

**SPECIAL ISSUES IN CARBON/ENERGY TAXATION:
MARINE BUNKER FUEL CHARGES**

**Annex I Expert Group on the United Nations Framework Convention on Climate Change
Working Paper No. 12**

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

Paris

62732

Document complet disponible sur OLIS dans son format d'origine

Complete document available on OLIS in its original format

ACKNOWLEDGEMENTS

This study was prepared by Laurie Michaelis of the OECD Secretariat, working with the Annex I Expert Group on the UN Framework Convention on Climate Change. Valuable comments and contributions were provided by John Crayston and Andrew Smith of ICAO and the ICAO Committee on Aviation Environmental Policy Working Group on Emissions.

Copyright OECD, 1997

Applications for permission to reproduce or translate all or part of this material should be made to:

Head of Publications Service, OECD, 2 rue André Pascal, 75775 Paris Cedex 16, France.

FOREWORD

This Working Paper is one of a series of 18 studies carried out under the project: "Policies and Measures for Possible Common Action". The project was carried out by the OECD, together with the International Energy Agency, in 1996 and 1997 for the Annex I Expert Group on the United Nations Framework Convention on Climate Change (UNFCCC). The goal of the project was to assess a range of cost-effective greenhouse gas mitigation policies and measures for countries and Parties listed in Annex I to the UNFCCC. The eighteen working papers have been made widely available as analytical input to negotiations under the UNFCCC Ad hoc Group on the Berlin Mandate. The working papers may also provide input to national decision making processes on greenhouse gas mitigation policies. The measures analysed do not necessarily represent policy preferences of Annex I Parties.

The project benefited greatly from substantial input from delegates. Three successive chairmen of the Annex I Expert Group provided outstanding leadership for the project: Doug Russell (Canada); Ross Glasgow (Canada); and Ian Pickard (United Kingdom). The work was supervised by Jan Corfee Morlot (OECD). Fiona Mullins (OECD) drafted the initial framework which was used to structure the eighteen working papers.

The Annex I Parties or countries referred to in this document refer to those listed in Annex I to the UNFCCC: Australia, Austria, Belarus, Belgium, Bulgaria, Canada, Czechoslovakia (now Czech Republic and Slovakia), Denmark, the European Community, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Lithuania, Luxembourg, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom and United States. Where this document refers to "countries" or "governments" it is also intended to include "regional economic organisations," if appropriate.

This document is published on the responsibility of the Secretary-General of the OECD.

TABLE OF CONTENTS

EXECUTIVE SUMMARY	9
CONTEXT	17
Emissions of Greenhouse Gas from Aviation in 1990	17
Key Aviation Trends	19
The Policy Context	24
Allocation of International Aviation greenhouse gas Emissions under the UNFCCC	26
POLICY OBJECTIVES AND DESCRIPTION	28
Alternative Measures for Greenhouse Gas Mitigation and Possible Common Action	29
APPROACH	30
Projections of future traffic and energy use	30
Estimating Effects of Charges	31
EFFECTS ON GREENHOUSE GAS EMISSIONS	32
Effects of an aviation fuel charge on greenhouse gas emissions	32
Other Measures	40
ECONOMIC, EMPLOYMENT, TRADE, AND OTHER EFFECTS	42
Economic Rationale for a Charge on Fuel	42
Economic Effects of a Charge	43
Costs of Non-Uniform Implementation of a Charge	45
COMMON ACTION	46
Advantages of common action	46
Regional Co-ordination	46
Co-ordination by route groups	47
Disadvantages of common action	47
Possible Common Actions	47
Political Feasibility/Barriers and Implementation Issues for Common Action	48
Options for Addressing Barriers	49
Possible participants, timing and vehicles for action	50
APPENDIX A. AVIATION GREENHOUSE GAS EMISSION SCENARIOS	52
Choice of Aviation Scenarios for this Study	52
ICAO Forecasts	53
APPENDIX B. THE ICAO POSITION ON TAXES AND CHARGES	57
APPENDIX C. ESTIMATING THE EFFECTS OF A CHARGE ON AVIATION FUEL	60

Regional Differences.....	60
Additional Analysis of Historical Data	
APPENDIX D. POSSIBLE TECHNICAL CHANGES IN RESPONSE TO FUEL CHARGES	64
Reducing NO _x emissions	65
Alternative aviation fuels	65
APPENDIX E. THE AERO PROJECT.....	66
APPENDIX F. EMISSION BUDGETS FOR CIVIL AVIATION: A SUGGESTION	68
A. General points on environmental taxes and trading	68
B. International Emissions Budgets for the Civil Aviation Sector	69
Elements of an International Emissions Budget System for the Aviation Sector	70
REFERENCES.....	75
ACRONYMS USED IN THIS REPORT	79

LIST OF FIGURES AND TABLES

FIGURE 1A. CO ₂ INTENSITY OF PASSENGER TRANSPORT.....	10
FIGURE 1B. CO ₂ INTENSITY OF FREIGHT TRANSPORT.....	10
FIGURE 2. EFFECT OF ACCELERATED ENERGY INTENSITY REDUCTIONS ON ANNEX I COUNTRY CARBON EMISSIONS FROM CIVIL AVIATION.....	13
FIGURE 3. REGIONAL SHARES OF WORLD SCHEDULED AIR TRAFFIC.....	19
FIGURE 4. AVIATION TONNE-KM PERFORMED (TKP) AND YIELD.....	20
FIGURE 5. ANNUAL TKP GROWTH AND ANNUAL REDUCTION IN YIELD.....	21
FIGURE 6. ENERGY INTENSITY, 1961-1995.....	22
FIGURE 7. AVIATION SHARE OF TRANSPORT ENERGY USE AND CO ₂ EMISSIONS.....	23
FIGURE 8. COMPARISON OF CARBON EMISSIONS FROM DIFFERENT TRANSPORT MODES.....	23
FIGURE 9. SCENARIOS OF CARBON EMISSIONS FROM CIVIL AVIATION.....	31
FIGURE 10. REAL FUEL PRICE AND ANNUAL GROWTH IN AIR TRAFFIC.....	34
FIGURE 11. AVERAGE ANNUAL RATE OF ENERGY INTENSITY DECREASE VS. FUEL COST PER TONNE-KM (REAL 1992 US¢) AND FUEL SHARE OF AIRLINE COSTS.....	36
FIGURE 12. EFFECTS OF ACCELERATED ENERGY EFFICIENCY INCREASES ON ANNEX I COUNTRY CIVIL AVIATION CARBON EMISSIONS.....	38
FIGURE 13. ANNUAL REDUCTION IN LABOUR COST AND YIELD VS. FUEL PRICE.....	63
FIGURE 14. AIRLINE OPERATING REVENUE MINUS EXPENSES VS. FUEL PRICE.....	63
TABLE 1. EFFECT OF A GLOBALLY APPLIED FUEL CHARGE ON INTERNATIONAL AIR PASSENGER TRAFFIC.....	12
TABLE 2. COMMERCIAL AIRLINE FUEL CONSUMPTION AND AIRCRAFT CAPACITY, 1990.....	19
TABLE 3. EFFECT OF A GLOBALLY APPLIED CO ₂ CHARGE ON INTERNATIONAL AIR PASSENGER TRAFFIC.....	34
TABLE 4. OPTIONS FOR AVIATION CHARGES.....	41
TABLE 5. OPERATING REVENUE AND OPERATING RESULT, AIRLINES BY WORLD REGION, 1992.....	44
TABLE 6. ICAO FORECASTS OF SCHEDULED PASSENGER TRAFFIC BY REGION OF AIRLINE REGISTRATION.....	53
TABLE 7. AIR PASSENGER KILOMETRES (BILLION PASSENGER KILOMETRES).....	54
TABLE 8. FREIGHT KILOMETRES.....	54
TABLE 9. PASSENGER TRANSPORT ENERGY INTENSITY.....	55
TABLE 10. FREIGHT TRANSPORT ENERGY INTENSITY.....	55
TABLE 11: TOTAL PASSENGER ENERGY (EJ).....	56
TABLE 12: TOTAL AIR FREIGHT ENERGY (EJ).....	56
TABLE 13. AVIATION REVENUES, FUEL PRICE, AND LANDING CHARGES BY ROUTE IN 1991: INTERNATIONAL SCHEDULED SERVICES.....	60
TABLE 14. AVIATION PRICE ELASTICITIES.....	61
TABLE 15. EFFECTS OF FUEL PRICE ON INTERNATIONAL AIR PASSENGER TRAVEL BY DIFFERENT ROUTES.....	62
TABLE 16 . EMISSIONS BY DIFFERENT AIRCRAFT ENGINE TECHNOLOGIES.....	65

EXECUTIVE SUMMARY

Context

World consumption of aviation fuel in 1990 was approximately 168 million tonnes, of which 138 million tonnes was consumed by civil aviation, and 133 million tonnes by commercial airlines. This study concentrates on air transport by commercial airlines. Commercial aviation in 1990 was responsible for approximately 420 million tonnes of CO₂ emissions (114 million tonnes of carbon), of which about half was due to international traffic. NO_x emissions from aircraft resulted in increased tropospheric ozone concentrations whose radiative impact may be as large as that of their CO₂ emissions. Annex I countries accounted for about 80 per cent of air traffic¹ and 75 per cent of aviation fuel sales.

Commercial air traffic grew at an average of 6.5 per cent per year during 1990-1995, while energy intensity² reductions, which had averaged 4 per cent per year during the period 1974 to 1988, slowed to 0.3 per cent per year during 1990-1995. This led to CO₂ emissions in 1995 of about 550 million tonnes (150 million tonnes of carbon). Air traffic growth trends are expected to continue well into the next century, as a result of rapid income growth in non-Annex I countries and airline deregulation in Annex I countries.

Figures 1a and 1b compare CO₂ emissions from the main transport modes. They show that aviation has the highest CO₂ intensity for many types of transport function. Care must be taken to compare like with like: for example, short haul air travel might be substituted by high speed rail travel, while long haul air travel has no real substitute. Meanwhile, air freight is a factor of two to twenty times more carbon intensive than road freight. For intercontinental freight, the fastest alternative to air transport is containerised maritime freight, whose carbon intensity is nearly two orders of magnitude lower.

Most countries follow the recommendation by the Council of the UN International Civil Aviation Organization (ICAO), that fuel used for international aviation should be tax-exempt. The recommendation does not preclude "charges" for environmental purposes. Some airports have landing fees related to aircraft noise levels, and various countries have considered or introduced more general environmental charges which could extend to cover aircraft greenhouse gas emissions. Aviation fuel taxation is also precluded in most countries by provisions in the bilateral Air Transport Agreements, which are the main legal frameworks for the operation of international civil aviation.

ICAO is currently reviewing its approach to aviation charges and, in particular, is considering the response the aviation industry should make to global environmental challenges. In response to a request from ICAO, the Intergovernmental Panel on Climate Change plans to produce a Special Report in 1998, examining aviation and the global atmosphere. The report will consider scientific aspects of the role of

¹ Air traffic is considered throughout this report includes freight, mail and passengers, all measured on a "tonne-kilometres performed" (TKP) basis.

² Energy intensity is defined as energy use per tonne-kilometre performed.

aviation in climate change and stratospheric ozone depletion, and explore the options for reducing these impacts.

Figure 1a. CO₂ Intensity of Passenger Transport (g carbon per passenger km)

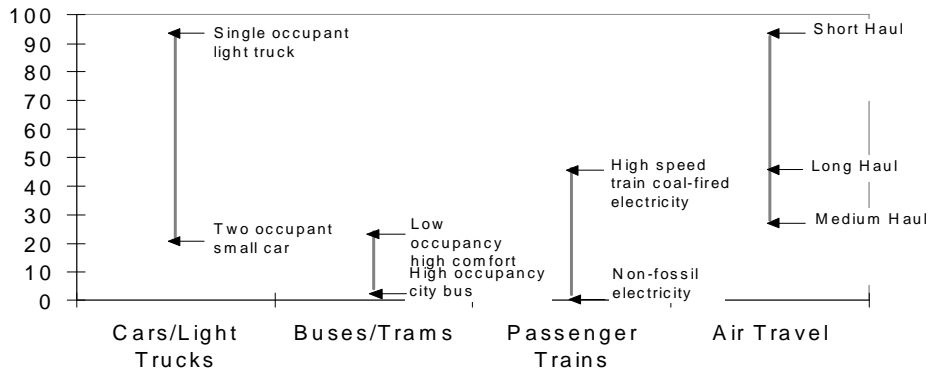
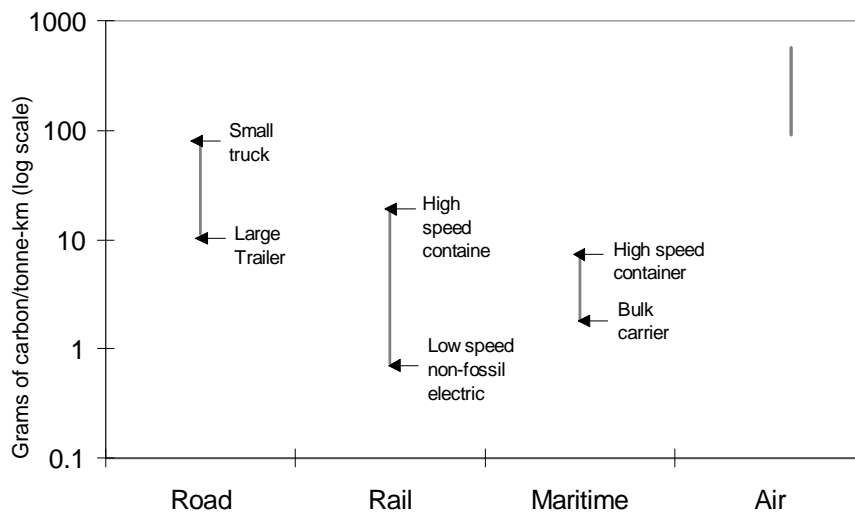


Figure 1b. CO₂ Intensity of Freight Transport (g carbon per tonne-km)



Description of Measures and their Policy Objectives

The focus of this study is a carbon charge on fuels used for international aviation. The primary aim of the charge would be to reduce the consumption of aviation fuel, and hence reduce the emission of greenhouse gases by aircraft, through internalisation of the social costs of CO₂ emissions.

There are several ways such a charge could be implemented. The **level** might fall anywhere in a wide range. This study considers charge levels of \$5, \$25 and \$125 per tonne of carbon on an illustrative basis. These equate to roughly 2 per cent, 10 per cent and 50 per cent of current prices of aviation fuel (at 20¢/litre), respectively. The study also considers the possibility of a charge that gradually increases the price of aviation fuel by 1-5 per cent per year. Various methods of collection and uses of the revenue are possible.

Alternative measures for greenhouse gas mitigation and possible common action are also considered. These include various types of charges on aviation emissions, voluntary agreements by airlines to reduce energy intensity, best practice programmes, and government support for research, development and demonstration. Aviation emissions could also, in principle, be included in an international emission trading scheme.

Approach

The study considers: the potential impact of fuel charges on aviation CO₂ emissions; the direct and wider economic costs that might be associated with aviation fuel charges; the other policy issues associated with fuel charges, including trade, employment and competition; issues that need to be considered in the implementation of charges; the rationale for common action to implement charges; and the possible approaches that Annex I countries might take to implement aviation fuel charges in common.

Two reference scenarios are used as the basis for estimating the greenhouse gas effects of fuel charges. These scenarios are derived from the transport sector scenarios designed by the World Energy Council in 1995, but are somewhat modified. The lower growth scenario is characterised as “Muddling Through”, and represents a situation where barriers to trade and regional differences in development are maintained or strengthened. This scenario has air traffic increasing at 4.9 per cent per year, with a fairly low rate of energy intensity reduction at 1.1 per cent per year. The higher scenario, “Markets Rule”, sees the removal of trade barriers and particularly rapid economic growth in developing countries and countries with economies in transition. This scenario has air traffic increasing at 7.5 per cent per year, with energy intensity falling at 2.2 per cent per year. World energy use for civil aviation increases by a factor of 2.8 to 3.2 between 1995 and 2020. These two scenarios are not intended to represent the full range of possible futures.

The quantitative effects of different charge rates on air traffic are estimated, using results from existing analysis in the literature. For the purposes of calculation, this study has considered the effect of a charge on fuel used for both international and domestic aviation. The energy intensity response to increased fuel prices is addressed on a more qualitative basis, based on a review of the historical relationship between fuel cost and the rate of energy intensity reduction in aviation. Historical data are also used to consider, on a qualitative basis only, the impacts of fuel prices on air traffic, airline profits and employment in the industry. Switching from aviation to other transport modes is discussed briefly in the study, also on a qualitative basis.

Greenhouse Gas Reduction Potential, Costs and Timing, Rationale for Common Action

Effects of a Fuel Charge

Any increase in aviation fuel prices would be likely to have effects on greenhouse gas emissions through several mechanisms:

1. Cost increases would be partly passed through to airline customers, resulting in lower demand for air transport, and reducing energy use and greenhouse gas emissions. A carbon charge on fuel would be likely to reduce air passenger traffic more than freight traffic. It is possible that some air travel would be substituted by other transport modes, resulting in higher greenhouse gas emissions from those modes.
2. Airlines might aim to reduce non-fuel costs to offset increased fuel costs. Analysis in this study shows that airlines have made continual progress in cutting labour and other costs over the last 35 years, but there is no evidence that these cost reductions accelerated during the period of high fuel prices from 1974 to 1985.
3. Airlines would reduce their fuel consumption through more efficient operation of aircraft. To the extent that these short- to medium-term measures reduced overall costs, their success would mean that the fuel price increase was not fully passed through to customers, but energy use and greenhouse gas emissions would fall. Literature sources anticipate that operational changes will save 10-20 per cent of aircraft energy use per passenger-km over the period to 2015.
4. Airlines would re-engine or retire some of their existing aircraft and seek to purchase more energy-efficient aircraft, while manufacturers would intensify their efforts to develop and supply them. While these aircraft might be more expensive than previous versions, they would reduce fuel costs. To the extent that they succeeded in reducing overall airline fuel, financing and other costs, the fuel price increase would not be fully passed through to customers, but energy use and greenhouse gas emissions would fall. Current pre-commercial technology could reduce aircraft energy use by 30-50 per cent.

Effects on traffic

The first-order effect of a global CO₂ charge on international air travel has been estimated in Table 3, assuming airlines pass the whole of the charge through to customers. As the table shows, the effect of a CO₂ charge on air passenger traffic is very uncertain: price elasticity estimates for air travel demand vary by a factor of more than three. Only for the highest level of charge do the reductions in traffic shown in Table 3 become comparable even with a single year's growth.

Table 1. Effect of a Globally Applied Fuel Charge on International Air Passenger Traffic

Charge on carbon emissions (\$/tC)	5	25	125
Change in traffic	-0.2 to -0.6 %	-0.9 to -2.9 %	-4.4 to -13.3 %

The effect of a carbon charge on air freight transport would probably be about two-thirds of the effect on passenger transport. Increased travel by other modes would slightly offset the reduction in greenhouse gas emissions due to reduced air travel.

Effects on Energy Intensity

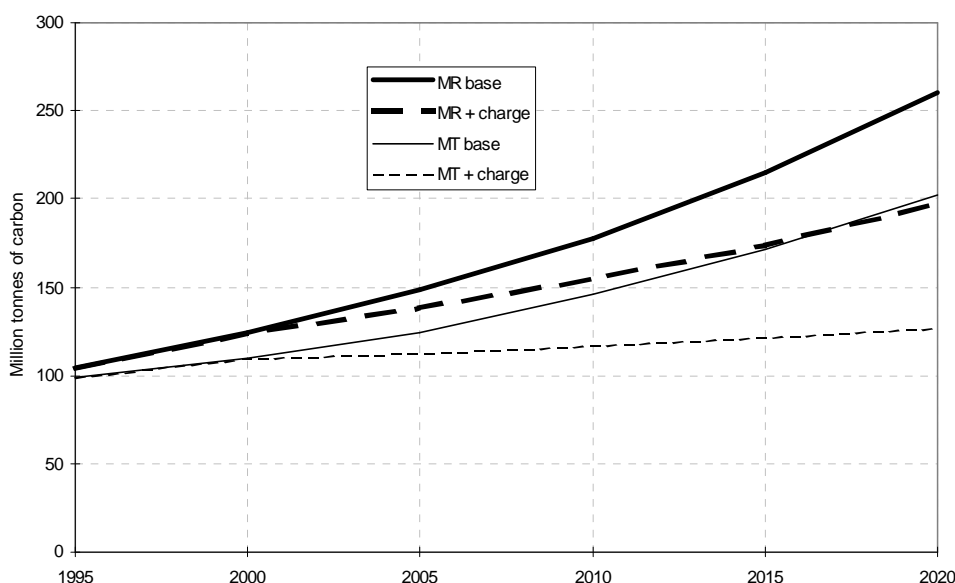
This study finds that the rate of energy intensity reduction in civil aviation (points 3 and 4 above) has been very responsive to fuel price in the past, following a “threshold” effect. Energy intensity reductions accelerated to a ceiling of 3-4 per cent per year when fuel costs exceeded about 15¢ per TKP, or about 14 per cent of airline costs. These rapid energy efficiency improvements resulted from a combination of operational improvements and fleet replacement. The source of the apparent threshold effect has not been investigated and is a possible area for future work, but the recent slowing of energy intensity reduction has coincided with an industry recession and low rates of fleet replacement.

As total aviation costs continue to fall faster than fuel costs, so that the energy share of airline costs increases, energy efficiency improvements are likely to receive renewed attention in future. This may be accentuated by the sharp increase in fuel prices in 1996. Operating restrictions on older, noisier aircraft are also likely to contribute to more rapid fleet replacement.

An international commitment to raise fuel prices at a moderate rate each year could increase the rate of energy intensity reduction. The study does not attempt to identify the direct relationship between fuel price and energy intensity over the scenario period. However, it does suggest that energy intensity reductions of 3.5 per cent per year would probably be technically possible over the 20 years from 2000, resulting in about 30 per cent reduction in aviation carbon emissions in 2020 relative to the reference scenarios (see Figure 2).

Figure 2. Effect of Accelerated Energy Intensity Reductions on Annex I Country Carbon Emissions from Civil Aviation

Two Scenarios, 1995-2020.



It is not possible to predict at this stage what rate of fuel price increase would be needed to achieve the potential emission reductions shown in Figure 2, but it would probably lie between 1 per cent and 5 per cent per year. A charge that increased the fuel price by 2 per cent per year from 2000³ would reach a level of \$125 per tonne of carbon after 20 years, assuming no change in the underlying fuel price.

Effects of non-Global Implementation of a Charge

If a fuel charge were applied at a non-uniform level, it would be less effective than a uniform, globally applied charge and could cause costly distortions in airline competition. Non-uniform application of a charge would mean that not all airlines would have an incentive to adopt energy-efficient technology. This would reduce the incentive for manufacturers to develop energy-efficient aircraft, or result in higher costs for those airlines that did wish to adopt such technology, relative to the case of a uniform charge. “Tankering”, where aircraft take on more fuel than is needed for a flight to avoid taking on more expensive or lower quality fuel at the next port of call, already occurs to some extent. More tankering would occur as a result of an unevenly applied fuel charge, and this might lead to an increase in CO₂ emissions due to the additional weight carried by aircraft.

Another effect of non-uniform charges might be to change patterns of air traffic, in particular, by affecting international competition between airlines for long-haul flights. This effect would be most likely occur in regions that include a mixture of participating and non-participating countries. Such changes in air traffic patterns could lead to increased CO₂ emissions. This distortion would be much smaller if the charge proceeds were used by governments to reduce other aviation industry costs, such as airport taxes, landing fees and routing charges.

Employment and Competitiveness Effects

Given the rapid rate of air traffic increase and cost reduction, the effect of a gradual fuel price increase on air traffic, employment in the aviation industry, and airline profits, would probably not be noticeable. However, for less than global application of a charge, the effects described above on competition among airlines might damage the aviation industry in countries imposing the charge. Meanwhile, airlines in non-participating countries would not pay the charge but would receive the benefits of energy-efficient technology. Countries that are particularly dependent on aviation for international trade, tourism and business would also be adversely affected by any new aviation charges. Charges that applied for fuel used for domestic as well as international flights would adversely affect large countries that depend heavily on aviation for internal travel.

Other Measures

Given that most of the effects of a charge would be on energy intensity rather than on traffic, it might not be necessary to increase the cost of air transport to reduce greenhouse gas emissions. Thus, the proceeds of the charge might be used to reduce other airline costs. Other measures to encourage energy intensity reductions might also be effective. Such measures range from best practice programmes, through incentive schemes such as airport emission fees that are revenue-neutral for the industry, to energy efficiency standards, or an industry-wide emission cap with trading among airlines. It was beyond the scope of this study to evaluate such measures in any detail.

³ The charge would start at 2 per cent of the fuel price in 2000, amounting to roughly \$5/tonne of carbon.

Implementation Issues

Airlines, not surprisingly, have expressed strong opposition to the idea of a fuel tax, and this position has in the past been shared by the Council of ICAO, which has issued a recommendation that Member states of ICAO should not impose revenue-raising taxes on fuel for international aviation. ICAO does, however, acknowledge the need for governments to impose charges to cover the costs of providing infrastructure and services for airlines, and also to remedy environmental problems caused by aircraft. Implementation of a revenue-raising tax would depend on the renegotiation of existing bilateral air transport agreements between most countries, which exclude the taxation of fuel used by each other's airlines.

It might be possible to implement an aviation fuel charge with less airline opposition if the proceeds were used within the aviation industry, to improve air traffic control, to fund research and development into energy-efficient aircraft technology, or even to subsidise the purchase of energy efficient aircraft. Such uses of the revenue might be opposed by governments which adhere to the principle, grounded in economic efficiency, that tax revenues should not be earmarked.

Discussion on the implementation of any aviation fuel charge would need to be carried out with the co-operation, or under the auspices, of ICAO. Additional assessment would be needed to consider the effect of the fuel charge on international trade, airline competitiveness and technology development. Alternative measures would also need to be assessed.

Conclusions

There are several possible types of possible common action:

1. **Replication by Parties of successful measures implemented elsewhere.** This approach would probably not be relevant for an aviation fuel charge, but it might be appropriate for several other types of measure which are briefly mentioned in the study, such as airport emission fees and best practice programmes.
2. **Agreement to take action in the aviation sector toward an aim or target.** Countries might agree explicitly to take effective action, with the objective of reducing international aviation emissions. Countries might further agree on a method for allocating national responsibility for greenhouse gas emissions from international aviation, bringing them into the scope of existing commitments under the UNFCCC to introduce and report on measures to mitigate national greenhouse gas emissions.
3. **Co-ordination to implement the same or similar measures.** Countries might agree to the legitimacy or even desirability of aviation fuel charges in principle, opening the way for those countries that wish to take unilateral action without contravening existing international agreements. A next step might be for groups of countries to introduce a charge, whether at the same level or at different levels.

4. **Specific policies and measures implemented together.** Countries might agree in the UNFCCC process, and subsequently in ICAO, to introduce a measure, such as an aviation fuel charge, at a harmonised level. In this case, countries might agree that national governments have responsibility for charge collection and revenue disbursement. Alternatively, countries might agree to some international body (e.g. the GEF or UN Commission for Sustainable Development) collecting the charge and disbursing it for climate change mitigation and adaptation purposes.

Common action to reduce greenhouse gas emissions from civil aviation might address international aviation alone, or both domestic and international aviation. Any approach to reducing greenhouse gas emissions from international aviation might be influenced by the decision taken by SBSTA and the UNFCCC Conference of the Parties on bunker allocation. Allocation to individual countries is not a prerequisite for greenhouse gas mitigation in this sector. However, if international aviation emissions remain unallocated, or are allocated to an international category, mitigation is more likely to depend on common action.

CONTEXT

Environmental concern with regard to aviation has been concentrated in the past on air quality and noise near airports and long distance and transboundary air pollution (ground-level ozone and acid deposition). Aircraft have only recently caused particular concern as a source of greenhouse gas emissions — rapid energy efficiency improvements meant that aviation energy use was not growing much faster than energy use by other transport modes. However, studies in the early 1990s showed that the NO_x emitted by aircraft might act as a very significant greenhouse gas precursor, having about 35 times the indirect radiative forcing effect of ground level NO_x emissions. This, combined with continuing rapid aviation growth and slower energy efficiency improvement, has led international organisations concerned with the environmental impacts of aviation to pay more attention to greenhouse gas emissions.

Emissions of Greenhouse Gas from Aviation in 1990

A comparison of sources (CAEP, 1995; IEA, 1993; Balashov and Smith, 1992; Olivier, 1995) indicates that civil and military air transport consumed between 158 to 168 million tonnes of fuel in 1990, mostly in the form of aviation kerosene. The exact figure is uncertain because some fuel supplied by oil companies as aviation fuel may be used for other purposes, while some fuel sold for other purposes may be blended in aviation fuel.

Any greenhouse gas mitigation measure adopted as a Common Action would be less likely to apply to military consumption than to civil consumption, which is estimated by Balashov and Smith (1992) to have amounted to 138 million tonnes, roughly consistent with a number of bottom-up inventories (CAEP, 1995). From the fuel consumption figures it can be estimated⁴ that aircraft emitted 512 million tonnes of CO₂ in 1990, of which 434 million tonnes (82 per cent) were from civil aviation. Aircraft also emitted 210 million tonnes of water vapour and roughly 1.9 million tonnes of NO_x, as well as smaller amounts of carbon monoxide, particulates, SO_x and other pollutants.

Radiative forcing of aviation greenhouse gas emissions

Emissions of CO₂ from aircraft have the same radiative forcing effect as ground level CO₂ emissions, but the radiative effects of other exhaust gases may be modified by the height at which they are emitted. Uncertainty, in particular, relates to the effects of NO_x and the combined effects of water vapour, unburned hydrocarbons, carbon monoxide, soot particles and SO₂ on contrail formation and the climate.

Early atmospheric modelling results indicate that ozone generated by NO_x emissions from aircraft at around 10-12 km altitude may have a radiative forcing effect similar in magnitude to that of aircraft CO₂ emissions (Fabian, 1990; Johnson, 1994; CEC, 1992). This effect has been examined in some depth by

⁴ Using emission co-efficients of 3 143 tonnes of CO₂, 1 286 tonnes of H₂O, and 11.4 kg of NO_x per tonne of fuel.

NASA in the United States, and the Aeronox project in Europe. Continued development of atmospheric models has not yet satisfactorily resolved the uncertainty in its magnitude. IPCC Working Group I treats the modelling results with caution, noting that the ozone generated by aircraft NO_x emissions have a radiative forcing effect which is very uncertain and is probably no greater than that of aircraft CO₂ (IPCC, 1995; Schimel *et al.*, 1996).

Other aircraft emissions, including water vapour, have the potential to cause radiative forcing, but their impact has not yet been properly assessed. The IPCC is beginning work on a Special Report, due to be completed at the end of 1998, which aims, *inter alia*, to resolve some of the scientific uncertainties.

NO_x from supersonic, stratospheric aircraft (i.e. at heights of around 25 km) is thought to affect ozone concentrations in the stratosphere, contributing to ozone depletion. This type of aircraft currently accounts for a very small proportion of civil aviation emissions (there are only thirteen in commercial operation), but a new generation of supersonic aircraft has been much discussed as a possible next step for the aviation industry. The effects of NO_x emissions from subsonic aviation on ozone depletion are thought to be small.

The role of NO_x has received considerable attention in recent years, and aircraft engine manufacturers have made particular efforts to find technical means of reducing emissions. This effort has been driven by a combination of concerns — acidification and local air quality problems in the vicinity of airports, the need to develop low-NO_x engines for supersonic, stratospheric aircraft, and need to avoid the ozone enhancing effects of NO_x from subsonic aircraft in the upper troposphere.

The ozone generated by NO_x from subsonic aircraft is thought to be short-lived (of the order of 30 days) and its radiative impact is therefore very different in character to that of CO₂ which has an atmospheric lifetime of the order of 100 years. Nevertheless, some consideration is warranted of the relative cost-effectiveness of measures to reduce NO_x emissions and those to reduce CO₂ emissions.

Breakdown of air traffic and emissions

Statistics do not differentiate between fuel use for passenger transport and that used for freight. Freight and passengers are often carried on the same flight. A crude estimate of the breakdown of energy use can be obtained from the relative tonne-km carried in the form of passengers and in the form of freight. Thus, in 1992, freight and mail accounted for 73 billion tonne-km and passengers for 178 billion tonne-km (ICAO, 1994a). Passenger transport therefore accounted for roughly 71 per cent of the load carried, and hence about 100 Mt in aviation fuel use. Freight accounted for roughly 32 Mt. Vedantham and Oppenheim (1994) further estimate that business travel accounted for about 26 per cent of passenger energy use.

In 1982, international travel accounted for 44 per cent of world passenger air travel (in passenger-km). By 1993, that figure had risen to 53 per cent (ICAO, 1994a). International air travel grew at 7 per cent per year during the same period whereas total air travel grew at 5 per cent per year. A similar pattern is seen in air freight, with international air freight growing from 72 per cent to 82 per cent of world air freight. International statistics do not differentiate between domestic and international aviation fuel use and few countries have provided a breakdown between domestic and international aviation in their greenhouse gas inventories for the FCCC. Balashov and Smith (1992) provide an estimate of this breakdown shown below in Table 2.

Table 2. Commercial airline fuel consumption and aircraft capacity, 1990

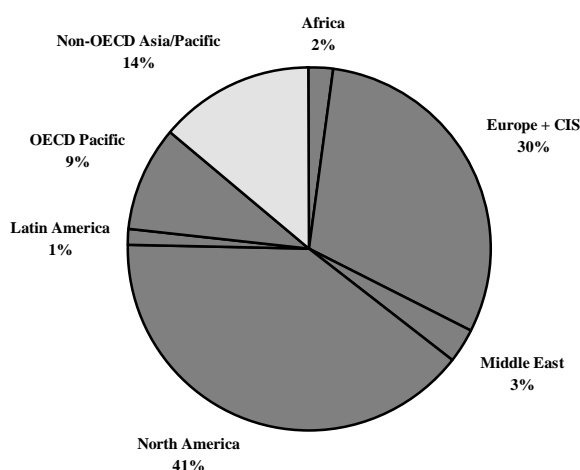
	Total Fuel Consumption (Mt)	Total Fuel Consumption (per cent of world)	CO ₂ Emissions (MtC)
International services			
Scheduled	53	40.0	45
Non-scheduled	10	7.5	9
Domestic services			
United States	38	28.6	33
Russian Federation	15	11.3	13
Other	17	12.8	15
World total	133	100	114

Source: Balashov and Smith, 1992

As Figure 3 shows, air traffic is dominated by three regions: North America, Europe and Asia/Pacific. Growth is most rapid in Asia/Pacific (see Appendix A) at 8 per cent per year during 1982-1992, followed by North America and the Middle East. In 1992, Annex I countries accounted for about 80 per cent of world scheduled air traffic, with non-OECD Asia/Pacific countries accounting for the majority of the rest.

Figure 3. Regional Shares of World Scheduled Air Traffic

1992: International and Domestic, Passenger and Freight



Share of tonne-km according to region of airline registration.

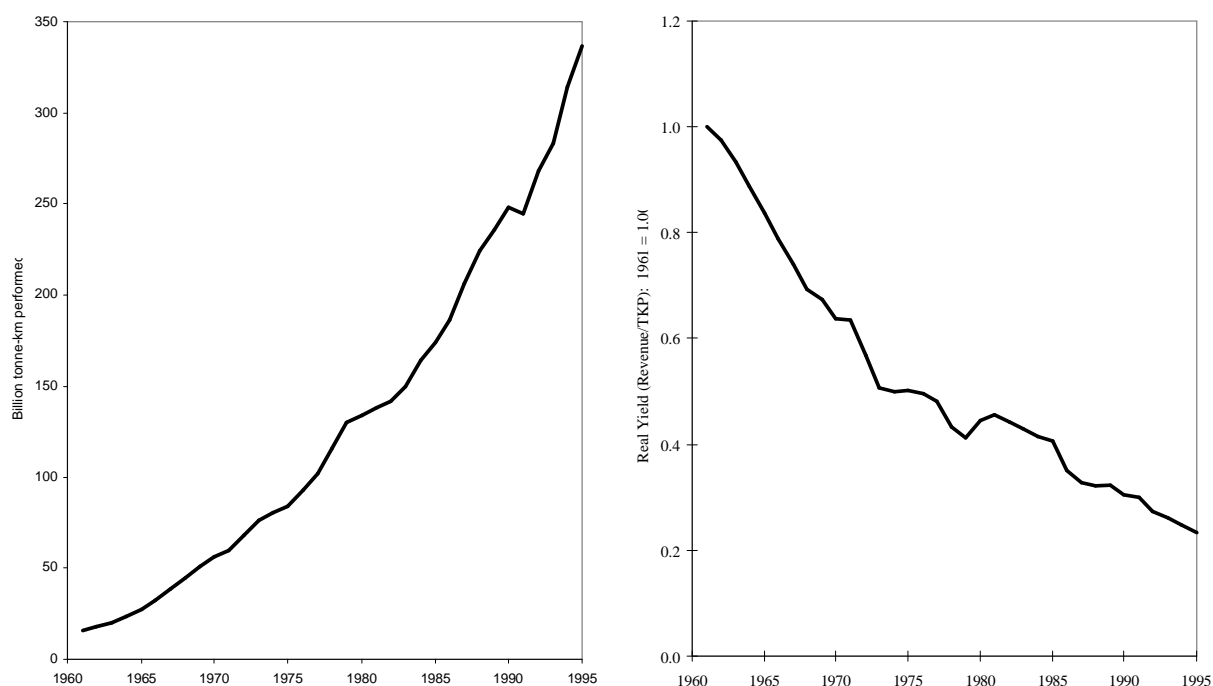
Source: ICAO Data

Key Aviation Trends

Traffic trends

Figure 4 illustrates the rapid growth in air traffic since 1961, shown in total tonne-km performed, including passengers, freight and mail. Air traffic grew about three times as fast as GNP in the early 1970s, but only about twice as fast since the early 1980s. Air traffic has fallen in only one year in the period shown — 1991 — following the Gulf War and fears about terrorism, which sharply curtailed American foreign travel. As Figure 4 also shows, aviation prices have fallen consistently at rates averaging about 3-5 per cent per year since 1961, with increases only in 1980 and 1981, following the second oil price rise.

Figure 4. Aviation Tonne-km Performed (TKP) and Yield
(Index of Revenue per TKP: 1961 = 1.0)

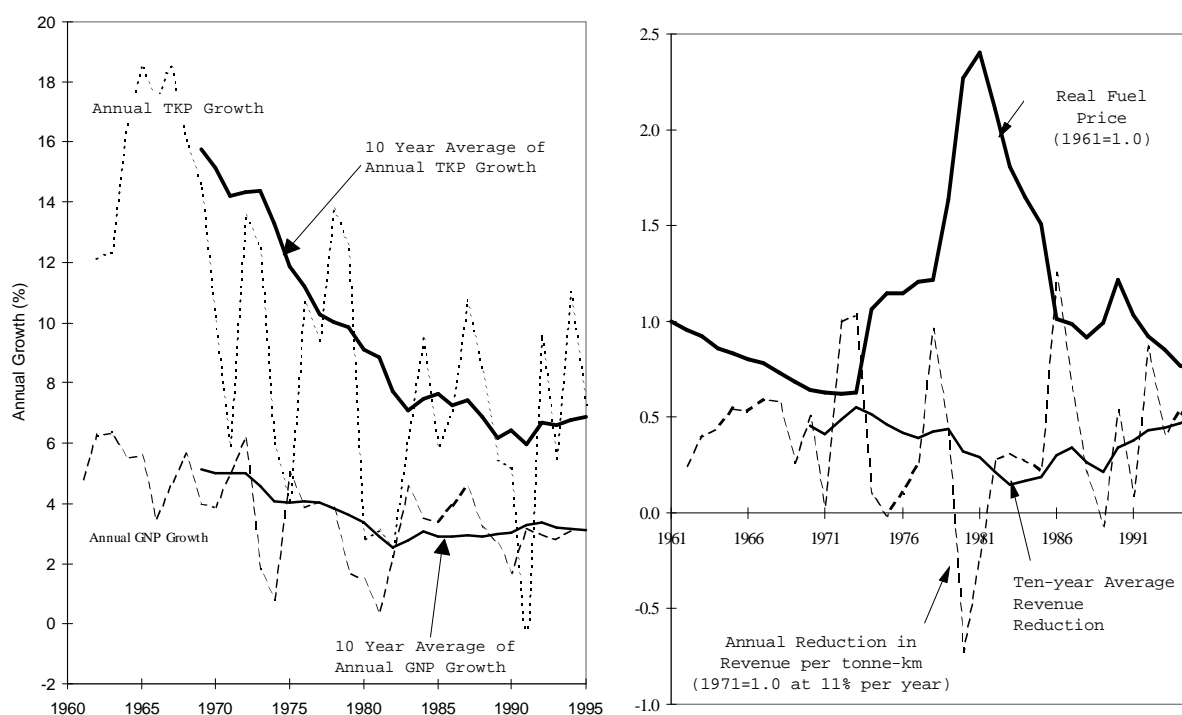


Source: ICAO Data

Econometric studies (e.g. ICAO, 1995b) find that the GDP elasticity of air traffic (tonne-kilometres performed or TKP) is in the region of +2. In fact, the rate of TKP growth shown in Figure 5 below probably displays some saturation effects: the short run GDP elasticity has increased so that aviation growth appears very sensitive to small, short-term changes in GDP growth. On the other hand, the long-run GDP elasticity has fallen substantially, so that, after allowing for the effects of continually falling prices, the elasticity of the 10-year average growth rate with respect to the 10-year average GDP growth is not much more than 1.0. Meanwhile, it is possible that oil price increases in 1973/74 and 1979/80 had some effect on the rate of yield reduction, also shown in Figure 5, but any effect on the rate of traffic growth appears to have been slight.

The rapid growth in aviation demand in the 1960s and 1970s, with a doubling period of less than 8 years, depended on a very high rate of aircraft fleet growth. Slower growth in recent years along with low fuel prices and hence a reduced incentive to replace old aircraft with more efficient new designs can be expected to lead to an increasing average aircraft age.

Figure 5. Annual TKP growth and annual reduction in yield



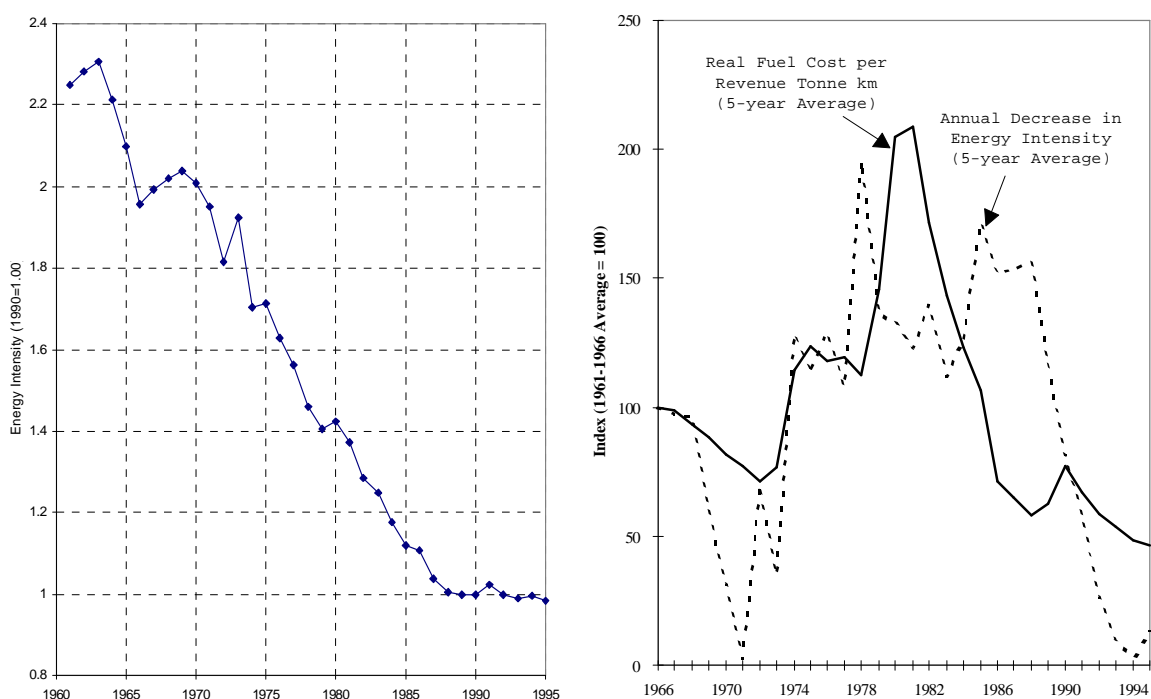
Source: ICAO Data

Energy intensity trends

Over the 30 years to 1990, the average energy intensity (fuel per tonne-km of passengers, freight and mail carried) of the civil aircraft fleet fell by about 2.7 per cent per year⁵. The fastest reduction was in the period 1974-1988, with a reduction rate of about 4 per cent per year (see Figure 6). This is very rapid compared to other areas of energy use, where technology and markets are more mature. Energy intensity in cars over the same period fell by 1-2 per cent per year, depending on the region. The reductions in energy intensity during the 1970s and 1980s resulted partly from developments in the technology used for new aircraft in the rapidly expanding civil aircraft fleet, and partly from increases in aircraft load factor (passengers per seat or percentage of cargo capacity filled). The aircraft weight load factor increased from 49 per cent in 1972 to 59 per cent in 1990, but nearly all of this rise occurred during the 1970s with an improvement of only one percentage point in the 1980s (ICAO, 1995b, 1995c). Operational changes (advances in routing and navigation, introduction of energy-conserving practices) may also have accounted for a few percentage points in savings, but the bulk of the reduction in energy intensity since 1960 has been through aircraft technology development.

⁵ Energy intensity is estimated as civil aviation energy use (for ICAO Member countries) divided by TKP (passengers, mail and freight). Aviation energy use is estimated by ICAO using a) equations derived from publicly available data that estimate fuel consumption for individual aircraft types; and b) scheduled airline timetables. Thus, it takes no account of changes in operational influences on energy use, such as air traffic congestion and changes in airline operating practices. The estimate does take account of changes in aircraft load factor.

Figure 6. Energy Intensity, 1961-1995



Source: ICAO Data

Figure 6 also shows that energy intensity reduction has been most rapid when fuel costs have been highest. High fuel prices encourage energy intensity reductions, partly by making it more cost effective for airlines and aircraft manufacturers to introduce new, efficient technology.

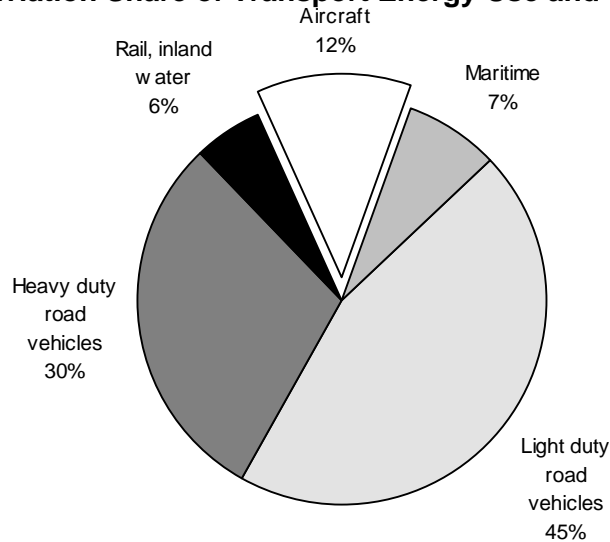
It appears from Figure 6 that energy intensity has been almost stationary since 1988. This may be partly an artifact of the way aviation fuel consumption is estimated by the International Civil Aviation Organization (ICAO)⁶. However, a reduction in aircraft load factor has probably played a role: a high rate of aircraft orders in the boom period of the late 1980s, followed by reduced demand growth during 1989 to 1991, when the aircraft were being delivered, contributed to a reduction in the load factor from 59 per cent in 1990 to 57 per cent by 1992 (ICAO, 1995c, 1995d). Load factors fell more in international services than in domestic services. There may also be a trend towards increasing levels of passenger comfort in aircraft (e.g. larger, heavier seats and increased space in business class). The number of tonne-kilometres available per aircraft-kilometre fell from 27.3 in 1990 to 26.6 in 1994, while the number of seat-kilometres available per aircraft-kilometre fell from 195 to 185 (ICAO, 1995c).

⁶ Comments from Tilly Costaguta, Chief, Statistics and Economic Analysis Section of ICAO indicate that the equations used to estimate fuel consumption were last modified in 1991. Hence, new technology introduced since 1991 does not show in the data, although changes in fleet composition to increase the use of technology that already existed in 1991 do show in the data.

Comparison of aviation and other transport modes

Aviation in 1990 was responsible for about 12 per cent of total transport sector CO₂ emissions (Figure 0: includes civil and other aviation). This share was roughly constant between 1974 and 1988 because rapid air traffic growth was compensated by rapid energy intensity reduction. The civil aviation share has grown in recent years with the reduced rate of energy intensity reduction, but the overall aviation share has not increased according to IEA Statistics, probably because of a decline in energy use for military aviation.

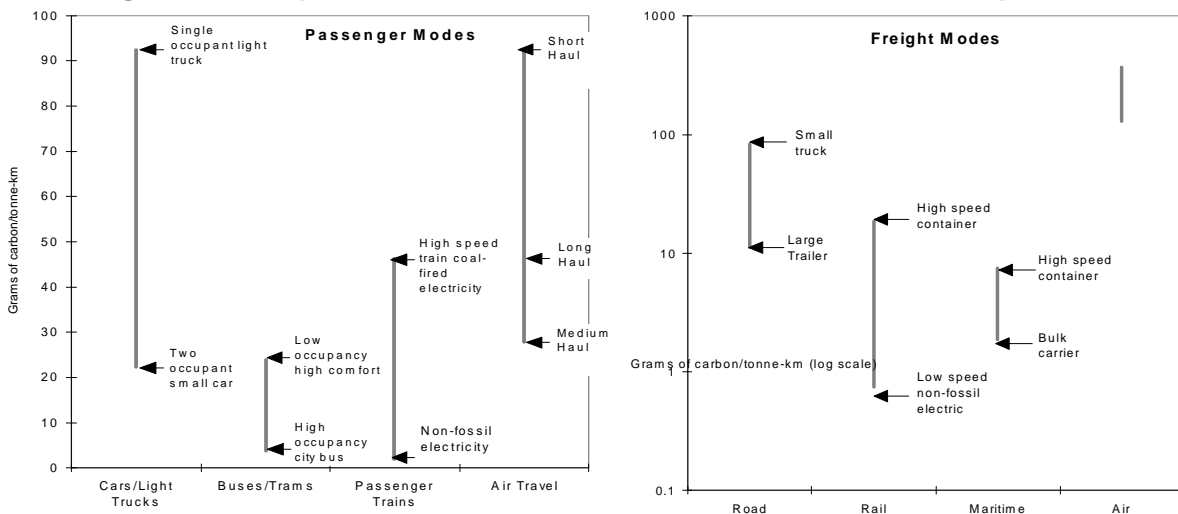
Figure 7. Aviation Share of Transport Energy Use and CO₂ Emissions



Source: IPCC, 1996

Figure 8 compares carbon emissions from the main transport modes. It shows that aviation has the highest carbon intensity for many types of transport function. Care must be taken to compare like with like: for example, short haul air travel might be substituted by high speed rail travel, while long haul air travel has no real substitute. Meanwhile, air freight is a factor of two to twenty times more carbon intensive than road freight. For intercontinental freight, the fastest alternative to air transport is containerised maritime freight, whose carbon intensity is nearly two orders of magnitude lower.

Figure 8. Comparison of Carbon Emissions from Different Transport Modes



The Policy Context

Fuel used in international aviation is not normally taxed, although there are a few countries that do tax aviation fuel, mainly for domestic use. Contracting states of the Chicago Convention of 1944, which set up the International Civil Aviation Organization (ICAO), have agreed in Article 24 of the Convention not to impose taxes on fuel and oil *in transit*. That is, if an aircraft arrives at its first port of call in a country carrying fuel, and leaves from its last port of call still carrying some of that fuel, the country cannot impose any duty on the remaining fuel. While the ICAO Council has consistently declared that aviation fuel should not be taxed, there is no general treaty that prevents countries from imposing tax on fuel for international aviation that is sold in, and removed from their territory. Nevertheless, taxes on fuel sold to a foreign airline are currently ruled out by nearly all of the 2500 or more bilateral air transport agreements which provide for exemption from fuel taxes on a reciprocal basis. It would be necessary to dismantle this structure of bilateral treaty obligations if a fuel tax were to be imposed on scheduled airlines.

ICAO policy in this area differentiates between environmental “charges” which are used for a specific purpose and which the ICAO Council considers legitimate in international air transport, and environmental “taxes” which are not earmarked and are considered to fit the existing ICAO recommendation excluding taxes. Charges and taxes are commonly imposed on airlines and their customers for the use of airports, airport services, air traffic control and routing services. In some instances, airlines pay landing charges that vary according to the noise produced by different aircraft types. There are also cases where taxes are imposed, although inconsistent with ICAO’s principles. These principles could be interpreted as advocating the hypothecation, or earmarking, of taxes, which conflicts with government policies in many Annex I countries.

Several European countries have advocated a relaxation of the ICAO position on fuel tax. Germany, Norway, Sweden and Switzerland have been in the forefront of this group, while the United Kingdom’s environment minister in his intervention at FCCC COP-2 called for consideration of the issue. Within the European Union, aviation fuel has a mandatory exemption from duty, including value added tax, although these exemptions are currently being reconsidered.

Sweden introduced a tax on aviation fuel in 1991 at 1 SK/kg of fuel (16.5 US¢ per kg of fuel or about US\$190 per tonne of carbon). This tax was additional to an emission-related tax imposed from 1989 on Swedish-registered aircraft on domestic flights, aimed at encouraging airlines to minimise engine emissions and encouraging passengers to take the train. Sweden has removed these taxes on becoming an EU member to conform with Community tax codes.

Norway introduced a passenger ticket tax from January 1995, described as a “green tax”, imposed on all domestic flights where there is a train alternative, and on all international flights. However, the tax does not differentiate among aircraft according to emissions.

Zurich airport imposes a surcharge on landing fees related to aircraft NO_x emissions; Switzerland is currently developing a more extensive system of environmental charges on airlines (see Box).

Proposed Aircraft Emission Charges in Switzerland

In 1993, the Swiss Federal Council charged the Federal Department of Transport and Energy with preparing a strategy for introducing a system of emission charges on air traffic. A working group coordinated by the Federal Office for Civil Aviation (FOCA) has now developed a proposal.

The aim of the charge is to act as an incentive to reduce air traffic emissions through the use of the best available technology. The charge is not intended to be an additional source of revenue for airports or the community, except in so far as it can be used to finance expenditures that reduce aviation emissions. The incentive mechanism could include rebates for very clean aircraft.

According to the proposal, aircraft would be assigned to one of five emission classes, depending on the total NO_x and unburned hydrocarbons produced in one landing and take off (LTO) cycle. The actual charge imposed would vary among airports.

Incentives to improve energy efficiency are not an element in the model, because “this is already one of the most important developmental goals in air traffic”

(FOCA, 1996).

Meanwhile, ICAO is in the course of re-examining its approach to environmental charges. On 9 December, 1996, the ICAO Council adopted a resolution on environmental charges and taxes (see Appendix B for full text), which:

“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;” and

Urges States that are considering the introduction of emission-related charges to be guided by ... 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 feasibility of any approach to taxation of aviation fuel, or other greenhouse gas-related charges, will clearly be influenced by the extent to which that approach fits the ICAO principles. In this study, the existence of the ICAO principles will not be taken to exclude any fuel charge or tax option, but the primary focus of the study is on measures that would meet the ICAO definition of “charges”.

Allocation of International Aviation greenhouse gas Emissions under the UNFCCC

Allocation of aviation emissions under the UNFCCC is ambiguous. The IPCC guidelines for producing national greenhouse gas emission inventories currently provide for greenhouse gas emissions from international aviation and marine bunker fuel use to be recorded under a separate category, not included under national totals. According to Article 4.2 of the UNFCCC, Annex I Parties are expected to introduce policies and measures aimed at returning “their” emissions of greenhouse gas emissions and absorption by sinks to 1990 levels by the end of the decade. Ostensibly, international aviation emissions are not included in “their” emissions, although domestic aviation emissions are included.

The UNFCCC Subsidiary Body for Scientific and Technological Advice (SBSTA), meeting in December 1996, will discuss a paper providing a number of options for emission allocation for Annex I Parties (FCCC, 1996). These include:

1. No allocation;
2. Allocation of bunker emissions to Parties in proportion to national emissions;
3. Allocation to Parties according to the country where the bunker fuel is sold;
4. Allocation to Parties according to the nationality of the transporting company, the country where the aircraft is registered, or the country of the operator;
5. Allocation to Parties according to the country of departure or destination of an aircraft or vessel. Alternatively the emissions related to the journey of an aircraft or vessel could be shared between the country of departure and the country of arrival;
6. Allocation to Parties according to the country of departure or destination of passenger or cargo. Alternatively, the emissions related to the journey of a passenger or cargo could be shared by the country of departure and the country of arrival;
7. Allocation to Parties according to the country of origin of the passenger or owner of the cargo; and
8. Allocation to the Party of emissions generated in its national space.

In the report of the SBSTA discussion (FCCC, 1997), it is noted that Options 1, 3, 4, 5 and 6 should be the basis of further work. In the context of Option 1, the report notes the role of ICAO and IMO in addressing international bunker fuel emissions, and the opportunity for UNFCCC Parties to work through these bodies to achieve emission reductions.

Any approach to reducing greenhouse gas emissions from international aviation might be influenced by the decision taken by SBSTA and the UNFCCC Conference of the Parties on emission allocation. Allocation to individual countries is not a prerequisite for greenhouse gas mitigation in this sector. However, if international aviation emissions remain unallocated, or are allocated to an international category, mitigation is more likely to depend on common action. In this case, the most economically efficient means of managing international aviation emissions would, in theory, be through a global carbon charge on all fuels, including those for international aviation, or through the inclusion of bunkers in an international emission trading scheme.

If Parties do agree to some means of allocation, the choice among Options 3 to 6 might have an influence on the implementation of policies and measures to manage aviation emissions. If the preferred measure

were a carbon charge, Parties would, in theory, find it most economically efficient to impose that charge on the emissions that fell within their national inventories. Thus:

- The choice of Option 3 would imply that Parties had an incentive to reduce their national sales of aviation fuel, making a national charge on aviation fuel sales the most economically efficient measure.
- Option 4 would give each country an incentive to manage fuel use by national carriers. An economically efficient national carbon charge in this case would in theory depend on recording the actual fuel use by airlines.
- Option 5 would imply managing fuel use at the point of departure or arrival of the aircraft. Again, an efficient national carbon charge would in theory depend on recording the actual fuel use associated with a particular flight and perhaps levying it through airport fees.
- The implications of Option 6 are similar to those of Option 5, but in this case an efficient national carbon charge would depend on recording the actual fuel use associated with a particular flight and somehow allocating it among passengers and/or freight.

In many cases, it might not be feasible or cost-effective to measure the actual emissions associated with a particular flight, passenger or freight consignment. This might mean that any carbon charge adopted under Options 4-6 might have to be based on simple formulae — e.g. by classifying aircraft according to their energy efficiency and imposing a charge based the aircraft classification and the length of the flight.

POLICY OBJECTIVES AND DESCRIPTION

The focus of this study is a carbon charge on fuels used for international aviation. The primary aim of the charge would be to reduce the consumption of aviation fuel, and hence reduce the emission of greenhouse gases (including NO_x, SO_x and H₂O) by aircraft, through internalisation of the social costs of CO₂ emissions.

Other policy objectives served by the charge might include:

- reducing the consumption of imported petroleum and improving national energy security;
- encouraging a shift to transport modes with lower greenhouse gas emissions per tonne-km or passenger-km; and
- reducing the level of air traffic, and hence reducing airport congestion, and local and regional environmental impacts of aviation.

The charge would increase the overall efficiency of the economy in meeting economic, social and environmental aims to the extent that it was used to reflect to aircraft operators the full economic, social and environmental costs of their consumption of fuel.

There are several ways in which an aviation fuel charge could be implemented:

- The **level** might fall anywhere within a wide range. This report considers charge levels of \$5, \$25 and \$125 per tonne of carbon on an illustrative basis⁷. These equate to roughly 2 per cent, 10 per cent and 50 per cent of current prices of aviation fuel (at 20¢/litre), respectively. The report also discusses the possibility of a charge that gradually increases the price of aviation fuel at somewhere in the range 1-5 per cent per year.
- Various **methods of collection** are possible. This draft assumes collection by national governments, based on national sales of fuel. This is the option most consistent with existing practice for other fuels.
- Various **uses of the revenue** are possible. While the ICAO Council has “strongly recommended” that any revenue from environmental charges on aviation should be used for specific purposes (see Appendix B), several countries have policies that exclude the “earmarking” or “hypothecation” of taxes and do not differentiate between “charges” and “taxes”.

⁷ Pearce *et al.* (1996) estimate in the IPCC Second Assessment Report that the marginal social cost of CO₂ emissions lies in the range \$5 to \$125 per tonne of carbon, and that this will rise over time. This upper and lower ends of this range, as well as the geometric midpoint, are taken in the current report on an illustrative basis as values that might be considered for an aviation fuel charge. However, it must be emphasised that an aviation fuel charge would not necessarily be set equal to any estimate of the social cost of CO₂ emissions. It must also be emphasised that Pearce *et al.* describe the range of social costs as “best guess estimates” that cannot be considered as a confidence interval.

Alternative Measures for Greenhouse Gas Mitigation and Possible Common Action

Other bases for a charge than fuel carbon content are possible. For example, a charge could set as a percentage of the fuel price; it could be levied in the form of routing or air traffic control charges, depending on the route taken and the type of aircraft; or it could be levied as a charge related to the energy intensity of newly purchased aircraft. These alternatives are not evaluated in detail in this study.

Additional alternatives include regulations on aircraft NO_x emissions, energy efficiency standards, voluntary agreements with manufacturers and airlines, and government funding or other support for research, development and demonstration on energy-efficient technology and alternative fuels. An approach much favoured by the aviation industry is increased government investment in air traffic control (ATC) systems. Other possible measures include energy efficiency incentives, on a revenue-neutral basis, included in airport landing fees and in *en-route* charges, or for new aircraft purchases, or in the taxation of airlines by the countries in which they are based.

Aviation (and marine) greenhouse gas emissions could in principle be included in an international emission trading scheme. A proposal for an aviation emission cap, with internal trading among airlines, has been submitted to the OECD by Environmental Defense Fund (EDF: a Washington-based environmental NGO) and is included as Appendix E of this paper.

APPROACH

The study considers: the potential impact of fuel charges on aviation CO₂ emissions; the direct and wider economic costs that might be associated with aviation fuel charges; the other policy issues associated with fuel charges, including trade, employment and competition; issues that need to be considered in the implementation of charges; the rationale for common action to implement charges; and the possible approaches that Annex I countries might take to implement aviation fuel charges in common.

Projections of future traffic and energy use

Until recently, most projections of future air traffic derived from industry sources. More recently, a number of independent analysts have produced aviation scenarios, in many instances for the purpose of considering energy use and greenhouse gas emissions from the sector. Several scenarios to 2010, 2015 or 2020 (Balashov and Smith, 1992; Greene, 1992, 1995; Olivier, 1995; Vedentham and Oppenheimer, 1994; WEC, 1995) are reviewed in Appendix A. Traffic (TKP) growth in these scenarios over the period considered is in the range 4 per cent to 8 per cent per year. Projections of passenger traffic growth are typically in the region of 5 per cent per year, somewhat lower than overall TKP growth. Few of the scenarios consider domestic and international aviation separately although many provide a regional breakdown of traffic.

Energy intensity projections are perhaps harder to make than traffic projections. The various sources range from 0.7 per cent to about 2.8 per cent per year decrease in energy use per passenger-km.

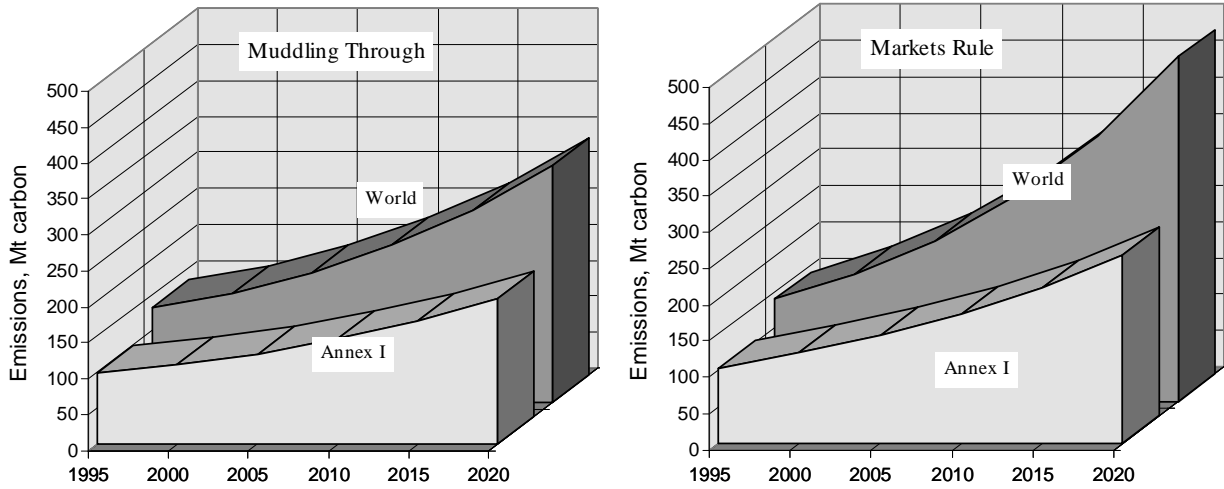
Two reference scenarios are used as the basis for estimating the greenhouse gas effects of fuel charges. These scenarios are derived from the transport sector scenarios designed by the World Energy Council (WEC, 1995), but have been modified to reflect the range of air traffic growth rates and energy intensity improvement rates considered reasonable by reviewers of previous drafts of this study.

The lower growth scenario is characterised as “Muddling Through”, and represents a situation where barriers to trade and regional differences in development are maintained or strengthened. This scenario has air traffic increasing at 4.9 per cent per year, with a fairly low rate of energy intensity reduction at 1.1 per cent per year.

The higher scenario, “Markets Rule”, sees the removal of trade barriers and particularly rapid economic growth in developing countries and countries with economies in transition. This scenario has air traffic increasing at 7.5 per cent per year, with energy intensity falling at 2.2 per cent per year.

In the two scenarios, illustrated in Figure 8, world energy use for civil aviation increases by a factor of 2.5 to 3.4 between 1995 and 2020. Aviation energy use in Annex I countries increases by a factor of 2 to 2.5. These two scenarios are not intended to represent the full range of possible futures.

Figure 9. Scenarios of Carbon Emissions from Civil Aviation
 (Domestic and International) Annex I and World, 1995-2020



Source: Modified Version of WEC (1995) Scenarios

Estimating Effects of Charges

The quantitative effects of different charge rates on air traffic are estimated using a range of price elasticities resulting from existing analysis in the literature. For the purposes of calculation, this study does not differentiate between international and domestic aviation or different classes of travel.

The energy intensity response to increased fuel prices is addressed on a more qualitative basis, based on a review of the historical relationship between fuel cost and the rate of energy intensity reduction in aviation. Historical data, including some of the information presented in the Context section, are also used to consider, on a qualitative basis only, the impacts of fuel prices on air traffic, airline profits and employment in the industry. Switching from aviation to other transport modes is also discussed briefly in the study, also on a qualitative basis.

EFFECTS ON GREENHOUSE GAS EMISSIONS

Effects of an aviation fuel charge on greenhouse gas emissions

A charge on aviation fuel would fall partly on fuel suppliers (through a reduction in the pre-charge fuel price) and partly on consumers (through an increase in the price including the charge). The relative incidence of the charge on suppliers and consumers can be described in terms of the relative price elasticities in supply and demand. Estimating the actual price response would be very complex, as it depends on the cost-effectiveness of changes in refinery investment and operation, and on the price elasticities of demand for other petroleum products. Nevertheless, correspondence and discussions with oil industry economists indicate that they would expect the supply elasticity to be very high compared with the demand elasticity — that is, the pre-charge fuel price would fall by a small amount compared with the charge itself⁸. Rigorous analysis of the effects of new charges on fuel demand would depend on being able to estimate the extent to which oil companies could adjust prices across their product slate. Part of any charge might in fact be passed on to road fuel markets (where taxes mean that retail prices are high and oil company margins are relatively slim) through an adjustment in pre-charge prices.

For the purposes of this study, it is assumed that the whole of any aviation fuel charge is reflected in an increase in aviation fuel prices. This price increase would be likely to have effects on greenhouse gas emissions through several mechanisms:

1. Cost increases would, at least in part, be passed through to airline customers in the form of increased tariffs, resulting in lower demand for air travel and freight. Any charge, however small, would be expected to reduce demand to some extent. Some of this reduction in use of air transport might occur through switching to other transport modes. Airlines would be likely to pass as much of the charge as possible through to their business class passengers, whose price elasticity of demand is low relative to other passengers (Oum *et al.*, 1990). Ticket prices for long haul flights would also tend to be affected more than short-haul flights, because fuel comprises a more substantial proportion of costs for longer flights. It is not possible to predict how important these various effects would be and this report does not attempt to differentiate effects on different types of air travel. Market effects are discussed in more detail in Appendix C.
2. A questionnaire survey of airlines (Alamdari and Brewer, 1994) indicated that a fuel charge would lead them to reduce non-fuel costs elsewhere. To the extent that they succeed in this, higher fuel costs will not be passed on to customers in the long term and will not result in long-term reductions in travel. However, the historical data reviewed for the current study

⁸ For example, James Arrowsmith and Jim Pinto of Texaco note that refiners have flexibility to cut back jet fuel supply by diverting kerosene streams to the middle distillate pool. They acknowledge the possibility of a price increase across the product slate but suggest it is highly unlikely, and that an aviation fuel charge might even lead to increased supply of diesel fuel and a hence reduction in price.

(see Appendix C) indicates that the rate of reduction in labour and other airline costs did not accelerate during the period of high oil prices in the 1970s and 1980s. Meanwhile, some reviewers of the first draft of this study have noted that there may be diminished potential for cost-cutting in the aviation industry in future, following deregulation in North America and Europe.

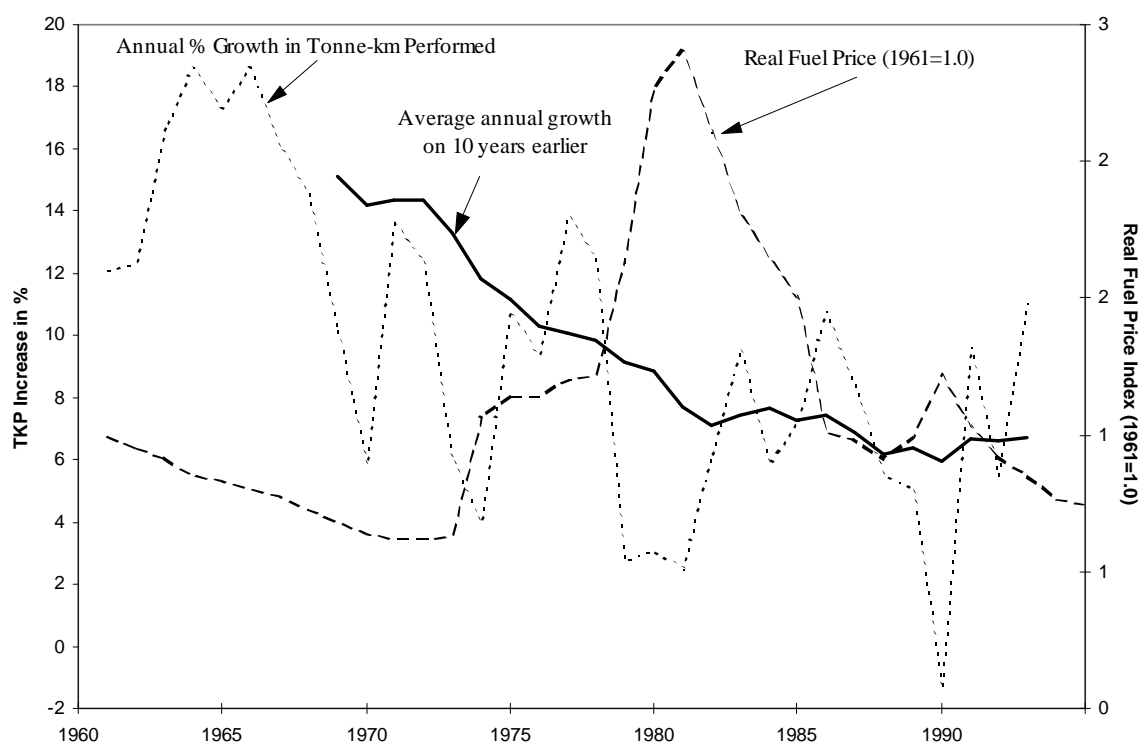
3. Airlines would reduce their fuel consumption through more efficient operation of aircraft, increasing their attention on measures they already adopt, such as routing to minimise fuel use, switching engines off when taxiing, modifying fare structures to maximise load factors etc. To the extent that these short- to-medium term measures reduce overall costs, their success will mean that the fuel price increase is not fully passed through to customers.
4. Airlines would re-engine or retire some of their existing aircraft (Alamdari and Brewer, 1994) and seek to purchase more energy-efficient aircraft, while manufacturers would intensify their efforts to develop and supply them. Some of the technology options are discussed in Appendix D. Again, to the extent that these measures save money overall, their success will mean that the fuel price increase is not fully passed through to customers. However, early aircraft retirement would pose disproportionate costs for airlines with older fleets. It should also be noted that one of the short-term effects of sudden and non-global price increases would be to reduce the money available to airlines for new investment.

This report examines each of these effects in turn.

Effects of charge on demand for air transport and mode switching

Analysis for the current study indicates that any historical price elasticity of air traffic with respect to fuel price is very hard to detect. While Figure 10 shows that the *rate of growth* of air traffic was reduced during the periods of high oil prices around 1974, 1980 and 1990, Figure 3 shows that in each case, the reduction followed a drop in the GDP growth rate. Indeed, in the first two cases, the reduction in air traffic growth occurred before most of the oil price increases. There is no evidence for any lasting effect of higher oil prices, for example, in the years between 1975 and 1979. Much of the short term impact on aviation growth can be explained by broader economic effects, including recession and inflation. Aviation demand may also have been influenced by factors such as the wars in the Middle East that precipitated the price increases. Based on this historical evidence, a charge on aviation fuel, if introduced gradually, might be expected to have relatively little effect on air traffic demand.

Figure 10. Real Fuel Price and Annual Growth in Air Traffic
(tonne kilometres)



Source: ICAO Data

Nevertheless, the first-order effect of a global CO₂ charge on international air travel has been estimated in Table 3, assuming airlines pass the whole of the charge through to customers and using price elasticities discussed in Appendix C. As the table shows, the effect of a CO₂ charge on air passenger traffic is very uncertain: price elasticity estimates for air travel demand vary by a factor of more than three. Meanwhile, only for the highest level of charge do the reductions in traffic become comparable even with a single year's normal growth.

Table 3. Effect of a Globally Applied CO₂ Charge on International Air Passenger Traffic

Charge on CO ₂ emissions (\$/tC)	5	25	125
Fuel Price Increase (¢/litre)	0.4	2	10
Percentage Increase in Ticket Prices	0.28	1.4	7
	Effect on traffic (%)		
Low	-0.2 %	-0.9 %	-4.4 %
High	-0.6 %	-2.9 %	-13.3 %

Given the price elasticities reviewed in Appendix C, the effect of a charge on freight traffic would probably be about two-thirds of the effect on passenger traffic.

Increased transport by other modes would slightly offset the reduction in greenhouse gas emissions due to reduced air travel. Oum *et al.* (1990) find that the mode substitution elasticity for air transport is much

lower than the simple demand elasticity: if air travel is reduced by a given amount, travel by other modes might increase by one fifth of this amount. Mode switching might occur in two main ways:

1. Some transport activity would be shifted directly to other modes. This is most likely to occur in the case of short haul air traffic, where both passenger and freight might shift to road or rail. As shown in Figure 8, the CO₂ emission intensity of transport by these modes is generally much lower than short haul air transport, the only exception being a light truck (this includes “minivans” and some types of “recreational vehicles”) with a single occupant. Even single-occupant light trucks may have a lower greenhouse gas emission intensity than aircraft, if the radiative impact of aircraft NO_x emissions is taken into account.
2. Reductions in medium and long-haul air traffic might lead to an increase in transport by other modes, with freight and passenger movements over shorter distances. Thus, there might be a reduction in intercontinental travel for vacation purposes, but an increase in vacation travel by car. While car travel might have the same energy use per kilometre as medium-haul air travel, the distances involved would be much shorter, so that total energy use and greenhouse gas emissions would be substantially reduced. Intercontinental goods movements by air might be substituted by local goods movements by road or rail, with increasing use of local suppliers.

In conclusion, if a carbon charge were to lead to a 10 per cent reduction in air traffic and the associated greenhouse gas emissions relative to trends, a small amount of this emission reduction — less than a fifth — might be offset by an increase in the use of other modes. This increase would be less likely to occur if all transport modes paid their full social and environmental costs — for example, if any carbon charge on aviation fuel were introduced as part of a more general carbon tax.

Reducing non-fuel costs

It is possible that the lower levels of a charge could be absorbed through airline efficiency improvements (i.e. cost-cutting), eliminating any effect on traffic. The higher level of a charge would be less likely to be fully absorbed through cost cutting elsewhere.

In fact, labour productivity increases in aviation have been quite impressive as shown in Appendix C. Increases in air traffic have been achieved with a decrease in employment in the aviation industry, although some of this decrease may have been a result of contracting out. Increasing labour productivity is the source of much of the reduction in air transport costs over the last 30 years. However, there appears to have been no link in the past between the price of fuel and the rate of labour productivity increase. Hence, it seems unlikely that a fuel charge would lead to any significant job losses. The evidence in Appendix C indicates that historical fuel price increases have been passed through to customers in the short term, and absorbed through energy intensity reductions in the long term.

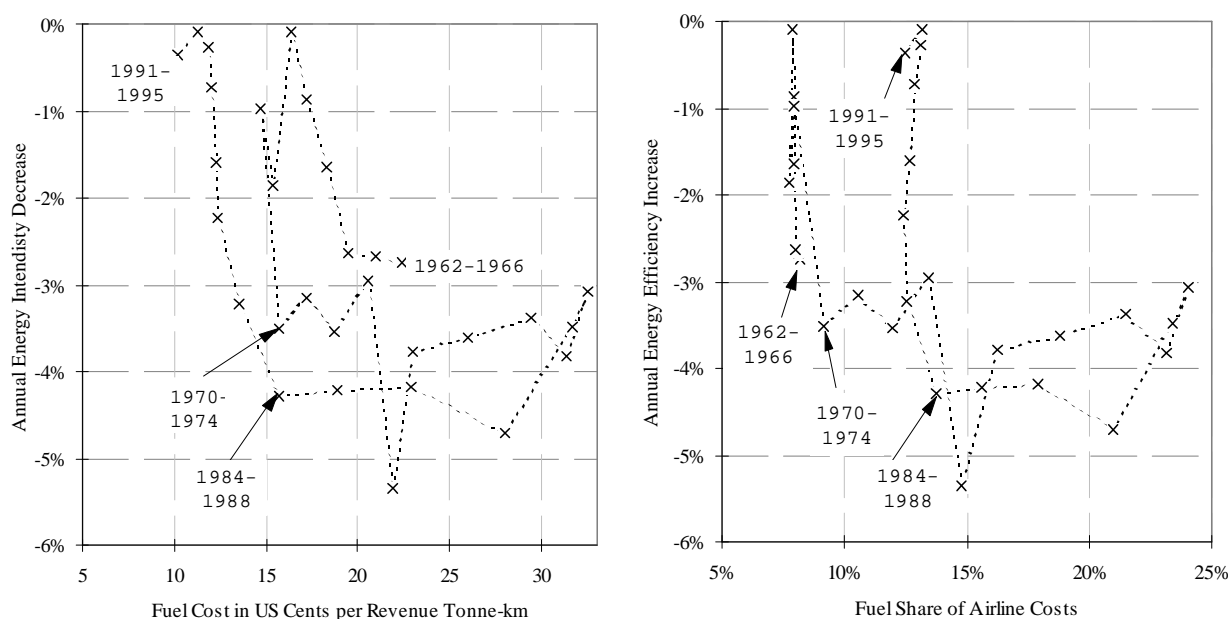
Reducing energy intensity — operational and technology changes

Whereas fuel price changes seem to have had relatively little lasting impact on air transport tariffs, they appear to have had an effect on energy intensity. This is illustrated in Figure 11, which plots the rate of energy intensity reduction in global civil aviation (i.e. annual percentage decrease in fuel use per TKP) versus the real fuel cost per TKP and versus the fuel percentage of total costs. While it can be argued that the period of rapid energy efficiency improvement during the period 1974 to 1988 coincided with rapid

growth in aviation generally, and with successive waves of newly designed aircraft being introduced, fleet renewal was also encouraged by the fuel price. The period of low energy efficiency increase from about 1989 coincides with three successive years of operating losses in the industry, which reduced the capital available for fleet renewal, but low fuel prices also reduced the pressure to replace old technology. Meanwhile, energy efficiency improvements slowed in 1988, during a boom period for the industry.

The path followed by energy intensity vs. fuel cost in Figure 11 strongly suggests a threshold effect. Such an effect might be explained as follows: with fuel costs per tonne-km declining in the 1960s, airlines paid decreasing attention to reducing energy use. Then, with fuel prices rising rapidly in the early 1970s, energy saving and fleet renewal were encouraged by the high running costs of older aircraft. Hence, much of airlines' and aircraft manufacturers' innovative efforts were turned to reducing energy use. While fuel costs remained above about 15¢/tonne-km and 15 per cent of total costs through to the mid-1980s, this pressure was maintained. From 1985, fuel prices were low and declining. The industry's innovative efforts turned away from fuel saving towards other priorities, such as quality of service and more general cost-cutting. Record aircraft orders in 1988-1989 led to a peak in deliveries in 1991, which happened to be the mid-point of an aviation industry recession with a drop in traffic (ICAO, 1995d). Thus, over-capacity may also have played a role in slower energy intensity reductions.

Figure 11. Average Annual Rate of Energy Intensity Decrease vs. Fuel Cost per Tonne-km (real 1992 US¢) and Fuel Share of Airline Costs



Notes: **Each graph shows a single series of points**, giving a trajectory of five-year averages, starting with 1962-1966 and finishing with 1991-1995

Energy intensity is estimated as civil aviation energy use (for ICAO Member countries) divided by TKP (passengers, mail and freight). Aviation energy use is estimated by ICAO using a) equations derived from publicly available data that estimate fuel consumption for individual aircraft types; and b) scheduled airline timetables. Thus, it takes no account of changes in operational influences on energy use, such as air traffic congestion and changes in airline operating practices. The estimate does take account of changes in aircraft load factor. The warning given in the Context section is repeated here: the equations used to estimate fuel consumption were last modified in 1991. Hence, new technology introduced since

1991 does not show in the data, although changes in fleet composition to increase the use of technology that already existed in 1991 do show in the data.

With the crude oil price 50 per cent higher in 1996 than a year earlier leading to higher aviation fuel prices, and with non-fuel airline costs continuing to fall, attention is likely to turn back to reducing fuel costs. Meanwhile, traffic growth is catching up with capacity and aircraft orders, which fell by a factor of four between 1989 and 1991, began to pick up again in 1995. With new technology entering the fleet in aircraft such as the Boeing 777, the Airbus A-340 and new versions of the Boeing 737 and other popular models, a more rapid reduction in energy intensity can be expected in the near future.

Considering longer term trends, there appears from Figure 11 to have been a ceiling of around 4 per cent on the historical rate of energy intensity reduction in the aviation industry. It is not clear whether such a rate could be sustained in the future, but no industry analysts are currently projecting that energy intensity reductions will exceed 3 per cent on average over the next 20 years. Greene (1992) identifies a range of technological developments that together could achieve 30-52 per cent reduction in energy intensity in aircraft sometime after 2000. Such an energy efficiency potential with known technology makes a rate of energy intensity reduction of 3-4 per cent per year imaginable. Greene (1995) notes that, under current market conditions, many of the technologies identified in Greene (1992) are unlikely to enter the civil aircraft fleet, and he finds a maximum rate of energy efficiency increase to 2015 in the region of 2.3 per cent per year.

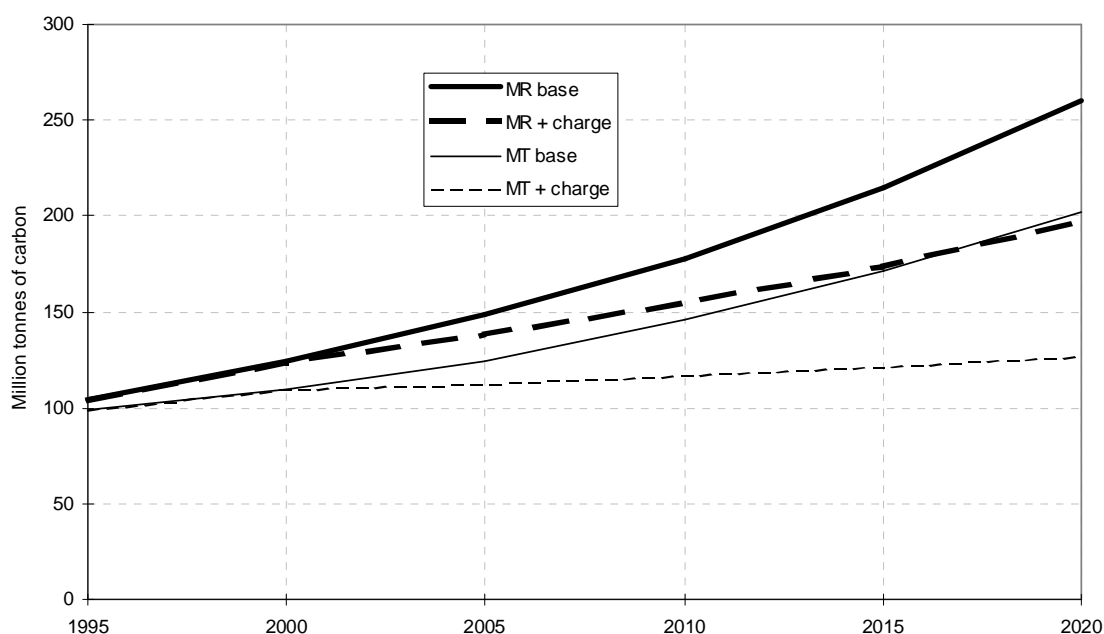
Greene (1995) also notes that aircraft manufacturers project an increase in aircraft passenger load factors to about 70 per cent by 2013-2014: the 1993 level was 66 per cent (ICAO, 1994a). This implies energy intensity reductions of about 6 per cent or 0.3 per cent per year. Olivier (1995) uses this same projection of load factor increasing by 4 percentage points in 2015 relative to 1990, but considers the potential to be about double this, implying an 11 per cent potential energy intensity reduction. The overall potential for load factor increase may be greater than that for passengers: the aircraft load factor in weight terms in 1993 was 58 per cent (ICAO, 1994a), although on short haul flights, the potential for increasing weight load factors by taking on freight is limited by the need to minimise turn-around times. Other operational changes can also lead to energy intensity reductions, including a combination of improved routing and flight management, energy savings on the ground, and improved air traffic control to reduce congestion. The opportunities in these areas are likely to be fairly small — probably less than 10 per cent energy savings overall. Thus the total potential for energy intensity reduction through operational changes might be in the range 10-20 per cent. Further energy intensity reductions might be achieved on passenger flights by reversing the current trend towards increasing comfort levels (larger, heavier seats, more equipment and baggage space).

Assuming that a fuel charge would have a substantial effect on aircraft engine and airframe design and could bring the technologies reviewed by Greene (1992) into the commercial fleet, this effect would take some time to be seen. Aircraft have working lives of at least 25-30 years. This life-time is not an absolute constraint on technology turnover as aircraft can be re-engined, but existing airframes may not be able to accommodate the considerable changes in engine designs needed to obtain energy savings as large as 30 per cent. The effects of a charge might also be delayed because of the long lead time needed for safety evaluation of new aircraft technologies. Despite these caveats, new aircraft technologies have been demonstrated delivering the energy savings indicated, and these might be ready for marketing by 2010. Technological changes induced by the charge might be present in half the global fleet by 2020⁹, and contribute overall energy intensity reductions of the order of 15-25 per cent. When combined with

⁹ With a 5 per cent annual growth rate in the aircraft fleet, and a 30-year aircraft life, half of the global fleet at any time is less than ten years old.

operational changes, the total potential for induced energy intensity reduction in aviation might be in the range 25-35 per cent by 2020. This is illustrated in Figure12, which shows the effect of increasing the annual rate of energy intensity reduction to 3.5 per cent per year. Emissions in 2020 are decreased by 27 per cent relative to the Markets Rule scenario (in which underlying energy intensity reductions are 2.2 per cent per year) and by 36 per cent relative to the Muddling Through scenario (where underlying energy intensity reductions are 1.1 per cent per year).

Figure12. Effects of Accelerated Energy Efficiency Increases on Annex I Country Civil Aviation Carbon Emissions



Note: Assumes rate of energy intensity reduction is increased to 3.5 per cent per year in both scenarios relative to an underlying rate of 1.1 per cent per year in the Muddling Through (MT) Scenario, and 2.3 per cent per year in the Markets Rule (MR) Scenario

It is not possible to conclude the precise level of charge that would be needed to achieve the greenhouse gas emission reductions shown in Figure12. Given the threshold effect discussed earlier, it might be necessary to increase the charge steadily in order to maintain both absolute fuel costs, and the fuel share of total costs¹⁰. With both overall costs and energy intensity decreasing at 3-4 per cent per year, the charge would need to result in fuel prices increasing by somewhere in the range 1 to 5 per cent per year from 2000 to 2020, reaching 5 - 33 ¢ per litre of fuel in 2020, taking a base price in 2000 of 20¢ per litre. The

¹⁰ For this study, it is not possible to provide more than a back-of-the-envelope calculation of the rate of price increase needed. Analysis of the historical data presented in Figure 1 suggests that energy intensity reductions may be influenced by a combination of absolute fuel costs per TKP and the fuel share of total costs. Thus, it is possible to fit annual energy intensity reduction to a curve of the form:

$$\text{Annual energy intensity decrease} = f(0.7 \times \text{fuel cost in cents/TKP} + 0.3 \times \text{fuel share of cost in percent}).$$

If both total costs and energy intensity were to decrease at 3-4 per cent per year with fuel prices constant, the argument of this function would decrease by 2-3 per cent per year. To keep the argument constant, and hence to maintain the rate of energy intensity decrease, fuel prices would need to increase by 2-3 per cent per year. A wider range of 1-5 is given in the text in acknowledgement of the crude and preliminary nature of this analysis.

effect on traffic can be estimated from Table 3 to be a few percent reduction, depending of course on the actual size of the charge.

The picture presented so far is complicated by the possible introduction of supersonic aircraft to the commercial civil fleet. Such aircraft would almost certainly have much higher energy intensity than existing subsonic aircraft. It is probable that they would capture the higher value-added end of the aviation market, leaving the more price-sensitive segments of the market to subsonic travel. It is not clear what effect this would have on the rate and type of technical change in subsonic aviation and on overall aviation energy use.

Conclusions — overall effects of a fuel charge

In the medium-to long- term, most of the effect of any fuel charge would probably be on the energy intensity of air transport — although the historical, top-down analysis given here cannot be taken as conclusive and more detailed analysis is needed.

It seems unlikely that a fuel charge, even at levels in the region of \$125/tonne of carbon, would have a substantial long-term effect on air traffic, although the charge might result in higher tariffs in the short term before energy intensity reductions eliminated this increase.

The analysis here does not allow determination of the effects of different levels of charge in any detail — rather it suggests that a 3-4 per cent per year reduction in energy intensity is possible, and that this might be achieved through continual fuel price increases by somewhere in the range 1-5 per cent per year. Further research is needed to understand the effects of different charge levels and rates of increase.

Part of the effect of higher fuel costs on energy use would be expected from changes in airline practices, changes in airline deployment of existing aircraft, and changes in their choices among aircraft currently on the market.

Rationale for common Action — effects of non-uniform charges

If a CO₂ charge were applied at a non-uniform level, it would be less effective than a uniform, globally applied charge. “Tankering”, where aircraft take on more fuel than is needed for a flight to avoid taking on more expensive or lower quality fuel at the next port of call, already occurs to some extent — indeed airlines have developed software to plan their refuelling patterns taking account of relative fuel prices. A non-uniform CO₂ charge would give airlines an incentive to buy more of their fuel in countries that imposed a lower charge, or did not impose a charge at all. This might simply mean that, when operating flights with ports in both participating and non-participating countries, airlines would tend to buy more of their fuel in the non-participating countries than they would otherwise have done.

Carrying extra fuel involves costs: it reduces the amount of cargo that can be carried, and increases the fuel consumption of the aircraft. Tankering is likely to be confined to short-haul flights, where these costs are least significant (Bleijenberg *et al.*, 1996). Airlines would be unlikely to reroute their flights to avoid charges for short haul flights, while on long-haul flights, there are other means of avoiding a charge. Where passengers on long-haul flights already have to make a stop, there might be an increased incentive to travel via non-participating countries. If a charge were imposed Annex I-wide, there would be few opportunities for this type of avoidance by passengers travelling between two Annex I countries. It might occur on journeys between Australia/New Zealand and European or American destinations, although many

of these journeys are already routed via non-Annex I countries. One possible outcome is that countries such as Hong Kong, Singapore and Tahiti might raise their fuel prices without imposing a charge as such.

If only a small number of scattered European countries imposed a charge, there might be an incentive for passengers taking long-haul flights to travel via countries without charges. For example, for a transatlantic flight, the average fuel use per passenger is in the region of 250-500 litres, so that airlines operating from countries imposing a charge of 10¢ per litre would have to charge each passenger an extra \$25-50.

If non-participation by some countries were to lead to changes in airline operations, any greenhouse gas emission reduction caused by the charge would be offset by additional emissions due to increased aircraft movements, and by the extra energy used in transporting “tankered” fuel.

Non-uniform application of a charge would mean that not all airlines would have an incentive to adopt energy-efficient technology. This would reduce the incentive for manufacturers to develop energy-efficient aircraft, or would increase the costs for those airlines that did wish to adopt such technology. A charge would be more cost-effective if it were widely applied.

Quantification of the “leakage” effects of a non-uniform charge is not possible without a detailed database of current aircraft movements and an economic model of the response of airlines to changes in costs. The AERO project (Appendix E) is the only attempt that the author is aware of to build such a model and examine this question. Results were released on 19 February, 1997, too late for inclusion in this study.

Other Measures

The preliminary analysis in this study has shown that fuel price increases may reduce aviation energy use substantially, but that most of the reduction would be achieved by enhancing the rate of energy intensity reductions in the industry. The analysis further suggested that fuel price may affect the rate of energy intensity reduction via a threshold effect (see Figure 11). If this is correct, it implies that many forms of incentive could, and perhaps should, be chosen to increase the amount of attention given to energy savings in the aviation industry. It may be most effective to adopt a variety of measures.

A further argument for adopting some combination of measures is the need for mitigation of non-CO₂ greenhouse gas emissions from aircraft — in particular NO_x, which is not directly related to fuel consumption.

Possible measures include:

- long-term targets (voluntary or mandatory) for energy intensity reduction or for stabilising greenhouse gas emissions, including NO_x and other gases, from aircraft, potentially linked to an airline trading system (see Appendix F for EDF proposal);
- energy efficiency or emission standards for aircraft;
- eco-labelling of air tickets;
- funding and incentives for research and development on energy efficiency and NO_x reduction;
- funding for improved air traffic control and aircraft routing systems.

All of these options have the advantage that they would not require any renegotiation of the ICAO position on taxes. Several could be pursued unilaterally, although they might benefit from common action.

Several options for charges are evaluated by Bleijenberg *et al.* (1996), who summarise the options as shown in Table 4.

Table 4. Options for Aviation Charges

Charge base	Levy point
Calculated emissions	Landing charge
	En-route charge
	Charge per carrier
	Passenger airport charge
Fuel consumption	Fuel charge
	Measured fuel consumption
Passenger movements	Passenger airport charge

(Bleijenberg et al., 1996)

The decision within the UNFCCC on allocation to Parties of greenhouse gas emissions from international bunkers could affect the choice of measure, as discussed in the Context section of this report.

Of the options, a charge on fuel consumption would be the most efficient means of internalising social costs associated with CO₂ emissions. The various options for charges on calculated emissions have the advantage that they could be designed to address NO_x and other greenhouse gas emissions, as well as non-climate environmental impacts of aviation.

Charges on calculated emissions would almost certainly need to be based on some kind of classification of aircraft according to performance in standard emission tests. Thus they would not provide an incentive for operational changes to reduce energy intensity. *En-route* charges might have an additional advantage in that they could be calculated on the basis of an aircraft's height and airspeed, in order to take account of variations in the NO_x emission factor and radiative impact.

Overall, the most economically efficient approach would probably be a combination of fuel charges and other charges, designed to reflect the range of greenhouse gas emissions and other environmental impacts of aviation.

ECONOMIC, EMPLOYMENT, TRADE, AND OTHER EFFECTS

Economic Rationale for a Charge on Fuel

Governments might have several reasons for considering introducing a charge on aviation fuel. The main economic rationale for doing so is to address the market failure represented by the existence of externalities related to climate change. However, other rationales might be relevant.

- (i) Charges might be established to take into account all environmental and social costs of air transport. For example, economic efficiency would be improved if air traffic congestion costs were internalised through some congestion pricing mechanism.
- (ii) Charges might be established to “level the playing field” between air transport and other transport modes.
- (iii) Charges could be designed specifically to raise revenue to invest in improved air traffic control, expand airport capacity to reduce congestion, or to invest in research, development, and demonstration for energy-efficient, low emission aircraft.

While all three of these are possible, economic efficiency arguments would suggest:

- that charges to address a range of environmental and social costs should be raised on a basis that directly reflects those costs, rather than through fuel sales. Thus, congestion charges are best imposed as en-route or landing fees related to the congestion level at the particular time and place, as already occurs in some countries;
- that “levelling the playing field” might well mean making other transport modes pay their full social and environmental costs in ways that more directly reflect those costs, rather than through the current most common mechanism of fuel taxes;
- that air traffic control and airport capacity should continue to be paid out of en-route and airport charges, rather than from a fuel charge.

There is some argument on economic efficiency grounds for subsidising research, development and demonstration that contributes to greenhouse gas mitigation in the long term, although such subsidies might not start with aviation. Research, development and demonstration in other areas — e.g. reducing methane emissions from rice farming or improving building energy efficiency — might be found to be more cost-effective as means of achieving long-term greenhouse gas mitigation.

Meanwhile, economic arguments would suggest that the externalities associated with climate change and oil depletion would be best addressed through Pigouvian taxes (externality charges) with the use of the revenue determined separately. There is no economic efficiency argument for using the proceeds of externality charges to subsidise the aviation industry. Thus the argument for charges that are “revenue

neutral” within the industry can be made only on the political grounds that it might be easier to reach international agreement on such charges.

Economic Effects of a Charge

Dependence on design of charge

Sudden, large fuel price increases in 1973/74 and 1979/80 had quite small effects on air traffic and on airline profits. Cost increases were passed through to customers, but the ticket price increases were absorbed within one or two years in efficiency improvements. Nevertheless, a large charge, suddenly imposed, would be likely to have economic costs and could cause job losses in the industry.

It seems unlikely that a charge introduced gradually, Annex I-wide, would have a noticeable effect on industry-wide profits or employment levels. Induced energy savings might result in a net reduction in airline costs in the long run. There might be some local effects where airlines are less competitive, or have ageing inefficient fleets resulting in large cost increases as a result of a fuel charge.

The overall economic effect of a charge would be likely to depend very much on how the proceeds are used. This is analogous to the effects of carbon taxes in general, which are reviewed by Baron (1996).

The effects of a charge would also depend on the uniformity with which it was applied. Airlines operating mainly from participating countries might be disadvantaged relative to those from non-participating countries. Airlines from either group of countries operating a particular route would face the same fuel costs on that route, but airlines from participating countries might have their margins cut more than those from non-participating countries, which would meanwhile see the advantages of accelerated energy efficiency improvements in new aircraft (i.e. there might be some free-rider effects).

A charge imposed as a percentage of the fuel price would have a different effect from a charge imposed as a flat rate (in \$/tonne carbon) fuel price increase; fuel prices vary by a factor of nearly two among regions although the variations among Annex I countries are relatively small (see Appendix C). A flat rate charge would cause less distortion in competition in the industry, and would also be more consistent with the rationale of addressing climate change externalities.

Aviation employment, revenues and profits

Employment in the world’s scheduled airlines peaked in 1989 at 1.53 million, and had fallen to 1.51 million in 1993. Airlines have continued to aim to reduce operating expenses through staff cuts in recent years, through lay-offs, redundancies, attrition and incentives for early retirement. Airlines in Europe and the United States have cut costs by creating subsidiary companies where non-unionised staff are paid salaries much lower than those for comparable jobs in the parent companies (ICAO, 1994a). Any effects of a charge on airline employment would be small compared with these underlying trends. It is even possible that higher fuel prices could lead to some substitution of fuel with labour.

World airline revenue in 1995 was about \$274 billion in 1995 (ICAO, 1995d). Following global operating losses in 1990-1992, the operating profit was about \$2.3 billion in 1993, rising to \$14 billion in 1995. However, after accounting for capital charges, the industry worldwide only returned to net profits of \$4.5 billion (1.6 per cent of revenues) in 1995. A fuel charge of \$25/tonne carbon (2¢/litre of fuel) would represent about 1.5 per cent of industry revenues in Annex I countries.

Table 5 summarises operating revenues and operating profits for the major world regions in 1992, the mid-point of the recent industry recession. As the table shows, American airlines saw the largest losses in this period — perhaps partly because the North American airlines were deregulated in the 1980s and so were more open to market pressures. Airlines in the European Union will be deregulated from 1997 (i.e. they will face open competition and will not receive government subsidies).

Table 5. Operating Revenue and Operating Result, Airlines by World Region, 1992

Region of Airline Registration	Operating Revenue (million US\$)	Percent of World Revenue	Operating Result (million US\$)	Operating Result as % of Revenue
Africa	5 700	2.6	300	5.3
Asia/Pacific	48 000	22.1	1800	3.8
Europe (excl. CIS)	66 700	30.7	-300	-0.5
Middle East	6 900	3.2	200	2.9
North America	80 200	36.8	-2900	-3.6
Latin America/Caribbean	10 000	4.6	-600	-6.0
World	217 500	100.0	-1500	-0.7

A fuel charge might have some effect on operating profits although the effects of fuel price increases in the past appear to have been very short term. Nevertheless, in a situation where some airlines are deregulated and others protected by their governments, deregulated airlines might be more affected by a charge than those that are protected.

Indirect effects on the economy

Air traffic plays an important role in international trade, especially tourism, in international business and in trade of high value goods. Reduction in all of these activities would have effects on many other areas of the economy. The largest effects would be on countries whose economies are particularly dependent on long distance transport for trade and tourism, and whose competitive position *vis-à-vis* non-participating countries might be damaged — in the Annex I group of countries, Japan, Australia and New Zealand might be most affected.

IATA (undated) estimates that aviation globally generated \$1 000 billion in economic activity in 1992 of which \$250 bn was in the industry itself, \$250 bn was indirectly due to the industry (through its suppliers), and \$500 bn was induced activity elsewhere in the economy (IATA, undated). IATA further estimates that aviation was responsible for creating 22 million jobs, of which 3 million were in the industry itself, 7 million were indirectly associated with the industry, and 12 million were induced elsewhere in the economy. These estimates of the economic benefits of aviation are based on the concept of macroeconomic multipliers — all goods and services consumed as inputs to aviation involve additional economic activity; the inputs to those goods and services generate yet more activity, and so on. However, most economic activities — not least government spending — have multiplier effects and there is no reason to suppose that aviation would have a greater effect than other services. If consumers and firms did not spend their money on aviation they would spend it on something else, perhaps generating even more economic activity with less environmental externalities. Karyd and Brobeck (1992) comment that aviation activity is, in fact, mainly induced by other activities, and suggest that: “It is better to recognise the futility of all attempts at calculating the value of aviation. It is not possible to arrive at a stable result and there is no use for it — not even IATA has to justify air transport in general”.

Costs of Non-Uniform Implementation of a Charge

In a situation where an aviation fuel charge is imposed unilaterally by a country, or multilaterally by a small group of countries, the economic cost is likely to be much larger for those countries than in situations where all countries or a large region of the world (e.g. Europe or North America) agrees to impose a charge.

Unilateral imposition of a charge by a small country would be likely to have more effect on freight markets than on passenger markets. These currently comprise about 10 per cent of airline revenues globally (ICAO, 1995b). Fuel is a larger share of the cost of air freight than of passenger travel, because a high proportion of passenger costs is made up by airport and other passenger services. Meanwhile, freight is usually somewhat less time-sensitive than passenger services. Freight shippers would have an incentive to move freight by surface to and from airports in neighbouring countries. This would raise the costs of transporting traded goods, as well as reducing the amount of aviation and related business in countries imposing the charge.

Unilateral imposition of a charge by a country might also encourage airlines to “tanker” — i.e. to carry extra fuel on flights stopping in that country in order to avoid refuelling there. This would result in additional costs to the airlines, additional energy use because of the extra weight of fuel transported by air, and reduced fuel sales in that country. There will be a threshold for any country below which tankering does not occur, depending on the trade-off for the airlines between the cost of paying the charge and the additional cost of transporting fuel.

The effects of unilateral imposition of a charge on passenger markets would probably be most noticeable in long-haul flights. Passengers would be more likely to fly via neighbouring countries not imposing the charge, leading to some concentration of long-haul hubs in these countries. This is one of the main mechanisms through which competition among airlines might be affected, favouring airlines in non-participating countries. To the extent that this would involve passengers taking an additional short flight to and from the long-haul departure point, it would again result in a net increase in greenhouse gas emissions, as well as raising the cost of flying.

If a charge were introduced on an Annex I-wide basis, the distortion of aviation markets in North America and Europe might be quite small, as the majority of air transport involving these two regions is either within or between them — it would take a very large fuel charge to justify re-routing a London-New York flight via North Africa. However, there might be some adjustment in routing patterns in Asia/Pacific region, which includes both Annex I and non-Annex I countries. Meanwhile, at least for fuel charges of 10 per cent or more, tankering might become common on medium haul flights between the Middle East and Europe, and between Annex I and non-Annex I countries in North and Central America and in the Asia Pacific region. For long-haul flights, tankering would only be cost-effective for airlines at relatively high levels of fuel charge, as the extra weight of tankered fuel would entail burning more fuel.

COMMON ACTION

Advantages of common action

It is broadly recognised that the large international component of air transport means that measures taken globally are likely to be much more cost-effective in tackling the problem than those taken at a national level (ICAO, 1995a). The advantages of uniform application of a charge, in terms of its impact on emissions and in terms of its economic cost, have already been discussed. These include:

- maximising the effects of the charge on technological development, as aircraft manufacturers would have more incentive to develop and sell energy-efficient aircraft
- maximising the economic efficiency of the charge by avoiding:
 - tankering of aircraft fuel resulting in higher airline costs and greenhouse gas emissions;
 - diversion of passengers and freight through countries not imposing charges, which would increase costs, overall fuel use and greenhouse gas emissions; and
 - adverse effects on goods transport and passenger travel to and from countries with higher fuel prices.

Alternative measures to encourage energy efficiency, including best practice programmes, energy efficiency standards and targets, and industry emission caps, would also be more cost-effective if applied internationally.

Regional Co-ordination

Many of the problems associated with non-uniform charges might be avoided by co-ordination of a charge at a regional level. As Figure 3 showed, world air traffic is dominated by Europe, Asia/Pacific and North America. These regions are likely to differ in their potential for agreeing on any charge. Europe is the region with the highest general levels of *en route* and airport charges, and might have the most potential to use fuel charges to cover existing costs or to modulate existing charges according to the environmental performance of aircraft. Meanwhile, the first countries to introduce environmental charges for aviation have been in Europe. The world's busiest international air traffic routes are: between Europe and North America; within Europe; and within Asia. The most rapid growth is on routes within Asia, while routes between Asia and other parts of the world are also growing rapidly in volume. The European routes primarily involve countries which are European Union members (and nearly all are Annex I Parties). Many routes within Asia and between Asia and other regions involve countries that are non-Annex I Parties.

Although North America accounts for a relatively small share of international traffic, it accounts for the largest share of traffic overall. Thus, Europe and North America account for nearly 70 per cent of world air traffic, and region-wide carbon charges in these two zones, or in either one, would be hard for airlines to avoid. Unilateral implementation of a charge by any one European country would be much more likely to lead to re-routing and tankering by airlines.

A regional charge would be less effective than a global or Annex I-wide charge in encouraging energy intensity reductions in the aviation industry, because it would provide less incentive for aircraft manufacturers to introduce energy efficiency improvements. However, an Annex I-wide charge, harmonised at a regional level but varying among regions, could have most of the advantages of a uniform charge, while allowing for some differences in the situation of different countries. The same arguments apply to other measures aimed at encouraging energy efficiency.

Co-ordination by route groups

A further option might be to co-ordinate a carbon charge by route groups. Thus, for example, all countries with North Atlantic routes might agree to impose a charge on trans-Atlantic flights. This charge would be hard to avoid and would be unlikely to lead to substantial traffic distortions. However, it would be hard to impose such a charge on fuel, and it might be more feasible if implemented as an en-route charge, one of the alternative measures listed on page 41.

Disadvantages of common action

The main disadvantages of common action on a carbon charge would be the difficulties in negotiating and implementing such a charge. These include:

- the need to agree on the principle of imposing a fuel charge;
- the need to agree on the level of the charge;
- the need to establish how the revenue should be collected and used (or whether this should be left to individual governments);
- the need to reword or dismantle the large number of bilateral agreements not to impose taxes on fuel for international aviation.

These issues will be discussed in the following section.

Many of the disadvantages could be avoided by adopting alternative measures aimed at encouraging energy intensity reductions.

Possible Common Actions

There are several possible types of common action:

1. **Replication by Parties of successful measures implemented elsewhere.** This approach would probably not be relevant for an aviation fuel charge, but it might be appropriate for several other types of measure that have been touched on in this study.
2. **Agreement to take action in the aviation sector toward an aim or target.** A first step towards a common action in aviation might be for UNFCCC Parties to agree that reducing emissions from international aviation is an important objective, and would contribute to the aim of the Convention. An agreement on a method for allocating national responsibility for bunker emissions might be one approach to this, bringing international aviation into the

scope of existing commitments under the UNFCCC to introduce and report on measures to mitigate national greenhouse gas emissions. A alternative approach might be to agree on a specific target or cap for global aviation greenhouse gas emissions, which could form the basis for an airline emission trading system, as presented in Appendix F.

3. **Co-ordination to implement the same or similar measures.** Countries might agree, perhaps through ICAO, to the legitimacy or even desirability of aviation fuel charges in principle, easing the way for those countries that wish to take unilateral action. A next step might be for groups of countries to introduce a charge, whether at the same level or at different levels.
4. **Specific policies and measures implemented together.** Countries might agree in the UNFCCC process and subsequently in ICAO, to introduce a measure, such as an aviation fuel charge, at a harmonised level. In this case, countries might agree that national governments have responsibility for charge collection and revenue disbursement either for national purposes or to offset existing aviation charges. Alternatively, countries might agree to some international body (e.g. the GEF) collecting the charge and disbursing it for climate change mitigation and adaptation purposes.

Political Feasibility/Barriers and Implementation Issues for Common Action

The political feasibility of an aviation fuel charge would depend on both the interest from governments in implementing such a charge, and the opposition from political lobbies. Aviation interests strongly oppose any new tax or charge, but the opposition is strongest to a tax used to raise revenue for general purposes. A charge levied on aviation fuel might meet less opposition from the aviation industry if it were:

- fully justified by the need for actual financial outlays in relation to aviation services, environmental or technology research and development, or environmental cleanup (see Appendix B);
- linked to a reduction in other charges and fees paid by airlines;
- agreed upon by a large number of countries, if not all countries, and set at a common level

The following paragraphs explore some of the political positions and interests that might influence the success of any attempt to implement an aviation fuel charge.

Industry concerns: effects on competition; the “taxation burden”

The ICAO policies discussed in Appendix B were designed to ensure fair treatment for international aviation by countries, and to avoid discriminatory practices (ICAO Doc 8632 introduction). It would be important to ensure that any aviation fuel tax was introduced in a non-discriminatory manner.

The airline industry is understandably opposed to the introduction of environmental taxes, and IATA has adopted a Policy Statement on Environmental Taxes on Aviation Fuel. This draft statement strongly endorses the ICAO Resolutions discouraging fuel taxes, and describes the “world-wide taxation burden on the aviation industry” as “onerous and inequitable”. It emphasises the industry’s continuing efforts to improve fuel efficiency, but states that it is “universally recognised that modern air transport technology is unable to make use of alternative fuels...with any reasonable degree of safety”. In conclusion, “IATA

urges all States not to impose any environmental taxes on aviation fuel” but goes on to say that where such taxes are introduced, they should be formulated in accordance with the ICAO principles.

The possibility of an environment-related charge has also been raised by other bodies. The United Nations Commission for Sustainable Development (CSD), at its Third Session (New York, 11 - 28 April 1995), suggested an in-depth study to evaluate the need for, and feasibility of, such a charge. The CSD recommended that the study should address environmental, economic, legal, administrative and political aspects of such a mechanism, taking into consideration the particular needs and conditions of developing countries and that the study should be undertaken in co-operation with ICAO and other relevant bodies. One suggestion to the CSD was that a 1 per cent levy on the price of aviation fuel might be used to provide a fund for general sustainable development activities.

Attitudes to alternative greenhouse gas mitigation measures

The aviation industry has been well aware of the discussions among scientists of the tropospheric ozone-promoting and stratospheric ozone-depleting effects of NO_x from aircraft, since the early 1990s. Aircraft engine companies have responded by increasing their efforts to develop engines with low NO_x emissions. The industry is thus likely to be ready to respond in the next few years should a new standard or charges be introduced to control in-flight NO_x emissions. The same level of preparation through recent development efforts does not exist with respect to technologies for CO₂ mitigation. Thus, the aviation industry may be more open to discussions of measures to control NO_x than those to control CO₂ emissions.

Aviation industry officials have commented that there is a trade-off between CO₂ and NO_x emissions although other analysts (including reviewers of previous drafts of this report) disagree. It is true that measures that increase aircraft engine efficiency in the past have also increased NO_x emissions, but new technologies such as staged combustors, which give lower NO_x emissions, do not appear to result in any sacrifice in energy efficiency. Meanwhile, given the uncertainty about the indirect radiative forcing effect of aircraft NO_x, and the short life of ozone generated by NO_x emissions, it seems unlikely that NO_x mitigation measures can be traded off against CO₂ mitigation measures. Governments may need to give a clear message — e.g. by introducing both CO₂ emission charges and standards for in-flight NO_x emissions — that both CO₂ and NO_x emissions need to be reduced as far as possible.

The industry has also repeatedly called for improvements in air traffic control improvements to reduce delays (e.g. IATA, undated). As discussed earlier in this report, air traffic control improvements could be funded out of fuel charges and might have the potential to bring greenhouse gas emission reductions in the region of 10 per cent.

Options for Addressing Barriers

Although there are no legal barriers to the implementation of charges by individual governments, introduction of a tax would require the renegotiation of existing bilateral air transport agreements. Meanwhile, the political climate described above might preclude successful implementation of a charge on a fully comprehensive, world-wide basis.

A global tax collection system might involve substantial costs which would need careful evaluation in relation to the other expected costs and benefits of the tax. Accounting infrastructure already exists within ICAO, which administers the Denmark/Iceland Joint Financing Agreements for charges levied for certain North Atlantic air navigation services, but expanding these to encompass a global tax collection system

would also involve substantial costs. Meanwhile, petroleum companies routinely act as tax collectors for governments and all major international companies have the accounting infrastructure and capability to extend this function to an aviation fuel tax.

A step towards agreeing on the level for a charge is the development of some agreement on the global warming potentials that should be applied to aviation greenhouse gas emissions. Until the early 1990s, little research was carried out into emissions from aircraft during the cruise phase of flight. It is at cruising height that the radiative impact of water vapour and of ozone generated from NO_x emissions are most uncertain and potentially highest. The IPCC Special Report on Aviation and the Global Atmosphere, to be completed in 1998, should be an important step towards clarifying these impacts. However, monetary valuation of the externalities associated with these emissions will remain a major challenge, even if the radiative impacts are known.

Possible participants, timing and vehicles for action

National governments

In most countries, national governments would need to negotiate the cancellation or alteration of their bilateral agreements not to tax aviation fuel, and pass laws to implement a tax. This would probably take many years. Governments would also need to be involved in international negotiations to establish the principle, form and level of the tax if it were to be adopted as a collective or co-ordinated measure.

International organisations

The negotiation process to establish a collective or co-ordinated charge might involve various types of international organisation in various ways:

- Intergovernmental bodies, including ICAO, the UNFCCC, the United Nations Environment Programme (UNEP), UNCSD, the World Trade Organisation (WTO); in addition to providing representation during negotiation of the charge, one of these organisations might provide the forum and secretariat for the negotiations and its charter or founding treaty might form the legal basis for the charge;
- Other intergovernmental organisations representing regions or countries with some common interest, such as the European Commission, the Organisation of Petroleum Exporting Countries (OPEC), the OECD or the G77;
- International financial organisations, including the multilateral development banks and the GEF that might act as focal points for disbursing revenues if a charge were to be collected on an international basis;
- Industry organisations, in particular, those representing the airlines and the petroleum companies;
- International environmental non-governmental organisations (ENGOS).

The choice of international organisation to act as the forum for negotiation and/or implementation of the charge would depend on whether agreement on the charge were intended to be legally binding, and on the

time frame for implementation. For example, ICAO agreements on policy matters tend to be voluntary, and are morally, rather than legally, binding. If the international will existed to implement a charge, the time frame for an agreement through ICAO could be quite short, as the Organisation has a permanent executive body in place. However, the implementation of the measure by ICAO Member States could be a lengthy and piecemeal process. Some Member States might never implement the charge.

Parties could adopt a binding agreement concerning the imposition, collection and disbursement of charges by some other institution. However, this approach would take longer to negotiate than an ICAO Resolution, and agreement might never be reached.

A further alternative would be for a charge to be negotiated and implemented regionally, possibly involving civil aviation organisations such as the European Civil Aviation Conference (ECAC), the Latin American Civil Aviation Commission (LACAC), and the African Civil Aviation Commission (AFCAC). Intergovernmental bodies such as the European Union (EU), the North American Free Trade Association (NAFTA), the European Conference of Ministers of Transport (ECMT), and others, might also be involved and might be more likely to form the basis for an agreement.

APPENDIX A. AVIATION GREENHOUSE GAS EMISSION SCENARIOS

Choice of Aviation Scenarios for this Study

The major manufacturers of aircraft and their engines (Airbus, Boeing, Rolls Royce, McDonnell Douglas) all forecast passenger traffic growth during 1990 to 2010 in the range 5 to 6 per cent per year. ICAO (1995b) forecasts 5 per cent per year growth in total passenger traffic and 6.5 per cent per year in international passenger traffic — more details are given below. These figures do not appear excessive, given that air traffic has grown even faster over the last three decades. However, the forecasts are based on a constant income elasticity of air traffic and do not reflect the fact that the growth rate has shown a long term decline from 9 per cent per year in the 1970s to just over 5 per cent per year in the 1980s¹¹. They may be over-estimates resulting from a combination of industry optimism and a growth spurt in the late 1980s — although it is also possible that market liberalisation in Europe and continuing rapid growth in the Asia/Pacific region might contribute to accelerated world growth in the late 1990s.

Vedantham and Oppenheimer (1994) produce a number of aviation scenarios building from the GNP assumptions in the IPCC IS92 scenarios. In IS92a, they generate a “base” case where aviation demand grows at 3.6 per cent per year and a “high” case at 5.5 per cent per year.

WEC (1995) has produced three scenarios of air traffic and associated energy use. Passenger travel grows in the period to 2020 at rates ranging from under 4 per cent per year to nearly 8 per cent, although the lower growth case is a scenario involving strong policies to achieve environmental objectives.

Olivier (1995) produces a set of three scenarios, in which air passenger traffic grows at between 4.8 and 5.7 per cent per year. The scenarios are based on various global patterns of GNP growth, along with a model of aviation traffic developed at the United Kingdom Department of Trade and Industry, incorporating assumptions about aviation price reductions (1 per cent per year) and saturation of the market.

Greene (1995) compares a number of air passenger travel and energy efficiency scenarios to 2015, from United States aircraft manufacturers, ICAO and the United States government. He finds that growth rates in world passenger miles to 2015 are likely to be in the range 4.5 to 4.9 per cent per year.

Based on continuing trends in real air transport prices (4-5 per cent reduction per year) presented in Figure 0, it seems possible that growth will be somewhat more rapid than that in the Olivier (1995) and the Vedantham and Oppenheimer (1994) scenarios.

Energy intensity projections are perhaps harder to make than traffic projections. The various sources range from 0.7 per cent per year decrease (Greene, 1995, LOW) to about 2.8 per cent (average rate in Vedantham and Oppenheim, 1994, consistent with Balashov and Smith, 1992). The WEC rates of decrease in energy intensity are from about 1.3 to 2.1 per cent per year.

¹¹ Passenger growth rates are somewhat slower than the overall tonne-km growth rates shown earlier.

Olivier produces scenarios of aviation NO_x emissions, assuming a reduction in emission factor of 17.5 per cent between 1990 and 2015. None of the sources mention here provide any exploration of the effects of a new fleet of supersonic, stratospheric aircraft. This issue may be further explored in a subsequent draft of this study.

ICAO Forecasts

As Table 6 shows, growth forecasts from ICAO differ substantially among regions, with the fastest growth anticipated in the Asia/Pacific region, and the slowest in Europe.

Table 6. ICAO forecasts of scheduled passenger traffic by region of airline registration

Region	Passenger-kilometres (billion)			Regional share of world traffic (%)			Annual percentage growth	
	Actual	Actual	Forecast	Actual	Actual	Forecast	Actual	Forecast
	1982	1992	2003	1982	1992	2003	1982-1992	1992-2003
Africa	33.7	44.0	65	3.0	2.3	1.9	3 %	4 %
Asia/Pacific	186.8	406.7	980	16.4	20.8	28.6	8 %	8 %
Europe	381.3	551.7	800	33.5	28.3	23.4	4 %	3 %
Middle East	33.2	53.1	100	2.9	2.7	2.9	5 %	6 %
North America	441.5	806.4	1340	38.8	41.3	39.1	6 %	5 %
Latin America and Caribbean	60.3	90.7	140	5.3	4.6	4.1	4 %	4 %
World	1136.8	1952.6	3425	100.0	100.0	100.0	6 %	5 %

Source: ICAO, 1995b

Scenarios for this Study

The following tables show the scenarios of air traffic, energy intensity and total energy use, constructed for this study and adapted in response to the comments of reviewers of previous drafts of this study. Two scenarios are shown: “muddling through”, in which demand grows slowly and energy intensity falls slowly; and “markets rule”, in which demand grows rapidly and energy intensity falls rapidly. The scenarios assume constant income elasticities which vary by region and scenario for air travel and air freight demand, along with rates of energy intensity improvement which vary by scenario, region and year.

Muddling Through	Europe	North America	Pacific	FSU	CEE	Asia	Africa	Latin America	World	Annex I	Growth Rate (World)	Growth Rate (Annex I)
1992	369	826	170	149	11	293	41	88	1947	1525		
1995	410	917	189	182	13	357	50	107	2224	1710	4.5%	3.9%
2000	488	1091	225	252	19	496	69	149	2789	2074	4.6%	3.9%
2005	580	1299	267	351	26	689	96	207	3516	2523	4.7%	4.0%
2010	691	1546	318	487	36	958	134	288	4458	3078	4.9%	4.1%
2015	822	1840	379	677	50	1332	186	400	5686	3768	5.0%	4.1%
2020	978	2190	451	941	69	1851	259	556	7295	4629	5.1%	4.2%
Markets Rule	Europe	North America	Pacific	FSU	CEE	Asia	Africa	Latin America	World	Annex I	Growth Rate	Growth Rate
1992	369	826	170	149	11	293	41	88	1947	1525		
1995	432	967	199	199	15	391	55	117	2375	1811	6.8%	5.9%
2000	561	1257	259	322	24	633	89	190	3335	2423	7.0%	6.0%
2005	730	1634	336	521	38	1025	143	308	4736	3260	7.3%	6.1%
2010	949	2124	437	844	62	1659	232	498	6805	4416	7.5%	6.3%
2015	1233	2761	568	1365	101	2685	376	806	9896	6029	7.8%	6.4%
2020	1603	3589	739	2210	163	4346	608	1305	14564	8305	8.0%	6.6%

Table 7. Air Passenger kilometres (billion passenger kilometres)

Muddling Through	Europe	North America	Pacific	FSU	CEE	Asia	Africa	Latin America	World	Annex I	Growth Rate (World)	Growth Rate (Annex I)
1992	369	826	170	149	11	293	41	88	1947	1525		
1995	410	917	189	182	13	357	50	107	2224	1710	4.5%	3.9%
2000	488	1091	225	252	19	496	69	149	2789	2074	4.6%	3.9%
2005	580	1299	267	351	26	689	96	207	3516	2523	4.7%	4.0%
2010	691	1546	318	487	36	958	134	288	4458	3078	4.9%	4.1%
2015	822	1840	379	677	50	1332	186	400	5686	3768	5.0%	4.1%
2020	978	2190	451	941	69	1851	259	556	7295	4629	5.1%	4.2%
Markets Rule	Europe	North America	Pacific	FSU	CEE	Asia	Africa	Latin America	World	Annex I	Growth Rate (World)	Growth Rate (Annex I)
1992	369	826	170	149	11	293	41	88	1947	1525		
1995	432	967	199	199	15	391	55	117	2375	1811	6.8%	5.9%
2000	561	1257	259	322	24	633	89	190	3335	2423	7.0%	6.0%
2005	730	1634	336	521	38	1025	143	308	4736	3260	7.3%	6.1%
2010	949	2124	437	844	62	1659	232	498	6805	4416	7.5%	6.3%
2015	1233	2761	568	1365	101	2685	376	806	9896	6029	7.8%	6.4%
2020	1603	3589	739	2210	163	4346	608	1305	14564	8305	8.0%	6.6%

**Table 8. Freight kilometres
(billion tonne kilometres)**

Muddling Through	Europe	North America	Pacific	FSU	CEE	Asia	Africa	Latin America	World	Annex I	Growth Rate (World)	Growth Rate (Annex I)
1992	20	38	9	6	0	16	2	4	95	73		
1995	23	42	10	7	0	20	2	5	109	82	4.5 %	3.8 %
2000	27	50	11	10	1	28	3	7	137	99	4.6 %	3.9 %
2005	32	59	14	14	1	39	5	9	172	120	4.7 %	3.9 %
2010	38	71	16	19	1	54	6	13	219	145	4.9 %	4.0 %
2015	45	84	19	27	2	75	9	18	279	177	5.0 %	4.0 %
2020	54	100	23	37	2	104	12	25	358	217	5.1 %	4.1 %
Markets Rule	Europe	North America	Pacific	FSU	CEE	Asia	Africa	Latin America	World	Annex I	Growth Rate (World)	Growth Rate (Annex I)
1992	20	38	9	6	0	16	2	4	95	73		
1995	23	43	10	8	1	21	3	5	113	84	5.7 %	4.9 %
2000	29	54	12	11	1	32	4	8	150	107	5.9 %	4.9 %
2005	36	67	15	17	1	47	6	11	201	137	6.0 %	5.0 %
2010	45	83	19	25	2	71	8	17	271	175	6.2 %	5.1 %
2015	56	104	24	38	3	106	13	25	369	225	6.4 %	5.2 %
2020	70	130	30	57	4	160	19	38	508	291	6.6 %	5.3 %

Table 9. Passenger Transport Energy Intensity

(kJ per passenger kilometre, net calorific value)

Muddling Through	Europe	North America	Pacific	FSU	CEE	Asia	Africa	Latin America	World	Annex I
1992	1866	2333	1866	3266	3266	2333	2799	2799	2311	2266
1995	1850	2312	1850	3237	3237	2312	2774	2774	2301	2256
2000	1675	2094	1675	2932	2932	2094	2513	2513	2101	2060
2005	1555	1944	1555	2721	2721	1944	2333	2333	1967	1929
2010	1480	1849	1480	2589	2589	1849	2219	2219	1888	1854
2015	1408	1760	1408	2464	2464	1760	2112	2112	1812	1783
2020	1339	1674	1339	2344	2344	1674	2009	2009	1739	1717
Markets Rule	Europe	North America	Pacific	FSU	CEE	Asia	Africa	Latin America	World	Annex I
1992	1866	2333	1866	3266	3266	2333	2799	2799	2311	2266
1995	1850	2312	1850	3237	3237	2312	2774	2774	2306	2260
2000	1675	2094	1675	2725	2725	2094	2452	2452	2086	2042
2005	1517	1897	1517	2295	2295	1897	2167	2167	1884	1841
2010	1374	1718	1374	1932	1932	1718	1916	1916	1698	1654
2015	1245	1556	1245	1627	1627	1556	1693	1693	1526	1480
2020	1127	1409	1127	1370	1370	1409	1496	1496	1369	1318

Table 10. Freight Transport Energy Intensity

(kJ per tonne kilometre, net calorific value)

Muddling Through	Europe	North America	Pacific	FSU	CEE	Asia	Africa	Latin America	World	Annex I
1992	15249	19062	15249	26686	26686	19062	26686	26686	18873	18201
1995	15113	18891	15113	26448	26448	18891	26448	26448	18801	18108
2000	13688	17110	13688	23954	23954	17110	23954	23954	17181	16518
2005	12706	15883	12706	22236	22236	15883	22236	22236	16097	15455
2010	12090	15112	12090	21157	21157	15112	21157	21157	15461	14836
2015	11503	14379	11503	20130	20130	14379	20130	20130	14852	14255
2020	10945	13681	10945	19153	19153	13681	19153	19153	14267	13710
Markets Rule	Europe	North America	Pacific	FSU	CEE	Asia	Africa	Latin America	World	Annex I
1992	15249	19062	15249	26686	26686	19062	26686	26686	18873	18201
1995	15113	18891	15113	26448	26448	18891	26448	26448	18820	18122
2000	13688	17110	13688	22268	22268	17110	23376	23376	17050	16367
2005	12398	15497	12398	18749	18749	15497	20661	20661	15428	14756
2010	11229	14036	11229	15786	15786	14036	18261	18261	13940	13274
2015	10171	12713	10171	13292	13292	12713	16140	16140	12577	11910
2020	9212	11515	9212	11191	11191	11515	14266	14266	11331	10654

Table 11: Total passenger energy (EJ)

Muddling Through	Europe	North America	Pacific	FSU	CEE	Asia	Africa	Latin America	World	Annex I	World	Annex I
1992	0.69	1.93	0.32	0.49	0.04	0.68	0.11	0.25	4.50	3.46		
1995	0.76	2.12	0.35	0.59	0.04	0.83	0.14	0.30	5.12	3.86	4.4 %	3.7 %
2000	0.82	2.29	0.38	0.74	0.05	1.04	0.17	0.37	5.86	4.27	2.7 %	2.1 %
2005	0.90	2.52	0.42	0.95	0.07	1.34	0.23	0.48	6.92	4.87	3.4 %	2.6 %
2010	1.02	2.86	0.47	1.26	0.09	1.77	0.30	0.64	8.41	5.71	4.0 %	3.2 %
2015	1.16	3.24	0.53	1.67	0.12	2.34	0.39	0.84	10.30	6.72	4.1 %	3.3 %
2020	1.31	3.67	0.60	2.21	0.16	3.10	0.52	1.12	12.68	7.95	4.3 %	3.4 %
Markets Rule	Europe	North America	Pacific	FSU	CEE	Asia	Africa	Latin America	World	Annex I	World	Annex I
1992	0.69	1.93	0.32	0.49	0.04	0.68	0.11	0.25	4.50	3.46		
1995	0.80	2.24	0.37	0.64	0.05	0.90	0.15	0.33	5.48	4.09	6.8 %	5.8 %
2000	0.94	2.63	0.43	0.88	0.06	1.33	0.22	0.47	6.96	4.95	4.9 %	3.9 %
2005	1.11	3.10	0.51	1.20	0.09	1.94	0.31	0.67	8.92	6.00	5.1 %	3.9 %
2010	1.30	3.65	0.60	1.63	0.12	2.85	0.44	0.95	11.55	7.30	5.3 %	4.0 %
2015	1.54	4.30	0.71	2.22	0.16	4.18	0.64	1.37	15.10	8.92	5.5 %	4.1 %
2020	1.81	5.06	0.83	3.03	0.22	6.12	0.91	1.95	19.94	10.95	5.7 %	4.2 %

Table 12: Total air freight energy (EJ)

Muddling Through	Europe	North America	Pacific	FSU	CEE	Asia	Africa	Latin America	World	Annex I	World	Annex I
1992	0.31	0.72	0.13	0.16	0.01	0.31	0.05	0.10	1.80	1.33		
1995	0.34	0.79	0.14	0.19	0.01	0.38	0.06	0.13	2.05	1.48	4.4 %	3.7 %
2000	0.37	0.85	0.16	0.24	0.02	0.48	0.08	0.16	2.35	1.63	2.8 %	2.0 %
2005	0.41	0.94	0.17	0.31	0.02	0.62	0.10	0.21	2.77	1.85	3.4 %	2.5 %
2010	0.46	1.07	0.20	0.41	0.03	0.81	0.14	0.27	3.38	2.16	4.0 %	3.1 %
2015	0.52	1.21	0.22	0.54	0.04	1.08	0.18	0.36	4.14	2.53	4.2 %	3.2 %
2020	0.59	1.37	0.25	0.71	0.05	1.42	0.24	0.47	5.11	2.97	4.3 %	3.3 %
Markets Rule	Europe	North America	Pacific	FSU	CEE	Asia	Africa	Latin America	World	Annex I	World	Annex I
1992	0.31	0.72	0.13	0.16	0.01	0.31	0.05	0.10	1.80	1.33		
1995	0.35	0.81	0.15	0.20	0.01	0.40	0.07	0.13	2.12	1.53	5.6 %	4.7 %
2000	0.40	0.92	0.17	0.25	0.02	0.54	0.09	0.18	2.55	1.75	3.8 %	2.8 %
2005	0.45	1.04	0.19	0.32	0.02	0.73	0.12	0.23	3.10	2.01	3.9 %	2.8 %
2010	0.51	1.17	0.21	0.40	0.03	1.00	0.15	0.31	3.78	2.32	4.1 %	2.9 %
2015	0.57	1.32	0.24	0.51	0.03	1.35	0.20	0.41	4.65	2.68	4.2 %	2.9 %
2020	0.65	1.49	0.27	0.64	0.04	1.84	0.27	0.54	5.75	3.10	4.4 %	3.0 %

APPENDIX B. THE ICAO POSITION ON TAXES AND CHARGES

ICAO, which currently has 185 Member States, is a Specialised Agency of the United Nations with responsibility for all aspects of international civil aviation. Its governing body, the ICAO Assembly, elects a Council of 33 States which is its executive body. ICAO's representatives come from civil aviation departments or authorities whose mandate is to promote the development of civil aviation. ICAO's founding Convention (the Chicago Convention of 1944) provides that fuel and lubricating oils on board an aircraft of an ICAO 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.

From as early as 1951, the ICAO Council had adopted a *Resolution* on the taxation of income and of aircraft and a *Resolution* on taxes related to the sale or use of international air transport. In 1966, these were revised, reinforced and published as a policy document, (ICAO, 1966). The *Resolution* on fuel taxation provided for reciprocal arrangements between states; airlines of a state involved in such an arrangement would be exempt or eligible for a refund of taxes or duties on fuel, lubricants and other consumables taken on board at the final international airport of call in the customs territory of the other state. The *Recommendation* on fuel taxation called on governments to grant such exemptions for fuel, lubricants and other consumables taken on board at *any* airport, not just the last port of call.

On 14 December 1993, in response to the wishes of the Assembly, which had reaffirmed the basic principles of ICAO's taxation policy and expressed concerns over the imposition of taxes by some states, the Council adopted revised policy statements (ICAO, 1994b). These reaffirm the basic principles. In the case of the *Resolution on fuel*, they reinforce and expand its scope to leased or chartered aircraft, and in the case of the *Recommendation on fuel*, they similarly expand its scope and upgrade it to a *Resolution*. The Council took this action based on information from States indicating that there was more general acceptance in recent years for the granting of exemptions from fuel duty.

ICAO's taxation policies have all been adopted by consensus although some Member States may be interested in establishing some form of environmental charge. The vast majority of States comply with the policies but some complying States would oppose any attempt to make ICAO taxation policy binding.

On 6 December, 1996, the ICAO Council adopted the following resolution.

ICAO Council Resolution on Environmental Charges and Taxes

Whereas aircraft engine emissions are contributing to air pollution and to global atmospheric problems such as climate change and depletion of stratospheric ozone, as indicated by recent international scientific assessments, and the scientific community is working towards a better definition of the extent of aviation's impact;

Whereas in recent years there has been increasing recognition by governments of the need for each economic sector to pay the full cost of the environmental damage it causes;

Whereas the 31st Session of the ICAO Assembly in 1995 requested the Council to consider the application of environmental charges or taxes to aviation and report to the next ordinary Session of the Assembly in 1998;

Recognizing that the subject of environmental charges or taxes on air transport has also been raised in other international policy-making bodies, in the context not only of controlling greenhouse gas emissions but also of mobilizing financial resources for sustainable development, and that it is necessary to make clear ICAO's position on environmental charges and taxes at this time;

Noting that ICAO policies make a distinction between a charge and a tax, in that they regard charges as levies to defray the costs of providing facilities and services for civil aviation, whereas taxes are levies to raise general national and local governmental revenues that are applied for non-aviation purposes;

Considering that once aircraft engine emission-related problems are better defined, developments in technology and new approaches to aircraft operations may offer a means of mitigating these problems in the long term;

Having in mind;

- a) that ICAO has established emission standards for new aircraft engines and the work programme of the Council's Committee on Aviation Environmental Protection (CAEP) is aimed at addressing emission-related problems and identifying appropriate solutions, taking into account technical feasibility, economic reasonableness and environmental effectiveness;
- b) that work on emission-related charges is in progress within CAEP, the results so far indicating that the environmental impact of aircraft emissions needs to be understood and quantified before determining the best method for reducing their impact and that both regulatory measures and charges can provide effective instruments in reducing emission levels, but that it is not possible to make any general conclusions at this time as to which of these is preferable;
- c) that Article 15 of the *Convention on International Civil Aviation* contains provisions regarding airport and similar charges, including the principle of non-discrimination, and that ICAO has developed policy guidance for States regarding charges (*Statements by the Council to Contracting States on Charges for Airports and Air Navigation Services*, Doc 9082/4); and
- d) that ICAO has developed separate policy guidance to States on taxation (*ICAO's Policies on Taxation in the Field of International Air Transport*, Doc 8632), which recommends *inter alia* the reciprocal exemption from all taxes levied on fuel taken on board by aircraft in connection with international air services, a policy implemented in practice through bilateral air service agreements, and also calls on States to the fullest practicable extent to reduce or eliminate taxes related to the sale or use of international air transport;

The Council

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 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:
 5. a) addressing the specific damage caused by these emissions, if that can be identified;
 6. b) funding scientific research into their environmental impact; or
 7. c) funding research aimed at reducing their environmental impact, through developments in technology and new approaches to aircraft operations;
8. *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.

APPENDIX C. ESTIMATING THE EFFECTS OF A CHARGE ON AVIATION FUEL

No literature estimates have been found of elasticities of air transport demand with respect to fuel price. Nevertheless, assuming constant energy intensity of air travel and air freight, first order estimates of their elasticities with respect to fuel price derive directly from their own-price elasticities and the share of fuel in costs.

Regional Differences

The world average price for aviation fuel for international scheduled services in 1991 was 20.0 US cents/litre (ICAO, 1994c), although this varied substantially by region. Table 13 summarises international variations in airline revenues and the share of fuel in overall costs.

Table 13. Aviation Revenues, Fuel Price, and Landing Charges by Route in 1991: International Scheduled Services

Route Group	Revenue in US¢ per scheduled passenger-km	Revenue in US¢ per scheduled freight-km (includes passenger and combination aircraft)	Fuel and oil price (US¢/litre)	Contribution to passenger costs in US¢/passenger-km	Landing and associated charges, \$ per departed tonne	Contribution to passenger costs in US¢/passenger-km
North-Central America	8.0	40.8	19.8	1.4	3.6	0.2
Central America	11.6	61.7	25.6	1.9	2.9	0.3
North America	8.0	37.1	18.3	1.4	3.4	0.2
North-South America	8.5	33.2	20.6	1.4	4.7	0.2
South America	10.5	41.1	22.9	2.0	5.4	0.5
Europe	21.9	86.4	20.6	1.7	19	1.7
Middle East	15.0	57.3	19.4	1.7	4.3	0.5
Africa	13.1	56.4	30.6	2.3	7.0	0.7
Europe-Middle East	10.9	38.8	20.6	1.3	9.6	0.4
Europe-Africa	10.3	39.9	23.6	1.6	10	0.4
North Atlantic	6.7	24.2	17.9	1.1	8.6	0.2
Mid Atlantic	7.3	27.7	21.2	1.4	8.5	0.2
South Atlantic	9.0	28.9	22.0	1.6	8.3	0.3
Asia/Pacific	9.9	37.1	22.3	1.2	7.8	0.4
Europe-Asia/Pacific	7.8	31.1	20.6	1.3	9.1	0.2
North/Mid Pacific	7.4	28.0	19.3	1.2	7.4	0.1
South Pacific	6.2	23.8	18.5	1.0	6.0	0.1
World	9.15	n.a.	20.0	1.29	9.5	0.36

Source: ICAO, 1994c

Effects of Fuel Price on Aviation Demand

A review of transport sector price elasticities (Oum *et al.*, 1990) finds the following own-price elasticities for air travel and air freight transport:

Table 14. Aviation Price Elasticities

	Own-Price Elasticity	Most Likely Range	No. of Studies
Vacation Travel	0.40 - 4.60	1.10 - 2.70	8
Business Travel	0.08 - 4.18	0.40 - 1.20	6
Mixed travel or not distinguished	0.44 - 4.51	0.70 - 2.10	14
Freight, Aggregate Commodities	0.82 - 1.60	0.80 - 1.60	3

Source: Oum *et al.*, 1990

Note: all elasticities are negative

ICAO (1995b) calculates somewhat lower elasticities (-0.66 for passenger transport, -0.51 for freight) than are considered “likely” by Oum *et al.* (1990). This may be because most of the literature reviewed by Oum *et al.* looked at individual routes, for which price elasticities may well be higher.

Combining the information from Table 13 with the passenger travel price elasticity estimates, the effects of the three levels of fuel price increase considered in this report are shown in Table 15. While both extremes of the “likely” range price elasticities are tested, slightly extended to include the ICAO estimate, it should be noted that the same price elasticities have been used for all regions. In fact, they are likely to vary among routes. Very little information is available to help estimate this variation although Doganis (1985), in one of the studies reviewed by Oum *et al.* (1990), provides estimates for the price elasticities of various routes out of the UK. Doganis cites a British Airports Authority study finding lower price elasticities for leisure travel to North America than to other parts of the world, including short-haul flights.

Table 15 indicates that, assuming uniform price elasticities, the international routes on which demand is likely to be most affected by a fuel price increase are: those within North America, those between North America and Central America, and those between North America and Europe. The routes least affected are those within Europe, within Asia/Pacific region, and within Africa.

Additional Analysis of Historical Data

Additional analysis was carried out for this study to evaluate the effects of past oil price changes on aviation, using data supplied by ICAO.

There is no visible link in Figure 13 between the fuel price and airline labour costs, except immediately following the fuel price increases, when traffic was suppressed and so labour intensity increased. Thus, there is no evidence for accelerated staff cuts during times of high fuel prices.

Nor is there any evidence that increased fuel prices had a long term effect on airline operating profits, although reduced traffic following the price rises did clearly effect profits for a short period. However, these reductions can also be ascribed to economic recessions and fears about flying at times of heightened instability in the Middle East.

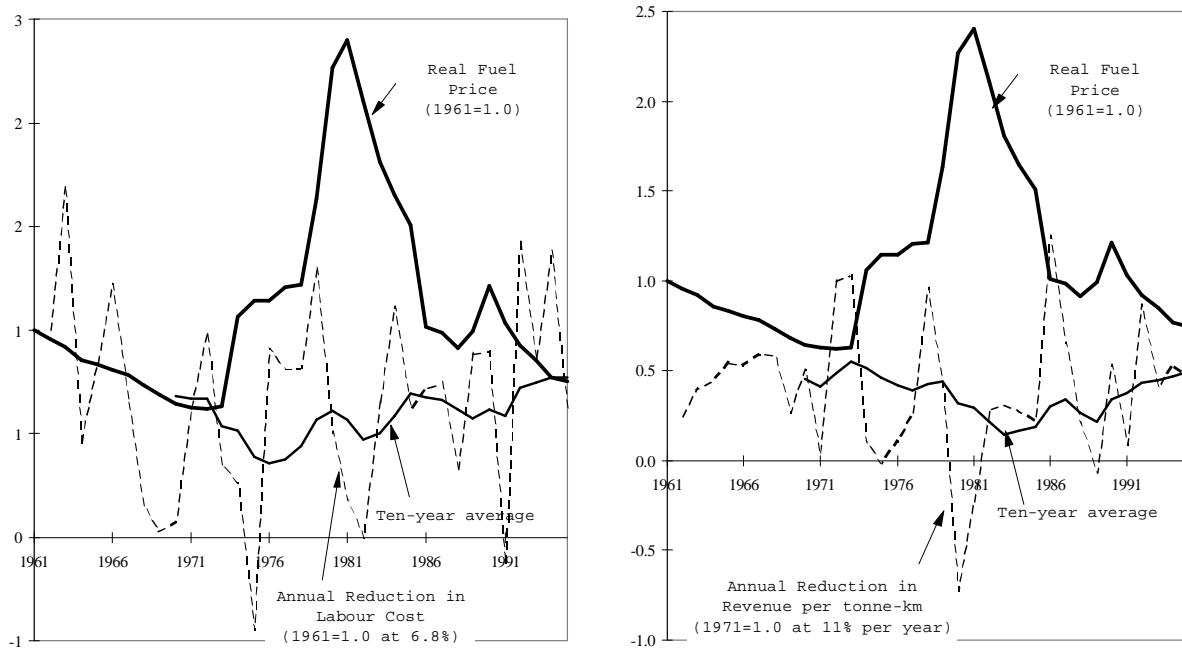
Table 15. Effects of Fuel Price on International Air Passenger Travel by Different Routes

Route Group	Effect on traffic (elasticity -0.66)			Effect on traffic (elasticity -2.1)		
	Fuel Price Increase (¢/litre)	0.4	2	10	0.4	2
North-Central America	-0.2 %	-1.1 %	-5.4 %	-0.7 %	-3.6 %	-16.3 %
Central America	-0.2 %	-0.8 %	-4.0 %	-0.5 %	-2.6 %	-12.2 %
North America	-0.3 %	-1.2 %	-5.8 %	-0.8 %	-3.9 %	-17.5 %
North-South America	-0.2 %	-1.0 %	-4.9 %	-0.7 %	-3.3 %	-14.9 %
South America	-0.2 %	-1.1 %	-5.1 %	-0.7 %	-3.4 %	-15.4 %
Europe	-0.1 %	-0.5 %	-2.4 %	-0.3 %	-1.6 %	-7.5 %
Middle East	-0.2 %	-0.8 %	-3.7 %	-0.5 %	-2.4 %	-11.2 %
Africa	-0.2 %	-0.8 %	-3.6 %	-0.5 %	-2.4 %	-11.1 %
Europe-Middle East	-0.2 %	-0.8 %	-3.6 %	-0.5 %	-2.4 %	-11.1 %
Europe-Africa	-0.2 %	-0.9 %	-4.1 %	-0.6 %	-2.7 %	-12.5 %
North Atlantic	-0.2 %	-1.2 %	-5.6 %	-0.8 %	-3.7 %	-16.8 %
Mid Atlantic	-0.2 %	-1.2 %	-5.6 %	-0.8 %	-3.7 %	-16.6 %
South Atlantic	-0.2 %	-1.1 %	-5.0 %	-0.7 %	-3.3 %	-15.1 %
Asia/Pacific	-0.1 %	-0.7 %	-3.4 %	-0.5 %	-2.2 %	-10.5 %
Europe-Asia/Pacific	-0.2 %	-1.1 %	-5.0 %	-0.7 %	-3.3 %	-15.1 %
North/Mid Pacific	-0.2 %	-1.1 %	-5.2 %	-0.7 %	-3.4 %	-15.6 %
South Pacific	-0.2 %	-1.1 %	-5.4 %	-0.7 %	-3.6 %	-16.1 %
World	-0.2 %	-0.9 %	-4.4 %	-0.6 %	-2.9 %	-13.3 %

Change in passenger demand calculated as follows:

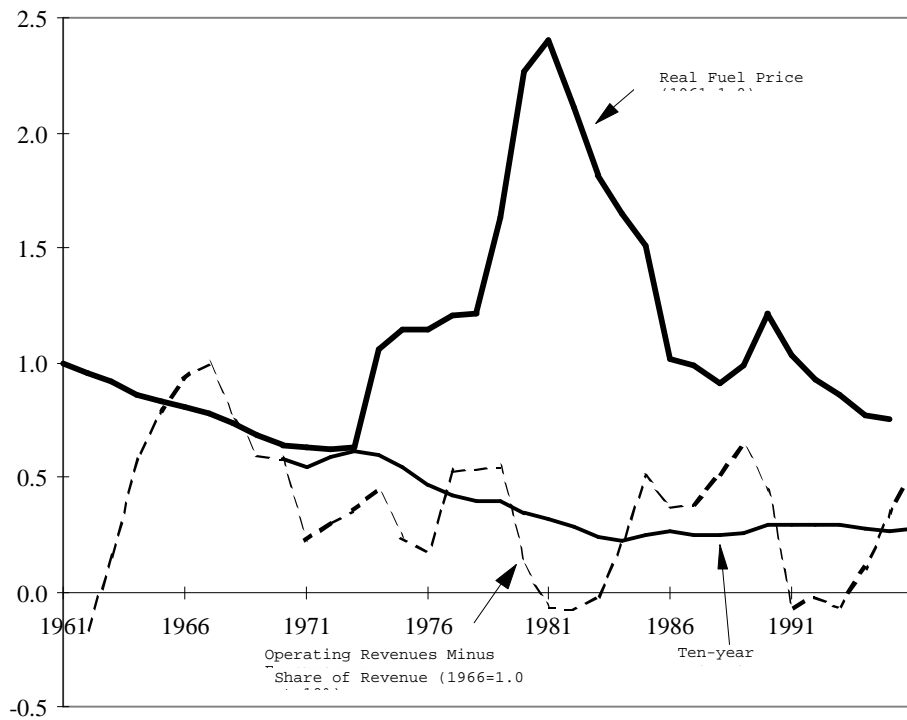
$\Delta PKM(\%) = 100 \times ((1 + \Delta FP / FP \times FS)^\eta - 1)$ where PKM=passenger traffic; FP=fuel price; FS=fuel share of costs; η =passenger traffic own-price elasticity

Figure 13. Annual Reduction in Labour Cost and Yield vs. Fuel Price



Source: ICAO Data

Figure 14. Airline Operating Revenue Minus Expenses vs. Fuel Price



Source: ICAO Data

APPENDIX D. POSSIBLE TECHNICAL CHANGES IN RESPONSE TO FUEL CHARGES

Balashov and Smith (1992) of ICAO estimate that fuel intensity in scheduled air passenger services will fall at an average of 3 per cent per annum during the 1990s, and 2.5 per cent per annum from 2000 to 2010. However, with traffic expected to grow at 5.5 per cent per annum in the 1990s and 5 per cent per annum from 2000 to 2010, they estimate that total fuel consumption could be about 65 per cent higher in 2010 than in 1990.

Greene (1995) provides a review of potential technology changes in aircraft offering energy efficiency and greenhouse gas reduction opportunities. He finds a potential rate of air travel energy intensity reduction to 2015 in the range 1-2 per cent, implying 21-37 per cent reduction in energy intensity in 2010 relative to 1990.

Other estimates of energy intensity improvements include those of ETSU (1994). This report observes that historical efficiency improvements have taken two forms: on the one hand, there have been gradual engineering improvements in existing technology, giving energy intensity reductions in the region of 1.9 per cent per year; on the other, there have been step changes resulting from the introduction of new engine and aircraft types which might offer 15 to 20 per cent reductions in fuel use. The last such change occurred in the 1970s with the commercialisation of the high-bypass turbofan engine and wide-body, high capacity aircraft such as the Boeing 747. Another such change is anticipated during the late 1990s with a further generation of engines such as General Electric's GE90, now being introduced on the Boeing 777.

Continuing airframe design improvements are likely to include the gradual phasing in of new materials, improvements in manufacturing processes, improvements in bonding techniques, and improvements in avionics. For engines, improvements will probably include the use of new materials and manufacturing processes, improved fuel management systems, higher injection pressures, improved combustion chamber design, reduced friction, and higher pressure ratios.

Beyond the GE90, fuel intensity improvements could come from the introduction of any of a range of new engine and airframe concepts. The propfan engine — essentially a propeller with specially designed curved blades allowing high speed operation — is one option which has been developed nearly to commercialisation by General Electric and Pratt and Whitney (Janes, 1991). The propfan has not been commercialised for a variety of reasons, including the development costs that would need to be incurred and concerns about noise and safety. Energy savings of 10-20 per cent are anticipated from the propfan, but do not justify the development costs at current fuel prices. Other possible technologies might include the use of advanced lightweight heat exchangers to provide charge cooling and recuperate exhaust heat from the engine. These technologies might, in theory, give 20-25 per cent energy savings (Grieb and Simon, 1990). Airframe concepts such as "laminar flow" systems to reduce air resistance can also reduce energy use by about 10 per cent (ETSU, 1994) although again, safety problems and costs mean that active laminar flow systems will not be introduced in the near future. Nevertheless, in the long term (i.e. towards 2040), 40 to 60 per cent reductions in energy intensity relative to the underlying 1.9 per cent per year trend might be possible.

The ETSU analysis is broadly consistent with that of Balashov and Smith, but like Greene (1995), it indicates that some of their predicted energy intensity improvements may not be achieved without increases in fuel price or other encouragement to develop and introduce new technology.

Reducing NO_x emissions

Aircraft engine manufacturers have been working on engine changes that reduce emissions of NO_x mainly because of the regulation of emissions during take off and landing in the vicinity of airports. Concern has also been expressed about the possible depletion of stratospheric ozone by NO_x emissions from very high flying, high speed aircraft, which manufacturers hope to develop for commercial use. There is, in general, a conflict between the aims of reducing CO₂ emissions and reducing NO_x emissions, because the engine conditions that minimise NO_x formation are also those that tend to increase fuel use. More significantly for the industry, some low NO_x-emission “lean-burn” engine designs have suffered from engine “flame-outs” (engine failure) during landing. Nevertheless, substantial reductions can in principle be achieved without compromising efficiency or safety, by modifying fuel combustion conditions. Development targets for NO_x emission reduction are in the region of 75 to 80 per cent. The GE90 was expected to achieve 30-50 per cent reductions using a staged fuel combustion approach (ETSU, 1994), but this has not been achieved (Michaelis et al., 1996).

Alternative aviation fuels

Both hydrogen and methane have been proposed as alternative fuels for aircraft (Grieb and Simon, 1990). A successfully developed liquid hydrogen powered engine is assumed by ETSU (1994) to have a 10-20 per cent energy-intensity advantage relative to kerosene, while liquid methane has a 5-10 per cent energy-intensity advantage. Where liquid hydrogen is produced from renewable energy, its use results in no CO₂ emissions but high water vapour emissions with uncertain radiative forcing effects (see Table 2). Meanwhile, high level NO_x emissions could be very much reduced by using methane, and emissions of water vapour would be much lower, but the benefit in reduced CO₂ emissions would obviously be smaller.

Table 16 . Emissions by Different Aircraft Engine Technologies

Technology	NO _x (g/MJ Fuel)	CO (g/MJ Fuel)	VOC (g/MJ Fuel)	CO ₂ (g/MJ Fuel)
Current Turbofan	0.3-0.5	0.3-0.4	0.05-0.1	67.8
Advanced Recuperated Propfan	0.2	0.3-0.4	0.05-0.1	67.8
Methane	0.05	negligible	negligible	50.2
Hydrogen	0.2	0	0	0

Source: ETSU, 1994

No reliable cost estimates are available for hydrogen or methane fuelled aircraft. However, it would not be possible to use these fuels in existing aircraft. Complete redesign of airframes would be necessary. It was assumed by ETSU (1994) that there is no long-term effect on engine costs of using such fuels. Due to the need for aircraft redesign and certification, it was also assumed that the fuels are not introduced before 2010. Nevertheless, ETSU did find that, with roughly doubled oil prices, or with an equivalent carbon tax, hydrogen does have the theoretical potential to make a substantial contribution as an aircraft fuel by 2025.

APPENDIX E. THE AERO PROJECT¹²

The AERO project is a modelling effort to examine the economic and environmental effects of a range of possible measures to reduce the environmental impacts of aviation. The project was initiated in 1994 by the Netherlands Civil Aviation Department, in the Ministry of Transport, Public Works and Water Management. Four organisations are involved in the project: MVA, a transport consultancy based in London; the Netherlands National Aerospace Laboratory; Resource Analysis, a consultancy based in Amsterdam, and the Netherlands Civil Aviation Department itself.

The AERO model consists of nine sub-models:

1. aviation cost (ACOS)
2. air transport demand and air traffic (ADEM)
3. flights and emission (FLEM)
4. other atmospheric immissions (OATI)
5. atmospheric processes and dispersion (APDI)
6. direct and indirect environmental impacts (ENVI)
7. direct economic impacts (global basis) (DECI)
8. macro-economic impacts (Netherlands only) (MECI)
9. cost-effectiveness (CEFF)

plus a shell, the Aviation Immission Modelling System (AIMS).

For the purposes of the current report on the effects of carbon charges, the most important elements of the model are sub-models 1, 2, 3, 7, 8 and 9.

In general, the models are operated on a non-interactive basis, but ACOS does interact with ADEM: ACOS estimates the cost of providing air transport capacity to meet demand forecast by ADEM, while that demand is influenced by the cost of air transport.

ADEM is calibrated on historical flight data on a global basis by city pair, including scheduled and non-scheduled passenger, freight and military flights. It projects the development of traffic between each city pair, using a trip-generation approach similar to an urban transport model (MVA, who developed the model, are in fact specialists in land-based transport network modelling). Demand is assumed to be determined by income and population, and by the cost of air transport (travel and freight). The mix of aircraft meeting the demand for each city pair is estimated from the historical mix of aircraft meeting similar types of demand (in terms of sector length and passenger and freight volume).

12 This appendix is based on Pulles *et al.* (1995) and on discussions with Hans Pulles and Steve Lowe.

ACOS estimates changes in the costs of meeting demand with different types of aircraft resulting from any charges, regulations, etc. It thus provides ADEM with a range of changes in costs of alternative means of satisfying demand between each city pair. ACOS takes account of the costs of currently available technology and allows for future trends in energy efficiency and emissions. It does not make choices regarding the choice among future alternative technologies of different costs and energy efficiencies. Thus, for each period modelled, there is a single generic aircraft technology available to ADEM within each of six types, of different sizes and suited to different ranges.

ADEM then calculates the change in demand and in the mix of aircraft satisfying demand for each route, resulting from charges and regulations. It should be noted that demand changes are currently calculated using uniform price elasticities — it has not been possible to identify econometric studies that evaluate differences in price elasticities for different city pairs on a systematic basis.

FLEM calculates the various types of emission for each flight between each city pair, including the three-dimensional distribution of those emissions in the atmosphere.

DECI calculates the airline costs and revenues associated with each flight and thus calculates the effects of any policies.

OATI, APDI and ENVI evaluate the indirect effects of the aircraft emissions and the effects of any policies.

MECI evaluates macroeconomic effects of changes in aviation activity resulting from policies, for the Netherlands only.

CEFF produces various indices of “cost-effectiveness” for the various policies.

While AERO does not evaluate macroeconomic effects on a global basis, the results from the Netherlands, as well as regional results from DECI, should be useful to illustrate regional impacts. Meanwhile, the model is capable of evaluating policies such as a carbon charge, changes in routing charges, etc., implemented on a regional basis. It is thus highly relevant to the current study.

The AERO model has now (September 1996) been run on a trial basis, and results are beginning to be generated. The first public results are anticipated in early 1997, and should therefore be ready to feed into the final draft of this study.

APPENDIX F. EMISSION BUDGETS FOR CIVIL AVIATION: A SUGGESTION

Suggested Language to Address Emissions Budgets for Civil Aviation Put Forward by the Environmental Defense Fund, Washington, DC

A. General points on environmental taxes and trading

Experience with emissions trading indicates that if properly designed, such systems can meet or exceed environmental targets at much lower cost than other types of regulation.¹³ Furthermore, because these systems turn the traditional regulatory system on end by encouraging and rewarding over-control, when properly designed, they have produced more reductions and environmental protection than traditional regulatory programs. Emissions trading can increase transparency by giving emitters and governments strong incentives to use standardized, publicly understandable monitoring and reporting. Since trading requires knowledge of emissions performance, trading systems substitute the precise emissions information from monitoring for the traditional assurances from requiring specific control technologies. And these systems can facilitate technology innovation and transfer. Careful system design is essential to obtain the desired results. To address the questions that arise in the unique context of international efforts to limit and reduce greenhouse gas (greenhouse gas) emissions from the civil aviation sector, an **Emissions Budget Agreement for the Civil Aviation Sector** has been proposed.¹⁴

Emissions trading approaches differ from taxes and charges in several key respects. While they are theoretically similar policy instruments for controlling pollution, taxes set “P”, or price; depending on demand elasticity, price may be high enough to discourage demand, such that the pollution target is met. Taxes are readily understood; widely accepted as a tool of public policy; and effective, if set correctly. For the international civil aviation sector, a collection apparatus would need to be established, and difficult allocation questions would need to be resolved. Aviation taxes could raise revenue that, in theory at least, could be targeted to improving ATC systems in order to improve efficiency.

However, as a general matter, taxes are politically unpopular, difficult to set at correct levels for meeting environmental targets, and difficult to adjust upward or downward. Aviation taxes at the international level, as the Report indicates, are likely to be difficult to implement internationally. They may have potentially significant equity effects among consumers.

Environmental trading approaches set “Q”, or quantity. “Q can be set precisely to meet pollution limitation and reduction goals. Depending on supply elasticity, the price of trading-based regulation may

¹³ See Dudek & Tripp, “Institutional Guidelines for Designing Tradeable Permit Systems,” Yale Journal of Regulation (1992).

14. For a detailed explanation of the Emissions Budget approach, see Dedek, D., “Emissions Budgets: Creating Rewards, Lowering Costs and Ensuring Results,” Climate Change Analysis Workshop, Springfield, Virginia, USA, June 6-7, 1996.

be high or low. Trading approaches are highly effective in hitting environmental target. They can be very effective in stimulating innovation and research and development. They provide a built-in incentive for technology transfer, and, properly designed, they can readily be applied internationally. Transactions can create environmental assets that can aid in financing.

Environmental trading systems can be difficult to explain to the public crisply. Political agreement on allocation may be difficult if an allowance approach is used. (The allocation problem is tempered in the Budget approach proposed below). Steps may be needed to prevent undue market concentration.

With taxes, the enforcement point is at the point of collection. With trading, the enforcement point is at the point of emission. Both require monitoring of environmental outputs. Both require careful attention to transactions costs. For either, environmental performance basis and transparency are key.

B. International Emissions Budgets for the Civil Aviation Sector

Under an international emissions budget approach for the civil aviation sector, a group of airlines that operate internationally, probably initially consisting of airlines principally associated with OECD members, would adopt ten-year cumulative greenhouse gas (greenhouse gas) emission budgets as legally binding quantified emission limitation and reduction obligations. The airlines could enter into a contractual agreement under IATA auspices to adopt and enforce these budgets. The airlines' agreement could be formally recognized by their associated nations in the context of the OECD, and/or the United Nations Framework Convention on Climate Change (UNFCCC), and/or ICAO.

Under the contractual agreement, each member airline would commit to limit its net emissions of greenhouse gas to a specified budget amount over the decade. The budget amount would be set as a percentage reduction from greenhouse gas emitted by the airline during a base year or group of base years. Over the ten-year period, airlines that reduce their net emissions below the budgeted amount would accrue "savings." An airline that accrues savings could hold the savings for use in future budget periods or could sell the savings to another airline, which could apply the savings toward meeting that airline's emissions budget. Airlines that hold savings for a specified period of time could earn a "premium" on early reductions. Non-member airlines, i.e., those international airlines that have not adopted budgets but would like to participate in emissions reduction activities on a voluntary basis, could offer member airlines and investors opportunities to invest in emissions reduction activities. In the event that an emissions trading system is developed in the context of the UNFCCC, transactions could occur between the member airlines and economic actors in the context of the trading system.

Early in the first budget decade, member airlines, in consultation with the UNFCCC, ICAO, the IPCC, and IATA, would undertake an assessment of climate science that would provide a basis for establishing the next decade's emissions budget. Halfway through the first decade, the member airlines would announce the second decade's emissions budget, repeating the process for successive science-based emissions budgets. Consultation with the UNFCCC would be particularly important, since if the airlines did not adopt budgets consistent with the UNFCCC goals of preventing dangerous anthropogenic interference with the climate system, UNFCCC governments might decide that additional measures should be applied to the aviation sector to reduce emissions.

Elements of an International Emissions Budget System for the Aviation Sector

- a) *A reductions-oriented approach that reduces the difficulties of “initial allocation” negotiations.*

The international emissions budget approach proceeds by structuring an international agreement so as to provide airlines with incentives to reduce emissions in order to generate transactable savings. This same goal could also be accomplished through an international aviation greenhouse gas allowance - or certificate-based trading system. Various commentators have argued that holding an “allocation” negotiation to allocate allowances or certificates would be extremely difficult in the context of an international agreement among nations, where each nation would have an incentive to inflate assessments of its future needs and to understate its emission reduction opportunities, in order to try to convince the participants that it should receive more allowances. Some of these same issues would arise in the context of an international aviation emissions trading system.

Of course, every environmental regulation, whether domestic or international, involves an allocation. Some regulations allocate to polluters the right to emit specified amounts of pollution below control levels (as did the 1992 UNFCCC, in a non-binding way, and as do engine emissions standards). Other regulations allocate to polluters the right to emit unlimited amounts of pollution, provided the polluters install a particular technology. And some allocate to polluters the right to emit unlimited amounts of pollution provided the polluters pay a tax.

The emissions budget approach can lessen the difficulties of the international allocation negotiation. If applied to the civil aviation context, international airlines would agree on a uniform percentage reduction from a common historical baseline. The “allocation” negotiation would occur over the selection of the historical base year or years against which the reduction would be calculated. A negotiation over the selection of historical base years is more likely to reach agreement than would a negotiation over the allocation of future allowances.¹⁵

- b) *The budget approach would apply to airlines; each airline would have the flexibility to choose its own implementation mechanisms.*

Aviation greenhouse gas emissions (and emissions from international maritime services) present difficult allocation problems under the UNFCCC, not only because they occur in the international context, but also because sovereigns have not been able to reach agreement on how to allocate the emissions from the sector. Emissions limitation and reduction policies for this sector that require governments to allocate international aviation emissions are therefore unlikely to reach agreement easily, whether the policies involve allocation of emissions allowances or allocation of tax incidence and revenue. The logical locus of control is the international airline that generates the emissions, regardless of the nationality of that airline, its passengers, freight, or hull.

Under an international emissions budget approach to controlling aviation sector emissions, each international airline would have to adopt a budget as a condition of operating in the national territory of UNFCCC Parties. But each airline would be free to achieve its budget and earn savings in any way that it chooses, consistent with its own corporate priorities. One airline might choose to meet its budget by purchasing highly efficient aircraft and/or engines. Another might choose to increase its

15. See, e.g., Dubash, Navroz, “Commoditizing Carbon: Social and Environmental Implications of Trading Carbon Emissions Entitlements,” (University of California at Berkeley, Energy and Resources Group, 1994).

load factor and reduce its overall number of flights. A group of governments in a particular geographic region might provide that if airlines operating in its region failed to meet budget requirements, the airlines would have to pay fines on a per-ton basis, with the revenue from the fines going to ATC modernization. A group of airlines operating in that geographic region might work aggressively with host country governments to facilitate ATC modernization. Another group of airlines might choose to establish a regional emissions allowance trading program, issuing emissions allowances to themselves for operations within that region, and letting group participants use, bank, and trade allowances within the group and in the international marketplace.

An important issue for governments and airlines to resolve at the outset would be whether the airlines could procure reductions from outside the immediate civil aviation sector. For example, airlines might be permitted to obtain reductions from the air services ground transportation sector. Looking more broadly, airlines might be permitted to obtain reductions from any other sector, on a sectoral, national, or project-by-project basis, provided the external reductions were truly additional to what otherwise would have occurred in the absence of the airline emissions budget transaction system. Access to off-sector emissions reduction opportunities would greatly increase airlines' flexibility to achieve emissions reduction at significantly lower cost. This is particularly important for a sector like civil aviation, which has long capital stock design and use lifetimes. And since, from the greenhouse perspective, it is important to reduce greenhouse gas emissions wherever they occur around the world, the geographical flexibility that off-sector reductions provides adds to the potential for achieving significant reductions through technology innovation in a range of sectors.

c) *Transparent tracking and reporting of emissions.*

Transparent tracking and reporting is essential for any emissions reduction system to operate credibly. One important feature of the emissions budget approach is that it provides an incentive for improved greenhouse gas emissions tracking and reporting. The emissions budget system as applied to the international aviation sector would utilize transparent double-entry book-keeping on an airline-by-airline basis, with annual reporting to the UNFCCC Secretariat, for tracking emissions, reductions, transactions, and budget balances. Airlines that have taken a budget would find that reductions earned under strong, transparent corporate tracking and reporting systems will be able to command a higher market price than reductions earned under weaker systems. For airlines that have not taken a budget but want to participate in emissions reduction activities on a voluntary basis, those airlines have an incentive to provide transparent and accurate greenhouse gas emissions reduction tracking and reporting, since reductions so earned will be more readily transactable and command a higher market price than will emissions reductions from airlines that lack transparent and accurate reporting. In fact, as the industry goes through a period of alliance-building and potential consolidation, an international airline emissions budget system would introduce a competitive pressure for potential alliance partners to improve their environmental performance in order to make themselves more attractive to potential suitors seeking to ally with savings-rich airlines.

d) *A ten-year budget cycle to provide "when" flexibility and clear market signals.*

The ten-year cycles of the emissions budget system are long enough to provide the airlines, the airframe, engine, and operational technologies manufacturers, and the aircraft leasing companies with a stable but flexible regulatory environment in which to plan long-term capital stock investments. The cycles are also short enough to provide clear signals to economic actors about the kinds of actions that will be needed to meet budget obligations. While some argue that very short-term targets are needed to spur innovation and provide accountability, others argue that allowing economic actors a degree of "when" flexibility can reduce costs significantly. Targets as short as one year and as long as 75 years

have been proposed in the UNFCCC context. While very short-term targets do not provide flexibility, very long-term targets do not provide the clear signal to the private sector that will be needed to spur cost-saving technological innovations over time. Moreover, a single long-term target leaves no opportunity to recalculate trajectories based on new science and new learning from accumulated technological and capital experience. Governments and economic actors are reluctant to enter into very long-term obligations that cannot be revised, particularly when the ability to revise commitments based on new learning may lower costs and reduce uncertainties. Airlines have demonstrated, however, that they are willing to enter into economic arrangements lasting one or two decades (as illustrated by the recent American Airlines announcement to purchase Boeing equipment).

The ten-year cycle of the emissions budget approach is long enough to allow airlines and other economic actors significant “when” flexibility to plan for emissions reductions, taking into account the investment cycles that exist in the civil aviation sector, including national and corporate planning cycles, capital stock lifetimes, product and infrastructure development, and political decision-making cycles on such issues as ATC modernization. At the same time, it is short enough to ensure that the program delivers clear market signals and provides accountability. In addition, setting new budgets every ten years allows the budget-setting process to benefit from the learning and experience gained in previous budget cycles, so that airlines may set new cumulative budgets upward or downward based on historical experience and inputs from the IPCC, the UNFCCC, ICAO, and other relevant bodies.

e) Savings and a premium for early reductions.

The availability of savings provides airlines with an incentive to accrue reductions early in the budget period in order to provide greater flexibility later on. Significant early reductions will be needed if the increase in Earth’s temperature is to be limited to a sustainable rate (e.g., one degree C. per century). Early reductions are especially environmentally significant in light of the long atmospheric lifetime of carbon dioxide (CO₂), on the order of 100 years, and the global warming contribution of aviation NO_x, which may be as important as its CO₂ contribution. The emissions budget system includes an emissions premium that accrues on savings held and not utilized, providing an important additional incentive for early reductions.

f) Savings available for all greenhouse gas reductions, with interpollutant trading, and off-sector reductions including carbon sequestration/sinks.

In the emissions budget system, budgets are set on a net emissions/GWP basis per airline. This would be particularly important for the aviation sector, since it would provide airlines and manufacturers a way of dealing with the NO_x-CO₂ relationship flexibly, while at the same time providing incentives to add to the knowledge base about greenhouse gas, including the NO_x-CO₂ relationship. This is because in transactions involving reductions of a greenhouse gas whose role in global warming is not well understood, the market will reflect those uncertainties, and economic actors considering such transactions will seek to strengthen the knowledge base in order to improve the economic value of the transaction. Adding off-sector reduction transactions, including sinks, would provide additional incentives for improving the knowledge base about the role of forests in the carbon cycle, as well as for protecting forests that would otherwise disappear. Thus, the availability of off-sector reductions would, for example, provide an incentive for a European airline to protect the greenhouse by investing in protection of a rain forest in Latin America. A rule that excluded such transactions would remove the incentives for both the transactions and the improved understanding, with significant environmental costs. For example, such a rule might subject high-biodiversity tropical ecosystems to deforestation while reducing the incentive to learn more about their role in carbon sequestration.

g) *Trading with airlines that have not adopted legally binding budgets; off-sector reductions.*

The emissions budget approach includes recognition of, and transactions in, emissions reductions generated by airlines that have not adopted budgets but want to participate in emissions reduction activities on a voluntary basis. Where a voluntary project with a non-member airline reduces greenhouse gas emissions below what the airline otherwise would have emitted, those reductions are fully transactable in the emissions budget system. Such reductions could be purchased by an airline that has adopted a budget and applied by that airline toward the satisfaction of its budget obligations. Such reductions could also be transactable in a nation's domestic greenhouse gas trading system or in the international emissions budget system among nations if nations adopt such systems.

Some argue that voluntary transactions with non-member airlines and off-sector transactions should not be permitted, because the transactions would encourage "leakage", and because excluding such transactions provides non-member airlines and off-sectors with stronger incentives to adopt legally binding budgets. The emissions budget approach, however, recognizes that virtually all greenhouse gas reduction arrangements involving less than all economic actors in the world entail some leakage; the environmental and developmental benefits of non-member and off-sector voluntary transactions outweigh the costs of including them in the system. Through these transactions, non-member airlines and off-sectors can, on a voluntary basis, gain important experience with project finance in the context of international climate protection efforts. Many nations, developing country airlines, and off-sectors currently lack the investment capital they would need to comply with legally binding emissions reduction obligations. A ban on transactable voluntary reductions with these sectors would lock rapidly industrializing non-budget nations into cheaper, dirtier, long-lived capital stock. For non-budget nations facing rapid deforestation, a ban on these transactions might mean that some forests and species would be lost forever.

Transaction cost differences will provide strong incentives for non-member airlines and off-sector actors over time to adopt legally binding budgets when they are able. To generate transactable reductions, such transactions will need to demonstrate credible emissions tracking and verification - and the additionality of reductions obtained - on a transaction-by-transaction basis. On-budget reductions, by contrast, will enjoy lower transactions costs, since those transactions can utilize corporate, sectoral, or national tracking and reporting systems and are backed by sovereign legally binding obligations or corporate legally binding contractual arrangements to comply with emissions budgets.

h) *Savings and reductions identified by earner and date.*

Some have argued that an emissions trading system should be transacted in standardized, serialized, undated "commodities", such as the "right" to emit one ton of carbon anywhere at any time. In the emissions budget system, by contrast, the concept of "reductions" is used to describe and value an activity that has already occurred - a ton of carbon has been reduced by a particular airline at a particular time. Where, when and under what circumstances reductions are earned necessarily affects the value those reductions will command in the market. That is, the value of any particular block of reductions will depend on the credibility of the airline's emissions tracking and verification program. Reductions in the emissions budget system, therefore will be identified by origin and date in order to allow the market to fulfill the important self-enforcement function of communicating to potential purchasers information that enables each purchaser to make judgments about the relative quality of different reductions. Identifying reductions by origin and date will enable reductions earned by

airlines with internationally respected reporting and tracking systems to command higher market prices than would reductions earned under less confident circumstances.

i) *Sanctions against airlines that fail to meet budget obligations.*

In an international emissions budget system, airlines would agree contractually that any airline whose emissions exceed its budget would be subject to sanction unless it purchased savings to make up the deficit. Market forces would provide a strong sanction, since the trading market would enable airlines with the best budget performance to command the highest market prices in emissions transactions, while the market would discipline weak performers by exerting downward pressure on the prices they could command. Including a mechanism for annual “check-ins,” conducted by certified independent financial/environmental auditors, to assess how well airlines are meeting their budgets, and using the results of those “check-ins” as an input into establishing the next cycle’s budget, would strengthen the self-enforcing function of the market. Airlines could agree contractually that if any airline persistently fails to meet its budget obligations, sanctions could include suspension of emissions transactions with that airline. In addition, nations of airlines could agree to impose financial penalties on non-compliers.

REFERENCES

- Alamdari, F.E. and D. Brewer, (1994), Taxation policy for aircraft emissions. *Transport Policy* 1994 1 (3) 149-159.
- Balashov, B. and A. Smith, (1992), ICAO Analyses trends in fuel consumption by world's airlines. *ICAO Journal*, August 1992.
- Baron, R., (1996), Policies and Measures for Common Action, Working Paper 4: Economic/Fiscal Instruments: Taxation (i.e. Carbon/Energy). IEA/OECD, Paris.
- Bleijenberg, A.N., R.C.N. Wit, P.M.J. Mendes de Leon, S.A. Mirmina and D.N.M. Starkie. *A European aviation charge: Preliminary study*. Centrum voor energiebesparing en schone technologie (Centre for energy conservation and environmental technology), Delft, Netherlands.
- CAA [Civil Aviation Authority], (1991), UK Airlines Annual Operating, Traffic and Financial Statistics 1990. CAA, London.
- CAEP [ICAO Committee on Aviation Environmental Protection], (1995), Report of the Emissions Inventory Subgroup. CAEP Working Group 3, Bonn, Germany.
- CEC [Commission of the European Communities], (1992), Research and Technology Strategy to Help Overcome the Environmental Problems in Relation to Transport. (SAST Project No 3.) *Global Pollution Study. Report* EUR-14713-EN. [Commission of the European Communities Directorate-General for Science, Research and Development]. CEC, Brussels and Luxembourg.
- CEC [Commission of the European Communities], (1994), The Way Forward for Civil Aviation in Europe. *Report of the Comité des Sages*, 1 June, 1994, CEC, Brussels.
- Doganis, R., (1985), *Flying Off Course: The Economics of International Airlines*. George Allen & Unwin, UK.
- ERM [Environmental Resources Management], (1996), *Allocation of Emissions from International Bunker Fuels under the UN Framework Convention on Climate Change*. Consultants report to the UK Department of the Environment. ERM, Oxford, England.
- ETSU [Energy Technology Support Unit], (1994), Appraisal of UK Energy Research, Development, Demonstration and Dissemination. Volume 7. *Transport*. HMSO, London.
- EUROCONTROL, (1982), *Fuel Savings in Air Transport. Possible Contributions of Air Traffic Services in Europe*. Document no. 812007, EUROCONTROL. Brussels?

- Fabian, P., (1990), *Constituents and transport properties of the atmosphere above and below the tropopause*. In *Air Traffic and the Environment - Background, Tendencies and Potential Global Atmospheric Effects*. [ed. U. Schumann]. Springer Verlag, Berlin.
- FCCC [UN Framework Convention on Climate Change], (1997), *Report of the Subsidiary Body for Scientific and Technological Advice on the Work of its Fourth Session, Geneva, 16-18 December 1996*. FCCC/SBSTA/1996/20. FCCC, Bonn.
- FCCC [UN Framework Convention on Climate Change], (1996), *National Communications: Communications from parties included in Annex I to the Convention: guidelines, Schedule and Process for Consideration: Addendum; Detailed Information on Electricity Trade and International Bunker Fuels*. FCCC/SBSTA/1996/Add.2. FCCC, Bonn.
- FOCA [Swiss Federal Office of Civil Aviation], (1996). *Swiss Clean Air Concept, Programme of Measures: Emission charges according to type of aircraft, Description of Model*. FOCA, Berne.
- Greene, D.L., (1995), *Commercial Air Transport Energy Use and Emissions: Is Technology Enough?*. Presented at the 1995 Conference on Sustainable Transportation-Energy Strategies, July 31 to August 3, 1995, Asilomar, CA. Prepared by Oak Ridge National Laboratory for the US Department of Energy under contract DE-AC05-84OR21400. ORNL, Tennessee.
- Greene, D.L., (1992), Energy-efficiency improvement potential of commercial aircraft. In *Annual Review of Energy and the Environment* **17**:537-73.
- Grieb, H. and B. Simon., (1990), Pollutant emissions of existing and future engines for commercial aircraft. In *Air Traffic and the Environment - Background, Tendencies and Potential Global Atmospheric Effects*. [ed. U. Schumann]. Springer Verlag, Berlin.
- FCCC [UN Framework Convention on Climate Change], (1996), *National Communications: Communications from parties included in Annex I to the Convention: guidelines, Schedule and Process for Consideration: Addendum; Detailed Information on Electricity Trade and International Bunker Fuels*. FCCC/SBSTA/1996/Add.2. FCCC, Bonn.
- IATA [International Air Transport Association], undated: *The Economic Benefits of Air Transport: 1992 Data*. IATA, Geneva.
- ICAO [International Civil Aviation Organization], (1966), *ICAO's Policies on Taxation in the Field of International Air Transport*. Doc 8632. ICAO, Montreal.
- ICAO [International Civil Aviation Organization], (1991), *Report of the Conference on Airport and Route Facility Management*. Doc 9579. ICAO, Montreal.
- ICAO [International Civil Aviation Organization], (1993), Annex 16 to the Convention on International Civil Aviation. Volume II - Aircraft Engine Emissions. Second Edition - July 1993. Montreal, ICAO.
- ICAO [International Civil Aviation Organization], 1993b: *Civil Aviation Statistics of the World, 1992*. ICAO, Montreal.

- ICAO [International Civil Aviation Organization], 1994a: The World of Civil Aviation, 1993-1996. Circular 250-AT/102. ICAO, Montreal.
- ICAO [International Civil Aviation Organization], 1994b: ICAO's Policies on Taxation in the Field of International Air Transport. Doc 8632-C/968. ICAO, Montreal.
- ICAO [International Civil Aviation Organization], 1994c: Regional Differences in Fares, Rates and Costs for International Air Transport, 1991. Circular 248-AT/101. ICAO, Montreal.
- ICAO [International Civil Aviation Organisation], 1995a; Final Report of the Economic Analysis Subgroup. Working Paper 4, CAEP Working Group 4 Meeting, Bonn, Germany, June 1995. ICAO, Montreal.
- ICAO [International Civil Aviation Organization], 1995b: Outlook for Air Transport to the Year 2003. Circular 252-AT/103. ICAO, Montreal.
- ICAO [International Civil Aviation Organization], 1995c: Civil Aviation Statistics of the World, 1994. Doc 9180/20. ICAO, Montreal.
- ICAO [International Civil Aviation Organization], 1995d: The World of Civil Aviation, 1995-1998. Circular 265-AT/109. ICAO, Montreal.
- ICAO [International Civil Aviation Organization], (1996), *Environmental Charges and Taxes on International Civil Aviation*. Paper presented by the Secretariat to the 14th Session of the Council. AT-WP/1794. ICAO, Montreal.
- IEA [International Energy Agency], (1993), Energy Statistics and Balances of Non-OECD Countries, 1990-1991. OECD, Paris.
- IEA [International Energy Agency], (1992), Energy Statistics and Balances of Non-OECD Countries, 1989-1990. OECD, Paris.
- IPCC [Intergovernmental Panel on Climate Change], (1996), *Technologies, Policies and Measures for Mitigating Climate Change* [eds. R. T. Watson, M. C. Zinyowera and R. H. Moss]. ISBN: 92-9169-100-3. IPCC, Geneva.
- IPCC [Intergovernmental Panel on Climate Change], (1995), Summary for Policymakers in Climate Change 1994: Radiative Forcing of Climate Change and An Evaluation of the IPCC IS92 Emission Scenarios. Cambridge University Press, Cambridge, UK.
- IPCC, (1996), SAR WGIII Report. Chapter reference to be included.
- Jane's, (1991), All the World's Aircraft 1991-92. [Ed. M. Lambert]. Jane's Information Group, London.
- Karyd, A. and H. Brobeck, (1992), The delusion of social benefits. In *The Avmark Aviation Economist*, January, 1992.
- Martin, D.J. and L.A. Michaelis, (1992), *Research and Technology Strategy to Help Overcome the Environmental Problems in Relation to Transport. (SAST Project No 3.) Global Pollution Study.*

Report EUR-14713-EN. [Commission of the European Communities Directorate-General for Science, Research and Development]. CEC, Brussels and Luxembourg.

- Michaelis, L, D. L. Bleviss, J-P. Orfeuil and R. Pischinger, (1996), Mitigation options in the transportation sector. In: *Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses. Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change* [Watson, R.T., M. C. Zinyowera, and R.H. Moss (eds.)]. Cambridge University Press, Cambridge and New York.
- Oum, T.H., W.G. Waters II and J-S. Yong, (1992), Concepts of price elasticities of transport demand and recent empirical estimates: an interpretative survey. *Journal of Transport Economics and Policy*, 26 (2) 139-154.
- Oum, T.H., W.G. Waters II and J-S. Yong, (1990), *A Survey of Recent Estimates of Price Elasticities of Demand for Transport*. Policy, Planning and Research Working Paper WPS 359. World Bank, Washington, DC.
- Pearce, D.W., W. R. Cline, A.N. Achanta, S. Fankhauser, R.K. Pachauri, R.S.J. Tol and P Vellinga, (1996), The Social Costs of Climate Change: Greenhouse Damage and the Benefits of Control. in *Climate Change 1995: Economic and Social Dimensions of Climate Change: Contribution of Working Group III to the Second Assessment Report of the Intergovernmental Panel on Climate Change*. [Bruce et al., eds]. Cambridge University Press, Cambridge and New York.
- Pulles, J. W., S. Lowe, R. van Drimmelen, G. Baarse and P. McMahon, (1995), The AERO-project: Aviation Emissions and Evaluation of Reduction Options. Model descriptions and current status. Netherlands Civil Aviation Administration, The Hague.
- Schimel, D., D. Alves, I. Enting and M. Heimann, (1996), Radiative Forcing of Climate Change. in *Climate Change 1995: The Science of Climate Change: Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change*. [Houghton *et al.*, eds]. Cambridge University Press, Cambridge and New York.
- Shelby, M., A. Cristofaro, R. Shackleton and B. Schillo. (1994), The climate change implications of eliminating U.S. energy (and related) subsidies. Unpublished paper for OECD project on The Environmental Implications of Subsidies to Energy and Transport. EPA, Washington.
- Shock, R.A.W., (1989), Air transport. In: *Energy Use and Energy Efficiency in UK Transport up to the Year 2010*. Department of Energy, Energy Efficiency Series 10. HMSO, London.

ACRONYMS USED IN THIS REPORT

ATC	Air traffic control
CAEP	ICAO Committee on Aviation Environmental Protection
CSD	UN Commission for Sustainable Development
UNFCCC	UN Framework Convention on Climate Change
GHG	Greenhouse gases
GPS	Global positioning by satellite
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IPCC	Intergovernmental Panel on climate Change
SBSTA	Subsidiary Body for Scientific and Technological Advice (one of the subsidiary bodies of the UNFCCC)
TKP	Tonne-kilometres performed