ENVIRONMENTAL CHARGES FOR CONTROLLING GREENHOUSE GAS EMISSIONS FROM CIVIL AVIATION

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Discussion paper

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It is a discussion paper and any comments on it would be gratefully received. Please contact:

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SUMMARY

This discussion paper reports research into the possibility of using environmental charges or taxes as a policy measure for controlling the environmental impacts of aviation. The aim of the research is to develop ideas and promote discussion of this topic. The complexity of the aviation system and the uncertainties involved are such that it will require much more work before definitive results, and recommendations following from those results, can be produced: this at least is the opinion of the author.

The contents of the paper are as follows.

First an introduction and brief summary of the environmental impacts of aviation to be controlled is given. Following this is an outline of the possible items to which charges might be applied, and the possible points of application of charges.

The next sections describe some of the possible ways in which consumers and providers of aviation services might respond to changes in aviation costs brought about by charges.

An Aviation Analysis model (***AviAn***) has been developed to simulate the behaviour of providers and consumers, and to calculate the resultant economics and pollution emissions. This model was used to explore global aviation scenarios in which different levels of fuel charge and operator response are assumed.

It was found that fuel charges could play an important role in reducing the emissions and consequent environmental impacts of aviation. Fuel use and related emissions might be reduced by between 3% and 20% by fuel charges. This wide range of possibility reflects the different charges explored and the many uncertainties involved.

The last section contains a concluding discussion and some suggestions for further work.

There an appendix that briefly discusses the requirements for international frameworks for applying charges and allocating fuel use and emissions.

1. OVERVIEW

Aviation has a significant and rapidly growing impact on the global environment. The objective of the research described in this report is to explore how charges or taxes might be used to control the environmental impacts of pollutants emitted by aircraft.

The purpose of this paper is not to discuss the science of aviation's impact on the environment. Some documents covering other such aspects are hereafter mentioned in case the reader wishes to explore further. Detailed scientific and technical analyses covering various aspects of the environmental effects of aircraft emissions have been produced by the World Meteorological Organisation (WMO, 1995), the Intergovernmental Panel on Climate Change (IPCC, 1995), the National Aeronautics and Space Administration (NASA: 1992) and the International Civil Aviation Organisation (ICAO, 1992). These research programmes generally continue. To date there are few publications by official and industry bodies indicating how aviation policy should comprehensively include environmental concerns. A general introduction to aviation and the environment and a discussion of policy is to be found in previous reports such as those by the World Wide Fund for Nature (WWF, 1991,1994), Vedanthan and Oppenheimer (1994), Bleijenberg et al (1993), Archer (1993) and Olivier (1991).

The objective of this report is to explore policies for reducing global or regional environmental impacts brought about by pollution emission. The focus is on global warming and ozone depletion rather than other impacts such as noise or local air pollution. The causal links between consumer demand and emissions to the global atmosphere are set out in Figure 1 below in schematic form. The arrows in the figure indicate the connections between these global impacts and the emission of pollutants from aircraft.

Aircraft presently release some 2 or 3% of the global emissions of carbon dioxide and 1 or 2% of nitrogen oxides from fossil fuels. This fraction will grow rapidly with unchanged policies. Aircraft also emit a mixture of other pollutants including soot, carbon monoxide and hydrocarbons. About half of these emissions is injected into the atmosphere at altitudes 8 to 12 km. At this height pollutants can have more serious and enduring effects than at ground level - even water may have adverse impacts. There are special concerns about the possible indirect and direct contributions of nitrogen oxides and water emission to global warming; and of these pollutants to stratospheric ozone depletion.

Great uncertainties remain about these effects, but twenty years of atmospheric science on this subject has taken us to a position where it is clear that the effects might be appreciable.. The following Table gives a recent example of estimates of the global warming effects of various aviation pollutants. It may be seen that global warming due to water and NO_x may be of the same order as that due to CO_2. This augments the CO_2 contribution of aviation to global warming, and this fact should not be ignored when considering allocation, charging and regulation frameworks for impact control.

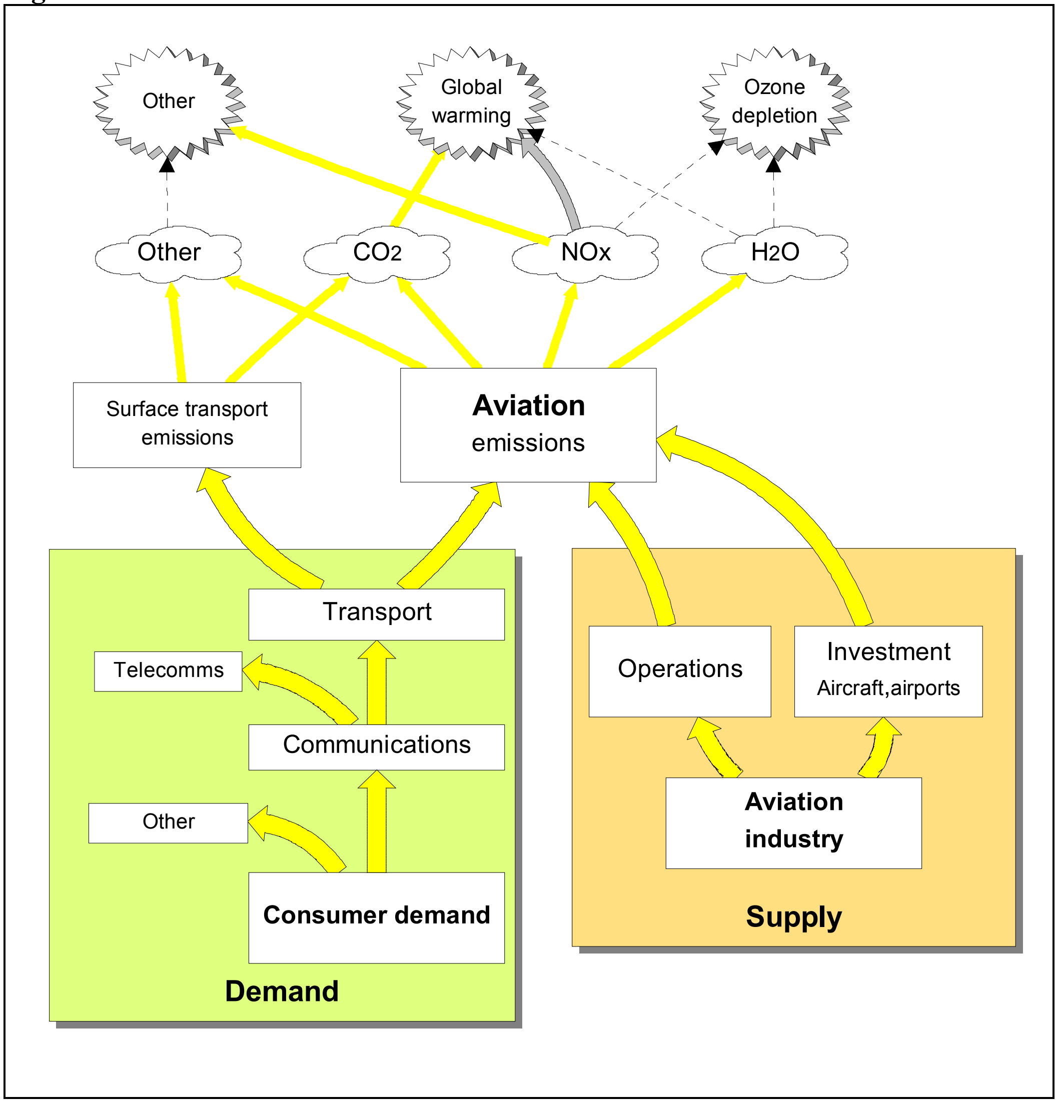
Table 1 : Global warming of aviation pollutants: a recent estimate

Substance	CO_2 equivalent		Reliability
	Low	High	
CO_2	1.0	1.0	High
Stratospheric H_2O	0.1	0.5	Medium
Ozone (from NO_x)	0.4	1.1	Medium
Condensation trails	0.1	2.0	Low
TOTAL	**1.7**	**4.6**	

Source: Greenpeace Germany (1996)

Consumer expenditure or demand is the fundamental driving force of pollution. This is divided between expenditure on communications and all other expenditure on other goods and services. The expenditure on communications can itself be divided between that on physical transport by surface and other modes; and that on other communication means such as telecommunications. The demand for transport (as opposed to telecommunications) or transport, can be by surface mode or by air. These transport demands are the fundamental driving forces of pollution emission from transport. The effect of transport demand depends greatly on details such as the length and timing of journeys.

Figure 1 : Overview



The aviation industry provides the requisite services by (*inter alia*) investment in capital stock such as aircraft and airports in combination with operational regimes. Emission levels are moderated by the strategies of the aviation industry.

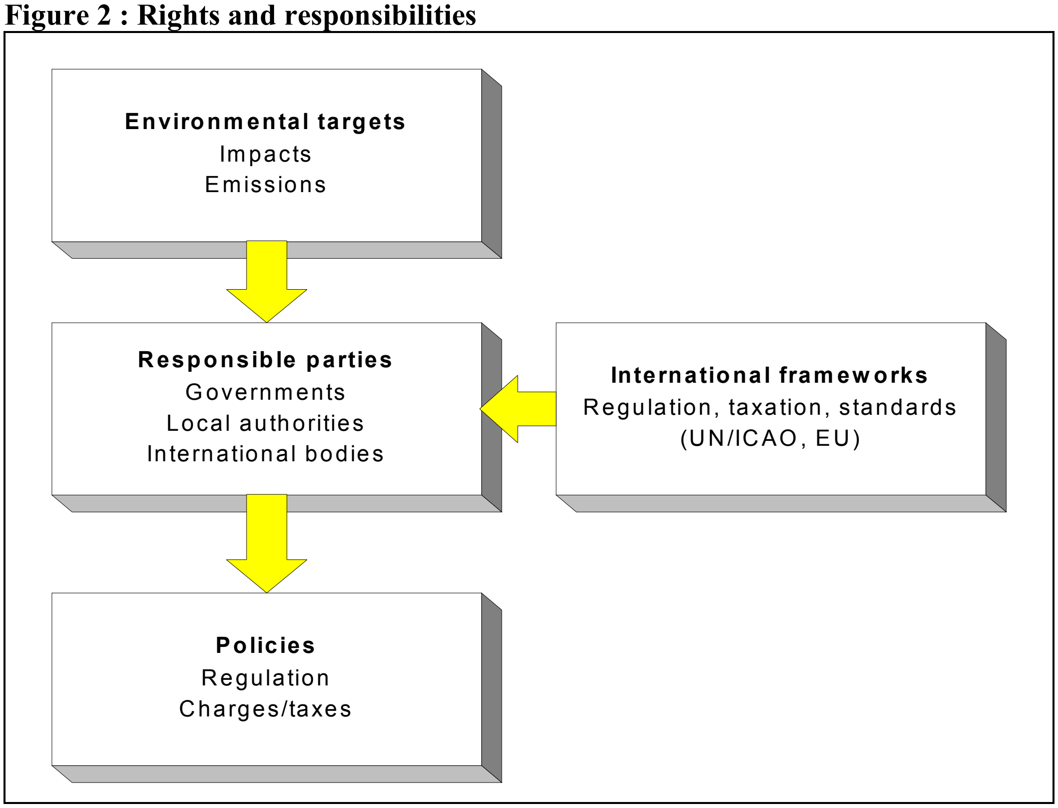
Aviation is a global industry; about half of its physical production comprises international passenger and freight services (as opposed to domestic). Furthermore a large proportion of aviation services are sold by airlines of one nationality to people and operators of other nationalities on both domestic and international routes. The global impacts of aviation such as global warming are perhaps more significant because of their persistency and geographical scale as compared to more local effects such as noise pollution. (This is not to downplay the importance of noise, but it is not the specific concern of this report.)

These characteristics have led to aviation being subject to detailed international regulation and agreement covering many aspects: from technical standards for engines and aircraft through to safety procedures; from navigation rights and routeing agreements to rulings on government subsidy in the EU.

There is a complex relationship between environmental objectives or targets, the responsibilities for achieving those targets, and international frameworks. Environmental targets such as those for global warming or ozone depletion are proposed by international bodies. These targets, in the context of atmospheric pollutants under study here, are translated into practical measurable goals such as the emission limits required to meet the targets. These emission limits are then allocated to particular responsible bodies whose duty is then to ensure limits are met. These bodies are presently often national governments, although duties can be extensively devolved to local government. The role of supranational bodies such as the EU is continually growing. The responsible bodies meet limits by implementing the appropriate policies. However the extent and nature of instruments available to these bodies can be heavily constrained by international frameworks - particularly in the case of aviation. Care has to be taken that duties are not given to bodies to meet limits, without also the rights to deploy the requisite policy instruments.

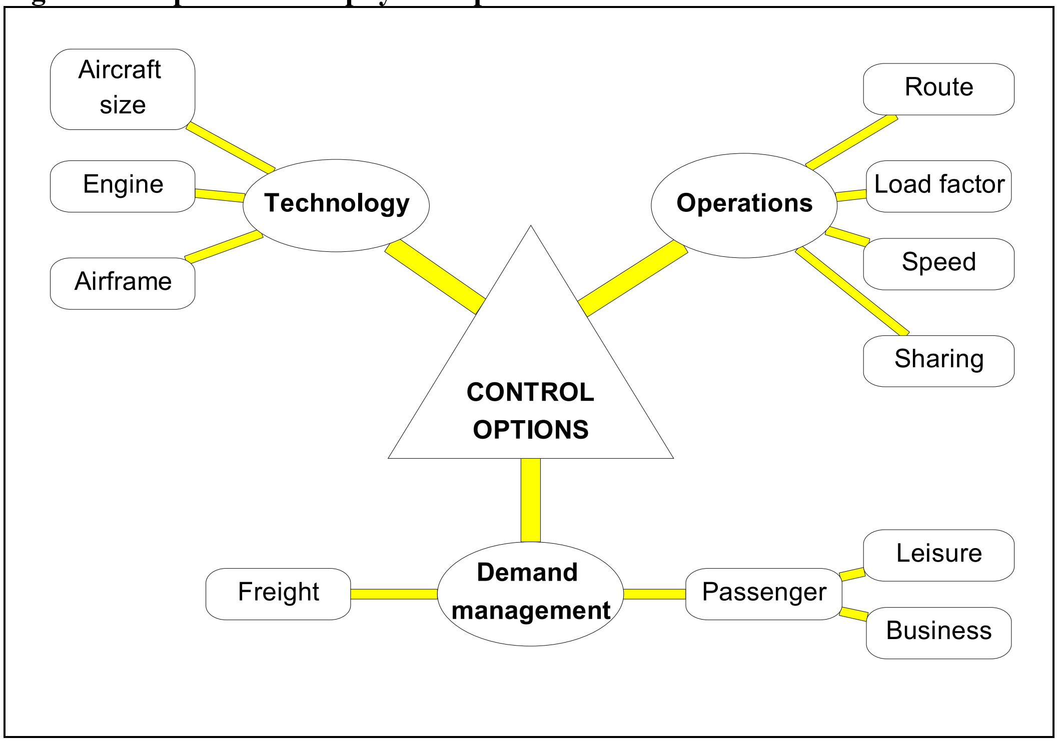
[For example the emission of sulphur under the Large Combustion Plant Directive of the EU is allocated to the EU Member States who then have to implement the appropriate policies.]

Figure 2 : Rights and responsibilities



Impact control can be divided into two parts: the physical options for changing aviation system; and the instruments which might be used to implement those physical options. The physical options for control have been summarised elsewhere (e.g. WWF, 1994) and may be divided into technology, operations and demand management options.

Figure 3 : Impact control: physical options



As for other sectors there is a range of regulatory and fiscal instruments which can be employed to reduce the environmental impacts. Many economic sectors are now subject to international frameworks which impose general and specific regulation for the application of these instruments. For example: the WTO has a wide ranging general effect on trade and thence production; and many economic sectors in the EU are now subject to EU wide regulation. These frameworks have become more extensive with the internationalisation of an increasing proportion of production and consumption.

In order to investigate the effects of charges on the aviation industry and its environmental impacts the following questions are addressed in this report

i. Which environmental impacts of aviation are to be controlled by charges?

ii. To which parts of the aviation industry can charges be applied to?

iii. What levels and structures of charges are possible?

iv. What will the effects of charges be on the environmental impacts of aviation?

v. What regulatory constraints on charges exist?

The main focus is to explore an aviation fuel charge as a means to controlling pollution from civil aircraft. Charging aviation fuel will increase the costs of fuel and thereby the total operational cost of air transport. This will depress the demand for aviation and increase pressure for fuel efficiency which in turn will decrease fuel use and carbon emissions and thereby reduce environmental impacts. However, there may be some disadvantages such as cruising at higher altitudes or increasing NOx emission from high efficiency engines. Such potential drawbacks must be identified.

There are several difficulties in appraising the possible structures and effects of charges.

First, there is the sheer complexity and global scale of the air transport system: and the effects of charges have to be assessed over several decades into the future when uncertainties concerning fundamental factors such as demand and technology become very large. This necessitates much simplification of the analysis.

Second, understanding about the interactions between the parts of the aviation system is patchy. The response of aviation service consumers and suppliers to changes in cost structures which charges would bring about is very uncertain. The relationship between air transport costs and other factors, such as load factor or technological improvement is generally little understood. Some bodies forecast on a large, possibly global, scale (e.g. ICAO, Boeing) and assume relationships between factors such as GDP, aviation costs and demand Some studies have resulted in estimates of elasticities for certain routes and regions. The responses to charge can interact in complex ways: for example Barrett showed (WWF 1994, pp38-40) how the costs increases due to a 100% fuel charge might be offset by an increase in load factor such that consumer costs do not increase at all (although carbon emission would be reduced).

The remainder of this report expands on the topics introduced above. In the second main section, environmental objectives are summarised and various aspects of charges are discussed. The third section describes the use of a model to estimate the possible effects of charges. In the fourth section some issues relating to the international framework for charging and emission inventories are raised. The last section is summarises the work and draws some conclusions.

2. CHARGES

This section summarises some of the objectives of charging, and then proceeds to describe what charges are, and how they might be applied to aviation.

2.1. Policy objectives of charging

The charges discussed in this report aim to secure particular environmental and socioeconomic objectives. These are outlined below.

2.1.1. Environmental

With respect to aviation, the impacts of concern, and the emissions which bring them about are global warming and high altitude ozone depletion.

- **Global warming**. Aviation emissions which contribute to this include carbon dioxide (CO_2), and high altitude nitrogen oxide (NO_x) and water (H_2O).
- **Ozone depletion.** Aviation emissions which may contribute to this include carbon dioxide (CO_2), and high altitude nitrogen oxide (NO_x) and water (H_2O).

The environmental objective is to apply charges such that the quantities of pollutants causing these impacts are reduced.

2.1.2. Other

Objectives other than environmental improvement should be included in aviation policy. These objectives might include:

- **Equal access to environmental resources.** There is a great disparity between countries in their use of aviation fuel and their emission of aviation related pollutants. Such disparities are important in international environmental negotiations, and international aviation policy, including charging, may aim to reduce such inequities.
- **Economic efficiency.** The pursuit of environmental objectives should be carried out in an economically efficient manner. It is widely argued by economists that charges are more efficient than regulation, and therefore insofar as this is true, the charges explored below may be efficient. However it is not proven that charges will always be more efficient. In practice regulation has been more widely used for the control of pollution than charges. There is no reason why a mix of regulation and charging can not be applied, and therefore this paper is not to be seen as recommending one instrument to the exclusion of the other.

It is outside the scope of this report to explicitly include these objectives in a detailed and quantified manner in this report.

2.2. A rose is a rose

A tax is a levy on a good or service where the revenue goes into a local or national treasury. This revenue may be used to cover general public expenditure, or it may, more unusually, be hypothecated: that it to say that particular revenue is earmarked for a certain purpose.

It is presumed that the costs of most goods and services within aviation are covered by current charges for landing and take-off (LTO), navigation and so on. Therefore, if these charges are increased, or new ones introduced, then the additional levies must be charges since costs are already covered. In current market terms this may be the case. However estimates of the economic value of environmental impacts are made (although there may be fierce debates about the accuracy, ethics and policy implications of these); and this economic value, not presently expressed in the market, may be internalised. One way of doing this is by the use of an environmental charge.

To a degree this is a question of nomenclature and the greater acceptability of the word 'charge' than 'tax'. For example, when VAT was introduced on domestic fuel in the UK, certain politicians claimed this was a charge applied to protect the environment, rather than just a general revenue raising tax.

Whether or not it is possible to accurately estimate the economic costs of environmental damage, it may be useful to employ the term 'environmental charge' for a number of reasons. First it helps integrate environmental objectives into social and economic planning conducted by public bodies and private enterprise. Second those who are to pay the charge or tax, are less likely to object if it has an explicit environmental tag.

Accordingly the term 'charge' is used throughout this report. This is so despite the fact that there are few estimates of the economic value of the environmental impacts of aviation.

2.3. To whom the spoils?

An important issue is what party applies charges, and where the revenue goes.

In general taxes and charges are set and collected by governments, and revenues go into Treasury coffers without being marked for expenditure on specific items. This is so for a wide range of levies including income tax, excise duties on fuel and VAT.

One possibility is that revenue raised from environmental charges should be used for specific purposes. This is called hypothecation. For example: the revenue from environmental charges on aviation might be specifically allocated to measures which would enhance the environmental performance of the industry, such as investment in improved air traffic control so as to relieve some congestion.

Alternatively, if charges were applied by some international body (a unique precedent?) then hypothecating the revenues to international facilities such as atmospheric pollution monitoring or enhancing air navigation facilities might be xx

The question as to which of these options would be adopted can not be answered independently of the question of how charges would be applied, and indeed of the emission allocation issue. For example, if charges were applied by countries, then it might be appropriate and politically expedient because of precedent, for revenues from these charges to be treated as any other national charge or tax - that is they would be set and collected by government, and the revenues would not be hypothecated. These issues are discussed at greater length in the appendix

2.4. Justifying levels of charge

A number of aspects can be considered when judging what an appropriate level of a charge might be.

i. **External costs**. The past two decades have seen attempts to internalise market externalities. In this context this is to include environmental costs in market costs generally through the application of taxes or charges, and to account for these externalities in regulation such as standards. Because many environmental costs do not appear ‘naturally’ in economic markets, studies have been made of what these external costs should be, and how they should be expressed in the market. For example, the IPCC Working Group III has argued that the social value of carbon emission should be in the range 5-135 $/tonne. (This translates into an aviation fuel cost increment of up to about $100 per tonne.)

ii. **Comparison with other means and sectors.** The costs of emission control through aviation charges may be compared with the costs of emission control with other means and in other sectors. Thus if a general aim is the limitation of CO_2 emission to a certain level, then aviation charges would be applied to the level that they produced CO_2 reduction at a cost less than or equal to the cost of reduction by any other means or in any other sector within the agreed CO_2 limit: i.e. aviation charges would be a cost-effective option.

iii. **Comparison with other modes.** Given a certain inter-substitutabililty between modes of transport, it may be argued in some instances that it is inconsistent to apply environmental charges to one mode (say fuel charges on surface transport), and not to another (aviation).

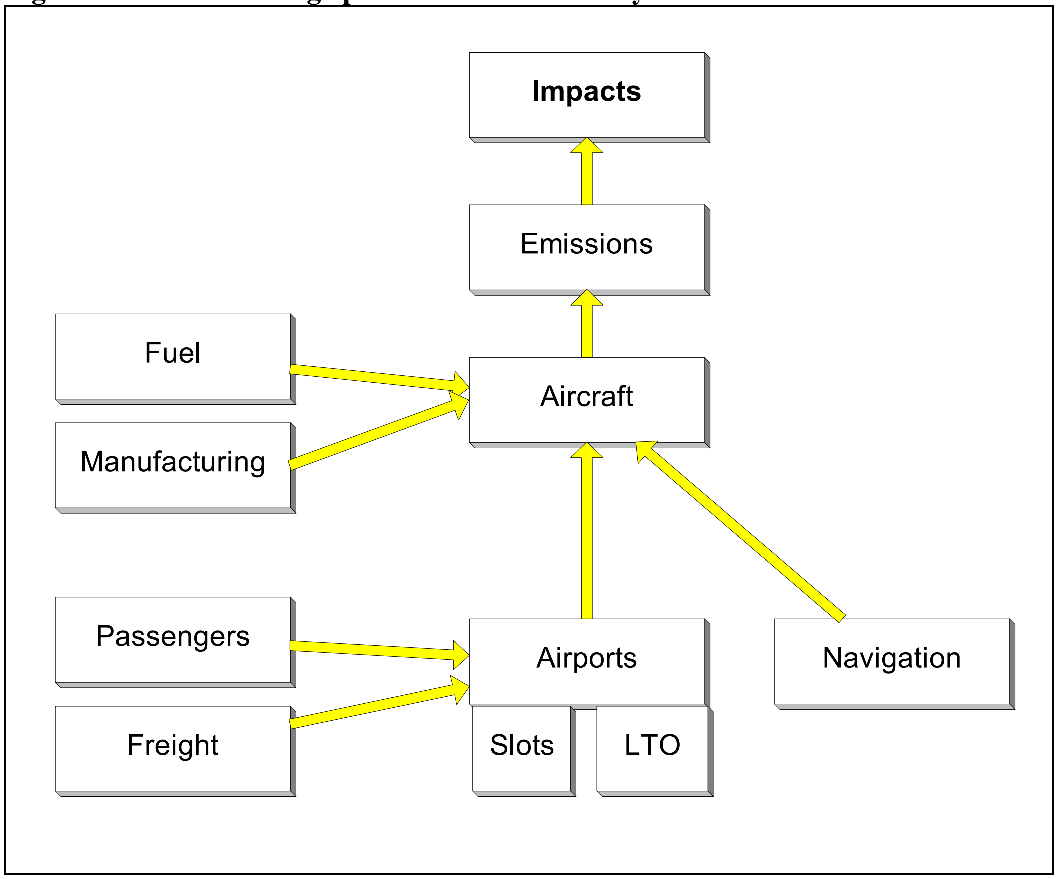
Like taxes, charges can be revenue neutral if the income from the charges displaces other public income from charges or taxes. Charges will generally be redistributive and may not impose a net extra cost to society.

Currently the external values of pollution are generally not known with any precision. The uncertainty is particular great for global warming, and even greater for high altitude pollution from aviation. Given this, and the scope of this study, there is no justification of the levels of charge assumed within this report.

2.5. Charge points and categories

Charges can be applied to different parts of the aviation demand and supply system and can take different forms. Charges may be applied to a number of commodities and services in aviation, and to the environmental impacts of aviation. Commodities and services which may be charged include fuel; airport charges for aircraft movement or passenger movement; and consumer charges (e.g. passenger tickets or freight costs). Charges could be applied to environmental impacts including engine emissions and noise.

Figure 4 : Possible charge points in the aviation system



The effects of charges will vary according to the sectors of aviation. These sectors may be defined by the categories of demand, supply and route geography. These categories are important since they affect, inter alia, the political scope for charges and the impact of charges. Demand sectors could include passenger (leisure and business), freight, (military). Supply categories could include scheduled and charter. Geographical categories might be domestic (i.e. within one state) and international: international conventions concerning taxation differentiate strongly between these categories.

Charges can be applied in various forms; as constant proportions (e.g. VAT); as fixed additions (e.g. the UK ticket charge); or as some more complex function (e.g. threshold plus increasing proportion as LTO charges).

Table 2 : Possible charge points

	Item charged
Impacts	Total in flight (global warming, ozone depletion)
Emissions	Total in flight (CO_2, NO_x, H_2O, ...)
Payload	Passenger (number carried, p.km)
	Freight (tonnes carried, t.km)
Airport services	Passenger (number carried, p.km)
	Freight (tonnes carried, t.km)
	Aircraft movement (landing and take-off)
Aircraft	Environmental inefficiency (e.g. fuel per seat.km)
Flight consumables	Fuel (tonnes consumed)
Navigation	Air traffic control (aircraft movement/distance)
	Route allocation
Manufacture	Environmental inefficiency (e.g. fuel per seat.km)

The application of charges at these different points is explored below.

2.5.1.Impact and emission charges

Plainly a charge on the actual environmental impacts caused would be most appropriate in that it directly bears on environmental objectives.

Emission charges would be applied to the mass of pollutant emitted. Emissions would have to be regularly calculated for each aircraft operation. A charge on NO_x emission might be problematic to apply because there is presently no reliable and cheap way of estimating in service emissions. A charge on carbon emission would be directly comparable with one on fuel unless unconventional fuels were used.

If the charge related to impact (e.g. global warming), rather than emission, then the contribution to impacts of emissions incurred during a flight might have to be calculated. This would take into account factors such as altitude and latitude of emission. The charge would then be applied to an impact: e.g. for global warming, $ per tonne of carbon equivalent.

2.5.2.Movement charges

Charges aimed at air transport more generally could be applied; the movement of people, freight, and aircraft would be charged. This would generally encourage a switch to alternatives and better operational patterns.

Passenger movements or distance

Charges on passenger movements or passenger distance directly suppress demand. It is slightly easier technically to apply a charge to passenger movements than to distance. A charge could be added to the cost of an air ticket. ICAO recommends that the passenger charge should be levied on the airlines and the cost recouped through the ticket. Most European and third world airlines do these, elsewhere it is charged directly to the passenger. In the USA landing fees are low and passenger charges imposed by airports are forbidden. (Doganis p141).

Freight movement and distance

A charge on freight transport is a possibility: the charge could relate to tonnes lifted or to tonne kilometres. For most freight there is no vital need for speed and alternative modes are widely available - therefore a charge on air freight transport might be politically acceptable and not have an undue economic or social penalty. Freight accounts for perhaps 10-20% of aircraft emissions. A charge on air freight could radically alter the competitive position of alternatives such as rail, road or ship.

2.5.3.Aircraft movement

Landing and take-off costs

[1]Extra charges on aircraft movements could be applied at airports. The effect of these would be to increase the ratio of passenger movement and distance to aircraft distance - i.e. airlines would try to move more passengers with fewer aircraft. The charge would thus encourage both higher load factors and the use of larger aircraft. In addition congestion of airports and air routes would be lowered due to less movement. These effects all generally reduce pollution. In addition there would be less pressure for more airport capacity.

Except in the USA, airport charges consist of two components: an aircraft landing fee based on the weight of the aircraft and a passenger charge per passenger. Costs vary widely between airports and with time. E.g. (Doganis p 181) Boeing 757 with150 passengers would have paid £2398 at Heathrow airport, £2003 at Gatwick (but £342 off peak), and £1718 at Luton.

Weight and LTO related

Presently the LTO costs are generally structured in the form of a fixed cost per aircraft movement plus a cost related to the take-off weight (TOW) of the aircraft: the charge form is thus similar to

Cost = Fixed + constant . TOW

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[1] Note that fees for take-off are usually termed charges, these are here termed costs in order to avoid confusion with environmental charges.

If the fixed charge were made larger relative to the variable weight related charge, then movements of aircraft of any size would be penalised, and operators would be encouraged to use larger aircraft with more passengers or freight on board.

According to ICAO (1992c) these charges varied from $2.9 per departed tonne (maximum take off weight of aircraft) in the Central America/Caribbean region to $13.6 per tonne in Europe: the world average was $8.2 per tonne. On average these charges accounted for 4% of total costs for international passenger operations. Plainly a charge would have to be a very large proportion of current take off charges to make a significant difference. It might be better that a charge be applied to aircraft movements as well as, or rather than, weight. A movement charge would further encourage the use of large aircraft and high load factors.

Emission related

A charge which relates to the environmental performance (e.g. grammes NO_x or CO_2 per km) of an aircraft landing or taking off at an airport could be applied.

Slots

Landing and take-off slots are allocated to airlines for the operation of particular services. The current costs of these slots could be subjected to a supplementary charge. This charge could vary with time such that slots in congested periods increase in cost relative to those in off-peak periods.

Navigation

At present operators have to pay for air traffic control and other services related to flying through different air spaces at different times. A charge could be applied to these services. A more complex charge could be applied which relates to the distance flown by the aircraft; this could vary according to factors such as the environmental sensitivity of the atmospheric segment and the degree of congestion.

2.5.4.Fuel charge

A fuel charge should encourage fuel savings and thence reduce total emissions. However, it may encourage operators to cruise their aircraft higher where fuel efficiency is higher, and this may increase environmental impacts due to the emission of NO_x and water near the tropopause.

In general tax is not paid on aviation fuel whether it used on domestic or international flights.. This is primarily because of agreements concerning the taxation of consumables on international transport, and because countries do not want to put their domestic aviation industries at a disadvantage by charging their inputs more than competitors.

Even so, fuel prices vary. ICAO (1992c) report a wide range of 1.6:1 in the prices of aviation fuel in 1989: the price varied from a high of 26.8 cents per litre in Africa to a low of 16.3 cents per litre in North America. The impact of a charge would therefore differ according to the base cost of the region.

The question arises as to what the rate of charge should be, and whether it should be a proportional charge (e.g. % of cost per litre) or an absolute charge (cents per litre). An absolute charge would tend to reduce regional differences between fuel costs.

2.5.5.Manufacture

A charge could be applied to aircraft purchase. The charge would be related to the 'environmental inefficiency' of the aircraft. For example the charge might be proportional to the difference between the specific NOx emission of the aircraft (measured for example, in grammes of NOx per seat kilometre) and best practice specific emission. This would be analogous to charges suggested for road vehicles such as a charge related to the fuel consumption as measured in a standard test.

3. QUANTIFYING THE EFFECTS OF CHARGES

Consumers and suppliers of aviation services will respond in a variety of ways to any changes to cost and price structures brought about by charges. It is these responses which will determine the changes in environmental impact of aviation, and therefore the benefits (or possibly costs) of any charge. The physical changes determining the environmental impacts of aviation may be categorised under demand, technology and operations.

The aviation system is very complex technically, economically and politically.

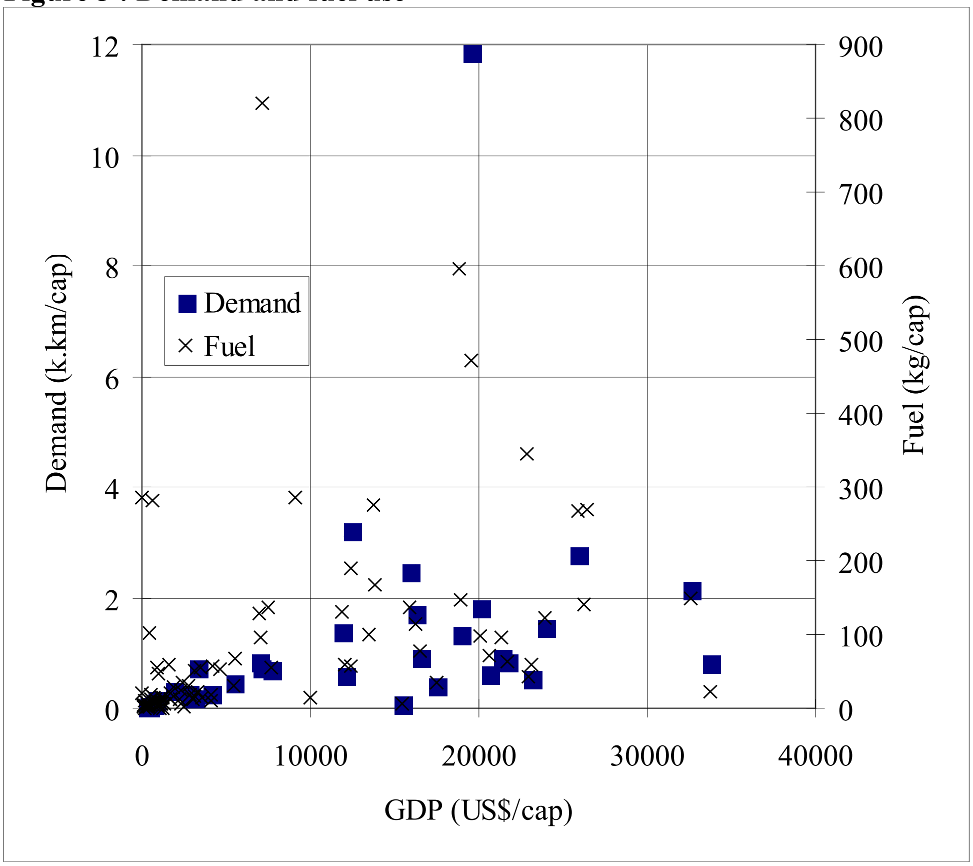
Specific problems of complexity include:

- There are many different load types and customer classes (passenger/freight, ordinary/business/first class passengers) with each customer segment having different characteristics.
- The total cost of transport diminishes sharply with increasing stage length, and the composition of costs changes. Therefore charges will differentially affect different lengths of flight.
- A large proportion of freight is carried in passenger aircraft. The marginal cost of this portion of freight much smaller than that carried on freight only aircraft.
- The response of operators could range from more or less investment in new aircraft, to altered operations, to attracting different customers.
- The temporal variation in demand directly impacts on airlines operations and thence on environmental performance. Daily and weekly variations are relatively easy to handle because training, maintenance and chartering can be slotted in slack period, but seasonal swings are more difficult. Seasonal peak to trough variation may range from 1.5:1 to over 3:1. There may be a directional imbalance in demand over a given time period. Such variations are accommodated by surplus capacity, changing load factor, and fare variation. Operators often cannot afford to vary

scheduled services over short periods (e.g. weekly) because of the need to maintain good will of customers and plan flights etc. Such variations can mean more congestion, lower load factors and the use of 'dirtier' aircraft which leads to more pollution.

The following Figure depicts the variation of the demand for scheduled passenger services and total aviation fuel use with GDP on a per capita basis. Each point represents data for one country. Plainly, neither demand nor fuel use is simply correlated with average per capita GDP: this underlines the importance of viewing models and their results as being indicative rather than definitive.

Figure 5 : Demand and fuel use



Sources: Demand - ICAO; Fuel loaded - IEA energy statistics; GDP - CIA yearbooks.

3.1. Unintended effects of charges

Because of the complexity of interactions, charges may not have the desired effect. Charges may suppress environmental impact at one point in the system, but increase it at others: this is the displacement problem. Some examples follow.

i. Putting a charge on kerosene will increase the costs of fuel and thereby the total operational cost of air transport. This will depress the demand for aviation and increase pressure for fuel efficiency. This will decrease fuel use and carbon emissions and thereby reduce environmental impact in this respect. However operators may try to offset this by increasing fuel efficiency by cruising at higher altitudes. This may further affect high altitude ozone or global warming from NOx. Alternatively operators may purchase and operate engines which have very high fuel efficiency but at the expense of increases NOx emission.

ii. Differences in fuel costs could lead to fuel tankering which is when operators purchase fuel cheaply at one location and then transport it by air for use elsewhere. This leads to greater aircraft weights and distances than necessary, and thence to more pollution.

iii. Applying environmental charges at some airports but not others may lead to an overall increase in impacts. Operators may switch some services to airports with lower charges. This could lead to consumers using more remote airports. This in turn could lead to more surface transport and greater aircraft distance, and thence to more pollution overall.

iv. If the profitability of operators is badly hit by poorly designed charges then their environmental performance might be worsened. For example operators might make less investment in new 'cleaner' aircraft.

At this stage it is not possible to generally quantify such effects, not least because the projections extend to situations several decades distant. A general observation is that the nearer to the point of environmental impact a charge is imposed, the smaller these problems will be.

4. CONSUMER RESPONSES

Extra charges will change the pattern of demand for aviation by altering total aviation demand and the pattern of services required. Some air transport demand may shift to other modes. If so then the use of other modes will have environmental impacts.

4.1. Mix of aviation services purchased

Within a given physical consumption of aviation services (i.e. total p.km or t.km) consumers may try to minimise cost increases entailed because of charges by buying cheaper services.

Consumers might:

i. Increase their use of advanced booking or charter flights.

ii. Use more off-peak services.

iii. Purchase less expensive capacity; e.g. economy or tourist class rather than first or club class.

iv. Take flights from/to different airports; e.g. a passenger might take a cheaper flight from an airport more remote from their journey origin (home or office).

v. Switch some demand from short to long flights.

Responses **i** and **ii** tend to increase the load factor of aircraft. This in itself reduces fuel use and pollution per load.km. Also, assuming no size change, fewer aircraft fly leading to less congestion and pollution. The need for fewer aircraft means that the most polluting may not be required. Response **iii** increases the load factor of the aircraft because seat spacing will be reduced.

Response **iv** may increase the load factor and improve the environmental performance of the long distance flight in terms of emission per load kilometre. However the passenger will incur pollution in travelling to the more distant airport whether it is by surface or air transport. Response **v** might also reduce emission per kilometre, but a greater fraction of emission would be at high altitude.

4.1.1.Freight

Freight services may be divided into carriage in the belly of aircraft underneath passengers, and operations in which only freight is carried. These observations can be made:

- The amount of 'with passenger' freight that can be carried is dependent on passenger demand (including its routeing and timing), and the design of the passenger aircraft used.
- The marginal cost of carrying 'with passenger' freight is relatively small in economic and environmental terms. It is quite possible that the incremental environmental impact of this freight is less than for other modes such as ship or rail. This segment of freight demand will be quite insensitive to flight related charges.
- Conversely, freight only operations have a large incremental environmental and cost impact; and these operations will in general be more sensitive to cost changes brought about by charges.

4.2. Decreased overall demand

Increasing the cost of air transport will make the overall demand less than would otherwise be the case. Demand may be reduced in terms of the passenger or tonne kilometres flown by reducing the be achieved by some combination of number of flights and flight distance: i.e. consumers might fly less frequently and/or make shorter flights. Consumer expenditure would be redirected to other goods and services. In general these will are likely to be less polluting per unit of expenditure.

The degree of demand suppression will depend on the elasticities of demand in the various segments of the passenger and freight markets. The elasticities will depend on factors including: demand category (e.g. business/leisure passengers); the total cost of the trip; overall and disposable income of customers; existing demand; geography; economic structure; and culture. These factors vary widely from country to country and route to route.

4.3. Supply substitution

4.3.1. Modal shift

The costs of air transport will increase relative to other modes of transport and communication, and therefore some aviation demand will shift to other modes. First the environmental advantage of alternatives should be established. For similar speeds air may be as good as other modes. As for demand, the degree of shift from air will depend on many factors including the relative availability, costs and convenience of alternative modes. These factors are very dependent on the route considered particularly in terms of distance and whether the route is over land, over sea or over both.

4.3.2. Telecommunication

Increasing the cost of air transport will augment the substitution of telecommunications for physical transport. In modern times this means technologies such as Fax, electronic mail and teleconferencing. It is assumed for current purposes that the environmental impacts of these technologies are negligible compared to those of long distance air or indeed surface transport.

4.4. Demand model

The preceding has set out some possible consumer responses. This section sets out the demand model used at present in the Aviation Analysis Model (***AviAn*).** At present an econometric model of demand is employed. This uses elasticities to determine the response of passenger and freight demand to exogenous variables: for passenger these are wealth (GDP) and cost; for freight they are value of trade and cost.

It is again emphasised that the models generally employed are simplifications of the actual systems. The models are almost invariably employ some fitting to historical data: and history was dominated by regions such as north America and the trans-Atlantic route, whereas the future may belong to Asia and the Pacific rim with different characteristics.

For example, it is generally agreed that income is an important determinant of demand. However quantifying how it affects demand, especially in its details, is not easy. Table 3 quotes some values which illustrate how the elasticities vary with customer class and distance. These elasticities will be different across incomes and across time. Some segments of demand, such as business travel, may be more related to trade volumes than income.

Table 3 : Demand: income elasticities

	Short-haul	Long-haul
Leisure	2.3	2.0
Business	1.6	1.2

Source: Doganis

Price elasticities are even more difficult to handle. The above problems exist, but in addition there are others. For example: which price should be used? It could be some weighted average of fares for all classes (first, business, ordinary) or some segmented treatment could be undertaken. Also it might be appropriate to include other costs of a trip such as hotel and subsistence expenses in econometric demand projection.

4.4.1.ICAO demand model

ICAO has made projections of demand using econometric models (ICAO, 1989). Currently these demand models and their coefficients are used in ***AviaAn***.

These models are of the form:

$y = a\, x_1^{\,b1}\, x_2^{\,b2}$

For the passenger model:

- y is passenger-kilometres performed
- x_1 is gross domestic product in real terms
- x_2 is passenger revenue per passenger-kilometre in real terms
- The coefficients are
- $a = 1.65$
- $b_1 = 2.08$
- $b_2 = -0.67$

For the freight model:

- y is freight tonne-kilometres performed
- x_1 is world exports in real terms
- x_2 is freight revenue per freight tonne-kilometre in real terms
- The coefficients are
- $a = 1.09$
- $b_1 = 1.47$
- $b_2 = -0.55$

The coefficients of these models have been determined by regression against historical data and the R^2 correlation statistic is greater than 0.995 for both models. This does not of course imply that these models and coefficients will be accurate for demand projections even if exogenous variables, GDP/exports and costs, are accurately forecast.

Note that this model results in passenger and freight kilometres. It does not provide projections of other variables such as number of passengers and their breakdown by class, or of the distribution of demand by length of flight. The estimation of fuel use and emissions requires several further calculations beyond demand concerning the supply side which we now turn to.

5. SUPPLIERS' RESPONSES

Charges will increase operators costs. Given that the market share and profitability of operators are affected by these costs, there will be competitive pressures eliciting a range of complex responses. These may be divided into operational and investment responses. The two most important are increasing the load factor and enhancing the technical fuel efficiency of aircraft. Judging the operators' response with these means is difficult.

5.1. Operational

Increased load factor

Flight cost per load kilometre may be reduced by increasing the load factor: either by increasing the proportion of capacity utilised (number of seats filled or fraction of freight capacity used), or by increasing the load capacity of passenger aircraft by increasing the number of seats on the aircraft. Logistic and marketing difficulties arise when trying to increase the load factor.

One possibility might be an increase in the fraction of services provided by charter. Studies (see Doganis) show that charter costs are some 64% lower, with about half of this saving due to indirect cost reduction, and the rest due to higher seat densities and load factors (occupancy).The drawbacks of charter flying include limited flexibility in departure and return and costly cancellation. Its advantage is a higher load factor and therefore, *ceteris paribus*, less pollution per unit of demand. Typically, as compared to scheduled services, seating densities are 15-25% higher and the load factor 20% points higher. Charter do not generally have traffic rights for freight carriage and so, in the present circumstances, this has implications for 'with passenger' freight.

Apart from increasing load factor, there are other operational changes which can affect fuel consumption and pollution emission, although their impact would probably be small. Lowering the weight of the aircraft by carrying less inessential items such as sophisticated in flight entertainment systems and excess drinks could save some fuel. Slower cruising speeds and more flexible flight routeing could produce savings.

5.2. Investment in 'environmental efficiency'

The environmental efficiency of the airlines stock of aircraft may be improved by investing in aircraft with lower emissions per seat kilometre. This may be achieved by purchasing aircraft with higher fuel efficiency and less NO_x emission brought about by technological advance or increasing aircraft size.

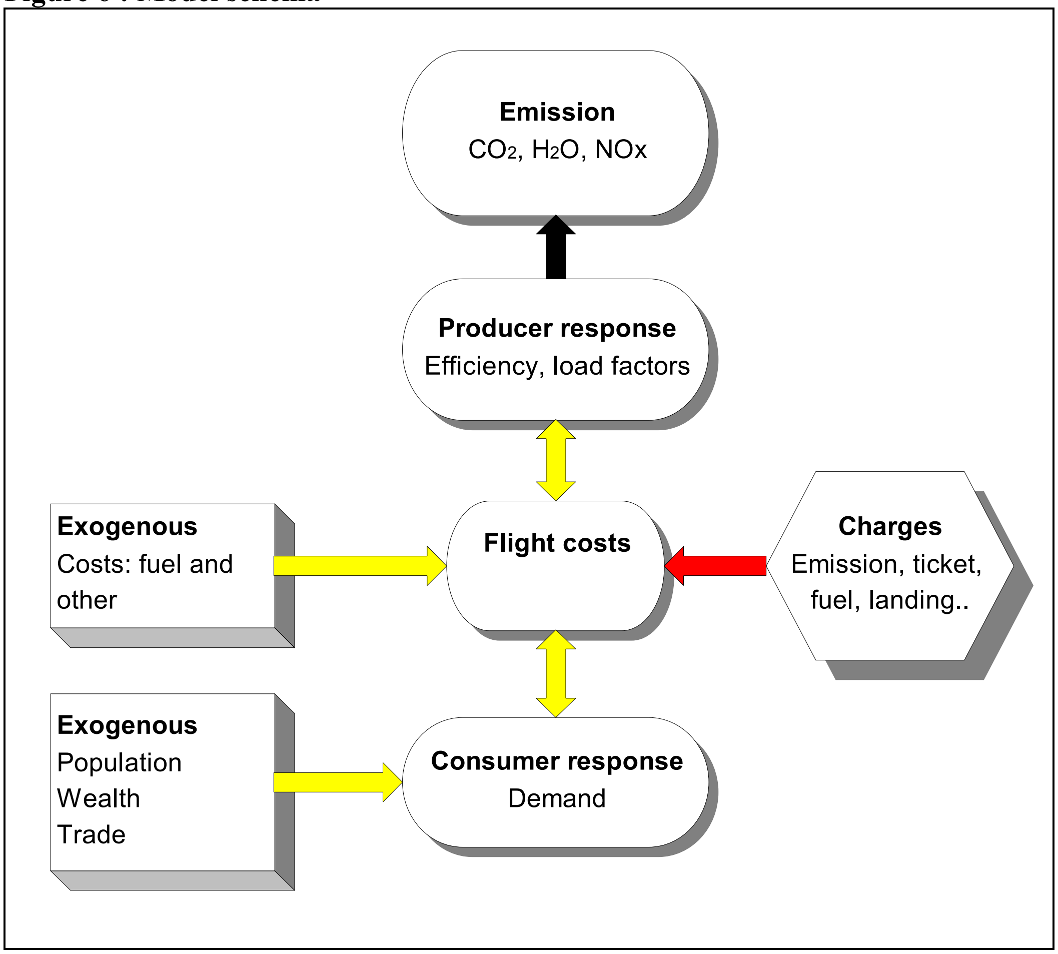
6. SCENARIOS

This section explores some aviation emission scenarios in which different charges are assumed to apply, and different responses are assumed by aviation service suppliers. The model used is first briefly described. Then the key exogenous assumptions made are laid out and the scenarios explored.

6.1. Model structure

An Aviation Analysis Model (***AviAn***) has been developed for this work. A schema of the model is shown below.

Figure 6 : Model schema



The model's calculations can be summarised into four steps.

i. Exogenous data are in input including population, wealth, trade and fuel costs.

ii. Charges for fuel and etc. are set.

iii. Demand is calculated.

iv. Supply is calculated including operator responses, costs and emissions.

It is required to find an equilibrium between the demand and supply cost curves. Therefore steps iii and iv are iterated until converges on a solution: this is when the change in the unit cost of flying is less then 0.01%.

It is necessary to apply ***AviAn*** to different segments of the aviation market because the factors such as GDP, trade and fuel vary so much. Accordingly ***AviAn*** has been run for six standard ICAO regions. ***AviAn*** can be used to explore different segments defined by flight length, but there is insufficient data about factor such as demand elasticities to do this at present. The next subsection highlights the importance of flight length.

6.1.1.Flight length

The length of a flight has a great effect on the total cost per load kilometre, the cost structure, the emissions per load kilometre, and the distribution of these emissions at different altitudes. In consequence the effects of different charges can be expected to vary according to flight length. Figures 6 and 7 indicate how the total cost and cost structure of a flight changes with distance for passenger travel.

The average costs are based on actual historical data, and varied according to whether these costs are fixed or distance related. It is emphasised that these figures are illustrative only: the actual variations depend in a complex way on many factors including aircraft type, load factor, and route congestion. As flight length increases, emission per load kilometre diminishes but the fraction emitted at high altitude increases.

Figure 7 : Variation of cost with distance: absolute

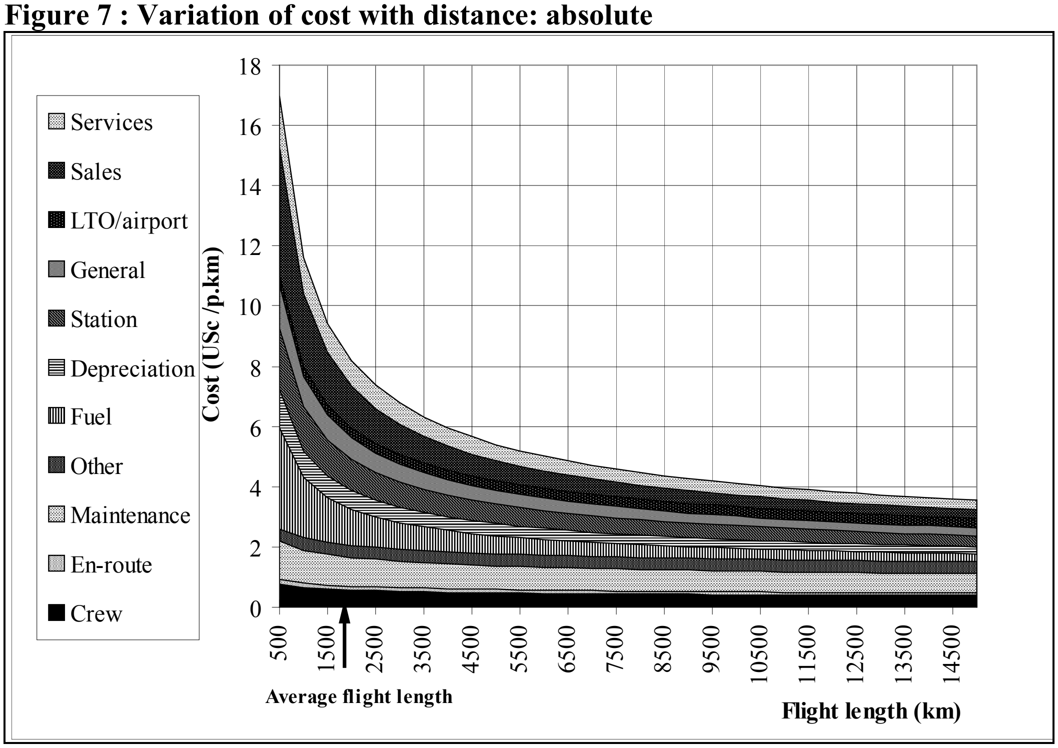
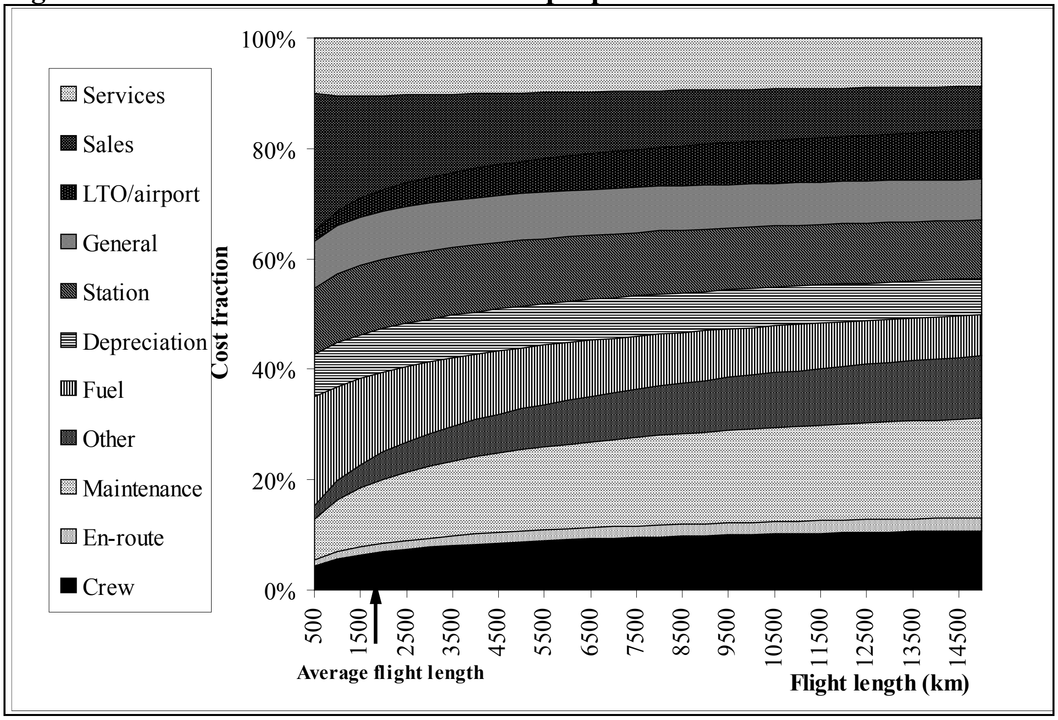


Figure 8 : Variation of cost with distance: proportions



6.2. Base scenario exogenous assumptions

A great number of historical data and exogenous assumptions about the future go into the scenarios generated. Some of the key exogenous assumptions used in the scenarios are laid out below.

6.2.1.Population and wealth

Key exogenous inputs to the projections are population and economic output. The IPCC have utilised a number of scenarios. These are summarised in the Table below; it may be seen that very large variations in the rate of population and economic growth are assumed.

Figure 9 : Summary of assumptions in the six IPCC 1992 alternative scenarios.

Scenario	**Population**	**Economic Growth**
IS92a,b	World Bank 1991 11.3 billion by 2100	1990-2025: 2.9% 1990-2100: 2.3%
IS92c	UN Medium-Low Case 6.4 billion by 2100	1990-2025: 2.0% 1990-2100: 1.2%
IS92d	UN Medium-Low Case 6.4 billion by 2100	1990-2025: 2.7% 1990-2100: 2.0%
IS92e	World Bank 1991 11.3 billion by 2100	1990-2025: 3.5% 1990-2100: 3.0%
IS92f	UN Medium-High Case 17.6 billion by 2100	1990-2025: 2.9% 1990-2100: 2.3%

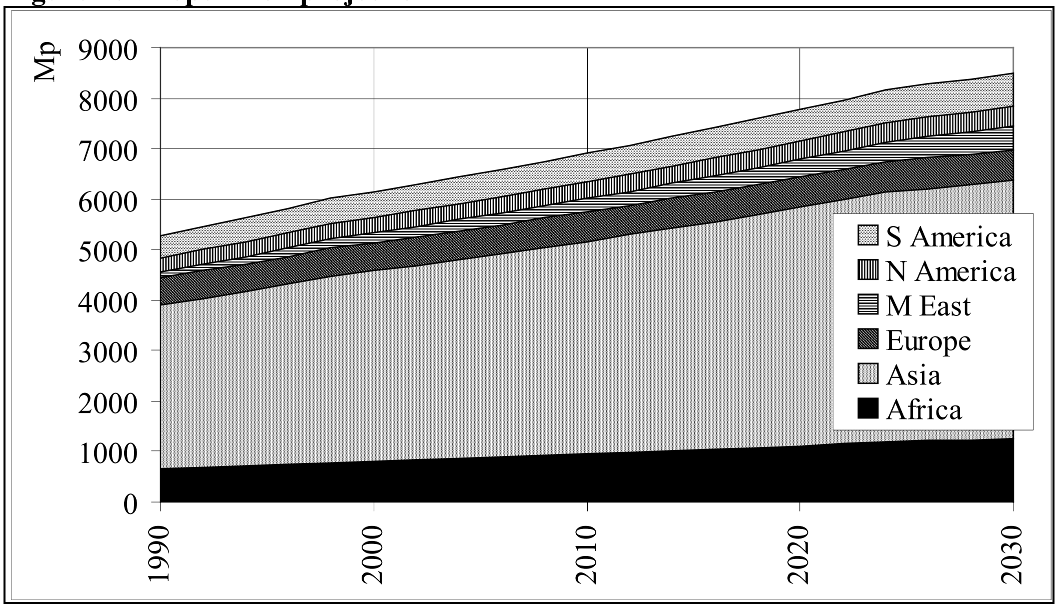
For the scenarios in this report, population and economic growth projections are loosely based on the IS92a,b scenarios. Statistics for population and GDP have been collated on a country by country basis. These have been aggregated into six ICAO regions: south America, north America, Middle East, Europe, Asia and Africa.

Table 4 : Population and GDP assumptions

	Population						**GDP/cap**			
	Million		Annual change %				k$US	Annual change %		
	1990	1994	1990	2000	2025	2050	1990	1990	2000	2025
World	5284	5633	1.6	1.1	0.6	0.3	4	1.7	1.3	1.0
Africa	645	708	2.3	1.6	0.9	0.4	0.7	1.5	1.4	1.2
Asia	3245	3460	1.6	1.1	0.6	0.3	2.2	3.0	2.1	1.5
Europe	546	554	0.4	0.3	0.1	0.1	11.4	1.0	0.9	0.8
M East	124	148	4.6	3.2	1.8	0.8	11.1	1.0	0.9	0.8
N America	276	290	1.2	0.9	0.5	0.2	26.4	1.0	0.9	0.8
S America	448	474	1.4	1.0	0.5	0.2	2.8	1.5	1.2	1.0

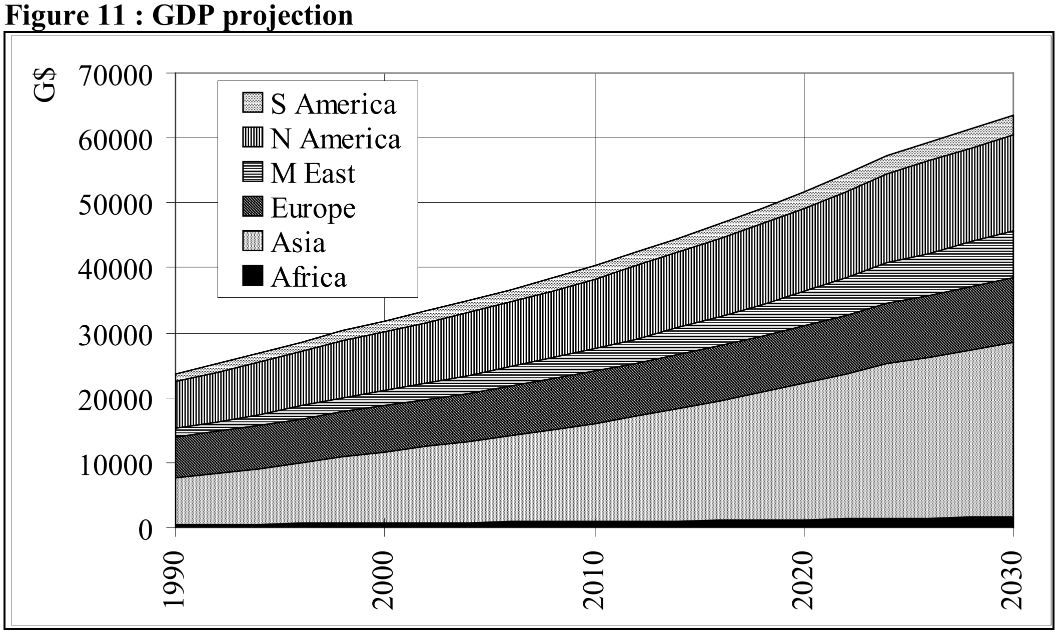
The following two Figures show how these assumptions translate into projections over the period 1990 to 2010.

Figure 10 : Population projection



Global GDP growth averages 2.5%/a over the period 1990 to 2030.

Figure 11 : GDP projection



Historical fuel consumption for the regions is based on IEA statistics. Technological development and aircraft stock renewal are assumed to result in an annual increase in fuel efficiency of 0.5% in all regions; none of this improvement is due to other factors such as increased load factor. Fuel costs in 1990 are based on ICAO statistics. These costs are assumed to increase by 1% per year in all regions except Africa.

Table 5 : Fuel - consumption, efficiency, costs

	Mt	Aircraft efficiency changes			Costs $US90/t	changes		
	1990	1990	2000	2025	1990	1990	2000	2025
World	136.4	*0.5%*	*0.5%*	*0.5%*	145	*0.8%*	*0.8%*	*0.8%*
Africa	3.0	0.5%	0.5%	0.5%	221	0.0%	0.0%	0.0%
Asia	24.8	0.5%	0.5%	0.5%	156	1.0%	1.0%	1.0%
Europe	42.5	0.5%	0.5%	0.5%	143	1.0%	1.0%	1.0%
M East	3.4	0.5%	0.5%	0.5%	153	1.0%	1.0%	1.0%
N America	56.3	0.5%	0.5%	0.5%	134	1.0%	1.0%	1.0%
S America	6.3	0.5%	0.5%	0.5%	180	1.0%	1.0%	1.0%

The following table shows, for 1990, the average size of passenger aircraft and passenger load factor. The assumed annual increases in passenger load factor are also shown.

Table 6 : Aircraft size and load factor

	Size seats	Load factor			
	1990	1990	1990	2000	2025
World	225	68%	*0.18%*	*0.10%*	*0.10%*
Africa	150	66%	0.25%	0.25%	0.25%
Asia	300	71%	0.18%	0.13%	0.13%
Europe	260	66%	0.00%	0.00%	0.00%
M East	220	64%	0.20%	0.00%	0.00%
N America	220	63%	0.30%	0.25%	0.20%
S America	225	61%	0.15%	0.00%	0.00%

NOx emission is calculated by multiplying a coefficient in units of kg NOx per tonne of fuel by the amount of fuel consumed. The NOx coefficient is assumed to be 12 in 1990, and to decline by 1% per annum to a value 25% less than 1990 by 2030. Because fuel efficiency is assumed to improve by 0.5% per annum over the same period the average emission of NOx per aircraft kilometre declines by 36% over the same period.

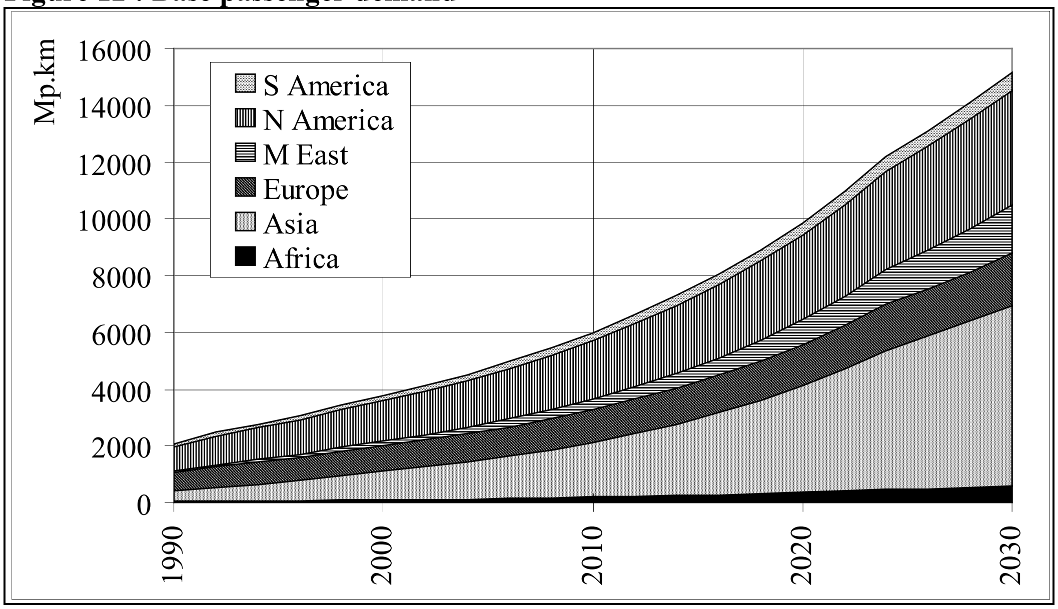
These are taken with the ICAO projection methodology to produce a base projection of carbon emission from aircraft.

6.3. Scenarios

6.3.1.Base case

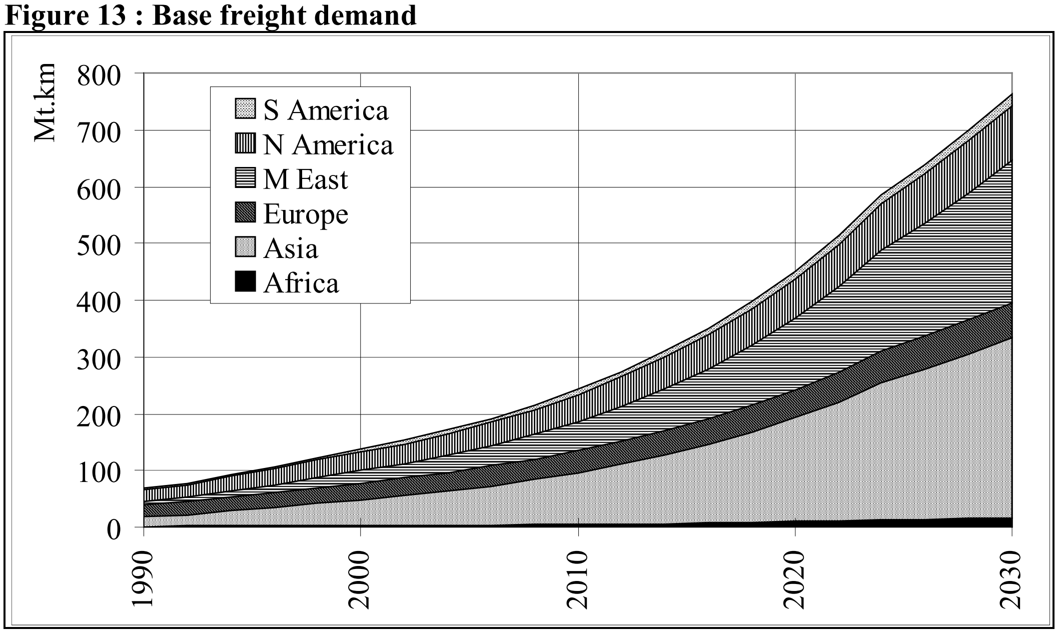
Passenger demand in Mp.km increases by 630% over the period 1990 to 2030, an average of 5.1% per year.

Figure 12 : Base passenger demand



Freight demand in Mt.km increases by 1300% over the period 1990 to 2030, an average of 6.2% per year.

Figure 13 : Base freight demand



These growth projections are consistent with historical growth, and with projections made by bodies in the industry including those by ICAO, Boeing and Airbus. IATA do not make projections, they report those of their airlines. The projections made in this paper are not inconsistent with the short term forecast of IATA.

The essential point is that all forecasts are for demand growth such that pollution emission increases greatly whatever technical and operational measures are applied (see previous WWF reports, 1991, 1994). Therefore measures of some sort will have to be introduced if emissions are to be controlled effectively.

It has been argued that airport capacity will act as a major constraint on growth. There is no doubt that limited airport capacity will act as a slight brake on growth, but the author's opinion that it is unlikely to be much more significant in the medium term future than in the past. This view is supported with these observations:

- Most of the growth is projected to occur in regions such as Asia. It is not clear why airport capacity will not expand in such regions in the future to accommodate demand growth, just as it has historically in wealthy regions such as North America and Europe.
- Even in high demand regions airport capacity expansion continues. For example: the UK is one of the largest providers of aviation services and has a high population density particularly in the London region. Currently there is a proposal to increase the passenger throughput of Heathrow airport by about 60%. Yet other airports the same distance from London have spare capacity. Many other such examples exist.

6.3.2.Variant scenarios

Two effects are considered. First where the fuel charge only affects demand. Second where operators are assumed to respond to the increased fuel costs.

Charges

The charges which may be explored in the model are summarised below. Charges are all measured in 1990 US dollars.

Table 7 : Charge possibilities

Point	**Quantity**	**Charge unit**
Passsenger	Movement	$US1990 / ticket
	Load distance	$US1990 / p.km
Freight	Movement	$US1990/tonne lifted
	Load distance	$US1990 / t.km
Airport	LTO	$US1990/ LTO
Navigation	Routes	$US1990 / a.km
Fuel		**$US1990/t**
Emissions	Carbon	$US1990 /t
	NOx	$US1990 /t (alt)
	Water	$US1990 /t (alt)
Impacts	Global warming	$US1990 /t Ceq

In the scenarios fuel charges alone are explored. Two fuel charge regimes were studied. These were assumed to be increases of $75 and $150 per tonne of fuel, this represents about 50% and 100% increases in fuel costs to airlines. These increases were assumed to introduced in two stages in 2000 and 2010 as summarised in the Table.

Table 8 : Fuel charges

Label	$/tonne	2010
F1	37.5	75
F2	75	150

Fuel tax change		
Label	$/tonne	2010
F1	37.5	50%
F2	75	100%

Operator response				
	1	2	3	4
Fuel efficiency	0.5	0.75	1	1.25
Aircraft size	0.25	0.375	0.5	0.625
Load factor	0.25	0.375	0.5	0.625

Operator response

Four operator response regimes are incorporated in the model: changing load factor, changing the fuel efficiency and size of aircraft, and changing the engine NOx emission factor. Regime 0 where no response was assumed, and regimes 1, 2, 3 and 4 where it is assumed that the operators response is determined by the change in average total cost per passenger kilometre.

The response of the operator is calculated using this formula:

Operator response = change in cost . proportionate response

For example, if the cost per passenger or tonne kilometre increases by 10%, and the operator aircraft fuel efficiency response is 0.25, then the fuel efficiency is calculated to increase by 10% X 0.25 or 2.5%.

Table 9 : Operator response regimes

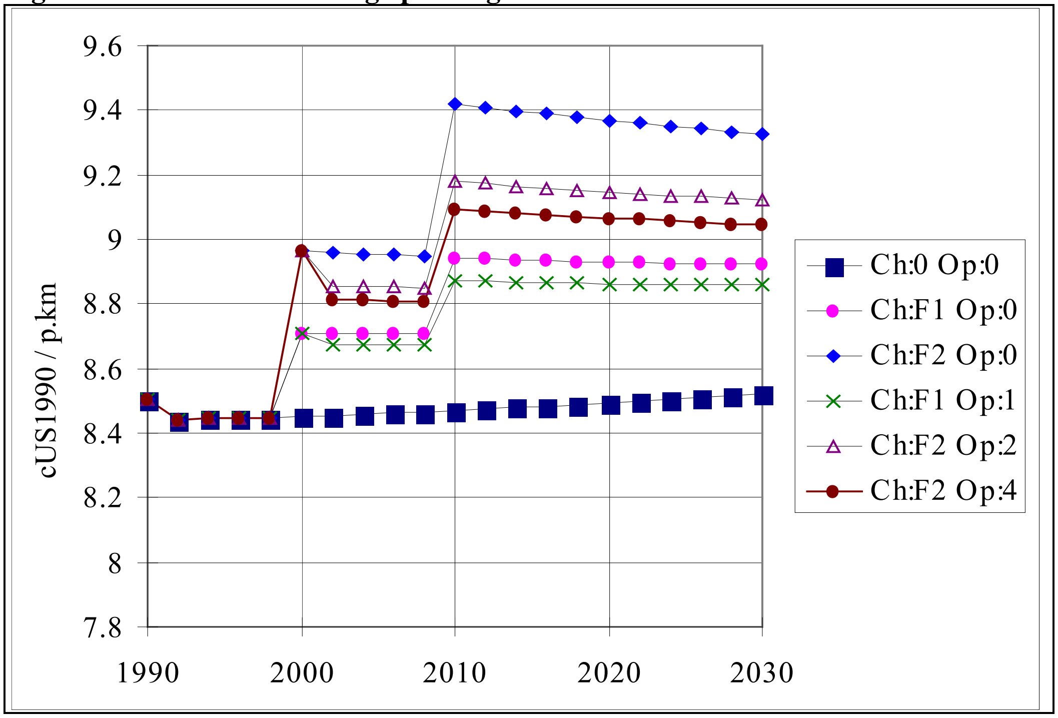
	1	2	3	4
Fuel efficiency	0.5	0.75	1	1.25
Aircraft size	0.25	0.375	0.5	0.625
Load factor	0.25	0.375	0.5	0.625

Changes to demand and operator responses will affect costs. For example, increasing fuel efficiency reduces fuel costs and increases aircraft investment costs, these in turn will change demand. Therefore the model has to make iterative calculations; these are done until the solution converges to within a given cost change between calculations.

Various combinations of fuel charges and operator response regimes were put into the model. The results are shown below.

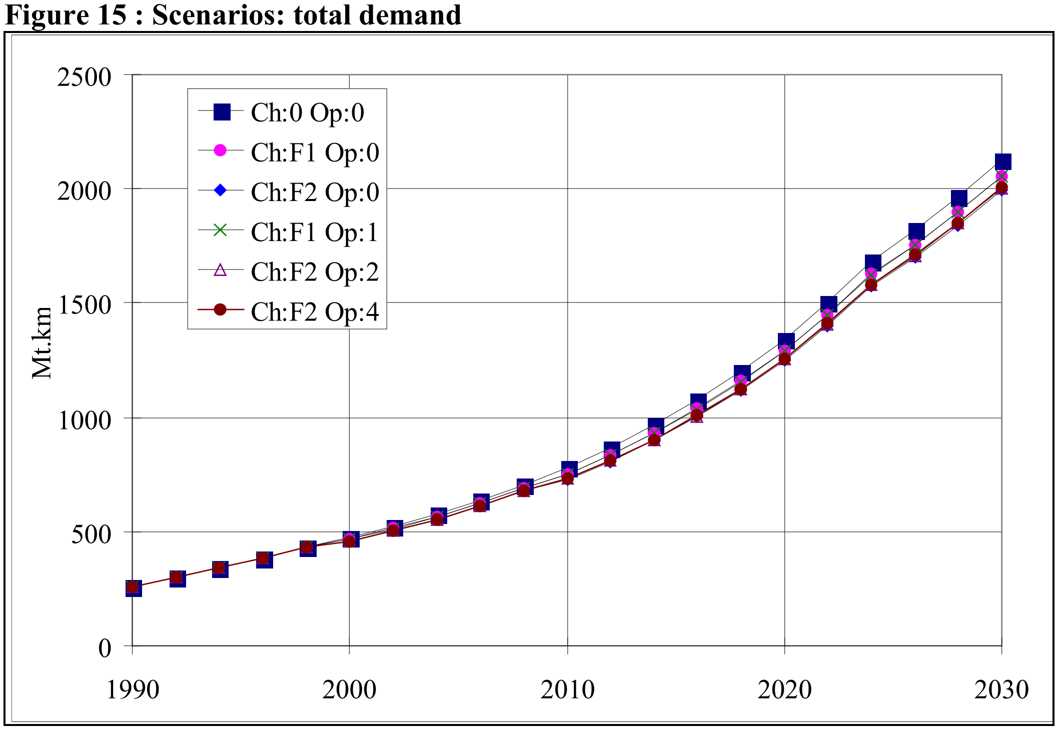
The following Figure shows the impact of the fuel charges on the average costs of passenger travel.

Figure 14 : Scenarios: average passenger costs



From 2010 to the end of the period total demand is reduced by 3% through the application of fuel charge 1, and by 7% with fuel charge 2. The operator response makes little difference to these demands.

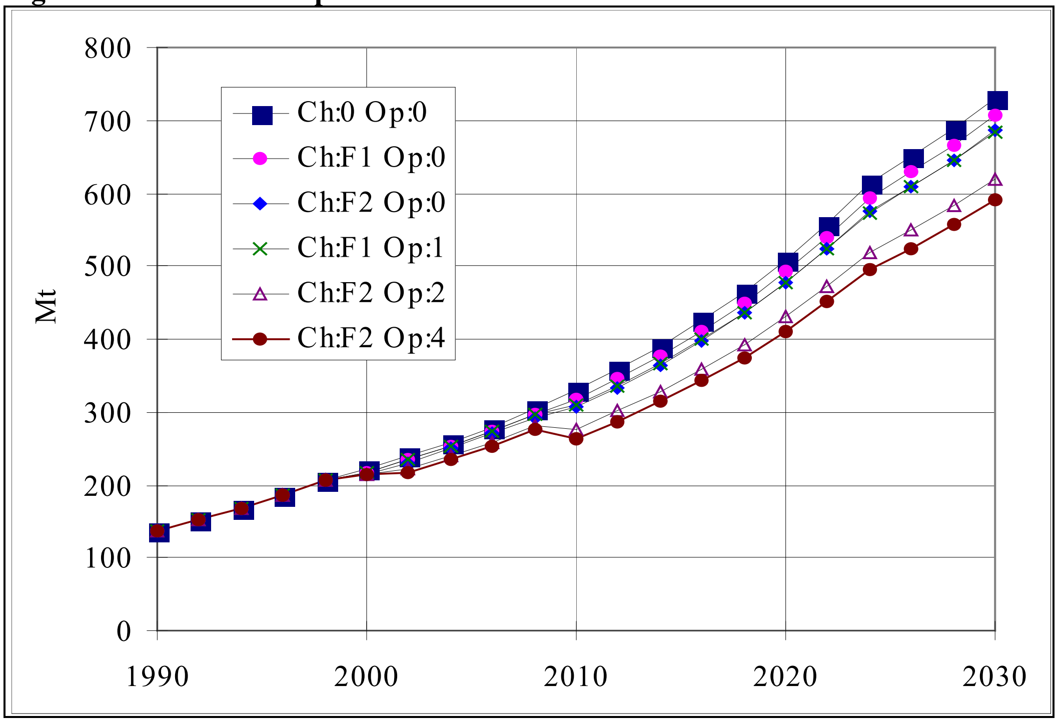
Figure 15 : Scenarios: total demand



The following Figure depicts the fuel consumption in six scenarios. Note that when operator responses are included, the effect on fuel consumption, and later, emissions, is abrupt. In reality these responses would extend over a period of time as operators adjusted to new charges. ***AviAn*** would have to be refined to make some account of this.

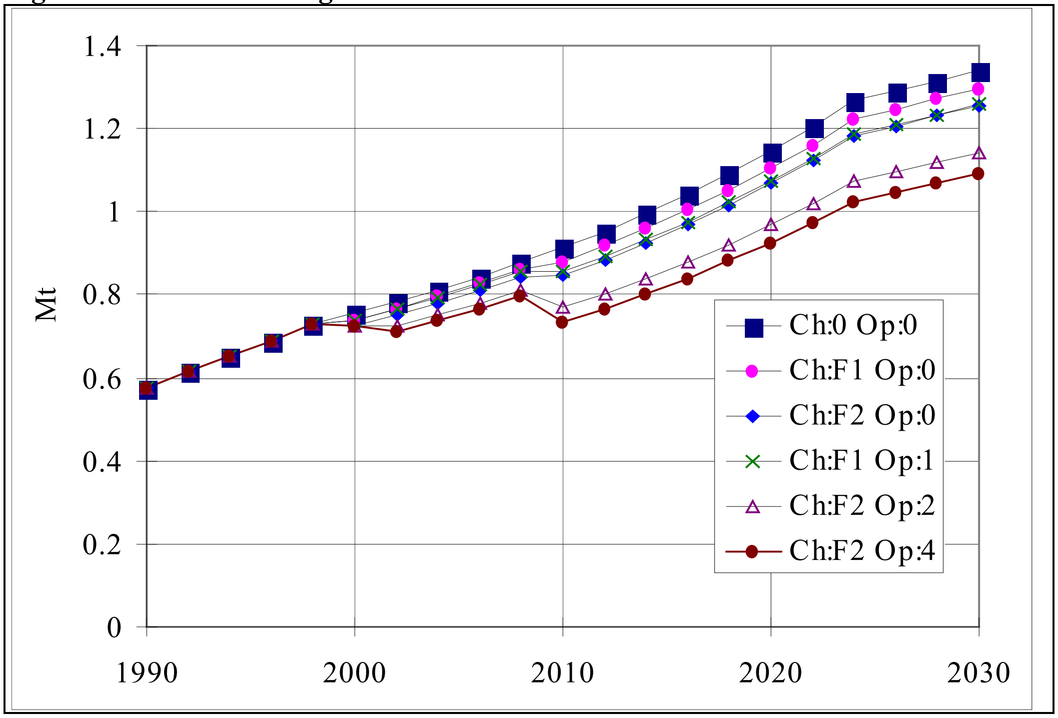
In the base scenario fuel consumption increases by more than five times - a lower increase than demand because of the assumed improvement in technical fuel efficiency and load factor.

Figure 16 : Fuel consumption scenarios



NOx emission per passenger kilometre reduces because of lower NOx emission per unit of fuel consumption, and because of improved aircraft fuel efficiency. In the scenarios presented in this report, a NOx emission charge is not explored. Consequently the NOx emission per unit of fuel consumption is the same for any particular year in all scenarios and differences arise solely because of variations in fuel consumption. There is the possibility that fuel charges will increase NOx emission per unit of fuel consumption because increased fuel efficiency can bring about higher NOx emission.

Figure 17 : Scenarios: high altitude NOx emission



The table below summarises key emission results for the scenarios.

Table 10 : Scenarios: emissions compared to base

	Fuel/ CO_2 /water		**High altitude NOx**	
	2005	**2030**	**2005**	**2030**
Ch:F1 Op:0	98.1%	96.9%	98.0%	96.7%
Ch:F2 Op:0	96.4%	93.9%	96.1%	93.6%
Ch:F1 Op:1	97.9%	93.6%	97.9%	93.8%
Ch:F2 Op:2	92.5%	84.8%	92.5%	85.0%
Ch:F2 Op:4	90.8%	81.0%	90.8%	81.3%

6.4. Conclusions and observations

The passenger and freight demands, and fuel consumption, are not inconsistent with projections made by other bodies such as ICAO. This is as it should be given the similarity in assumptions and demand models used. Nonetheless, it is again emphasised here that there are many uncertainties in forecasting - the only certain thing is that the forecasts will be wrong. This is so for demand, but even more so when models are extended to include operator responses. At this stage therefor, the scenarios should therefore be viewed as a means for making explicit assumptions, and for identifying the possible interactions between the various processes in the aviation industry.

With the above in mind some conclusions may be made.

- The base forecast is for enormous increases in demand by 2030 as compared to 1990: over sevenfold for passenger demand, and by a factor of more than thirteen for freight. Even then, these demand increases are at rates somewhat less than the shorter term forecasts made by other official bodies.
- The form and coefficients of the ICAO demand models used coupled with the assumed growth in GDP lead to the fuel charges assumed having a small, but not negligible, effect on demand, fuel consumption and those emissions directly related to fuel consumption.
- When operator responses are assumed to take place, reductions in fuel consumption and emissions are roughly doubled. The effect on demand is small.

7. CONCLUDING DISCUSSION

Effects of charges

The fuel charges explored affect demand, fuel use and emissions to a small but significant degree. If operator responses are included then emissions would be reduced by 10% to 20%.

Frameworks

It is probable that international regulatory frameworks will need to be changed so as to allow the application of charges. The best framework depends on which charging options are considered best.

A possible approach to charging

It has been argued above that the closer charging is to the points of environmental impacts, and the more unambiguous its effects, the clearer its role.

Ideally, therefore, charges should be imposed on global warming, ozone depletion, or other impact brought about by aviation. This charging method would give consumers and the aviation industry the greatest scope for manoeuvre. To take a hypothetical example, rather than charging for carbon dioxide, high altitude NOx and water emission separately, a global warming charge could be applied. This would be calculated, for example, using the Global Warming Potentials of the individual pollutants.

An important advantage of impact charging is that it should not bring about as many unforeseen deleterious effects.

One problem with this approach is that the impacts would have to be calculated and would depend on sophisticated models. This however, is also an advantage, in that the charging would ‘automatically’ accommodate changes in scientific understanding. Thus, for example, if the present understanding of the global warming effects of NOx and water changes substantially, the charging system would not have to be structurally adjusted.

A concomitant advantage is that the number of charges would be related to the number of impacts: for example there might be three for noise, global warming and ozone depletion. The further from the impact points charges are applied the more numerous they might become.

The next step away from impact charging is emission charging. The problem with this is that, particularly in the case of aircraft, the impacts of emissions are not simply related to the mass of pollutants emitted. For example: the global warming caused per tonne of NOx emitted may depend on many factors including altitude, latitude and timing of emissions; and thus may be very different on short range flights of lower altitude than long range flights.

There may be feasible developmental paths leading from fuel charges through to emissions and thence to impacts. A standard model would be used to estimate the emissions and fuel use of each flight. Inputs would include actual (rather than planned) flight path and aircraft type. Certain of the model results could be checked - particularly fuel consumption.

This system would then result in the estimation of emissions and impacts for each flight. These emissions could then be allocated to countries by one of the methods discussed (i.e. by passenger/airline nationality etc.).

One advantage of this system is that demand and emissions are brought closely together. This means that both airlines and passengers could be made directly aware of the environmental charges they are bearing. This would enhance the response of these agents. This information could also be used in advertising and exhortation to amplify the effects of environmental charges.

Further work

The research in this report represents but an initial step towards analysing the possible role of charges in the control of the environmental impacts of aviation. Further research should be addressed to all facets of the problem: the fundamental basis for the global demand for aviation, technical and economic issues, and international political frameworks.

Further development of the model ***AviAn*** and its application could include the following.

i. A more detailed analysis and projection of demand, especially of the economics of different flight lengths.

ii. An account of how much demand is taken up by other forms of transport with their own impacts.

iii. A better depiction of operator response.

iv. The application of charges to items other than fuel.

v. Applying the model to a more fine segmentation of the market, especially to flights of different length.

8. APPENDIX: INTERNATIONAL FRAMEWORKS

The international frameworks required for application of charges and the allocation of emissions from aviation are not central to this study. However such frameworks are essential elements of most policies aimed at controlling the environmental impacts of aviation. This section briefly discusses some aspects of frameworks, but is not intended to be comprehensive.

8.1. General considerations

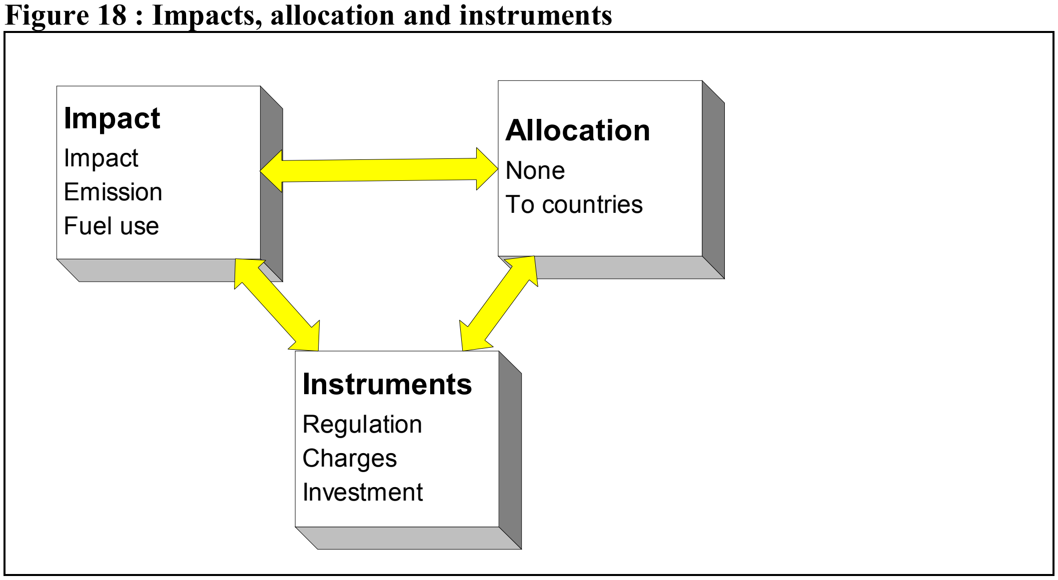
There are interdependencies between the impact being controlled, the means of allocating impacts to responsible parties, and the instruments which might be used to control impacts. The aim is to find a means of allocation which allows instruments to be applied to control impacts.

The difficulty is finding an option with responsibilities and rights, that is one which meets two key criteria, there is both:

- a fair, clear, and easily administered allocation of fuel emissions and responsibility for those emission to a party, probably a country; and
- the powers for the control of the emissions which may be wielded by the responsible party

All of the listed options have advantages and disadvantages according to these criteria.

Figure 18 : Impacts, allocation and instruments



8.2. The application of charges

International transport

Currently international resolutions of the ICAO Council that hinder or prohibit many of the charges on fuel and movements outlined in this report.

The Council has resolved that *"the fuel, lubricant, and other consumable technical supplies"* on board an aircraft when it lands in a State other than that in which it is registered, or taken on board when it departs from a State other than that in which it is registered, are exempt from all customs and other duties (Section I, ICAO, 1966).

The Council also resolved that *"Each Contracting Sate shall reduce to the fullest practicable extent and make plans to eliminate as soon as its economic conditions permit all forms of charges on the sale or use of international transport by air, including charges on gross receipts of operators and charges levied directly on passengers or shippers;"* (Section IV, ICAO, 1966).

It is the case however that taxes or charges are directly or indirectly intended to finance the cost of aviation facilities would be considered acceptable and not falling within the scope of this Resolution. Thus might open possibilities such as the allocation of revenues from environmental charges to some improvements to the aviation system such enhancing air traffic control facilities.

Plainly these Resolutions would have to be substantially modified or eliminated to allow some of the forms of charges discussed below. It is not clear whether these Resolutions and the general surrounding philosophy would allow charges designed to facilitate environmental improvement.

Domestic transport

The ICAO conventions apply, in the main to international transport and it might be easier to apply charges to domestic services. However, even here there restrictions. First there are bilateral agreements concerning the access and taxing of foreign airlines serving domestic markets.

Second there are international restrictions applying to certain regions. For example, in the EU, under Directive 92/82/EEC, kerosene for civil aviation has to be exempt from mineral oil excise duties within the EU: and this Directive means that EU Member States are not allowed to raise a kerosene charge even from domestic airlines under Directive 92/82/EEC.

Plainly extensive restructuring of the frameworks controlling charging is required at the UN level, in regions such as the EU, and in bilateral arrangements. This process would be slow which is the reason why the fuel charges explored in the scenarios are not assumed to apply before 2000.

8.3. Fuel use and emission allocation

There are a number of options for allocating the emissions of fuel use and pollution from international sea and air transport.

Fuel use

Currently there is a detailed process for collecting data on fuel used by international transport: it is allocated to so called 'bunkers'.

The UN (1984) is considering this issue:

> *"A. The concept of "bunkering" in energy statistics*
>
> *20. The term bunkers, according to the United Nations recommendations for energy statistics, refers to fuels used by transport operators whose activities take place partly or wholly outside the territory of a given country. The obvious example is ships engaged in the carriage of passengers or freight to other countries. By extension, the concept also covers air, road and rail transport that crosses national frontiers. In the case of ships, the concept also includes fuel used by warships and by fishing vessels, but fishing and water transport in territorial waters and on inland waterways are considered to be domestic consumption.*
>
> *21. According to the United Nations recommendations for energy statistics, bunkers taken on board abroad by nationally registered carriers should theoretically be treated as imports by the country under consideration. Bunkers supplied by the country under consideration to foreign-registered transport companies should be treated as "export-like" bunkers. Such a practice would correspond to common procedures for balance-of-payments statistics.*
>
> *22. In practice, this extra-territoriality aspect of bunkers causes problems in national and international statistics. It is common practice that all deliveries of fuel for international transport are classified as bunkers, while fuel acquired abroad is ignored. In keeping with this practice, the United Nations energy statistics list air bunkers and sea (or marine) bunkers separately from national consumption, which is derived from data on the amount of fuel sold within the country. The energy statistics of OECD/IEA and of EUROSTAT, the Statistical Office of the European Community, likewise list international marine bunkers as a separate category, but include international air bunkers in the national accounts. All fuels used for road and rail transport are included in national accounts. "*

The UN is studying various options for allocation. The list below includes some of these and other possibilities.

Bunker (international transport) fuels and related emissions could be allocated to:

i. the country in which the bunker fuel is sold.

ii. the country in which the bunker fuel is sold, but listing these in separate accounts.

iii. the nationality (country of registration) of the transporting company.

iv. the country where a ship or aircraft is registered.

v. the country of destination of cargo or passenger.

vi. the country of origin of cargo or passengers.

vii. the nationality of the passengers on flights, or the ownership of cargo, on a pro rata basis.

8.4. FCC

General considerations (FCCC/SBSTA/1996/9/Add.1)

1. In relation to the allocation options for emissions from bunker fuels, the following questions are relevant:

(a) Would it be feasible for the Party to control the emissions allocated to it?

(b) Could the required data be generated with sufficient precision?

(c) Is the method based on the "polluter pays" principle?

(d) Is the method equitable?

(e) Does the allocation method cover all international emissions?

(f) Is the method suitable for all greenhouse gases?

(g) Should the method apply to both aviation and marine emissions?

(h) Does the method provide a suitable basis for making projections?

2. In addition to the above points, the following factors could be considered:

(a) If international emissions are allocated to Parties, these Parties would need to decide whether and how to develop control measures. This could be in the form of action at the national level and/or at the level of cooperation with other Parties and/or at the international level;

(b) If the Parties decide not to allocate bunker fuel emissions to specific Parties, the international aviation and marine shipping sector will still need to be considered in relation to Article 4.2 of the Convention. In that case, Parties may need to determine whether and how emissions should be controlled. In this respect, ICAO and IMO may be of assistance;

(c) Also the Parties would need to consider whether to apply allocations retrospectively or as of some future date. For instance, the Parties could make a retrospective correction for international emissions from the reference year 1990

or to any future year. This could affect whether Parties would meet their national goals and may therefore need further consideration by other Convention bodies;

(d) Option 8 would lead to incomplete coverage at the global level, since emissions over international territories would not be allocated.

8.5. Control options

8.6. Impact measurement

Ultimately the objective is to control the impacts of pollutants. In this case the chain from emitter (e.g. aircraft) to receptor (e.g. biological system) can be deemed to terminate before the receptor with the impact of global warming, ozone depletion, acidification and etc.

In general the impacts of pollutants are related to the mass emitted, and to when and where they are emitted. Mass and impact are separately considered below.

8.6.1.Mass

The masses of CO_2 and H2O is directly related to the mass of carbon in the fuel which is completely oxidised. Given that the carbon content of the relevant transport fuels does not vary greatly, nor does : a good approximation is simple to multiply the mass of fuel by some constant which is itself a multiplicand of the percentage of carbon in the fuel by weight and the proportion fully oxidised.

The masses of certain other pollutants (e.g. sulphur, emitted are also directly related to the masses in the fuel whether or not they are :

However, the masses emitted of some of these pollutants, such as NOx, depends on a range of factors, such as technologies and operational regime, and can therefore vary widely.

8.6.2.Impacts

For some pollutants, most notably CO_2, the connection between impact (global warming) and emission is, to a first approximation, directly and linearly proportionate to the total mass emitted. In the case of CO_2 this is because it has a long residence time, is well mixed in the atmosphere, and has a similar chemical and physical impact (radiative forcing) irrespective of location.

For other pollutants, such as NO_x, water and acidic substances including sulphates, the impact of a unit emission of pollutant (impact per unit mass) can vary with factors such as altitude, latitude/longitude and time when emitted. The impacts per unit mass of some of these pollutants can vary from significant to nothing, or even change sign: e.g. the global warming impact of high altitude water emission might possibly positive or negative. In the case of aviation's impact, it is currently thought that global warming due to NOx and water emission may be of the same order as CO_2 emission.

8.7. Arguments for allocating to countries

8.7.1.Importance of aviation

Countries will derive different benefits from aviation, and be faced with different costs (both absolute and relative) in controlling its emissions. The aviation sector in some countries is very important economically and a large fraction of aviation output is exported.

The aviation industry argues that aviation is a special case and should not be subject to the same pro rata emission control as other sectors. Allocation to countries would enable such arguments to be appraised within the specific context of that country.

8.7.2.Economic efficiency

As far as possible emission control objectives should be pursued with economic efficiency in mind. There are many factors which would determine the how a country would allocate emission control to aviation and to other sectors such as power generation, and these factors will vary from country to country.

The absolute costs to a nation of reducing aviation emissions will depend on characteristic factors such as the pattern of demand (load type, route lengths/densities, etc.) and the initial composition of its aircraft stock (age, size etc.).

The costs of emission reduction in aviation relative to other sectors will depend on factors such as economic structure, the initial capital stocks, and the availability of resources such as hydropower and natural gas.

8.7.3.Charging and taxing

Charges (or taxes) could be one instrument employed to control emissions. To date this has been carried out by countries and there is no (?) precedent for a supranational body to do this. Experience of discussion in the EU concerning charges such as carbon taxes or road pricing suggest that countries would relinquish control over taxation vary reluctantly if at all.

8.7.4.Flexibility

Individual countries can respond more rapidly and flexibly to changing circumstances. An international body responsible for ExtEm would have to undertake global analysis and consult all countries affected before changing a charging regime. Experience indicates that this would probably be very time consuming.

8.7.5.Lowest consensus level of instruments

International agreements as to technical standards, and presumably to charges, tend to settle on low levels which are acceptable to a majority, if not to all parties.

8.7.6. Integration with pre-existing frameworks

Targets

Insofar as ExtEm can be incorporated into existing frameworks matters are simplified because national targets being negotiated could be extended to include ExtEm. No separate processes for aviation and shipping would be required.

Serious problems can be envisaged in negotiating global sectoral targets. For example a particular country might greatly expand its aviation and consequent emissions. Given a global limit for that sector, this would mean other countries not being allowed as much emission forcing greater control costs for all, or less allowance for expansion, or both.

Commitment and enforcement

Commitments to emission control can be unenforceable in law (e.g. CO_2 stabilisation)

Governments have powers over their own nations to ensure that the sum of sectoral outputs does not exceed xx

8.7.7. Voluntary

8.8. Arguments for allocating to international body

8.8.1. Technical

Technology standards

To date these are in the main applied internationally by ICAO because of the international nature of the production and use of aircraft.

REFERENCES

Alamdari F: June, 1994: *Taxation Policy for Aircraft Emissions*.

xxArcher LJ: 1993: *Aircraft Emissions and the Environment: COx SOx HOx & NOx*:

WWF (Barrett MA): 1991: *Aircraft Pollution : Environmental Impacts and Future Solutions*:

WWF (Barrett MA): 1994: *Pollution Control Strategies for Aircraft*:

xxBleijenberg A, Moor R: August, 1993: *Air pollution by air traffic: overview of problems and possible solutions*:

xxDoganis R: 1991: *Flying Off Course*:

xxFCCC

xxIPCC, 1995

International Air Transport Association (IATA): 1992: *International Traffic Forecast: 1992-1996 - Scheduled Passengers*:

XxICAO: 1966

xxInternational Civil Aviation Organisation: 1989: *The Economic Situation of Air Transport: Review and outlook, 1978 to the Year 2000*:

xxInternational Civil Aviation Organisation: August, 1992: *ICAO Analyses trends in fuel consumption by world's airlines*:

International Civil Aviation Organisation: 1992: *Outlook for Air transport to the Year 2001*:

Xx?International Civil Aviation Organisation: 1992: *Regional Differences in Fares, Rates and Costs for International Air Transport 1989*:

International Civil Aviation Organisation: 1992: *Statements by the Council to Contracting States on Charges for Airports and Air Navigation Services: Fourth edition- 1992*:

International Civil Aviation Organisation: 1993: *Civil Aviation Statistics of the World: 1992*:

International Civil Aviation Organisation: 1993: *ICAO's Policies on Taxation in the Field of International Transport*:

International Civil Aviation Organisation: 1993: *Survey of International Air Transport Fares and Rates: September 1991*:

International Civil Aviation Organisation: 1994: *Manual of Airport and Air Navigation Facility Tariffs*:

International Civil Aviation Organisation: 1994: *Regional Differences in Fares, Rates and Costs for International Air Transport 1991*:

International Civil Aviation Organisation: 1995: *Outlook for Air transport to the Year 2003*:

Johnson C, Henshaw J: May, 1991: *The Impact of NOx Emissions from Tropospheric Aircraft*:

Johnson C, Henshaw J, McInnes G: 1992: *The Impact of NOx Emissions on the Tropospheric Ozone and Global Warming*:

Johnston H, Kinniston D, Wuebbles D: 1989: *Nitrogen Oxides from High-Altitude Aircraft: an Update of Potential Effects on Ozone*:

McInnes G, Walker C: 1992: *The Global Emission of Aircraft Air Pollutant Emissions*:

xxNational Aeronautics and Space Administration: May, 1992: *Atmospheric Effects of Stratospheric Aircraft Flyer (special annual meeting reports issue)*:

xxNational Aeronautics and Space Administration: January, 1992: *The Atmospheric Effects of Stratospheric Aircraft: A First Program Report*:

OECD: 1992: *Main Issues*:

xxOlivier J: 1991: *Inventory of Aircraft Emission: A Review of Recent Literature*:

Prather M, Wesoky H, Miake-Lye R, Douglass AR, Turco RP, Wuebbles DJ, Ko MKW, Schmeltekopf AL: 1992: *The Atmospheric Effects of Stratospheric Aircraft: A First Program Report*:

Pueschel R, Snetsinger K, Hansen A: May, 1992: *Stratospheric Soot : Abundance, Type, Single Scatter Albedo*:

Schumann U: February, 1993: *On the Effect of Emissions from Aircraft Engines on the State of the Atmosphere*:

Schumann U, Arnold F, Hermann D, Reinhardt ME, Suasen R, Schlager H: May, 1992: *On the Effect of High-Flying Air-Traffic on the Atmosphere*:

Shearman P: 1992: *Air Transport: Strategic Issues in Planning and Development*:

XxUN: 1984

xxWorld Meteorological Organization: February, 1995: *Scientific Assessment of Ozone Depletion: 1994*:

XueXi T, Brasseur G, Cranier C, Rasch P: May, 1992: *The Impact of High Altitude Aircraft on the Ozone Layer in the Stratosphere*: