or a relatively high aspect ratio wing, the relative effect of a more advanced wingtip device may be to small to justify the modification or retrofit;
- adding a wingtip device alters the loads on a wing and a very well designed wing does normally not have much residual strength to aleviate extra loads;
- economic arguments: new wingtip devices require not only the technical development of them, but also a new certification for the aircraft; this will alle add to the total cost of the retrofit or redesign.

On current aircraft endplates, winglets or raked wingtips are offered on Boeing 747-400, Boeing 777-200LR and Boeing 777-300ER, Boeing 767-400ER, Boeing 737NG family (as an option only), airbus A300-600, Airbus A310-300, Airbus A319/A320A321, Airbus A330 (all models) and Airbus A340 (all models). This means only a (small) part of the world airliner fleet may be retrofitted with wingtip devices.

Figure 23 Revenue from the application of winglets in different aircraft types, baseline scenario

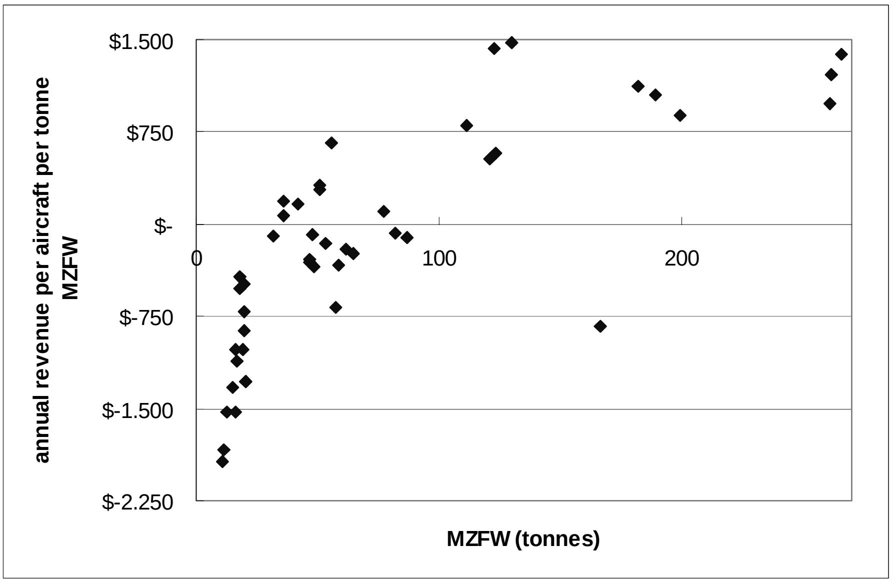
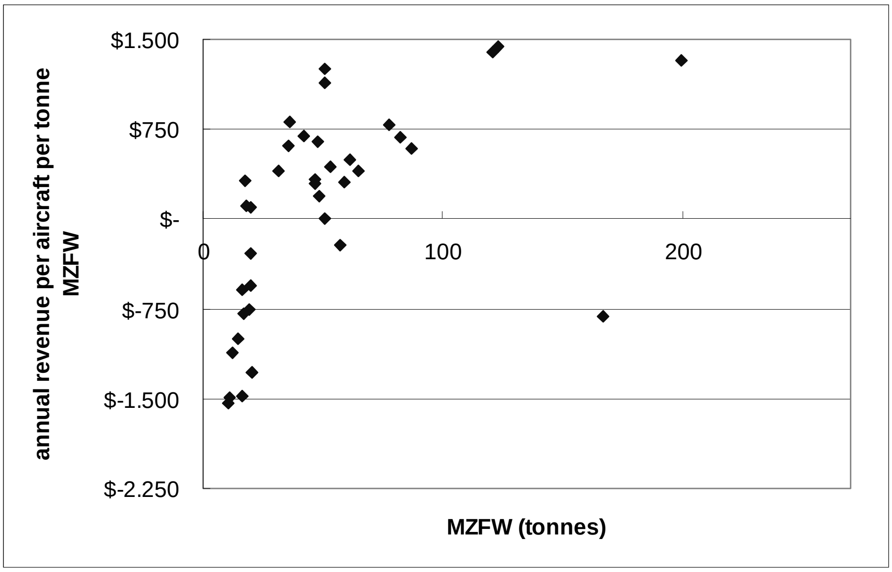


Figure 24 Revenue from the application of winglets, scenario incentive on CO_2 and NO_X of € 50 per tonne and € 6 per kg respectively



It can be seen that in the baseline scenario, application of winglets is only attractive in aircraft over 70 tonnes MZFW (aircraft types 3 and larger), and in the maximum incentive scenario, application is attractive to all aircraft over 30 tonnes MZWF (most aircraft types 1 and 2).

F.3 Riblets

Riblets are small grooves in flow direction added to the surface of an aircraft, with the aim to reduce skin-friction. As skin friction drag amounts to about 40-50% of the total drag at cruise every 2% of skin friction drag reduction may result in 1% fuel savings (Filippone, A., 1999; Viswanath, P. R., 1999). At long haul flights this will be further increased due to the decreasing mean weight of the aircraft during the flight (less fuel for flight and reserves).

Measured drag reductions are in the range of 5-11%, most of the values converging to 8%. This of course is only valid for the whole aircraft if the whole surface can effectively be covered with riblets, which will almost certainly not be the case. A test on an Airbus A320 scale model (1:11) in a windtunnel at mach 0.7 showed a reduction of drag with 4.85%, with 66% of the aircraft covered with riblets film (Filippone, A., 1999; Viswanath, P. R., 1999). This means 7.3% effect on the sections covered with riblets. A flight test with a T-33 jet trainer with slightly swept wings covered for 76% with riblet film showed reduction of 6% at the places with riblets and mach number between 0.35-0.70. . Interesting is the drag reduction due to riblets on wings increases with increasing angle of attack of the wing up to some maximum near 10°, which is a very high angle never reached during the main stages of a normal flight.

There seem to be no real problems concerning other vital aerodynamic properties in adding riblet film to real aircraft: surface contamination seems no problem for aircraft, flow mis-alignment has no effect up to 15°, pressure gradients have a minor effect, lift characteristics are almost untouched by riblets, except for a slight increase of the lift curve slope (Filippone, A., 1999; Viswanath, P. R., 1999).

The final drag reduction attainable on a real aircraft will be about 2-3% (Viswanath, P. R., 1999).

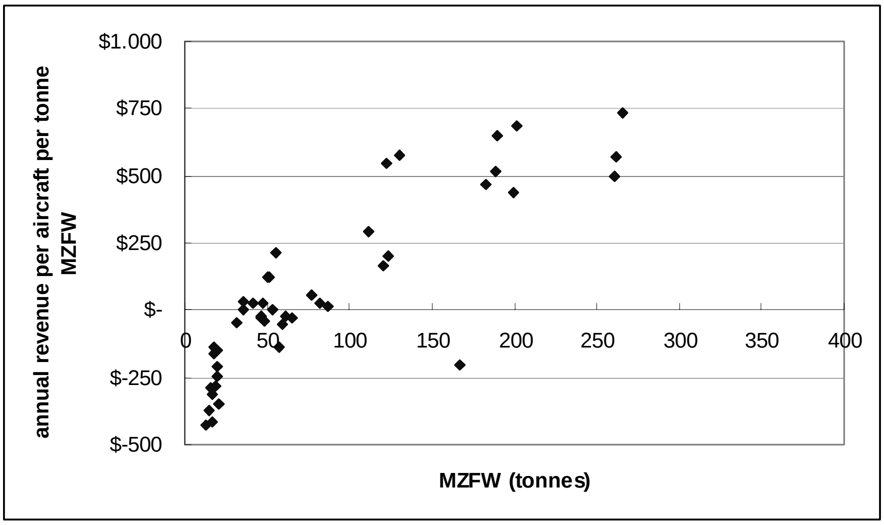
The 3M company is offering Paint Replacement (Appliqué) Technology to replace a normal painting on aircraft (information from 3M Aerospace). With this technology the riblets may be added. The cost of it is unknown yet as is the extra weight. But these films are only 0.2 mm thick, which is not much more or less than a normal layer of paint. The total area of a type 2 aircraft is typically about 600 m2, for the type 7 aircraft it is 2700 m^2. The first one will add a film weight of less than 200 kg, the other one of 800 kg. Removing paint and filling 66% of the total area with the riblet film will add approximately 50 kg to a type 2 and 200 kg to the type 7 aircraft empty weight.

The cost of the film and of its handling is not explicitly referred to in the literature, but it will probably not be much different from a paint job. In order to stay at the conservative side, we used the cost estimates as described in (Hagler Bailly, 2000). At the moment the risk (it is not yet a commercially accepted strategy) is probably one of the most important barriers for introduction.

Table 45 Assumptions made in the evaluation of riblets

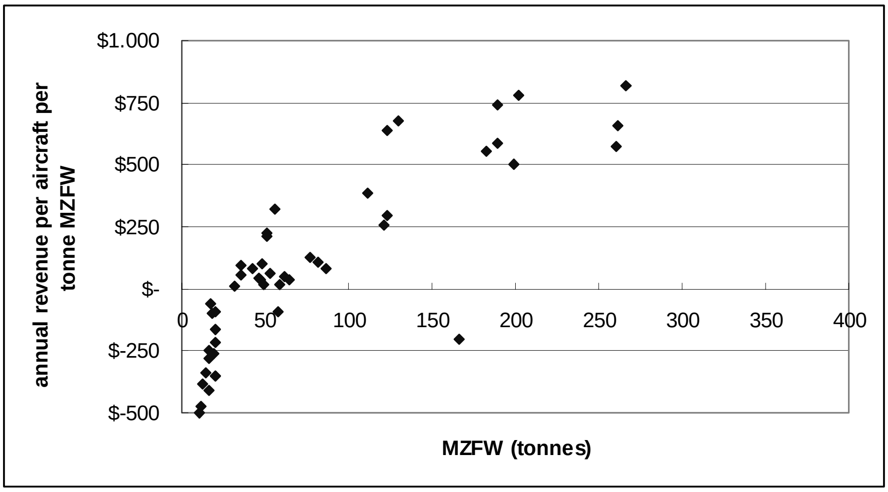
aircraft type	fuel savings at different stage lengths				costs per 5 years
	500	2,000	6,000	10,000	
1	0.5%	1%	2%	2%	30,000
2					50,000
3					75,000
4					100,000
5					150,000
6					200,000
7					250,000

Figure 25 Financial return from riblets per aircraft per tonne MZFW per year, for some 70 different aircraft types, under the base fuel price of $ 0.28 per kg



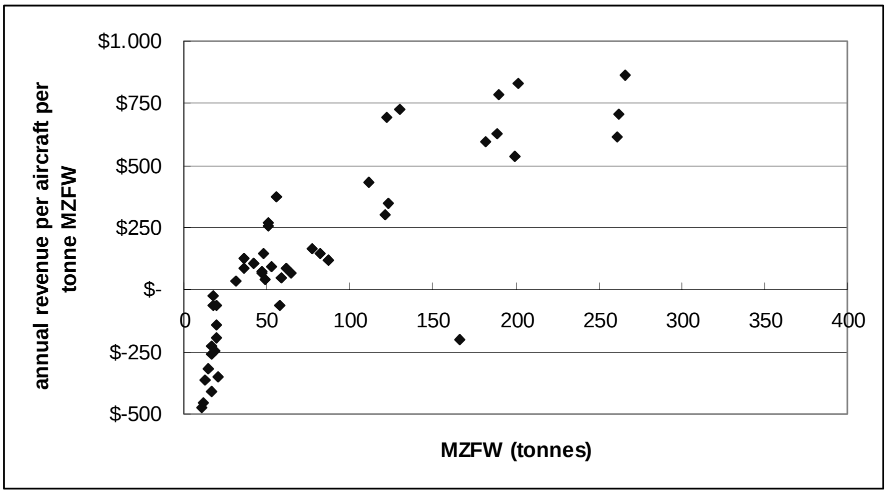
It can be seen that in this base case, retrofit of riblets is already theoretically attractive for virtually all large aircraft. However, for most aircraft under 70 tonnes MZWF (about 140 pax) retrofit of riblets does not seem commercially attractive under the assumptions made.

Figure 26 Financial return from riblets per aircraft per tonne MZFW per year, for some 70 different aircraft types, under the base fuel price of $ 0.28 per kg plus a CO_2 incentive of EUR 30 per tonne



It can be seen that in this case, retrofit of riblets is theoretically attractive for most aircraft over 40 tonnes MZFW (about 100 pax).

Figure 27 Financial return from riblets per aircraft per tonne MZFW per year, for some 70 different aircraft types, under the base fuel price of \$ 0.28 per kg plus a CO_2 incentive of EUR 30 per tonne and EUR 3.6 per kg of NO_X



It can be seen that in this case, retrofit of riblets is theoretically attractive for virtually all aircraft over 25 tonnes MZFW (about 50 pax).

The potential of riblets with larger aircraft is not substantially improved by changes in incentives, because the incentive only works at a limited part of the flights of such large aircraft (only in EU airspace).

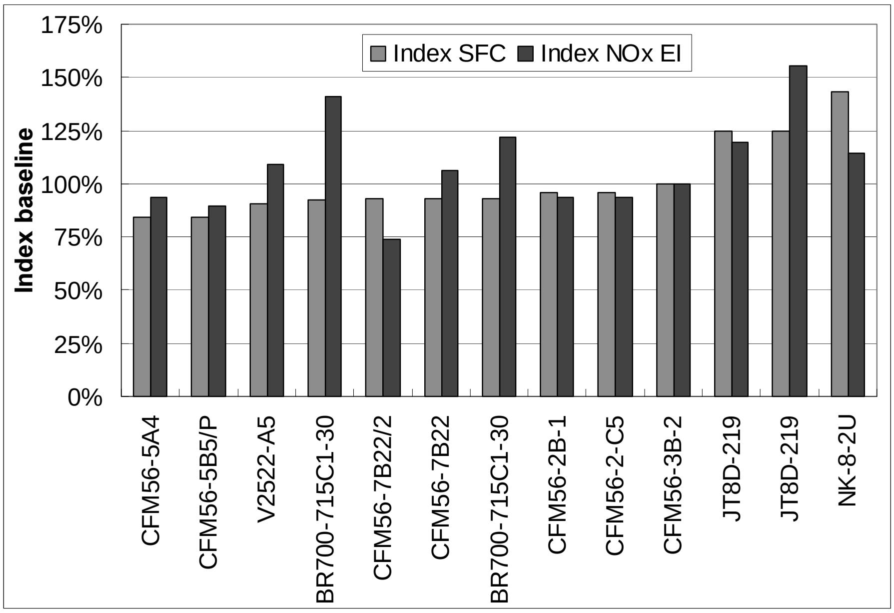
F.4 Re-engining case studies

Case study B737-400

The 737-400 was introduced in 1988. It is currently not any more on production: the 'classic 737-family' has been replaced by the 'next generation' of the 737-600/700/800/900 family.

These 737's use the CFM56-7 engine as a base. This engine has a fan-diameter of 61", which is 1" more as for the CFM56-3 series.

Figure 28 Alternative engines for the Boeing 737-400/CFM56-3B-2 representative aircraft engine thrust class



As the actual fleet of the 737-400 has an age of about 10 years we may assume the following:

- market for the CFM56-3 engines to be replaced is zero in Europe and very weak elsewhere: 10% resale value;
- the new engines and investment will be written of in 20 years;
- SFC has been reduced with 7%;
- NO_X emissions factors has been used for the CFM56-7B22/2;
- the new engines weighs 2366 kg in stead of 1951 kg increasing total empty weight with 830 kg;
- adjustments to landing gear gives an extra weight of 300 kg;
- the new engines maintenance cost is 15% lower (see Hayes, S., 2001) plus a reduction of 10% due to the fact they are new.

The results are given in Table 46.

Table 46 Results re-engining case study B737-400

Case	Incentive on CO_2 EUR/tonne	Incentive on NO_X EUR/kg	Part of flight with incentive (fraction)	Break-even investment Million $
Base	0	0	n/a	1.417
Case 1	30	3.6	1.0	2.178
Case 2	30	3.6	0.9	2.102
Case 3	50	6.0	1.0	2.686
Case 4	50	6.0	0.9	2.559

It is easy to see the savings will never allow for the investment of two new engines of at least $ 5,000,000 plus the investment for replacing the engines, adjusting avionics, adjusting the main landing gear and the engine cowlings to accommodate the larger fan diameter, etc. Re-engining the 737-400 is no option within the range of incentives considered.

Case study B747-400

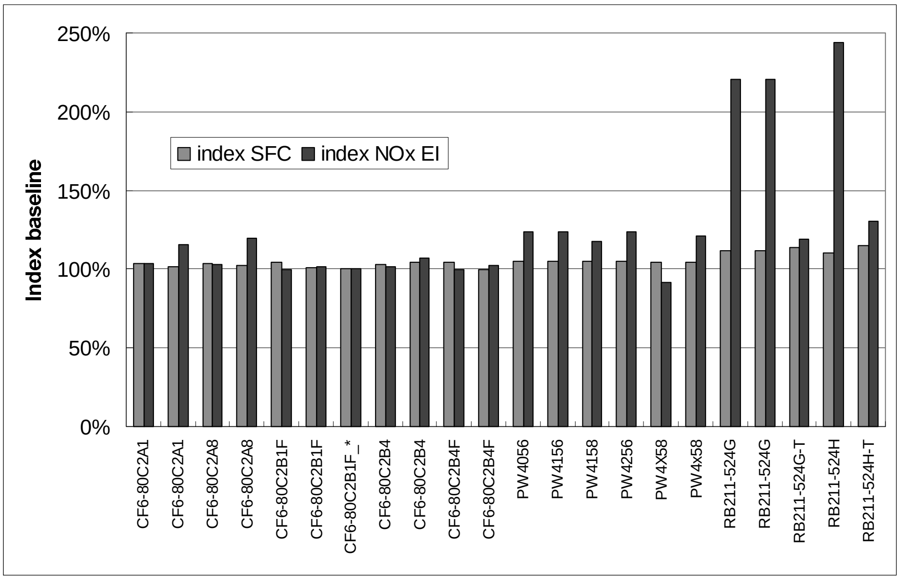
Aircraft type 7 (LRLS) contains the whole 747 family. We will first discuss the 747-400 as a case. The 747-400 has six engine options as given in Table 47.

Table 47 Current engine options for the 747-400

Type	#aircraft ordered by 1-07-2000	MTO thrust [kN]	Certification year	Market status	Index SFC	Index NO_X EI
CF6-80C2B1F	286	254,3	1989	on sale	100%	100%
RB211-524G-T	236	253	1998	?	+14%	+19%
PW4056	53	252,4	1989	on sale	+5%	+24%
RB211-524H-T	7	258	1998	on sale	+15%	+30%
RB211-524G	57	253	1989	?	+12%	+121%
RB211-524H	6	258	1990	on sale	+10%	+144%

In the same thrust class we may consider the engines as given in Figure 29.

Figure 29 Engines in the thrust class for the 747-400 compared on emissions and fuel consumption



From this figure it is clear that the most popular engine (GE CF6-80C2B 1F) is the best both for LTO CO_2 and NO_X emissions. The only candidate for reducing NO_X emissions is the PW4x58 engine (with Talon II combustor). However this engine has a 4% higher LTO SFC which will result in no gain for the case only CO_2 is charged and almost no gain in the case both CO_2 and NO_X are charged.

As over half of the engines offered by Boeing have considerable higher emissions and fuel consumption we will consider the possibility to replace the RB211-524 derivatives and PW4056 engines with GE CF6-80C2b 1F engines.

We now will try to find the break even investment for replacing the existing RB211-524G-T with the GE CF6-C2B 1F engines under the following assumptions:

- the replacement time is halfway the serviceable live of the aircraft (after 15 years);
- the original engines cannot be sold to another operator (as they will likely have the same incentive for replacement); this of course is a somewhat conservative assumption;
- the total replacement investment is written off in the remainder of the serviceable live of the aircraft (15 years);
- the new engines have a residual value of 15% of the acquisition cost;
- the maintenance cost of the new engines have been reduced with 12.5%.

With these assumptions the following breakeven investments are found for replacing the RB211-524G-T engines with CF6-C2B 1F engines.

Table 48 Break-even investments for re-engining the 747-400

Case	Incentive on CO_2 € /tonne	Incentive on NO_x € /kg	Part of flight with incentive (fraction)	Break-even investment Million $
Base	0	0	n/a	22.93
Case 1	30	3.6	1.0	32.62
Case 2	30	3.6	0.2	24.87
Case 3	50	6.0	1.0	39.08
Case 4	50	6.0	0.2	26.16

The engines themselves cost $ 6.1 million each (Jenkinson, L. R., Simpkin, P. and Rhodes, D., 2001), making the total investment to be at least $ 24.4 million. This means the replacement is not very likely in cases 2 and 4, with only an incentive on the European part of the flights. If the charge is valid for the whole flight there seem to be possibilities. However, the engine choice depends not only on DOC but also on aspects like:

- performance in terms of flat-rating and take-off thrust (take-off weight restrictions);
- engine maintenance cost;
- fleet strategy.

F.5 Operational measures, aircraft level

Operational measures only come into play if emissions are calculated on *an ex* post basis, on the basis of real flight data. Given a certain aircraft and a certain flight, a flight path and speed leading to minimum emissions can be identified as well as a flight path and speed leading to maximum emissions. The difference between these can be as large as 15-25%.

In this section we have performed a number of APD model runs on optimising the flight path and speed towards a DOC minimum. This implies that the trade-off between crew and depreciation costs on one hand and fuel savings on the other hand has been studied for several charging variants.

The following variants have been worked out with respect to their impacts on the DOC optimum.

Table 49 Overview of variants considered

Case	Incentive on CO_2	Incentive on NO_X
	EUR/tonne	EUR/kg
1 (base)	0	0
2	50	0
3	50	6
4	30	3.6

Table 50 Results from DOC-optimised cruising for aircraft type 2

Case	DOC	block time	CO_2 emissions	NO_x emissions
	$	minutes	tonne	kg
1	6355	125	15.92	56.61
2 (index base)	113.2	101.4	-1.8%	-3.7%
3 (index base)	117.6	101.7	-2.0%	-4.3%
4 (index base)	110.6	101.4	-1.8%	-3.7%

Table 51 Results from DOC-optimised cruising for aircraft type 4

Case	DOC	block time	CO_2 emissions	NO_X emissions
	$	minutes	tonne	kg
1 (base)	25286	370	83.597	362.2
2 (index base)	116.5	100.2	-0.3%	-0.7%
3 (index base)	124.9	100.6	-0.2%	-5.0%
4 (index base)	115.0	100.5	-0.5%	-1.3%

Table 52 Results from DOC-optimised cruising for aircraft type 5

Case	DOC	block time	CO_2 emissions	NO_X emissions
	$	minutes	tonne	kg
1	32204	441	118.4	551.4
2 (index base)	118.0	101.9	-2.4%	-5.4%
3 (index base)	127.6	102.8	-3.1%	-7.2%
4 (index base)	116.7	102.5	-2.8%	-6.7%

Table 53 Results from DOC-optimised cruising for aircraft type 7

Case	DOC	block time	CO_2 emissions	NO_X emissions
	$	minutes	tonne	kg
1	67988	566	288.4	1059
2 (index base)	121.1	100.6	-0.6%	-1.4%
3 (index base)	130.1	102.0	-0.9%	-7.6%
4 (index base)	118.2	100.7	-0.7%	-1.7%

The following conclusions can be drawn:

- The impacts of the charge programmes on cruise speeds and altitudes, and thus on DOC and fuel consumption and emission, is highly variable across the four aircraft/typical range combinations studied. CO_2 is reduced by a few tenth of per cents to three per cent.
- The reduction of NO_X emissions is generally about twice that of CO_2 and sometimes even more. The lower speeds require lower thrust and

therefore lead to lower NO_X emission indices. The impact can be as high as 7%, up from 0.7%.

G AERO Model and results

G.1 Introduction

This annex gives a brief description of the AERO Model and the scenario results for the different options. The model description is based on a report published by the Dutch Civil Aviation Administration who is the owner of the AERO model. For a detailed description of the model we would like to refer to that report. The authors wish to extend their special thanks to the Dutch CAA for making the AERO model available for this study.

G.2 Background and objectives

In 1994, the Dutch Civil Aviation Authority started a major policy analysis called the AERO-project (Aviation emissions and Evaluation of Reduction Options). The objectives of this project were to assess the problems related to air pollution from aircraft engine emissions and to analyse possible measures to reduce the impacts of air transport on the atmosphere, taking in account the environmental benefits and the economic impacts of such measures. In order to achieve these objectives, an extensive global information and modelling system was developed which is referred to as the AERO modelling system (AERO-MS).

The AERO-MS covers a sequence of steps from the description and generation of air transport demand to the assessment of the environmental and economic impacts of aircraft engine emissions, providing a comprehensive integration of the relevant economic, commercial, technological and environmental forces. In essence, the AERO-MS is a policy-testing tool to evaluate the environmental and economic consequences of responses to emission-related measures within the context of relevant future developments in the air transport sector.
Potentially, a great many possible measures and different future developments are relevant. Consequently, the AERO-MS had to be capable of analysing a wide range of measures (including economic, regulatory, technical and operational measures) within a variety of autonomous (economic and technological) developments. The AERO-MS was therefore designed to meet the following analysis requirements:
- to provide an adequate description of the economic and environmental aspects of the air transport system (in particular the extent and effects of aircraft engine emissions);
- to adequately reflect the economic and technological developments in air transport; and
- to assess the effects of a range of possible measures to reduce the environmental impact of air transport, taking into account the responses of the major actors (airlines, consumers, manufacturers) to such measures.

The design philosophy and architecture underlying the AERO-MS allow the user a large degree of flexibility in analysing the effects of specific developments and measures in a 'what-if' fashion. This was implemented by creating a great many user options to change key assumptions, schematisation aspects, (scenario) developments and possible measures (policy options).

The AERO project and the AERO-MS were principally developed to analyse the impacts of aircraft engine emissions on a global scale and therefore provide a complete description of world-wide aviation activity. In addition, within the analysis capabilities of the modelling system, specific options were provided to allow for a more detailed analysis of the aviation sector in the European context (the EU-countries as of the end of the 20th century). Within the European context, a number of specific options are provided for the analysis of the Netherlands' aviation (in particular involving the aviation activity at Amsterdam Airport). These different spatial levels of analysis all reflect the areas of interest to the Dutch Civil Aviation Authority, which – as noted already – commissioned the AERO project.

G.3 Applications of the AERO modelling system

From the very start of the AERO project, activity has strongly focused on developing the AERO-MS as a comprehensive tool for analysing the complex environmental and economic effects of policy measures in different scenarios. This was ultimately achieved in five project phases, though the system has been actively applied since the second phase.

From the second phase of the project onwards, versions of the AERO-MS have been available for analysis. In subsequent phases, the modelling system was further expanded, updated and improved. Based on earlier versions of the AERO-MS a number of rather substantial analyses were carried out. In addition to the intermediate analyses directly carried out for the Dutch Civil Aviation Authority, these include:

- a global analysis of emission charges and taxes for the Focal Point on Charges (carried out for CAEP/4) (FPC, 1998);
- an analysis of the impact of fuel taxation in the European context carried out for the European Commission (Resource Analysis et al, 1999);
- a study commissioned by the Dutch Civil Aviation Authority to facilitate the debate on the national allocation of CO_2 between the Subsidiary Body for Scientific and Technological Advice (SBSTA) of the UN Framework Convention on Climate Change (UNFCCC) and ICAO's Committee on Environmental Protection (CAEP) (Resource Analysis / CE, 2000);
- an analysis of market-based options for the reduction of CO_2 emissions from aviation for the Forecast and Economic Support Group of ICAO (CAEP/5) (Pulles et al, 2000).

As described in the present documentation, the now available version of the AERO-MS provides a powerful and flexible tool to support the analysis of economic and environmental (atmospheric) impacts on the aviation sector arising from a wide variety of possible developments and measures.

G.4 Set-up of the overall AERO documentation

The complete documentation of the AERO project includes the following parts:

A Main report
- Part I: Description of the AERO modelling system;
- Part II: Analysis preparation, execution and results.

B Reports on individual models
- General reports
  - Aircraft Technology Model (ATEC);
  - Air Transport Demand and Traffic Model (ADEM);

- Aviation Operating Cost Model (ACOS);
- Economic impact models: Direct Economic Impact Model (DECI) and Macro-Economic Impact Model for the Nederlands (MECI);
- Flights and Emissions Model (FLEM);
- Atmospheric impact models: Other Atmospheric Immissions Model (OATI), Chemical Tracer Model KNMI (CTMK), Environmental Impact Model (ENVI);

– System documentation
  - Aircraft Technology Model (ATEC);
  - Air Transport Demand and Traffic Model (ADEM);
  - Aviation Operating Cost Model (ACOS);
  - Economic impact models: Direct Economic Impact Model (DECI) and Macro-Economic Impact Model for the Netherlands (MECI);
  - Flights and Emissions Model (FLEM);
  - Atmospheric impact models: Other Atmospheric Immissions Model (OATI), Chemical Tracer Model KNMI (CTMK), Environmental Impact Model (ENVI).

C AERO Modelling system
- Technical report;
- User manual;
- Scenario and policy variables.

D CD-ROM of AERO project
The CD-ROM of the AERO project is split into two parts. The first part contains an electronic version of selective AERO documentation. The electronic documentation relates to both a description of the AERO-MS and the main results of the AERO analysis. The second part is involved with a demonstration version of the AERO-MS. It provides an insight in the functionality and use of the AERO-MS.

G.5 Results AERO for this study

This section presents the results from the AERO model for this study.

Definition cases and presentation formats

The following cases (policy options) are defined.

Table 54 Policy options

Emission charge		
1	CO_2-50global	Global route charge with charging level of Euro 50 per ton CO_2
2	CO_2-50	Route charge in EU air space with charging level of Euro 50 per ton CO_2
3	CO_2-30	Route charge in EU air space with charging level of Euro 30 per ton CO_2
4	CO_2-10	Route charge in EU air space with charging level of Euro 10 per ton CO_2
5	CO_2-50/NOx-6global	Global route charge with charging level of Euro 50 per ton CO_2 and Euro 6 per kg NO_x
6	CO_2-50/NOx-6	Route charge in EU air space with charging level of Euro 50 per ton CO_2 and Euro 6 per kg NO_x
7	CO_2-30/NOx-3,6	Route charge in EU air space with charging level of Euro 30 per ton CO_2 and Euro 3,6 per kg NO_x
8	CO_2-10/NOx-1,2	Route charge in EU air space with charging level of Euro 10 per ton CO_2 and Euro 1,2 per kg NO_x
Revenue neutral PSI		
9	RN CO_2-50global	Global revenue neutral route charge based on charging level of Euro 50 per ton CO_2
10	RN CO_2-50	Revenue neutral route charge in EU air space based on charging level of Euro 50 per ton CO_2
11	RN CO_2-30	Revenue neutral route charge in EU air space based on charging level of Euro 30 per ton CO_2
12	RN CO_2-10	Revenue neutral route charge in EU air space based on charging level of Euro 10 per ton CO_2
13	RN CO_2-50/NOx-6global	Global revenue neutral route charge based on charging level of Euro 50 per ton CO_2 and Euro 6 per kg NO_x
14	RN CO_2-50/NOx-6	Revenue neutral route charge in EU air space based on charging level of Euro 50 per ton CO_2 and Euro 6 per kg NO_x
15	RN CO_2-30/NOx-3,6	Revenue neutral route charge in EU air space based on charging level of Euro 30 per ton CO_2 and Euro 3,6 per kg NO_x
16	RN CO_2-10/NOx-1,2	Revenue neutral route charge in EU air space based on charging level of Euro 50 per ton CO_2 and Euro 1,2 per kg NO_x

Results are presented by:
Route group
Carrrier region.

The following route groups are distinguished:
Intra EU
EU- North America
EU – Asia
EU – Other Europe
EU – Other World
All other (i.e. all other flight stages in the world)

NB. An effect for a route group relates to the effect on the flight stages in two directions (EU – North America (NA) f.e. thus relates to effects on flights from EU to NA and NA to EU).

The effects of cases are presented as a percentage effect relative to the AERO-M 2010 scenario (Business as Usual case for 2010). The absolute quantities for the AERO-M 2010 are indicated in the tables.

The following carrier regions are distinguished:
EU carrier
Other carriers (i.e. all other carriers in the world).

Again, the effects of cases are presented as a percentage effect relative to the AERO-M 2010 scenario (with a few exceptions – see below), whereby the absolute quantities for the AERO-M 2010 are indicated in the tables. With respect to the carrier region tables (tables 2 and 4), there are a number of remarks:
For the effect on operating result the effect is not presented as a % change relative to the scenario. For both the scenario and the policy cases, the operating result is presented as a % of revenues.
Change in consumer surplus: applies to the clients of the home carriers of the specific region (effect not presented as % effect but in US$);
Revenue from taxation/charges; applies to the governments of countries within the specific region (effect not presented as % effect but in US$);
All other quantities: apply to the home carriers of the specific region.

Computational results

The effects are presented in the following tables.

Table 55	Effects by route group of charges per ton CO_2 (cases 1 through 4)
Table 56	Effects for EU carriers versus other carriers of charges per ton CO_2 (cases 1 through 4)
Table 57	Effects by route group of charges per ton CO_2 and kg NO_x (cases 5 through 8)
Table 58	Effects for EU carriers versus other carriers of charges per ton CO_2 and kg NO_x (cases 5 through 8).
Table 59	Effects by route group of revenue neutral charges per ton CO_2 (cases 9 through 12)
Table 60	Effects for EU carriers versus other carriers of revenue neutral charges per ton CO_2 (cases 9 through 12)
Table 61	Effects by route group of revenue neutral charges per ton CO_2 and kg NO_x (cases 13 through 16)
Table 62	Effects for EU carriers versus other carriers of revenue neutral charges per ton CO_2 and kg NO_x (cases 13 through 16)

Table 55 Effects by route group of charges per ton CO_2 computed with the AERO-MS (cases 1 through 4)

Effects	Route group	Unit	AERO-M 2010	CO2-50global	CO2-50	CO2-30	CO2-10
Air transport and aircraft operation							
Passenger Km	Intra EU	billion pax-km pa	505.0	-4.4%	-4.4%	-2.7%	-0.9%
	EU - North America	billion pax-km pa	611.6	-6.9%	-1.5%	-0.9%	-0.3%
	EU - Asia	billion pax-km pa	435.2	-6.8%	-0.8%	-0.5%	-0.2%
	EU - Other Europe	billion pax-km pa	189.3	-4.4%	-2.8%	-1.7%	-0.6%
	EU - Other World	billion pax-km pa	418.0	-6.8%	-2.5%	-1.5%	-0.5%
	All Other	billion pax-km pa	3673.6	-5.0%	-0.1%	-0.1%	0.0%
	Total	billion pax-km pa	5832.8	-5.4%	-0.9%	-0.6%	-0.2%
Cargo Km	Intra EU	billion tonne-km pa	3.8	-5.3%	-5.3%	-3.3%	-1.1%
	EU - North America	billion tonne-km pa	38.5	-6.6%	-1.4%	-0.9%	-0.3%
	EU - Asia	billion tonne-km pa	24.1	-5.1%	-0.6%	-0.3%	-0.1%
	EU - Other Europe	billion tonne-km pa	1.8	-4.2%	-2.5%	-1.5%	-0.5%
	EU - Other World	billion tonne-km pa	18.3	-4.8%	-1.8%	-1.1%	-0.4%
	All Other	billion tonne-km pa	158.5	-5.9%	0.0%	0.0%	0.0%
	Total	billion tonne-km pa	244.9	-5.8%	-0.5%	-0.3%	-0.1%
Revenue Tonne-Km	Intra EU	billion RTK pa	54.3	-4.5%	-4.5%	-2.8%	-1.0%
	EU - North America	billion RTK pa	99.6	-6.8%	-1.5%	-0.9%	-0.3%
	EU - Asia	billion RTK pa	67.7	-6.2%	-0.7%	-0.4%	-0.1%
	EU - Other Europe	billion RTK pa	20.7	-4.4%	-2.8%	-1.7%	-0.6%
	EU - Other World	billion RTK pa	60.1	-6.2%	-2.3%	-1.4%	-0.5%
	All Other	billion RTK pa	525.8	-5.3%	-0.1%	0.0%	0.0%
	Total	billion RTK pa	828.2	-5.5%	-0.8%	-0.5%	-0.2%
Flights	Intra EU	million flights pa	8.5	-4.2%	-4.2%	-2.6%	-0.9%
	EU - North America	million flights pa	0.5	-7.1%	-1.5%	-0.9%	-0.3%
	EU - Asia	million flights pa	0.2	-9.0%	-1.4%	-1.0%	-0.6%
	EU - Other Europe	million flights pa	1.7	-4.7%	-3.0%	-1.9%	-0.7%
	EU - Other World	million flights pa	0.5	-6.5%	-2.6%	-1.6%	-0.5%
	All Other	million flights pa	40.0	-5.4%	0.0%	0.0%	0.0%
	Total	million flights pa	51.4	-5.2%	-0.9%	-0.5%	-0.2%
Total aircraft km	Intra EU	billion ac-km pa	6.3	-4.6%	-4.6%	-2.9%	-1.0%
	EU - North America	billion ac-km pa	3.4	-7.2%	-1.5%	-0.9%	-0.3%
	EU - Asia	billion ac-km pa	1.8	-9.1%	-1.3%	-0.9%	-0.6%
	EU - Other Europe	billion ac-km pa	2.1	-5.1%	-3.3%	-2.1%	-0.7%
	EU - Other World	billion ac-km pa	2.4	-6.8%	-2.5%	-1.5%	-0.5%
	All Other	billion ac-km pa	36.5	-5.8%	-0.1%	0.0%	0.0%
	Total	billion ac-km pa	52.6	-5.9%	-1.0%	-0.6%	-0.2%
Aircraft km	Intra EU	billion ac-km pa	3.1	-7.9%	-7.9%	-4.9%	-1.7%
technology age > 12 years	EU - North America	billion ac-km pa	1.6	-19.2%	-4.2%	-2.6%	-1.1%
	EU - Asia	billion ac-km pa	0.7	-31.7%	-3.8%	-2.3%	-0.8%
	EU - Other Europe	billion ac-km pa	1.1	-8.9%	-5.6%	-3.6%	-1.3%
	EU - Other World	billion ac-km pa	1.3	-15.7%	-5.6%	-3.5%	-1.3%
	All Other	billion ac-km pa	17.7	-11.5%	-0.2%	-0.2%	-0.1%
	Total	billion ac-km pa	25.5	-12.2%	-2.0%	-1.3%	-0.5%
Aircraft km	Intra EU	billion ac-km pa	3.2	-1.4%	-1.4%	-0.8%	-0.2%
technology age <= 12 years	EU - North America	billion ac-km pa	1.8	4.0%	1.0%	0.7%	0.4%
	EU - Asia	billion ac-km pa	1.1	5.6%	0.3%	0.0%	-0.4%
	EU - Other Europe	billion ac-km pa	1.0	-1.1%	-0.8%	-0.6%	-0.2%
	EU - Other World	billion ac-km pa	1.1	3.3%	1.0%	0.7%	0.3%
	All Other	billion ac-km pa	18.8	-0.4%	0.1%	0.1%	0.1%
	Total	billion ac-km pa	27.1	0.1%	0.0%	0.0%	0.1%
Fuel consumption							
Fuel use	Intra EU	billion kg pa	19.5	-4.7%	-4.7%	-2.7%	-0.9%
	EU - North America	billion kg pa	23.8	-9.3%	-1.9%	-1.1%	-0.3%
	EU - Asia	billion kg pa	15.7	-11.8%	-1.6%	-1.1%	-0.6%
	EU - Other Europe	billion kg pa	6.6	-4.9%	-3.0%	-1.9%	-0.6%
	EU - Other World	billion kg pa	15.6	-8.4%	-3.0%	-1.8%	-0.6%
	All Other	billion kg pa	160.5	-6.6%	0.0%	0.0%	0.0%
	Total	billion kg pa	241.7	-7.1%	-1.0%	-0.6%	-0.2%
CO2 emission	Intra EU	billion kg pa	61.7	-4.7%	-4.7%	-2.7%	-0.9%
	EU - North America	billion kg pa	75.0	-9.3%	-1.9%	-1.1%	-0.3%
	EU - Asia	billion kg pa	49.6	-11.8%	-1.6%	-1.1%	-0.6%
	EU - Other Europe	billion kg pa	21.0	-4.9%	-3.0%	-1.9%	-0.6%
	EU - Other World	billion kg pa	49.2	-8.4%	-3.0%	-1.8%	-0.6%
	All Other	billion kg pa	506.7	-6.6%	0.0%	0.0%	0.0%
	Total	billion kg pa	763.2	-7.1%	-1.0%	-0.6%	-0.2%

Table 56 Effects for EU carriers versus other carriers of charges per ton CO_2 computed with the AERO-MS (cases 1 through 4)

Effects	Region	Unit	AERO-M 2010	CO2-50global	CO2-50	CO2-30	CO2-10
Air transport and aircraft operation							
Revenue Tonne-Km	EU	billion RTK pa	187.0	-5.9%	-2.1%	-1.3%	-0.5%
	Other	billion RTK pa	641.1	-5.4%	-0.4%	-0.2%	-0.1%
	Total	billion RTK pa	828.1	-5.5%	-0.8%	-0.5%	-0.2%
Aircraft km	EU	billion ac-km pa	11.7	-5.8%	-3.0%	-1.8%	-0.6%
	Other	billion ac-km pa	40.9	-5.9%	-0.3%	-0.2%	-0.1%
	Total	billion ac-km pa	52.6	-5.9%	-0.9%	-0.6%	-0.2%
Effects on airlines							
Operating costs	EU	billion 1992 US$ pa	141.1	0.8%	0.3%	0.2%	0.0%
	Other	billion 1992 US$ pa	407.5	2.0%	0.0%	0.0%	0.0%
	Total	billion 1992 US$ pa	548.5	1.7%	0.1%	0.1%	0.0%
Operating revenues	EU	billion 1992 US$ pa	144.1	0.8%	0.3%	0.2%	0.0%
	Other	billion 1992 US$ pa	419.3	1.9%	0.1%	0.0%	0.0%
	Total	billion 1992 US$ pa	563.4	1.6%	0.1%	0.1%	0.0%
Operating results	EU	% of revenues	2.1%	2.1%	2.1%	2.1%	2.1%
	Other	% of revenues	2.8%	2.7%	2.8%	2.8%	2.8%
	Total	% of revenues	2.6%	2.6%	2.6%	2.6%	2.7%
Contribution to gross value added (GVA)	EU	billion 1992 US$ pa	67.8	-4.4%	-2.2%	-1.4%	-0.5%
	Other	billion 1992 US$ pa	230.5	-4.4%	-0.2%	-0.1%	0.0%
	Total	billion 1992 US$ pa	298.2	-4.4%	-0.7%	-0.4%	-0.1%
Airlines related employment	EU	thousand employees	760	-6.0%	-2.8%	-1.7%	-0.6%
	Other	thousand employees	2844	-5.6%	-0.3%	-0.2%	-0.1%
	Total	thousand employees	3605	-5.7%	-0.9%	-0.5%	-0.2%
Economic effects for other actors							
Consumer surplus	EU	billion 1992 US$ pa	n.a.	-8.4	-3.8	-2.3	-0.8
	Other	billion 1992 US$ pa	n.a.	-28.2	-1.6	-1.0	-0.3
	Total	billion 1992 US$ pa	n.a.	-36.6	-5.3	-3.2	-1.1
Total fleet	EU	# aircraft	6661	-6.2%	-3.8%	-2.4%	-0.9%
	Other	# aircraft	26347	-7.1%	-0.3%	-0.2%	-0.1%
	Total	# aircraft	33008	-6.9%	-1.0%	-0.6%	-0.2%
Revenue from taxation	EU	billion 1992 US$ pa	n.a.	7.7	5.4	3.3	1.1
	Other	billion 1992 US$ pa	n.a.	29.0	0.0	0.0	0.0
	Total	billion 1992 US$ pa	n.a.	36.7	5.4	3.3	1.1
Fuel consumption and emissions							
Fuel use	EU	billion kg pa	53.6	-7.6%	-2.7%	-1.6%	-0.6%
	Other	billion kg pa	188.1	-7.0%	-0.4%	-0.2%	0.0%
	Total	billion kg pa	241.7	-7.1%	-0.9%	-0.5%	-0.1%
CO2 emission	EU	billion kg pa	169.2	-7.6%	-2.7%	-1.6%	-0.6%
	Other	billion kg pa	593.9	-7.0%	-0.4%	-0.2%	0.0%
	Total	billion kg pa	763.2	-7.1%	-0.9%	-0.5%	-0.1%
Operating efficiency							
Cost/RTK	EU	US$/tonne-km	0.75	7.0%	2.4%	1.5%	0.5%
	Other	US$/tonne-km	0.64	7.8%	0.4%	0.2%	0.1%
	Total	US$/tonne-km	0.66	7.6%	0.9%	0.5%	0.2%
Fuel/RTK	EU	kg/tonne-km	0.29	-1.9%	-0.6%	-0.3%	-0.1%
	Other	kg/tonne-km	0.29	-1.6%	0.0%	0.0%	0.0%
	Total	kg/tonne-km	0.29	-1.7%	-0.1%	-0.1%	0.0%
RTK/ATK	EU	factor	0.70	-0.5%	-0.1%	0.0%	0.0%
	Other	factor	0.66	-0.4%	0.0%	0.0%	0.0%
	Total	factor	0.67	-0.4%	0.0%	0.0%	0.0%
RTK/aircraft-km	EU	tonne-km/ac-km	16.03	-0.1%	0.9%	0.5%	0.2%
	Other	tonne-km/ac-km	15.67	0.5%	-0.1%	0.0%	0.0%
	Total	tonne-km/ac-km	15.75	0.4%	0.1%	0.1%	0.0%
Revenues/RTK	EU	US$/tonne-km	0.77	7.1%	2.4%	1.5%	0.5%
	Other	US$/tonne-km	0.65	7.7%	0.4%	0.3%	0.1%
	Total	US$/tonne-km	0.68	7.5%	0.9%	0.5%	0.2%
Fuel/aircraft-km	EU	kg/ac-km	4.60	-2.0%	0.2%	0.2%	0.1%
	Other	kg/ac-km	4.60	-1.1%	-0.1%	0.0%	0.0%
	Total	kg/ac-km	4.60	-1.3%	0.0%	0.0%	0.1%

Table 57 Effects by route group of charges per ton CO_2 and kg NO_x computed with the AERO-MS (cases 5 through 8)

Effects	Route group	Unit	AERO-M 2010	CO2-50/Nox-6global	CO2-50/Nox-6	CO2-30/Nox-3,6	CO2-10/Nox-1,2
Air transport and aircraft operation							
Passenger Km	Intra EU	billion pax-km pa	505.0	-6.4%	-6.4%	-4.0%	-1.4%
	EU - North America	billion pax-km pa	611.6	-10.3%	-2.3%	-1.4%	-0.5%
	EU - Asia	billion pax-km pa	435.2	-10.1%	-1.2%	-0.7%	-0.2%
	EU - Other Europe	billion pax-km pa	189.3	-6.3%	-4.0%	-2.5%	-0.8%
	EU - Other World	billion pax-km pa	418.0	-10.0%	-3.8%	-2.3%	-0.8%
	All Other	billion pax-km pa	3673.6	-7.3%	-0.1%	-0.1%	0.0%
	Total	billion pax-km pa	5832.8	-7.9%	-1.4%	-0.8%	-0.3%
Cargo Km	Intra EU	billion tonne-km pa	3.8	-7.5%	-7.5%	-4.7%	-1.6%
	EU - North America	billion tonne-km pa	38.5	-9.8%	-2.2%	-1.3%	-0.5%
	EU - Asia	billion tonne-km pa	24.1	-7.7%	-0.9%	-0.5%	-0.2%
	EU - Other Europe	billion tonne-km pa	1.8	-6.0%	-3.6%	-2.2%	-0.8%
	EU - Other World	billion tonne-km pa	18.3	-7.2%	-2.8%	-1.7%	-0.6%
	All Other	billion tonne-km pa	158.5	-8.6%	-0.1%	0.0%	0.0%
	Total	billion tonne-km pa	244.9	-8.6%	-0.8%	-0.5%	-0.2%
Revenue Tonne-Km	Intra EU	billion RTK pa	54.3	-6.5%	-6.5%	-4.0%	-1.4%
	EU - North America	billion RTK pa	99.6	-10.1%	-2.2%	-1.4%	-0.5%
	EU - Asia	billion RTK pa	67.7	-9.3%	-1.1%	-0.7%	-0.2%
	EU - Other Europe	billion RTK pa	20.7	-6.3%	-4.0%	-2.5%	-0.8%
	EU - Other World	billion RTK pa	60.1	-9.1%	-3.5%	-2.1%	-0.7%
	All Other	billion RTK pa	525.8	-7.7%	-0.1%	-0.1%	0.0%
	Total	billion RTK pa	828.2	-8.1%	-1.2%	-0.7%	-0.3%
Flights	Intra EU	million flights pa	8.5	-5.6%	-5.6%	-3.5%	-1.2%
	EU - North America	million flights pa	0.5	-10.5%	-2.3%	-1.4%	-0.5%
	EU - Asia	million flights pa	0.2	-13.5%	-1.9%	-1.3%	-0.7%
	EU - Other Europe	million flights pa	1.7	-6.1%	-3.9%	-2.4%	-0.9%
	EU - Other World	million flights pa	0.5	-9.1%	-3.8%	-2.3%	-0.8%
	All Other	million flights pa	40.0	-7.2%	0.0%	0.0%	0.0%
	Total	million flights pa	51.4	-7.0%	-1.1%	-0.7%	-0.3%
Total aircraft km	Intra EU	billion ac-km pa	6.3	-6.1%	-6.1%	-3.8%	-1.3%
	EU - North America	billion ac-km pa	3.4	-10.6%	-2.3%	-1.4%	-0.5%
	EU - Asia	billion ac-km pa	1.8	-13.7%	-1.9%	-1.3%	-0.7%
	EU - Other Europe	billion ac-km pa	2.1	-6.7%	-4.3%	-2.7%	-1.0%
	EU - Other World	billion ac-km pa	2.4	-9.5%	-3.7%	-2.3%	-0.8%
	All Other	billion ac-km pa	36.5	-7.9%	-0.1%	0.0%	0.0%
	Total	billion ac-km pa	52.6	-8.1%	-1.3%	-0.8%	-0.3%
Aircraft km	Intra EU	billion ac-km pa	3.1	-10.2%	-10.2%	-6.4%	-2.3%
technology age > 12 years	EU - North America	billion ac-km pa	1.6	-27.8%	-6.2%	-3.9%	-1.5%
	EU - Asia	billion ac-km pa	0.7	-46.5%	-5.9%	-3.6%	-1.3%
	EU - Other Europe	billion ac-km pa	1.1	-11.4%	-7.2%	-4.5%	-1.7%
	EU - Other World	billion ac-km pa	1.3	-22.2%	-8.2%	-5.1%	-1.8%
	All Other	billion ac-km pa	17.7	-15.5%	-0.2%	-0.2%	-0.1%
	Total	billion ac-km pa	25.5	-16.6%	-2.7%	-1.7%	-0.7%
Aircraft km	Intra EU	billion ac-km pa	3.2	-2.1%	-2.1%	-1.3%	-0.4%
technology age <= 12 years	EU - North America	billion ac-km pa	1.8	5.2%	1.3%	0.9%	0.4%
	EU - Asia	billion ac-km pa	1.1	7.7%	0.8%	0.3%	-0.3%
	EU - Other Europe	billion ac-km pa	1.0	-1.7%	-1.2%	-0.8%	-0.3%
	EU - Other World	billion ac-km pa	1.1	4.7%	1.3%	0.9%	0.4%
	All Other	billion ac-km pa	18.8	-0.8%	0.1%	0.1%	0.1%
	Total	billion ac-km pa	27.1	0.0%	0.0%	0.0%	0.0%
Fuel consumption							
Fuel use	Intra EU	billion kg pa	19.5	-6.5%	-6.5%	-4.1%	-1.3%
	EU - North America	billion kg pa	23.8	-14.0%	-3.0%	-1.8%	-0.6%
	EU - Asia	billion kg pa	15.7	-17.7%	-2.4%	-1.6%	-0.7%
	EU - Other Europe	billion kg pa	6.6	-6.9%	-4.3%	-2.6%	-0.9%
	EU - Other World	billion kg pa	15.6	-12.1%	-4.6%	-2.8%	-0.9%
	All Other	billion kg pa	160.5	-9.5%	-0.1%	0.0%	0.0%
	Total	billion kg pa	241.7	-10.3%	-1.4%	-0.9%	-0.3%
CO2 emission	Intra EU	billion kg pa	61.7	-6.5%	-6.5%	-4.1%	-1.3%
	EU - North America	billion kg pa	75.0	-14.0%	-3.0%	-1.8%	-0.6%
	EU - Asia	billion kg pa	49.6	-17.7%	-2.4%	-1.6%	-0.7%
	EU - Other Europe	billion kg pa	21.0	-6.9%	-4.3%	-2.6%	-0.9%
	EU - Other World	billion kg pa	49.2	-12.1%	-4.6%	-2.8%	-0.9%
	All Other	billion kg pa	506.7	-9.5%	-0.1%	0.0%	0.0%
	Total	billion kg pa	763.2	-10.3%	-1.4%	-0.9%	-0.3%

Table 58 Effects for EU carriers versus other carriers of charges per ton CO_2 and kg NO_x computed with the AERO-MS (cases 5 through 8)

Effects	Region	Unit	AERO-M 2010	CO2-50/Nox-6global	CO2-50/Nox-6	CO2-30/Nox-3,6	CO2-10/Nox-1,2
Air transport and aircraft operation							
Revenue Tonne-Km	EU	billion RTK pa	187.0	-8.6%	-3.4%	-2.1%	-0.8%
	Other	billion RTK pa	641.1	-8.0%	-0.6%	-0.3%	-0.1%
	Total	billion RTK pa	828.1	-8.1%	-1.2%	-0.7%	-0.3%
Aircraft km	EU	billion ac-km pa	11.7	-8.0%	-4.4%	-2.8%	-1.0%
	Other	billion ac-km pa	40.9	-8.1%	-0.4%	-0.3%	-0.1%
	Total	billion ac-km pa	52.6	-8.1%	-1.3%	-0.8%	-0.3%
Effects on airlines							
Operating costs	EU	billion 1992 US$ pa	141.1	1.3%	0.5%	0.3%	0.1%
	Other	billion 1992 US$ pa	407.5	3.1%	0.1%	0.0%	0.0%
	Total	billion 1992 US$ pa	548.5	2.6%	0.2%	0.1%	0.0%
Operating revenues	EU	billion 1992 US$ pa	144.1	1.2%	0.4%	0.3%	0.1%
	Other	billion 1992 US$ pa	419.3	2.8%	0.1%	0.1%	0.0%
	Total	billion 1992 US$ pa	563.4	2.4%	0.2%	0.1%	0.0%
Operating results	EU	% of revenues	2.1%	2.0%	2.1%	2.1%	2.1%
	Other	% of revenues	2.8%	2.6%	2.8%	2.8%	2.8%
	Total	% of revenues	2.6%	2.4%	2.6%	2.6%	2.6%
Contribution to gross value added (GVA)	EU	billion 1992 US$ pa	67.8	-6.6%	-3.6%	-2.2%	-0.8%
	Other	billion 1992 US$ pa	230.5	-6.6%	-0.3%	-0.2%	-0.1%
	Total	billion 1992 US$ pa	298.2	-6.6%	-1.1%	-0.6%	-0.2%
Airlines related employment	EU	thousand employees	760	-8.6%	-4.4%	-2.7%	-1.0%
	Other	thousand employees	2844	-8.0%	-0.5%	-0.3%	-0.1%
	Total	thousand employees	3605	-8.2%	-1.4%	-0.8%	-0.3%
Economic effects for other actors							
Consumer surplus	EU	billion 1992 US$ pa	n.a.	-12.5	-6.2	-3.8	-1.3
	Other	billion 1992 US$ pa	n.a.	-42.1	-2.5	-1.5	-0.5
	Total	billion 1992 US$ pa	n.a.	-54.5	-8.6	-5.3	-1.8
Total fleet	EU	# aircraft	6661	-8.2%	-5.6%	-3.5%	-1.3%
	Other	# aircraft	26347	-9.3%	-0.4%	-0.2%	-0.1%
	Total	# aircraft	33008	-9.1%	-1.4%	-0.9%	-0.3%
Revenue from taxation	EU	billion 1992 US$ pa	n.a.	11.19	8.64	5.29	1.81
	Other	billion 1992 US$ pa	n.a.	42.31	0.00	0.00	0.00
	Total	billion 1992 US$ pa	n.a.	53.50	8.64	5.29	1.81
Fuel consumption and emissions							
Fuel use	EU	billion kg pa	53.6	-11.1%	-4.3%	-2.7%	-0.9%
	Other	billion kg pa	188.1	-10.1%	-0.6%	-0.4%	-0.1%
	Total	billion kg pa	241.7	-10.3%	-1.4%	-0.9%	-0.3%
CO2 emission	EU	billion kg pa	169.2	-11.1%	-4.3%	-2.7%	-0.9%
	Other	billion kg pa	593.9	-10.1%	-0.6%	-0.4%	-0.1%
	Total	billion kg pa	763.2	-10.3%	-1.4%	-0.9%	-0.3%
Operating efficiency							
Cost/RTK	EU	US$/tonne-km	0.75	10.8%	4.0%	2.4%	0.8%
	Other	US$/tonne-km	0.64	12.0%	0.6%	0.4%	0.1%
	Total	US$/tonne-km	0.66	11.7%	1.4%	0.8%	0.3%
Fuel/RTK	EU	kg/tonne-km	0.29	-2.7%	-1.0%	-0.6%	-0.2%
	Other	kg/tonne-km	0.29	-2.4%	-0.1%	0.0%	0.0%
	Total	kg/tonne-km	0.29	-2.4%	-0.2%	-0.1%	0.0%
RTK/ATK	EU	factor	0.70	-0.9%	-0.2%	-0.1%	0.0%
	Other	factor	0.66	-0.7%	0.0%	0.0%	0.0%
	Total	factor	0.67	-0.7%	-0.1%	0.0%	0.0%
RTK/aircraft-km	EU	tonne-km/ac-km	16.03	-0.7%	1.1%	0.7%	0.2%
	Other	tonne-km/ac-km	15.67	0.2%	-0.1%	-0.1%	0.0%
	Total	tonne-km/ac-km	15.75	0.0%	0.1%	0.1%	0.0%
Revenues/RTK	EU	US$/tonne-km	0.77	10.7%	4.0%	2.4%	0.8%
	Other	US$/tonne-km	0.65	11.7%	0.7%	0.4%	0.1%
	Total	US$/tonne-km	0.68	11.4%	1.4%	0.9%	0.3%
Fuel/aircraft-km	EU	kg/ac-km	4.60	-3.4%	0.1%	0.1%	0.1%
	Other	kg/ac-km	4.60	-2.2%	-0.2%	-0.1%	0.0%
	Total	kg/ac-km	4.60	-2.5%	-0.1%	0.0%	0.0%

Table 59 Effects by route group of revenue neutral PSI per ton CO_2 (cases 9 through 12)

Effects	Route group	Unit	AERO-M 2010	RN CO250global	RN CO2-50	RN CO2-30	RN CO2-10
Air transport and aircraft operation							
Passenger Km	Intra EU	billion pax-km pa	505.0	-0.3%	-0.2%	-0.1%	0.0%
	EU - North America	billion pax-km pa	611.6	-0.1%	0.0%	0.0%	0.0%
	EU - Asia	billion pax-km pa	435.2	-0.1%	0.0%	0.0%	0.0%
	EU - Other Europe	billion pax-km pa	189.3	-0.3%	-0.2%	-0.1%	0.0%
	EU - Other World	billion pax-km pa	418.0	-0.1%	0.0%	0.0%	0.0%
	All Other	billion pax-km pa	3673.6	-0.3%	0.0%	0.0%	0.0%
	Total	billion pax-km pa	5832.8	-0.3%	0.0%	0.0%	0.0%
Cargo Km	Intra EU	billion tonne-km pa	3.8	-1.0%	-1.0%	-0.6%	-0.2%
	EU - North America	billion tonne-km pa	38.5	-0.1%	0.0%	0.0%	0.0%
	EU - Asia	billion tonne-km pa	24.1	-0.1%	0.0%	0.0%	0.0%
	EU - Other Europe	billion tonne-km pa	1.8	-0.5%	-0.3%	-0.2%	-0.1%
	EU - Other World	billion tonne-km pa	18.3	-0.2%	0.0%	0.0%	0.0%
	All Other	billion tonne-km pa	158.5	-0.3%	0.0%	0.0%	0.0%
	Total	billion tonne-km pa	244.9	-0.3%	0.0%	0.0%	0.0%
Revenue Tonne-Km	Intra EU	billion RTK pa	54.3	-0.3%	-0.3%	-0.2%	-0.1%
	EU - North America	billion RTK pa	99.6	-0.1%	0.0%	0.0%	0.0%
	EU - Asia	billion RTK pa	67.7	-0.1%	0.0%	0.0%	0.0%
	EU - Other Europe	billion RTK pa	20.7	-0.3%	-0.2%	-0.1%	0.0%
	EU - Other World	billion RTK pa	60.1	-0.1%	0.0%	0.0%	0.0%
	All Other	billion RTK pa	525.8	-0.3%	0.0%	0.0%	0.0%
	Total	billion RTK pa	828.2	-0.3%	0.0%	0.0%	0.0%
Flights	Intra EU	million flights pa	8.5	-1.9%	-1.8%	-1.1%	-0.4%
	EU - North America	million flights pa	0.5	-1.1%	-0.2%	-0.1%	0.0%
	EU - Asia	million flights pa	0.2	-3.4%	-0.7%	-0.6%	-0.5%
	EU - Other Europe	million flights pa	1.7	-2.2%	-1.3%	-0.8%	-0.3%
	EU - Other World	million flights pa	0.5	-1.0%	-0.3%	-0.2%	-0.1%
	All Other	million flights pa	40.0	-2.4%	0.0%	0.0%	0.0%
	Total	million flights pa	51.4	-2.3%	-0.4%	-0.2%	-0.1%
Total aircraft km	Intra EU	billion ac-km pa	6.3	-1.7%	-1.6%	-1.0%	-0.4%
	EU - North America	billion ac-km pa	3.4	-1.1%	-0.2%	-0.1%	0.0%
	EU - Asia	billion ac-km pa	1.8	-3.5%	-0.7%	-0.5%	-0.4%
	EU - Other Europe	billion ac-km pa	2.1	-2.1%	-1.3%	-0.8%	-0.3%
	EU - Other World	billion ac-km pa	2.4	-1.1%	-0.3%	-0.2%	-0.1%
	All Other	billion ac-km pa	36.5	-2.0%	0.0%	0.0%	0.0%
	Total	billion ac-km pa	52.6	-1.9%	-0.3%	-0.2%	-0.1%
Aircraft km technology age > 12 years	Intra EU	billion ac-km pa	3.1	-5.2%	-5.2%	-3.2%	-1.1%
	EU - North America	billion ac-km pa	1.6	-13.8%	-2.9%	-1.9%	-0.8%
	EU - Asia	billion ac-km pa	0.7	-26.8%	-3.1%	-1.9%	-0.7%
	EU - Other Europe	billion ac-km pa	1.1	-6.2%	-3.8%	-2.4%	-0.8%
	EU - Other World	billion ac-km pa	1.3	-10.8%	-3.6%	-2.3%	-0.9%
	All Other	billion ac-km pa	17.7	-8.0%	-0.2%	-0.2%	-0.1%
	Total	billion ac-km pa	25.5	-8.6%	-1.4%	-0.9%	-0.4%
Aircraft km technology age <= 12 years	Intra EU	billion ac-km pa	3.2	1.7%	1.8%	1.1%	0.4%
	EU - North America	billion ac-km pa	1.8	10.6%	2.3%	1.5%	0.6%
	EU - Asia	billion ac-km pa	1.1	11.6%	0.9%	0.3%	-0.3%
	EU - Other Europe	billion ac-km pa	1.0	2.2%	1.3%	0.8%	0.3%
	EU - Other World	billion ac-km pa	1.1	9.9%	3.5%	2.2%	0.8%
	All Other	billion ac-km pa	18.8	3.6%	0.1%	0.1%	0.1%
	Total	billion ac-km pa	27.1	4.4%	0.7%	0.4%	0.2%
Fuel consumption							
Fuel use	Intra EU	billion kg pa	19.5	-1.0%	-1.0%	-0.6%	-0.1%
	EU - North America	billion kg pa	23.8	-3.0%	-0.5%	-0.3%	0.0%
	EU - Asia	billion kg pa	15.7	-6.2%	-1.0%	-0.7%	-0.5%
	EU - Other Europe	billion kg pa	6.6	-1.3%	-0.7%	-0.4%	-0.1%
	EU - Other World	billion kg pa	15.6	-2.0%	-0.5%	-0.3%	-0.1%
	All Other	billion kg pa	160.5	-2.1%	0.0%	0.1%	0.1%
	Total	billion kg pa	241.7	-2.4%	-0.2%	-0.1%	0.0%
CO2 emission	Intra EU	billion kg pa	61.7	-1.0%	-1.0%	-0.6%	-0.1%
	EU - North America	billion kg pa	75.0	-3.0%	-0.5%	-0.3%	0.0%
	EU - Asia	billion kg pa	49.6	-6.2%	-1.0%	-0.7%	-0.5%
	EU - Other Europe	billion kg pa	21.0	-1.3%	-0.7%	-0.4%	-0.1%
	EU - Other World	billion kg pa	49.2	-2.0%	-0.5%	-0.3%	-0.1%
	All Other	billion kg pa	506.7	-2.1%	0.0%	0.1%	0.1%
	Total	billion kg pa	763.2	-2.4%	-0.2%	-0.1%	0.0%

Table 60 Effects for EU carriers versus other carriers of revenue neutral PSI per ton CO_2 (cases 9 through 12)

Effects	Region	Unit	AERO-M 2010	RN CO250global	RN CO2-50	RN CO2-30	RN CO2-10
Air transport and aircraft operation							
Revenue Tonne-Km	EU	billion RTK pa	187.0	-0.2%	-0.1%	-0.1%	-0.1%
	Other	billion RTK pa	641.1	-0.3%	0.0%	0.0%	0.0%
	Total	billion RTK pa	828.1	-0.3%	0.0%	0.0%	0.0%
Aircraft km	EU	billion ac-km pa	11.7	-1.8%	-1.1%	-0.7%	-0.3%
	Other	billion ac-km pa	40.9	-2.0%	-0.1%	-0.1%	0.0%
	Total	billion ac-km pa	52.6	-1.9%	-0.3%	-0.2%	-0.1%
Effects on airlines							
Operating costs	EU	billion 1992 US$ pa	141.1	-0.6%	-0.3%	-0.2%	-0.1%
	Other	billion 1992 US$ pa	407.5	-0.5%	0.0%	0.0%	0.0%
	Total	billion 1992 US$ pa	548.5	-0.5%	-0.1%	-0.1%	0.0%
Operating revenues	EU	billion 1992 US$ pa	144.1	0.0%	0.0%	0.0%	0.0%
	Other	billion 1992 US$ pa	419.3	0.1%	0.0%	0.0%	0.0%
	Total	billion 1992 US$ pa	563.4	0.1%	0.0%	0.0%	0.0%
Operating results	EU	% of revenues	2.1%	2.7%	2.4%	2.3%	2.2%
	Other	% of revenues	2.8%	3.4%	2.9%	2.8%	2.8%
	Total	% of revenues	2.6%	3.2%	2.7%	2.7%	2.7%
Contribution to gross value added (GVA)	EU	billion 1992 US$ pa	67.8	1.1%	0.3%	0.1%	0.0%
	Other	billion 1992 US$ pa	230.5	0.9%	0.1%	0.1%	0.0%
	Total	billion 1992 US$ pa	298.2	0.9%	0.2%	0.1%	0.0%
Airlines related employment	EU	thousand employees	760	-1.3%	-0.8%	-0.5%	-0.2%
	Other	thousand employees	2844	-1.2%	0.0%	0.0%	0.0%
	Total	thousand employees	3605	-1.2%	-0.2%	-0.1%	0.0%
Economic effects for other actors							
Consumer surplus	EU	billion 1992 US$ pa	n.a.	-0.4	-0.3	-0.2	-0.1
	Other	billion 1992 US$ pa	n.a.	-1.8	-0.1	-0.1	0.0
	Total	billion 1992 US$ pa	n.a.	-2.3	-0.4	-0.2	-0.1
Total fleet	EU	# aircraft	6661	-3.4%	-2.3%	-1.5%	-0.5%
	Other	# aircraft	26347	-4.0%	-0.2%	-0.1%	-0.1%
	Total	# aircraft	33008	-3.9%	-0.6%	-0.4%	-0.2%
Revenue from taxation	EU	billion 1992 US$ pa	n.a.	-0.21	-0.01	0.01	0.01
	Other	billion 1992 US$ pa	n.a.	0.11	0.00	0.00	0.00
	Total	billion 1992 US$ pa	n.a.	-0.10	-0.01	0.01	0.01
Fuel consumption and emissions							
Fuel use	EU	billion kg pa	53.6	-2.4%	-0.8%	-0.5%	-0.2%
	Other	billion kg pa	188.1	-2.3%	-0.1%	0.0%	0.0%
	Total	billion kg pa	241.7	-2.4%	-0.2%	-0.1%	0.0%
CO2 emission	EU	billion kg pa	169.2	-2.4%	-0.8%	-0.5%	-0.2%
	Other	billion kg pa	593.9	-2.3%	-0.1%	0.0%	0.0%
	Total	billion kg pa	763.2	-2.4%	-0.2%	-0.1%	0.0%
Operating efficiency							
Cost/RTK	EU	US$/tonne-km	0.75	-0.3%	-0.2%	-0.1%	0.0%
	Other	US$/tonne-km	0.64	-0.2%	0.0%	0.0%	0.0%
	Total	US$/tonne-km	0.66	-0.2%	-0.1%	0.0%	0.0%
Fuel/RTK	EU	kg/tonne-km	0.29	-2.2%	-0.6%	-0.4%	-0.1%
	Other	kg/tonne-km	0.29	-2.1%	-0.1%	0.0%	0.0%
	Total	kg/tonne-km	0.29	-2.1%	-0.2%	-0.1%	0.0%
RTK/ATK	EU	factor	0.70	0.1%	0.1%	0.1%	0.1%
	Other	factor	0.66	0.0%	0.0%	0.0%	0.0%
	Total	factor	0.67	0.0%	0.0%	0.0%	0.0%
RTK/aircraft-km	EU	tonne-km/ac-km	16.03	1.6%	1.0%	0.6%	0.2%
	Other	tonne-km/ac-km	15.67	1.7%	0.1%	0.1%	0.0%
	Total	tonne-km/ac-km	15.75	1.7%	0.3%	0.2%	0.1%
Revenues/RTK	EU	US$/tonne-km	0.77	0.2%	0.1%	0.1%	0.0%
	Other	US$/tonne-km	0.65	0.4%	0.0%	0.0%	0.0%
	Total	US$/tonne-km	0.68	0.3%	0.0%	0.0%	0.0%
Fuel/aircraft-km	EU	kg/ac-km	4.60	-0.7%	0.3%	0.2%	0.1%
	Other	kg/ac-km	4.60	-0.4%	0.0%	0.0%	0.1%
	Total	kg/ac-km	4.60	-0.4%	0.1%	0.1%	0.1%

Table 61 Effects by route group of revenue neutral PSI per ton CO_2 and kg NOx (cases 13 through 16)

Effects	Route group	Unit	AERO-M 2010	RN CO2-50/Nox-6global	RN CO2-50/Nox-6	RN CO2-30/Nox-3,6	RN CO2-10/Nox-1,2
Air transport and aircraft operation							
Passenger Km	Intra EU	billion pax-km pa	505.0	-0.3%	-0.3%	-0.1%	-0.1%
	EU - North America	billion pax-km pa	611.6	-0.4%	-0.1%	0.0%	0.0%
	EU - Asia	billion pax-km pa	435.2	-0.7%	-0.1%	0.0%	0.0%
	EU - Other Europe	billion pax-km pa	189.3	-0.4%	-0.2%	-0.1%	0.0%
	EU - Other World	billion pax-km pa	418.0	-0.4%	-0.1%	-0.1%	0.0%
	All Other	billion pax-km pa	3673.6	-0.5%	0.0%	0.0%	0.0%
	Total	billion pax-km pa	5832.8	-0.5%	-0.1%	0.0%	0.0%
Cargo Km	Intra EU	billion tonne-km pa	3.8	-1.3%	-1.3%	-0.7%	-0.3%
	EU - North America	billion tonne-km pa	38.5	-0.6%	-0.1%	0.0%	0.0%
	EU - Asia	billion tonne-km pa	24.1	-0.5%	-0.1%	0.0%	0.0%
	EU - Other Europe	billion tonne-km pa	1.8	-0.7%	-0.4%	-0.3%	-0.1%
	EU - Other World	billion tonne-km pa	18.3	-0.5%	-0.2%	-0.1%	0.0%
	All Other	billion tonne-km pa	158.5	-0.6%	0.0%	0.0%	0.0%
	Total	billion tonne-km pa	244.9	-0.6%	-0.1%	0.0%	0.0%
Revenue Tonne-Km	Intra EU	billion RTK pa	54.3	-0.4%	-0.3%	-0.2%	-0.1%
	EU - North America	billion RTK pa	99.6	-0.4%	-0.1%	0.0%	0.0%
	EU - Asia	billion RTK pa	67.7	-0.6%	-0.1%	0.0%	0.0%
	EU - Other Europe	billion RTK pa	20.7	-0.4%	-0.2%	-0.1%	0.0%
	EU - Other World	billion RTK pa	60.1	-0.4%	-0.1%	-0.1%	0.0%
	All Other	billion RTK pa	525.8	-0.5%	0.0%	0.0%	0.0%
	Total	billion RTK pa	828.2	-0.5%	-0.1%	0.0%	0.0%
Flights	Intra EU	million flights pa	8.5	-2.1%	-2.1%	-1.3%	-0.4%
	EU - North America	million flights pa	0.5	-1.8%	-0.3%	-0.2%	-0.1%
	EU - Asia	million flights pa	0.2	-5.5%	-0.9%	-0.7%	-0.5%
	EU - Other Europe	million flights pa	1.7	-2.5%	-1.5%	-0.9%	-0.3%
	EU - Other World	million flights pa	0.5	-1.2%	-0.4%	-0.3%	-0.1%
	All Other	million flights pa	40.0	-2.8%	0.0%	0.0%	0.0%
	Total	million flights pa	51.4	-2.6%	-0.4%	-0.3%	-0.1%
Total aircraft km	Intra EU	billion ac-km pa	6.3	-1.8%	-1.8%	-1.1%	-0.4%
	EU - North America	billion ac-km pa	3.4	-1.9%	-0.4%	-0.2%	-0.1%
	EU - Asia	billion ac-km pa	1.8	-5.7%	-0.9%	-0.7%	-0.5%
	EU - Other Europe	billion ac-km pa	2.1	-2.4%	-1.5%	-0.9%	-0.3%
	EU - Other World	billion ac-km pa	2.4	-1.3%	-0.4%	-0.2%	-0.1%
	All Other	billion ac-km pa	36.5	-2.4%	0.0%	0.0%	0.0%
	Total	billion ac-km pa	52.6	-2.4%	-0.4%	-0.2%	-0.1%
Aircraft km	Intra EU	billion ac-km pa	3.1	-6.4%	-6.4%	-3.9%	-1.4%
technology age > 12 years	EU - North America	billion ac-km pa	1.6	-20.5%	-4.3%	-2.7%	-1.1%
	EU - Asia	billion ac-km pa	0.7	-40.4%	-4.9%	-3.0%	-1.1%
	EU - Other Europe	billion ac-km pa	1.1	-7.6%	-4.7%	-2.9%	-1.0%
	EU - Other World	billion ac-km pa	1.3	-15.6%	-5.3%	-3.3%	-1.2%
	All Other	billion ac-km pa	17.7	-10.7%	-0.2%	-0.2%	-0.1%
	Total	billion ac-km pa	25.5	-11.7%	-1.8%	-1.1%	-0.5%
Aircraft km	Intra EU	billion ac-km pa	3.2	2.6%	2.6%	1.6%	0.6%
technology age <= 12 years	EU - North America	billion ac-km pa	1.8	15.3%	3.3%	2.1%	0.9%
	EU - Asia	billion ac-km pa	1.1	16.8%	1.7%	0.8%	-0.1%
	EU - Other Europe	billion ac-km pa	1.0	3.1%	1.9%	1.2%	0.4%
	EU - Other World	billion ac-km pa	1.1	14.7%	5.1%	3.2%	1.2%
	All Other	billion ac-km pa	18.8	5.3%	0.2%	0.1%	0.1%
	Total	billion ac-km pa	27.1	6.4%	1.0%	0.6%	0.3%
Fuel consumption							
Fuel use	Intra EU	billion kg pa	19.5	-1.3%	-1.3%	-0.7%	-0.2%
	EU - North America	billion kg pa	23.8	-5.1%	-0.9%	-0.5%	-0.1%
	EU - Asia	billion kg pa	15.7	-9.9%	-1.4%	-1.0%	-0.5%
	EU - Other Europe	billion kg pa	6.6	-1.7%	-1.0%	-0.5%	-0.1%
	EU - Other World	billion kg pa	15.6	-3.2%	-1.0%	-0.5%	-0.1%
	All Other	billion kg pa	160.5	-3.2%	0.0%	0.0%	0.1%
	Total	billion kg pa	241.7	-3.6%	-0.4%	-0.2%	0.0%
CO2 emission	Intra EU	billion kg pa	61.7	-1.3%	-1.3%	-0.7%	-0.2%
	EU - North America	billion kg pa	75.0	-5.1%	-0.9%	-0.5%	-0.1%
	EU - Asia	billion kg pa	49.6	-9.9%	-1.4%	-1.0%	-0.5%
	EU - Other Europe	billion kg pa	21.0	-1.7%	-1.0%	-0.5%	-0.1%
	EU - Other World	billion kg pa	49.2	-3.2%	-1.0%	-0.5%	-0.1%
	All Other	billion kg pa	506.7	-3.2%	0.0%	0.0%	0.1%
	Total	billion kg pa	763.2	-3.6%	-0.4%	-0.2%	0.0%

Table 62 Effects for EU carriers versus other carriers of revenue PSI per ton CO_2 and kg NOx (cases 13 through 16)

Effects	Region	Unit	AERO-M 2010	RN CO2-50/Nox-6global	RN CO2-50/Nox-6	RN CO2-30/Nox-3,6	RN CO2-10/Nox-1,2
Air transport and aircraft operation							
Revenue Tonne-Km	EU	billion RTK pa	187.0	-0.5%	-0.2%	-0.1%	-0.1%
	Other	billion RTK pa	641.1	-0.5%	0.0%	0.0%	0.0%
	Total	billion RTK pa	828.1	-0.5%	-0.1%	0.0%	0.0%
Aircraft km	EU	billion ac-km pa	11.7	-2.2%	-1.2%	-0.8%	-0.3%
	Other	billion ac-km pa	40.9	-2.4%	-0.1%	-0.1%	0.0%
	Total	billion ac-km pa	52.6	-2.4%	-0.4%	-0.2%	-0.1%
Effects on airlines							
Operating costs	EU	billion 1992 US$ pa	141.1	-0.7%	-0.4%	-0.3%	-0.1%
	Other	billion 1992 US$ pa	407.5	-0.6%	0.0%	0.0%	0.0%
	Total	billion 1992 US$ pa	548.5	-0.6%	-0.1%	-0.1%	0.0%
Operating revenues	EU	billion 1992 US$ pa	144.1	0.0%	0.0%	0.0%	0.0%
	Other	billion 1992 US$ pa	419.3	0.2%	0.0%	0.0%	0.0%
	Total	billion 1992 US$ pa	563.4	0.1%	0.0%	0.0%	0.0%
Operating results	EU	% of revenues	2.1%	2.8%	2.5%	2.4%	2.2%
	Other	% of revenues	2.8%	3.5%	2.9%	2.9%	2.8%
	Total	% of revenues	2.6%	3.3%	2.8%	2.7%	2.7%
Contribution to gross value added	EU	billion 1992 US$ pa	67.8	1.4%	0.4%	0.3%	0.1%
(GVA)	Other	billion 1992 US$ pa	230.5	1.2%	0.2%	0.1%	0.0%
	Total	billion 1992 US$ pa	298.2	1.2%	0.2%	0.2%	0.1%
Airlines related employment	EU	thousand employees	760	-1.9%	-1.1%	-0.7%	-0.3%
	Other	thousand employees	2844	-1.7%	0.0%	0.0%	0.0%
	Total	thousand employees	3605	-1.8%	-0.2%	-0.1%	-0.1%
Economic effects for other actors							
Consumer surplus	EU	billion 1992 US$ pa	n.a.	-0.7	-0.4	-0.2	-0.1
	Other	billion 1992 US$ pa	n.a.	-2.9	-0.2	-0.1	0.0
	Total	billion 1992 US$ pa	n.a.	-3.6	-0.5	-0.3	-0.1
Total fleet	EU	# aircraft	6661	-4.1%	-2.8%	-1.7%	-0.6%
	Other	# aircraft	26347	-4.8%	-0.2%	-0.1%	-0.1%
	Total	# aircraft	33008	-4.7%	-0.7%	-0.4%	-0.2%
Revenue from taxation	EU	billion 1992 US$ pa	n.a.	-0.30	0.01	-0.08	-0.02
	Other	billion 1992 US$ pa	n.a.	0.31	0.00	0.00	0.00
	Total	billion 1992 US$ pa	n.a.	0.01	0.01	-0.08	-0.02
Fuel consumption and emissions							
Fuel use	EU	billion kg pa	53.6	-3.8%	-1.1%	-0.6%	-0.2%
	Other	billion kg pa	188.1	-3.5%	-0.1%	-0.1%	0.0%
	Total	billion kg pa	241.7	-3.6%	-0.4%	-0.2%	0.0%
CO2 emission	EU	billion kg pa	169.2	-3.8%	-1.1%	-0.6%	-0.2%
	Other	billion kg pa	593.9	-3.5%	-0.1%	-0.1%	0.0%
	Total	billion kg pa	763.2	-3.6%	-0.4%	-0.2%	0.0%
Operating efficiency							
Cost/RTK	EU	US$/tonne-km	0.75	-0.2%	-0.2%	-0.2%	-0.1%
	Other	US$/tonne-km	0.64	-0.1%	0.0%	0.0%	0.0%
	Total	US$/tonne-km	0.66	-0.1%	-0.1%	-0.1%	0.0%
Fuel/RTK	EU	kg/tonne-km	0.29	-3.4%	-0.9%	-0.5%	-0.2%
	Other	kg/tonne-km	0.29	-3.0%	-0.1%	0.0%	0.0%
	Total	kg/tonne-km	0.29	-3.1%	-0.3%	-0.2%	0.0%
RTK/ATK	EU	factor	0.70	0.1%	0.1%	0.1%	0.1%
	Other	factor	0.66	0.0%	0.0%	0.0%	0.0%
	Total	factor	0.67	0.0%	0.0%	0.0%	0.0%
RTK/aircraft-km	EU	tonne-km/ac-km	16.03	1.8%	1.1%	0.7%	0.2%
	Other	tonne-km/ac-km	15.67	2.0%	0.1%	0.1%	0.0%
	Total	tonne-km/ac-km	15.75	1.9%	0.3%	0.2%	0.1%
Revenues/RTK	EU	US$/tonne-km	0.77	0.5%	0.2%	0.1%	0.0%
	Other	US$/tonne-km	0.65	0.7%	0.0%	0.0%	0.0%
	Total	US$/tonne-km	0.68	0.6%	0.1%	0.0%	0.0%
Fuel/aircraft-km	EU	kg/ac-km	4.60	-1.6%	0.2%	0.1%	0.1%
	Other	kg/ac-km	4.60	-1.1%	0.0%	0.0%	0.0%
	Total	kg/ac-km	4.60	-1.2%	0.0%	0.0%	0.1%

Sensitivity analysis profit adjustment factor (fare adjustment behaviour)

This section presents the results from AERO assuming that airlines can *not* pass the whole cost increase due to the charge on to the customers.

AERO runs are carried out with a Profit Adjustment Factor (PAF) of 0.5. PAF = 0.5 implies that about half of the policy induced costs increases for airlines are passed on to the consumers. The analysis in the report is based on a PAF of 1 as no convincing arguments are found in this study that airlines could not pass the charge on to the customers (see also section 4.3).

The following cases (policy options) are computed as a sensitivity analysis under PAF = 0.5.

Table 63 Policy options (see also Table 54)

1	CO_2-50global	Global route charge with charging level of Euro 50 per ton CO_2
2	CO_2-50	Route charge in EU air space with charging level of Euro 50 per ton CO_2
3	CO_2-30	Route charge in EU air space with charging level of Euro 30 per ton CO_2
4	CO_2-10	Route charge in EU air space with charging level of Euro 10 per ton CO_2
5	CO_2-50/NOx-6global	Global route charge with charging level of Euro 50 per ton CO_2 and Euro 6 per kg NO_x
6	CO_2-50/NOx-6	Route charge in EU air space with charging level of Euro 50 per ton CO_2 and Euro 6 per kg NO_x
7	CO_2-30/NOx-3,6	Route charge in EU air space with charging level of Euro 30 per ton CO_2 and Euro 3,6 per kg NO_x
8	CO_2-10/NOx-1,2	Route charge in EU air space with charging level of Euro 10 per ton CO_2 and Euro 1,2 per kg NO_x

The effects are presented in the following tables:

Table 64	Effects by route group of charges per ton CO_2 - cases 1 through 4 – (PAF = 0.5)
Table 65	Effects for EU carriers versus other carriers of charges per ton CO_2 - cases 1 through 4 – (PAF = 0.5)
Table 66	Effects by route group of charges per ton CO_2 and kg NO_x - cases 5 through 8 – (PAF = 0.5)
Table 67	Effects for EU carriers versus other carriers of charges per ton CO_2 and kg NO_x - cases 5 through 8 – (PAF = 0.5)

Table 64 Effects by route group of charges per ton CO_2 - cases 1 through 4 – (PAF = 0.5)

Effects	Route group	Unit	AERO-M 2010 (PAF05)	CO2-50global	CO2-50	CO2-30	CO2-10
Air transport and aircraft operation							
Passenger Km	Intra EU	billion pax-km pa	505.0	-2.3%	-2.3%	-1.4%	-0.5%
	EU - North America	billion pax-km pa	611.6	-3.6%	-0.7%	-0.5%	-0.2%
	EU - Asia	billion pax-km pa	435.2	-3.5%	-0.4%	-0.2%	-0.1%
	EU - Other Europe	billion pax-km pa	189.3	-2.3%	-1.4%	-0.9%	-0.3%
	EU - Other World	billion pax-km pa	418.0	-3.5%	-1.3%	-0.8%	-0.3%
	All Other	billion pax-km pa	3673.6	-2.6%	0.0%	0.0%	0.0%
	Total	billion pax-km pa	5832.8	-2.8%	-0.5%	-0.3%	-0.1%
Cargo Km	Intra EU	billion tonne-km pa	3.8	-2.7%	-2.7%	-1.7%	-0.6%
	EU - North America	billion tonne-km pa	38.5	-3.4%	-0.7%	-0.4%	-0.1%
	EU - Asia	billion tonne-km pa	24.1	-2.6%	-0.3%	-0.2%	-0.1%
	EU - Other Europe	billion tonne-km pa	1.8	-2.2%	-1.3%	-0.8%	-0.3%
	EU - Other World	billion tonne-km pa	18.3	-2.5%	-0.9%	-0.6%	-0.2%
	All Other	billion tonne-km pa	158.5	-3.1%	0.0%	0.0%	0.0%
	Total	billion tonne-km pa	244.9	-3.0%	-0.3%	-0.2%	-0.1%
Revenue Tonne-Km	Intra EU	billion RTK pa	54.3	-2.3%	-2.3%	-1.4%	-0.5%
	EU - North America	billion RTK pa	99.6	-3.6%	-0.7%	-0.4%	-0.2%
	EU - Asia	billion RTK pa	67.7	-3.2%	-0.4%	-0.2%	-0.1%
	EU - Other Europe	billion RTK pa	20.7	-2.3%	-1.4%	-0.9%	-0.3%
	EU - Other World	billion RTK pa	60.1	-3.2%	-1.2%	-0.7%	-0.2%
	All Other	billion RTK pa	525.8	-2.7%	0.0%	0.0%	0.0%
	Total	billion RTK pa	828.2	-2.9%	-0.4%	-0.3%	-0.1%
Flights	Intra EU	million flights pa	8.5	-2.6%	-2.6%	-1.6%	-0.6%
	EU - North America	million flights pa	0.5	-4.2%	-0.8%	-0.5%	-0.2%
	EU - Asia	million flights pa	0.2	-6.4%	-1.0%	-0.8%	-0.5%
	EU - Other Europe	million flights pa	1.7	-3.2%	-2.0%	-1.2%	-0.4%
	EU - Other World	million flights pa	0.5	-3.8%	-1.5%	-0.9%	-0.3%
	All Other	million flights pa	40.0	-3.2%	0.0%	0.0%	0.0%
	Total	million flights pa	51.4	-3.1%	-0.5%	-0.3%	-0.1%
Total aircraft km	Intra EU	billion ac-km pa	6.3	-2.9%	-2.9%	-1.8%	-0.6%
	EU - North America	billion ac-km pa	3.4	-4.2%	-0.8%	-0.5%	-0.2%
	EU - Asia	billion ac-km pa	1.8	-6.5%	-1.0%	-0.8%	-0.5%
	EU - Other Europe	billion ac-km pa	2.1	-3.6%	-2.3%	-1.4%	-0.5%
	EU - Other World	billion ac-km pa	2.4	-4.1%	-1.4%	-0.8%	-0.3%
	All Other	billion ac-km pa	36.5	-3.6%	0.0%	0.0%	0.0%
	Total	billion ac-km pa	52.6	-3.7%	-0.6%	-0.4%	-0.1%
Aircraft km	Intra EU	billion ac-km pa	3.1	-6.3%	-6.3%	-3.9%	-1.4%
technology age > 12 years	EU - North America	billion ac-km pa	1.6	-16.5%	-3.5%	-2.2%	-0.9%
	EU - Asia	billion ac-km pa	0.7	-29.4%	-3.5%	-2.1%	-0.7%
	EU - Other Europe	billion ac-km pa	1.1	-7.5%	-4.7%	-2.9%	-1.0%
	EU - Other World	billion ac-km pa	1.3	-13.2%	-4.5%	-2.8%	-1.0%
	All Other	billion ac-km pa	17.7	-9.4%	-0.2%	-0.2%	-0.1%
	Total	billion ac-km pa	25.5	-10.2%	-1.6%	-1.0%	-0.4%
Aircraft km	Intra EU	billion ac-km pa	3.2	0.5%	0.5%	0.3%	0.1%
technology age <= 12 years	EU - North America	billion ac-km pa	1.8	7.0%	1.6%	1.0%	0.5%
	EU - Asia	billion ac-km pa	1.1	8.3%	0.6%	0.1%	-0.3%
	EU - Other Europe	billion ac-km pa	1.0	0.6%	0.2%	0.2%	0.1%
	EU - Other World	billion ac-km pa	1.1	6.2%	2.2%	1.4%	0.6%
	All Other	billion ac-km pa	18.8	1.9%	0.1%	0.1%	0.1%
	Total	billion ac-km pa	27.1	2.4%	0.4%	0.3%	0.1%
Fuel consumption							
Fuel use	Intra EU	billion kg pa	19.5	-2.6%	-2.6%	-1.5%	-0.6%
	EU - North America	billion kg pa	23.8	-6.3%	-1.2%	-0.7%	-0.2%
	EU - Asia	billion kg pa	15.7	-9.2%	-1.3%	-0.9%	-0.5%
	EU - Other Europe	billion kg pa	6.6	-3.0%	-1.8%	-1.1%	-0.3%
	EU - Other World	billion kg pa	15.6	-5.4%	-1.7%	-1.0%	-0.3%
	All Other	billion kg pa	160.5	-4.3%	0.0%	0.0%	0.1%
	Total	billion kg pa	241.7	-4.7%	-0.6%	-0.3%	-0.1%
CO2 emission	Intra EU	billion kg pa	61.7	-2.6%	-2.6%	-1.5%	-0.6%
	EU - North America	billion kg pa	75.0	-6.3%	-1.2%	-0.7%	-0.2%
	EU - Asia	billion kg pa	49.6	-9.2%	-1.3%	-0.9%	-0.5%
	EU - Other Europe	billion kg pa	21.0	-3.0%	-1.8%	-1.1%	-0.3%
	EU - Other World	billion kg pa	49.2	-5.4%	-1.7%	-1.0%	-0.3%
	All Other	billion kg pa	506.7	-4.3%	0.0%	0.0%	0.1%
	Total	billion kg pa	763.2	-4.7%	-0.6%	-0.3%	-0.1%

Table 65 Effects for EU carriers versus other carriers of charges per ton CO_2 - cases 1 through 4 – (PAF = 0.5)

Effects	Region	Unit	AERO-M 2010 (PAF05)	CO2-50global	CO2-50	CO2-30	CO2-10
Air transport and aircraft operation							
Revenue Tonne-Km	EU	billion RTK pa	187.0	-3.1%	-1.2%	-0.7%	-0.3%
	Other	billion RTK pa	641.1	-2.8%	-0.2%	-0.1%	0.0%
	Total	billion RTK pa	828.1	-2.9%	-0.4%	-0.3%	-0.1%
Aircraft km	EU	billion ac-km pa	11.7	-3.7%	-2.1%	-1.3%	-0.5%
	Other	billion ac-km pa	40.9	-3.7%	-0.2%	-0.1%	0.0%
	Total	billion ac-km pa	52.6	-3.7%	-0.6%	-0.4%	-0.1%
Effects on airlines							
Operating costs	EU	billion 1992 US$ pa	141.1	3.3%	1.7%	1.0%	0.3%
	Other	billion 1992 US$ pa	407.5	4.5%	0.2%	0.1%	0.0%
	Total	billion 1992 US$ pa	548.5	4.2%	0.6%	0.4%	0.1%
Operating revenues	EU	billion 1992 US$ pa	144.1	0.4%	0.1%	0.1%	0.0%
	Other	billion 1992 US$ pa	419.3	1.0%	0.0%	0.0%	0.0%
	Total	billion 1992 US$ pa	563.4	0.8%	0.1%	0.0%	0.0%
Operating results	EU	% of revenues	2.1%	-0.7%	0.6%	1.2%	1.9%
	Other	% of revenues	2.8%	-0.6%	2.6%	2.7%	2.8%
	Total	% of revenues	2.6%	-0.7%	2.1%	2.3%	2.5%
Contribution to gross value added (GVA)	EU	billion 1992 US$ pa	67.8	-8.3%	-4.4%	-2.7%	-0.9%
	Other	billion 1992 US$ pa	230.5	-8.4%	-0.4%	-0.2%	-0.1%
	Total	billion 1992 US$ pa	298.2	-8.4%	-1.3%	-0.8%	-0.3%
Airlines related employment	EU	thousand employees	760	-3.6%	-1.9%	-1.2%	-0.4%
	Other	thousand employees	2844	-3.3%	-0.2%	-0.1%	0.0%
	Total	thousand employees	3605	-3.3%	-0.5%	-0.3%	-0.1%
Economic effects for other actors							
Consumer surplus	EU	billion 1992 US$ pa	n.a.	-4.2	-2.1	-1.3	-0.4
	Other	billion 1992 US$ pa	n.a.	-14.3	-0.8	-0.5	-0.2
	Total	billion 1992 US$ pa	n.a.	-18.5	-2.9	-1.8	-0.6
Total fleet	EU	# aircraft	6661	-4.5%	-3.0%	-1.9%	-0.7%
	Other	# aircraft	26347	-4.8%	-0.2%	-0.1%	-0.1%
	Total	# aircraft	33008	-4.7%	-0.8%	-0.5%	-0.2%
Revenue from taxation	EU	billion 1992 US$ pa	n.a.	7.9	6.0	3.6	1.2
	Other	billion 1992 US$ pa	n.a.	29.7	0.0	0.0	0.0
	Total	billion 1992 US$ pa	n.a.	37.6	6.0	3.6	1.2
Fuel consumption and emissions							
Fuel use	EU	billion kg pa	53.6	-5.0%	-1.8%	-1.1%	-0.4%
	Other	billion kg pa	188.1	-4.6%	-0.2%	-0.1%	0.0%
	Total	billion kg pa	241.7	-4.7%	-0.6%	-0.3%	-0.1%
CO2 emission	EU	billion kg pa	169.2	-5.0%	-1.8%	-1.1%	-0.4%
	Other	billion kg pa	593.9	-4.6%	-0.2%	-0.1%	0.0%
	Total	billion kg pa	763.2	-4.7%	-0.6%	-0.3%	-0.1%
Operating efficiency							
Cost/RTK	EU	US$/tonne-km	0.75	6.6%	2.9%	1.7%	0.5%
	Other	US$/tonne-km	0.64	7.6%	0.4%	0.2%	0.1%
	Total	US$/tonne-km	0.66	7.3%	1.0%	0.6%	0.2%
Fuel/RTK	EU	kg/tonne-km	0.29	-2.0%	-0.6%	-0.3%	-0.1%
	Other	kg/tonne-km	0.29	-1.8%	0.0%	0.0%	0.0%
	Total	kg/tonne-km	0.29	-1.9%	-0.2%	-0.1%	0.0%
RTK/ATK	EU	factor	0.70	-0.2%	0.0%	0.0%	0.1%
	Other	factor	0.66	-0.2%	0.0%	0.0%	0.0%
	Total	factor	0.67	-0.2%	0.0%	0.0%	0.0%
RTK/aircraft-km	EU	tonne-km/ac-km	16.03	0.6%	0.9%	0.5%	0.2%
	Other	tonne-km/ac-km	15.67	0.9%	0.0%	0.0%	0.0%
	Total	tonne-km/ac-km	15.75	0.9%	0.2%	0.1%	0.1%
Revenues/RTK	EU	US$/tonne-km	0.77	3.5%	1.4%	0.8%	0.3%
	Other	US$/tonne-km	0.65	3.9%	0.2%	0.1%	0.0%
	Total	US$/tonne-km	0.68	3.8%	0.5%	0.3%	0.1%
Fuel/aircraft-km	EU	kg/ac-km	4.60	-1.4%	0.3%	0.2%	0.1%
	Other	kg/ac-km	4.60	-0.9%	0.0%	0.0%	0.0%
	Total	kg/ac-km	4.60	-1.0%	0.0%	0.1%	0.1%

Table 66 Effects by route group of charges per ton CO_2 and kg NO_X - cases 5 through 8 – (PAF = 0.5)

Effects	Route group	Unit	AERO-M 2010 (PAF05)	CO2-50/Nox-6global	CO2-50/Nox-6	CO2-30/Nox-3,6	CO2-10/Nox-1,2
Air transport and aircraft operation							
Passenger Km	Intra EU	billion pax-km pa	505.0	-3.3%	-3.3%	-2.0%	-0.7%
	EU - North America	billion pax-km pa	611.6	-5.5%	-1.2%	-0.7%	-0.2%
	EU - Asia	billion pax-km pa	435.2	-5.4%	-0.6%	-0.4%	-0.1%
	EU - Other Europe	billion pax-km pa	189.3	-3.3%	-2.1%	-1.3%	-0.4%
	EU - Other World	billion pax-km pa	418.0	-5.3%	-2.0%	-1.2%	-0.4%
	All Other	billion pax-km pa	3673.6	-3.8%	-0.1%	0.0%	0.0%
	Total	billion pax-km pa	5832.8	-4.2%	-0.7%	-0.4%	-0.1%
Cargo Km	Intra EU	billion tonne-km pa	3.8	-3.9%	-3.9%	-2.4%	-0.8%
	EU - North America	billion tonne-km pa	38.5	-5.2%	-1.1%	-0.7%	-0.2%
	EU - Asia	billion tonne-km pa	24.1	-4.1%	-0.5%	-0.3%	-0.1%
	EU - Other Europe	billion tonne-km pa	1.8	-3.1%	-1.8%	-1.1%	-0.4%
	EU - Other World	billion tonne-km pa	18.3	-3.8%	-1.4%	-0.9%	-0.3%
	All Other	billion tonne-km pa	158.5	-4.6%	0.0%	0.0%	0.0%
	Total	billion tonne-km pa	244.9	-4.5%	-0.4%	-0.3%	-0.1%
Revenue Tonne-Km	Intra EU	billion RTK pa	54.3	-3.4%	-3.4%	-2.1%	-0.7%
	EU - North America	billion RTK pa	99.6	-5.4%	-1.1%	-0.7%	-0.2%
	EU - Asia	billion RTK pa	67.7	-4.9%	-0.6%	-0.3%	-0.1%
	EU - Other Europe	billion RTK pa	20.7	-3.3%	-2.1%	-1.2%	-0.4%
	EU - Other World	billion RTK pa	60.1	-4.9%	-1.8%	-1.1%	-0.4%
	All Other	billion RTK pa	525.8	-4.1%	-0.1%	0.0%	0.0%
	Total	billion RTK pa	828.2	-4.3%	-0.6%	-0.4%	-0.1%
Flights	Intra EU	million flights pa	8.5	-3.3%	-3.3%	-2.1%	-0.7%
	EU - North America	million flights pa	0.5	-6.3%	-1.3%	-0.8%	-0.3%
	EU - Asia	million flights pa	0.2	-9.8%	-1.4%	-1.0%	-0.6%
	EU - Other Europe	million flights pa	1.7	-3.9%	-2.6%	-1.6%	-0.5%
	EU - Other World	million flights pa	0.5	-5.2%	-2.1%	-1.3%	-0.4%
	All Other	million flights pa	40.0	-4.2%	0.0%	0.0%	0.0%
	Total	million flights pa	51.4	-4.1%	-0.7%	-0.4%	-0.2%
Total aircraft km	Intra EU	billion ac-km pa	6.3	-3.7%	-3.7%	-2.3%	-0.8%
	EU - North America	billion ac-km pa	3.4	-6.4%	-1.3%	-0.8%	-0.3%
	EU - Asia	billion ac-km pa	1.8	-10.0%	-1.4%	-1.0%	-0.6%
	EU - Other Europe	billion ac-km pa	2.1	-4.3%	-2.9%	-1.8%	-0.6%
	EU - Other World	billion ac-km pa	2.4	-5.6%	-2.0%	-1.2%	-0.4%
	All Other	billion ac-km pa	36.5	-4.8%	0.0%	0.0%	0.0%
	Total	billion ac-km pa	52.6	-5.0%	-0.8%	-0.5%	-0.2%
Aircraft km	Intra EU	billion ac-km pa	3.1	-8.1%	-8.1%	-5.0%	-1.7%
technology age > 12 years	EU - North America	billion ac-km pa	1.6	-24.1%	-5.2%	-3.2%	-1.2%
	EU - Asia	billion ac-km pa	0.7	-43.6%	-5.4%	-3.3%	-1.1%
	EU - Other Europe	billion ac-km pa	1.1	-9.3%	-6.0%	-3.7%	-1.3%
	EU - Other World	billion ac-km pa	1.3	-18.7%	-6.6%	-4.1%	-1.5%
	All Other	billion ac-km pa	17.7	-12.7%	-0.2%	-0.2%	-0.1%
	Total	billion ac-km pa	25.5	-13.9%	-2.2%	-1.4%	-0.5%
Aircraft km	Intra EU	billion ac-km pa	3.2	0.5%	0.5%	0.4%	0.2%
technology age <= 12 years	EU - North America	billion ac-km pa	1.8	9.9%	2.3%	1.5%	0.6%
	EU - Asia	billion ac-km pa	1.1	11.9%	1.2%	0.5%	-0.2%
	EU - Other Europe	billion ac-km pa	1.0	0.9%	0.3%	0.2%	0.1%
	EU - Other World	billion ac-km pa	1.1	9.2%	3.2%	2.0%	0.8%
	All Other	billion ac-km pa	18.8	2.6%	0.1%	0.1%	0.1%
	Total	billion ac-km pa	27.1	3.4%	0.5%	0.3%	0.2%
Fuel consumption							
Fuel use	Intra EU	billion kg pa	19.5	-3.8%	-3.8%	-2.2%	-0.7%
	EU - North America	billion kg pa	23.8	-9.7%	-1.9%	-1.1%	-0.3%
	EU - Asia	billion kg pa	15.7	-14.0%	-1.9%	-1.3%	-0.6%
	EU - Other Europe	billion kg pa	6.6	-4.1%	-2.6%	-1.6%	-0.5%
	EU - Other World	billion kg pa	15.6	-7.9%	-2.7%	-1.6%	-0.5%
	All Other	billion kg pa	160.5	-6.3%	0.0%	0.0%	0.1%
	Total	billion kg pa	241.7	-6.9%	-0.9%	-0.5%	-0.1%
CO2 emission	Intra EU	billion kg pa	61.7	-3.8%	-3.8%	-2.2%	-0.7%
	EU - North America	billion kg pa	75.0	-9.7%	-1.9%	-1.1%	-0.3%
	EU - Asia	billion kg pa	49.6	-14.0%	-1.9%	-1.3%	-0.6%
	EU - Other Europe	billion kg pa	21.0	-4.1%	-2.6%	-1.6%	-0.5%
	EU - Other World	billion kg pa	49.2	-7.9%	-2.7%	-1.6%	-0.5%
	All Other	billion kg pa	506.7	-6.3%	0.0%	0.0%	0.1%
	Total	billion kg pa	763.2	-6.9%	-0.9%	-0.5%	-0.1%

Table 67 Effects for EU carriers versus other carriers of charges per ton CO_2 and kg NO_X - cases 5 through 8 – (PAF = 0.5)

Effects	Region	Unit	AERO-M 2010	CO2-50/Nox-6global	CO2-50/Nox-6	CO2-30/Nox-3,6	CO2-10/Nox-1,2
Air transport and aircraft operation							
Revenue Tonne-Km	EU	billion RTK pa	187.0	-3.1%	-1.8%	-1.1%	-0.4%
	Other	billion RTK pa	641.1	-2.8%	-0.3%	-0.2%	-0.1%
	Total	billion RTK pa	828.1	-2.9%	-0.6%	-0.4%	-0.1%
Aircraft km	EU	billion ac-km pa	11.7	-3.7%	-2.7%	-1.7%	-0.6%
	Other	billion ac-km pa	40.9	-3.7%	-0.3%	-0.2%	-0.1%
	Total	billion ac-km pa	52.6	-3.7%	-0.8%	-0.5%	-0.2%
Effects on airlines							
Operating costs	EU	billion 1992 US$ pa	141.1	3.3%	2.4%	1.5%	0.5%
	Other	billion 1992 US$ pa	407.5	4.5%	0.3%	0.2%	0.1%
	Total	billion 1992 US$ pa	548.5	4.2%	0.9%	0.5%	0.2%
Operating revenues	EU	billion 1992 US$ pa	144.1	0.4%	0.2%	0.1%	0.0%
	Other	billion 1992 US$ pa	419.3	1.0%	0.0%	0.0%	0.0%
	Total	billion 1992 US$ pa	563.4	0.8%	0.1%	0.1%	0.0%
Operating results	EU	% of revenues	2.1%	-0.7%	-0.1%	0.8%	1.7%
	Other	% of revenues	2.8%	-0.6%	2.5%	2.6%	2.8%
	Total	% of revenues	2.6%	-0.7%	1.9%	2.2%	2.5%
Contribution to gross value added (GVA)	EU	billion 1992 US$ pa	67.8	-8.3%	-6.5%	-3.9%	-1.3%
	Other	billion 1992 US$ pa	230.5	-8.4%	-0.6%	-0.4%	-0.1%
	Total	billion 1992 US$ pa	298.2	-8.4%	-2.0%	-1.2%	-0.4%
Airlines related employment	EU	thousand employees	760	-3.6%	-2.6%	-1.6%	-0.6%
	Other	thousand employees	2844	-3.3%	-0.3%	-0.2%	-0.1%
	Total	thousand employees	3605	-3.3%	-0.8%	-0.5%	-0.2%
Economic effects for other actors							
Consumer surplus	EU	billion 1992 US$ pa	n.a.	-4.2	-3.1	-1.9	-0.6
	Other	billion 1992 US$ pa	n.a.	-14.3	-1.2	-0.8	-0.3
	Total	billion 1992 US$ pa	n.a.	-18.5	-4.4	-2.7	-0.9
Total fleet	EU	# aircraft	6661	-4.5%	-3.8%	-2.4%	-0.8%
	Other	# aircraft	26347	-4.8%	-0.3%	-0.2%	-0.1%
	Total	# aircraft	33008	-4.7%	-1.0%	-0.6%	-0.2%
Revenue from taxation	EU	billion 1992 US$ pa	n.a.	7.90	8.84	5.37	1.82
	Other	billion 1992 US$ pa	n.a.	29.71	0.00	0.00	0.00
	Total	billion 1992 US$ pa	n.a.	37.61	8.84	5.37	1.82
Fuel consumption and emissions							
Fuel use	EU	billion kg pa	53.6	-5.0%	-2.6%	-1.6%	-0.5%
	Other	billion kg pa	188.1	-4.6%	-0.4%	-0.2%	0.0%
	Total	billion kg pa	241.7	-4.7%	-0.9%	-0.5%	-0.1%
CO2 emission	EU	billion kg pa	169.2	-5.0%	-2.6%	-1.6%	-0.5%
	Other	billion kg pa	593.9	-4.6%	-0.4%	-0.2%	0.0%
	Total	billion kg pa	763.2	-4.7%	-0.9%	-0.5%	-0.1%
Operating efficiency							
Cost/RTK	EU	US$/tonne-km	0.75	6.6%	4.3%	2.6%	0.9%
	Other	US$/tonne-km	0.64	7.6%	0.6%	0.4%	0.1%
	Total	US$/tonne-km	0.66	7.3%	1.5%	0.9%	0.3%
Fuel/RTK	EU	kg/tonne-km	0.29	-2.0%	-0.9%	-0.5%	-0.2%
	Other	kg/tonne-km	0.29	-1.8%	-0.1%	0.0%	0.0%
	Total	kg/tonne-km	0.29	-1.9%	-0.3%	-0.1%	0.0%
RTK/ATK	EU	factor	0.70	-0.2%	-0.1%	0.0%	0.0%
	Other	factor	0.66	-0.2%	0.0%	0.0%	0.0%
	Total	factor	0.67	-0.2%	0.0%	0.0%	0.0%
RTK/aircraft-km	EU	tonne-km/ac-km	16.03	0.6%	1.0%	0.6%	0.2%
	Other	tonne-km/ac-km	15.67	0.9%	0.0%	0.0%	0.0%
	Total	tonne-km/ac-km	15.75	0.9%	0.2%	0.1%	0.0%
Revenues/RTK	EU	US$/tonne-km	0.77	3.5%	2.0%	1.2%	0.4%
	Other	US$/tonne-km	0.65	3.9%	0.3%	0.2%	0.1%
	Total	US$/tonne-km	0.68	3.8%	0.7%	0.4%	0.1%
Fuel/aircraft-km	EU	kg/ac-km	4.60	-1.4%	0.1%	0.1%	0.0%
	Other	kg/ac-km	4.60	-0.9%	-0.1%	0.0%	0.0%
	Total	kg/ac-km	4.60	-1.0%	-0.1%	0.0%	0.0%

H Aircraft categories, data and units

H.1 Aircraft categories and stage length EU airspace

The following aircraft categories have been distinguished.

Table 68 Aircraft types by MTOW class, and their emissions in EU15 airspace in 2000

Type	MTOW (tonnes)	# seats (indicative)	most used	aircraft km EU15 (mln)		MZFW km EU15 (bln)		CO_2 emissions (Mtonnes)	
				mln	%	abs	%	abs	%
1	< 55	< 110	BAe 146	1,642	35%	30	7%	10,8	13%
2	55-70	110-140	MD87	1,945	42%	90	20%	21,1	26%
3	70-100	140-170	A320	1,062	23%	57	13%	11,1	14%
4	100-165	170-210	B757-200	707	15%	60	14%	10,1	13%
5	165-250	210-280	B767-300	458	10%	55	13%	8,3	10%
6	250-350	280-360	B777-200	414	9%	70	16%	8,5	11%
7	> 350	> 360	B747-400	354	8%	80	18%	10,4	13%
total				6,582	100%	444	100%	80,4	100%

Table 69 Average stage lengths of the 7 aircraft types considered in this study, in kilometres, year 2000

aircraft type	stage length O-D (origin-destination)	stage length in EUROCONTROL airspace	stage length in EU15 airspace (charged)	stage length EU15 as % of stage length O-D
1	491	424	390	79%
2	966	854	777	80%
3	1,075	934	840	78%
4	2,146	1,409	1,254	58%
5	4,333	1,523	1,340	31%
6	6,213	1,783	1,551	25%
7	6,878	1,730	1,488	22%
aver-age	1,238	772	696	56%

The ‘average’ row says the average stage distance of *aircraft* is 1,238 km. The average distance an individual *passenger* is transported is longer because larger aircraft make longer trips with more passengers on board.

As expected the larger the aircraft, the longer its average trip is, and the smaller part of this trip is made in EU15 airspace. The largest aircraft landing and/or departing in the EU15 on average fly about 20-25% of their stage in EU airspace, and thus 20-25% of their average trip is charged.

NO_X emission indices per aircraft type were derived using APD and AERO emission indices for the 4 sample aircraft and NO_X totals from the 1999 IPCC report.

Table 70 Average NO_X emission indices (EI) factors used for the different aircraft types in the different flight stages, in g/kg fuel

aircraft type	500 km	2,000 km	6,000 km	10,000 km
1	10.0	9.0	n.a.	n.a.
2	11.0	10.0	10.0	n.a.
3	12.0	10.5	10.5	11.0
4	13.0	11.5	11.0	11.5
5	14.0	12.5	12.0	12.5
6	15.0	13.5	13.0	13.5
7	15.0	13.0	12.5	13.0

Table 71 Total CO_2 and NO_X emissions in EU15 airspace in 2000 from the 7 aircraft types

Type	CO_2 (ktonnes)					NO_X (tonnes)				
	500	2000	6000	10000	total	500	2000	6000	10000	total
1	9335	1494			10829	29633	4269			33902
2	8788	12085	246		21119	30690	38364	781		69835
3	4361	6527	152	53	11092	16614	21757	505	183	39060
4	1221	7027	1647	213	10109	5041	25654	5752	778	37225
5	669	2327	4356	935	8287	2975	9232	16596	3710	32513
6	177	678	4731	2938	8524	844	2906	19524	12592	35866
7	259	598	4765	4805	10427	1233	2468	18909	19830	42439
total	24811	30736	15897	8943	**80387**	87031	104650	62067	37093	**290840**

H.2 Units

The following factors were used in this report:
- Fuel costs: $ 0.28 per kg;
- EUR/$ conversion rate 1:1 (EUR and $ are both used);
- Emission factor for CO_2 is 3.16 kg per kg fuel.