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Air travel, life-style, energy use and environmental impact

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Executive summary

This summary describes the results of a Ph.D. study that was carried out in the Energy Planning Group, Department for Civil Engineering, Technical University of Denmark, in a three-year period starting in August 1998 and ending in September 2001. The project was funded by a research grant from the Danish Energy Research Programme.

The overall aim of this project is to investigate the linkages between energy use, life style and environmental impact. As a case of study, this report investigates the future possibilities for reducing the growth in *greenhouse gas emissions from commercial civil air transport*, that is *passenger air travel and airfreight*. The reason for this choice of focus is that we found that commercial civil air transport may become a relatively large energy consumer and greenhouse gas emitter in the future. For example, according to different scenarios presented by Intergovernmental Panel on Climate Change (IPCC), commercial civil air transport's fuel burn may grow by between 0,8 percent a factor of 1,6 and 16 between 1990 and 2050. The actual growth in fuel consumption will depend on the future growth in airborne passenger travel and freight and the improvement rate for the specific fuel efficiency. As a central mid-term estimate the IPCC foresees that the fuel consumption may grow by around 3 percent per year until 2015.

The average specific CO_2 emissions per revenue passenger kilometre transported by the World's aircraft fleet is lower than the CO_2 intensity of an average Danish passenger car with one occupant. But because aircraft can travel over long distances within a relatively short period of time, one air trip can contribute considerably to the total yearly CO_2 emissions of air travellers. For example, on a long haul return flight (12400 kilometres) between Copenhagen and New York in a modern aircraft (for example a B767-300ER), around 300-500 kilograms of jet fuel may be burned per passenger emitting around 0,9-1,6 tonnes of CO_2. The lower figure represents a calculation where the fuel consumption that may be attributable to belly-hold freight is subtracted on an equal weight basis. Note that this estimate may change between types of aircraft and is dependent on the actual load factor. Furthermore, it should be taken into consideration that aircraft engine emissions per amount of fuel burned at

high altitude may contribute 2-4 times as much to climate change as emissions from fuel burned in for example passenger cars at sea level. Note also that there is currently relatively high uncertainty connected to this estimate. The relative importance of one such long-haul return trip can be exemplified by comparing to the average emissions of CO_2 from combustion of fossil energy sources per capita. On average, the World's citizens emit around 4 tonnes of CO_2 in a year, although the number is much higher in many industrialised countries and much lower in many developing countries.

There are considerable differences between the energy intensity of different types of aircraft and also between airlines. Old aircraft are generally less fuel-efficient than newer types, and aircraft used at short-haul are generally more fuel intensive than aircraft used at medium-haul and long haul. Therefore, airlines that operate new fuel-efficient aircraft over relatively long distances and at relatively high load factors are the most fuel-efficient.

European charter carriers that operate aircraft with a high-density seat-configuration at close to the optimum passenger load factor while only carrying insignificant amounts of freight are the most fuel-efficient passenger carriers in the airline industry. Conversely, the most fuel-intensive airlines are to be found among the regional carriers that operate relatively small aircraft at below average load factors at short-haul routes. Aircraft used at long haul routes consume more fuel per available seat kilometre than the most fuel-efficient aircraft operated at medium-haul. However, if taking into account that passenger aircraft used at long haul routes by scheduled carriers generally transport relatively high loads of belly-hold freight, the fuel intensity per revenue passenger kilometre, or per revenue tonne kilometre, is also relatively low on these routes. The division of the fuel consumed by passenger aircraft between passenger and freight loads is not straightforward, and different methodologies can be used.

Air traffic growth by far overrides the efficiency gains attained in the specific fuel consumption and emissions per revenue tonne kilometre performed by commercial civil aircraft. For example, the number of revenue tonne kilometres transported by the American air carriers grew by a factor of 3,8 between 1973 and 1997. In the same period, the specific fuel consumption per revenue tonne kilometre was reduced by 55%, leading to an increase in the total fuel consumption by a factor of 1,7. The major part of the reduction in the specific fuel consumption was achieved in the early part of

the period while the yearly improvements have slowed down in the later part of the period.

Even though the yearly growth rates in passenger air travel and freight have slowed down in the last decades, as compared to the earlier decades, many scenario studies expect that commercial civil air transport will continue growing faster than most other energy services. Furthermore, the yearly reduction of the fuel intensity is expected to slow down further in the future. Therefore, in a business as usual scenario, commercial civil air transport is likely to become a bigger source of greenhouse gas emissions in the future and its share of the total emissions is likely to rise.

The yearly improvement rate for the aircraft fleets' fuel efficiency can to some extent be speeded up by implementing new measures to promote development of new and more fuel-efficient aircraft as well as the phasing out of older and more fuel intensive aircraft. For example, a tax on jet fuel or emissions or voluntary agreements between governments and the airline industry on future goals for the reduction of the fuel intensity, may lead airlines to scrap some of the 5000 operating jets that are more than 23 years old earlier than what can otherwise be expected. Furthermore, on the longer term, the aircraft producers may choose to develop radically more fuel-efficient types of aircraft configurations, such as flying-wing aircraft, that are designed for cruising at lower speed and altitude, thereby perhaps also being less greenhouse gas intensive per amount of fuel burnt. Likewise, new fuel-efficient types of propulsion technologies, such as propfan engines, could be further developed to substitute current turbofans that seem to have reached a plateau in fuel-efficiency improvements. However, at the current fuel price a rather high kerosene tax may be needed to make such radically improved technologies economically attractive to airlines. And because the development cycles in aeronautical engineering tend to be relatively long, it may take several decades before such technologies can come into use in civil passenger aircraft.

Furthermore, a tax on jet fuel or emissions could potentially contribute by making current plans for developing GHG intensive high-speed and high-altitude aircraft types, such as sonic cruisers or a new generation of supersonics, less economically attractive to airlines. Currently, the major American aircraft producer Boeing considers launching the so-called sonic cruiser that will be able to cruise at higher speed and altitude than current state-of-the-art subsonic aircraft.

Alternative fuels, such as liquefied hydrogen or synthetic jet fuel produced from biomass, could theoretically also be used in commercial civil air transport, but development and implementation poses large technical and economical challenges. Most aviation experts seem to consider that alternative fuels will not be technically or economically viable in the next decades. Furthermore, the current knowledge about the impact on climate change of burning hydrogen at high altitude is relatively poor and highly uncertain.

There is also potential for using more efficient air traffic management systems and for improving the load factors. However, technical and operational efforts to improve the specific fuel consumption and the related emissions are not envisioned to be sufficient to keep pace with the growth in the air traffic volume at current growth rates.

The strong growth in passenger air travel and airfreight is generated by social, technical, political and economic changes. People living in industrialised countries have become accustomed to travel by air and the building up of a large socio-technical system surrounding commercial civil air transport facilitates air travel growth. Airport and aircraft capacity is constantly enlarged, while the real cost of air travel is reduced. The building up of commercial civil air transport's socio-technical system is furthered by government subsidies, which again contribute to reduce airfares.

National interests and geopolitics play important roles in the subsidisation of commercial civil air transport's socio-technical system. National governments support local airports, airlines and aerospace industries to maintain and increase the relatively large number of people employed in these industries. Further aspects are the prestige and power connected to maintaining aeronautical and military leadership as well as the prestige connected to operating national flag carriers. The commercial civil air transport industry becomes increasingly important for global and local economies.

Market forces contribute to reduce the cost of air travel in that aircraft producers compete to produce the most efficient aircraft at the lowest possible prices while airline competition in an increasingly global and liberalised market reduces real airfares.

Economic growth policy leads to increasing income in many countries thereby allowing more and more people to travel by air. Today, most air travel is related to leisure, holidays and visiting friends and family. Passenger air travel is an important social status maker and current trends in social values and preferences leads people to travel further away to discover new exotic cultures and resorts.

Globalisation of businesses and the economy in general are major drivers for passenger air travel. As businesses, political forums and personal relations become increasingly global the need to communicate over longer distances rises. Business travel is a major driver for passenger air travel growth in that business fares are substantially higher than normal economy fares and discount fares. Business travellers thereby subsidise leisure travellers, by allowing airlines to sell leisure tickets at artificially low fares. This structure is furthered by airline frequent flier programmes and other marketing tools.

People are basically restricted from passenger air travel by financial and time constraints as well as technology and geography. The financial constraints are mainly connected to airfares and incomes. Technology is an important constraint in the sense that aircraft speed, range and capacity limits the distance people are able to fly within the time available. Geographical characteristics also play an important part in the sense that the earth is a limited geographical area, and unless space-flight becomes available for a broad part of the population, there seems to be upper limits as to how far each person might want to travel in a year. Some current impeders to passenger air travel growth are congested airports and airspace. Also in the future some new environmental policies might emerge, such as kerosene taxes or personal emission quotas. And on the longer term a saturation in economic development could come to reduce air travel growth.

This report looks into the possibilities for reducing the growth in air traffic, as well as the possibilities for reducing the specific fuel consumption, to achieve an environmentally sustainable development. For commercial civil air transport the main challenge seems to lie in the strong growth rates currently envisioned by the aeronautical industry for the next decades.

The complexity of determinants of commercial civil air transport's environmental impact explains the difficulties of posing adequate proposals. No single measure, such as imposing a kerosene tax, is likely to come even near to reducing the growth in the air traffic volume as well as reducing the fuel intensity of the aircraft fleet, to levels that would lead to a saturation of energy use and emissions. For example, some studies of the likely impact of a kerosene tax suggest that a ten-times increase of the current fuel price may be needed to stabilise the emissions of CO_2 from commercial civil air transport activities. Such a level of tax is unlikely to be implemented in the current political context. Therefore, a multitude of measures in combination seems to be needed to achieve long-term environmentally sustainable commercial civil air transport. The current political negotiations in United Nations' International Civil Aviation Organisation (ICAO) on which measures to introduce indicate that the World's nations are not likely to agree upon such a package of measures, at least not in the foreseeable future.

Like it is the case with most other types of (fossil) energy intensive activities the bulk of air traffic is currently performed in and between industrialised countries. In an environmentally sustainable World countries should aim at distributing resources evenly between the World's citizens. Therefore, on the longer term, there are tremendous challenges to be overcome. Achieving environmentally sustainable commercial civil air transport will first of all require that people living in currently industrialised countries stop travelling ever more by air each year. As it is shown in this report, the current level of passenger air travel per capita in Europe may be considered within environmentally sustainable limits by the middle of this century provided that the current average greenhouse gas intensity of air travel is halved by then. Conversely, for example, an average American citizen today travels almost three times as much by air as an average European, thereby already exceeding the sustainability target for the World's citizens on average by the middle of this century that is proposed in this report.

Most importantly therefore, the search for environmentally sustainable development in commercial civil air transport activities does not seem to only include technical fixes but will also acquire some sort of changes in lifestyle development in industrialised countries. One suggestion that is considered in this report is that governments could stop planning mainly to achieve economic growth and instead look for alternative ways of achieving and measuring progress and welfare than by increasing the gross national

product. Such a solution could include that people living in currently industrialised countries choose to work less, reducing the economic growth and the growth in personal income and thereby also reducing the growth in consumption patterns, but leaving them more time available for family relations, leisure and other social activities.

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Acknowledgements

Introduction

A growing concern over emissions of greenhouse gases into the atmosphere has led governments to sign agreements on future reduction schemes [UNFCCC 1997]. Currently, the emissions from *international air traffic* are not included in these international commitments, but an increasing political focus on the sector internationally suggests that they might be in the future. In this respect it becomes relevant to assess the possible role of commercial civil air transport in a future greenhouse gas (GHG) reduction scheme.

Commercial civil air transport is currently estimated to emit approximately 2% of the CO_2 emissions associated with combustion of fossil fuels or about 12% of the CO_2 emissions from all transportation sources globally [IPCC 1999b]. Recently, a special report on "*Aviation and the Global Atmosphere*", requested from the Intergovernmental Panel on Climate Change (IPCC) by the International Civil Aviation Organisation (ICAO) and the Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer, concluded that aircraft engine emissions at high altitudes are considered to change the atmospheric composition by altering the "*concentration of atmospheric greenhouse gases, including carbon dioxide (CO_2), oxone (O_3) and methane (CH_4); trigger formation of condensation trails (contrails); and may increase cirrus cloudiness – all of which contribute to climate change*" [IPCC 1999, p. 3]. According to the IPCC, the current knowledge about commercial civil air transport's overall contribution to climate change suggests that the total positive radiative forcing (warming) effect might be 2-4 times higher than that of CO_2 emissions from aircraft alone [IPCC 1999, pp 3-10]. If taking this into account, air transport may account for almost 30% of the GHG contribution from all transportation sources in the OECD countries [Nielsen 2000]. However, this estimate is highly uncertain.

A number of studies have examined the likely future development in commercial civil air transport, and all of these foresee that greenhouse gas emissions will most likely grow in the next decades. Even though a relatively large technical and operational fuel-efficiency potential is identified, as a result of developing more fuel-efficient aircraft and

optimising operational procedures, such measures are still expected to be outpaced by further growth in air transport volume[1]. For example, the Intergovernmental Panel on Climate Change (IPCC) describes several long-term scenarios for global air traffic demand and associated fuel use and emissions until the middle of this century. These scenarios consider different combinations of developments in the demand for passenger air travel and airfreight and the specific fuel consumption and associated emissions of NO_x and water vapour. In the scenarios the demand for air traffic is assumed to grow by between 360 percent and 2140 percent by 2050 as compared to 1990 leading to increases in fuel consumption of between 160 and 1600 percent and increases in NO_x emissions of between 160 and 810 percent. A central IPCC estimate for the next fifteen years projects air traffic and fuel use to grow by 5 percent and 3 percent per year respectively [IPCC 1999, p. 5 and p. 329].

The future contribution to climate change of commercial civil air transport thus seems certain to grow, but the magnitude is highly uncertain. The impact will depend on a range of factors such as the development in passenger air travel and freight volumes, the geographical distribution of emissions (altitude and latitude) and the development in the specific emissions per passenger kilometre and per freight tonne kilometre[2]. The development of each of these factors will again depend on a number of other factors such as the general economic development, the development in personal income, price developments[3] and the international co-operation and regulatory framework[4]. It is the aim of this project to identify possible future developments and to examine the likeliness and preconditions for their implementation in individual, social, political and technical contexts in a way to achieve a development in commercial civil air transport which can fit into an environmentally sustainable energy future.

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[1] See for instance the following studies for a further description of these issues: [Greene 1990 and 1997] [Grieß and Simon 1990] [Barrett 1991 and 1994] [Balashov and Smith 1992] [Archer 1993] [Bleijenberg and Moor 1993] [ETSU 1994] [Vedantham and Oppenheimer 1994 and 1998] [Olivier 1995] [Baughcum et. al. 1996] [Dings et. al. 1997 and 2000b] [Gardner et. al. 1998] [Kalivoda and Kudrna 1998] [Allen 1999] and [IPCC 1999].

[2] The specific emissions per passenger kilometre and freight tonne kilometre are dependent on a lot of factors such as aircraft size, aircraft weight per passenger and freight capacity unit, engine fuel-efficiency, airframe design, airframe aerodynamic performance, aircraft speed, load factor, flight altitude, flight distance, air traffic management, type of fuel and so on.

[3] Air travel costs, fuel costs and costs of other related products and services.

[4] Stricter technical standards for the specific emissions from aircraft as well as market-based instruments or voluntary agreements, for improving the environmental performance of the aviation sector, seem likely to emerge in the future [CEC 1999a] [T&E/ICSA 2001].

Chapter 1

Purpose, methodological concepts and contents

This chapter describes the background for this study, and explains in broad terms the context in which the findings of the project can be of interest. Section 1.1 describes the purpose and the related overall research questions. Section 1.2 explains the focus on commercial civil air transport's energy consumption for passenger travel and freight transport. Section 1.3 points out some potential strategies for reducing commercial civil air transport's fuel consumption and greenhouse gas (GHG) emissions. Section 1.4 describes the overall methodology of the project. Section 1.5 explains the structure of the report and summarises in brief the contents and conclusions of each of the chapters.

1.1 The purpose of the study and the overall research questions

The overall purpose of this study is as follows:

> **The overall purpose of this study is to investigate the _potentials_ for reducing commercial civil air transport's fuel consumption and associated greenhouse gas (GHG) emissions through future _technical and lifestyle changes_ and to investigate possible future development paths which could be consistent with an environmentally sustainable development of the whole energy and transport system.**

The overall research questions that are discussed in the report are:

1. STATUS OF COMMERCIAL CIVIL AIR TRANSPORT AND ITS ENVIRONMENTAL IMPACT

-How much energy is used for commercial civil air transport (passenger travel and freight transport)?

-What are the energy intensities of different airlines and different aircraft models?

-What is the size and pattern of commercial civil air transport?

-What is the current knowledge on the contribution of commercial civil air transport to global warming?

-What are the criteria for an environmentally sustainable development in commercial civil air transport activities?

These questions are mainly discussed in Chapters 2, 3 and 5.

2. **DRIVERS AND IMPEDERS OF PASSENGER AIR TRAVEL DEVELOPMENT**

-What are the economic, physical, social and political determinants of passenger air travel development?

-Which factors seem to drive and to impede passenger air travel?

-What are the main dynamics in building up commercial civil air transport's socio-technical system?

These questions are mainly discussed in Chapter 2.

3. **TECHNICAL AND OPERATIONAL POTENTIALS FOR MITIGATING THE ENVIRONMENTAL IMPACT OF COMMERCIAL CIVIL AIR TRANSPORT**

-How much less GHG intensive might future types of aircraft become?

-What are the potentials for better operational procedures such as higher load factors, more direct flight routings, bigger aircraft and reduction of stacking above airports due to congestion and delays?

These questions are mainly discussed in Chapter 3.

4. GOVERNMENT OPTIONS FOR LIMITING AIR TRAVEL DEMAND

-Which government measures could be used to limit the growth in the demand for passenger air travel and airfreight?

-What could be the impact of such government measures?

-Which barriers and conflicting interests block the introduction of such measures?

These questions are mainly discussed in Chapters 2 and 4.

1.2 Focus of the study

As can be seen from Figure 1.1, the main focus of this study is on *commercial civil air transport greenhouse gas (GHG) emissions* (inner circle). This means that only the fuel consumption of scheduled and non-scheduled airlines, for transporting passengers and freight, is included in this study. The fuel consumed by military aircraft and general aviation[1] is not included as well as the fuel consumed in helicopters, spacecraft and rockets. The study compares commercial civil air transport's GHG emissions to those of other types of transportation modes, as well as to the overall global GHG emissions from combustion of fossil fuels. The main reason for choosing to look at air transport is that the sector has generally been overlooked by most energy and environment studies.

Figure 1.1: Study focuses on commercial civil air transport

(Total energy use / Energy use for transport / Energy for air transport / Energy for commercial civil air transport)

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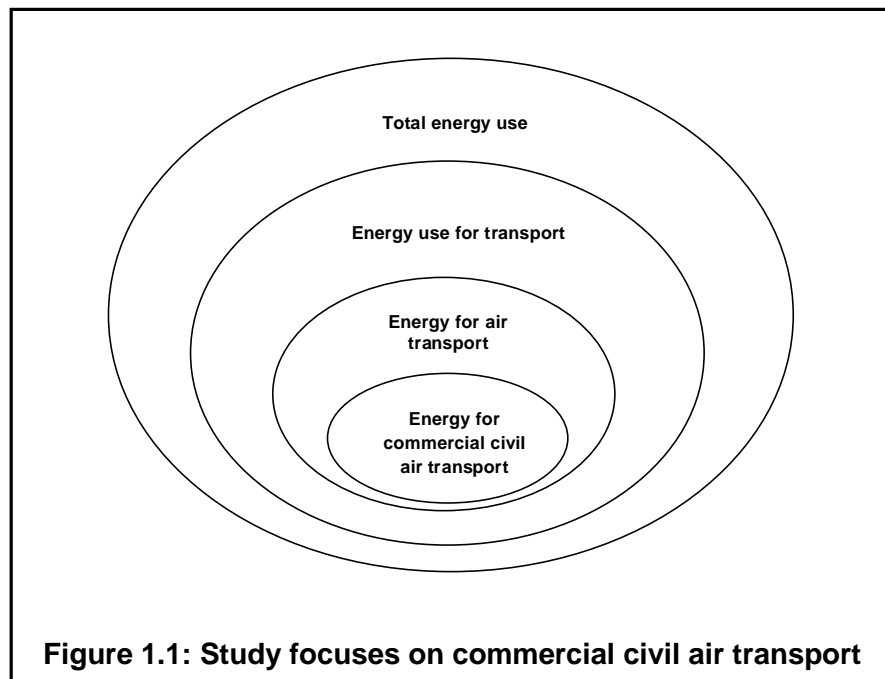
[1] General aviation refers to all civil aviation operations other than scheduled air services and non-scheduled air transport operations performed by scheduled and charter airlines. Examples of general aviation activities are instructional flying, business and pleasure flying and aerial work.

1.3 Possibilities to reduce emissions of GHGs from air transport

A reduction of the growth in commercial civil air transport could be part of a strategy for reducing the global emissions of greenhouse gases in the future. Such a strategy would benefit from people adapting their lifestyles towards fewer holiday and business trips and towards travelling less by air, for example by choosing less remote destinations as well as by choosing to travel in transportation modes that are less GHG intensive than aircraft. Furthermore, the aerospace industry could produce aircraft that are less GHG intensive and the airlines could optimise operational procedures and scrap or re-engine their oldest and most fuel intensive aircraft. Figure 1.2 exemplifies some main principles by which GHG emissions of civil air traffic can be reduced.

Figure 1.2: Examples of options for reducing GHG emissions from commercial civil air transport
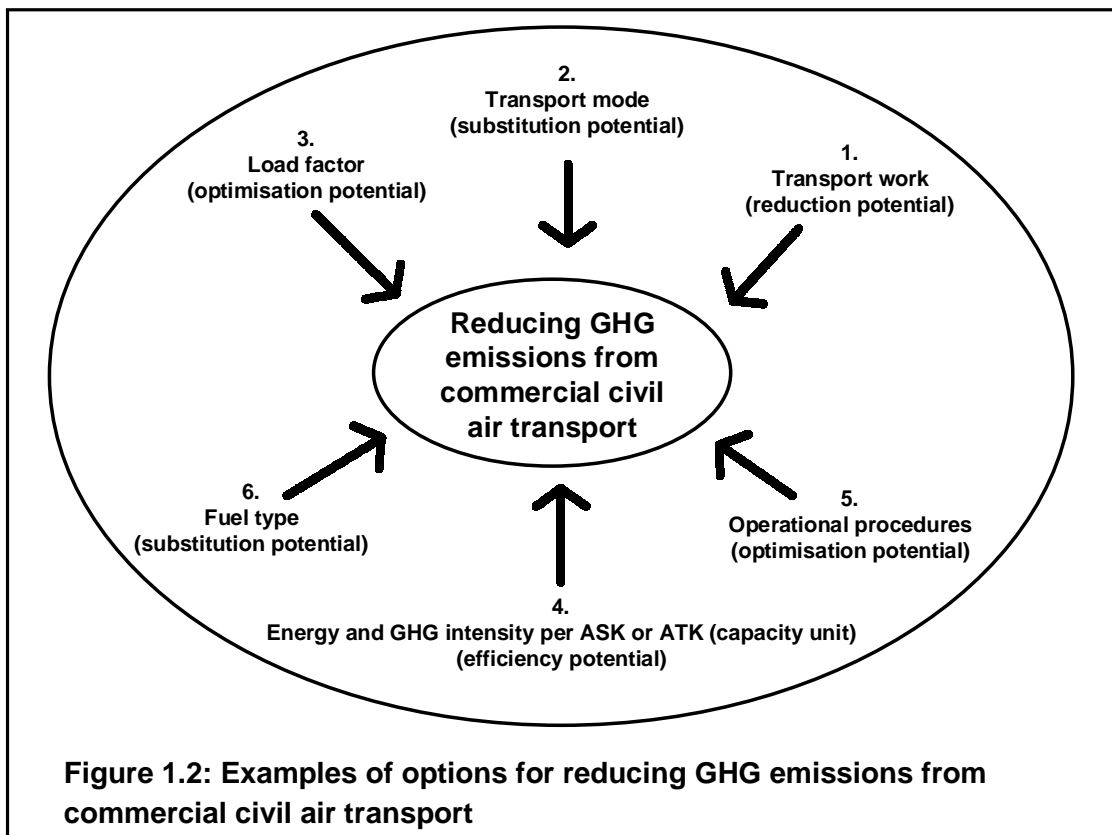
1. A reduction of the transport work or volume (revenue freight tonne kilometres (RFTKs)[2] and revenue passenger kilometres (RPKs)[3]) leads directly to less aircraft

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[2] A revenue freight tonne kilometre is a term describing when one tonne of revenue freight is transported one kilometre.

[3] A passenger kilometre is a term describing when a passenger is transported one kilometre. The term "revenue passenger kilometres" refers to the distance travelled by revenue passengers. For some airlines only passengers that have paid a certain percentage of the

movements (if the load factor is kept constant) and hence to reduced GHG emission. Generally, the transport work is growing rapidly, and therefore a reduction of the current growth rates seems to be essential [IPCC 1999] [T&E/ICSA 2001].

2. A shift to transport modes with lower GHG intensity than aircraft will reduce the emissions per amount of transport work performed, and can reduce the overall GHG emission (if the transport work and the load factors are kept constant). An example is a switch of passengers or goods from aircraft to railway, the latter being generally less GHG intensive than aircraft [Roos et. al. 1997] [IPCC 1996b and 1999].

3. Increasing the load factor (the passenger load factor and the freight load factor) involves better use of the aircraft capacity. This will reduce the necessary vehicle kilometres and hence the GHG emissions per unit of transport work performed [Daggett et. al 1999]. For example, the average passenger load factor of the World's scheduled airlines has been improved from around 50 percent in the early 1970s to around 70 percent in the late 1990s [Mortimer 1994a and 1994b] [ICAO 1998a].

4. A reduction of the energy intensity per seat or freight capacity unit of aircraft directly reduces the emissions of CO_2 (if the transport work, the fuel type and the load factor are kept constant). This involves the development of more fuel-efficient types of aircraft. Examples are the development of more fuel-efficient engine types [IPCC 1999] [Birch 2000] or new fuselage shapes offering larger capacity per weight unit or lower air resistance [Cranfield College of Aeronautics 2000a]. However, there is a trade-off between aircraft engine fuel-efficiency improvements and emissions of NO_x that act as a greenhouse gas precursor when emitted at high altitudes [IPCC 1999]. A strategy to reduce the greenhouse gas intensity therefore has to take this into account. Another possibility for reducing the greenhouse gas intensity of aircraft may be to design aircraft for cruising at lower speeds and altitude [Barrett 1994] [Dings et. al. 2000b].

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normal fare are counted as revenue passengers. Examples of non-revenue passengers are the pilots and crew onboard as well as other passengers travelling for free.

5. By improving the operational procedures the flow of air traffic can be optimised, thereby reducing the GHG emissions for a given trip. One example is that stacking and queuing in and above airports could be reduced leading the aircraft to consume less fuel for take-off and landing [Lufthansa 1999]. Another example is that aircraft could be allowed to fly more direct routings. Many routes are today longer than the shortest great circle distances because of restrictions in the use of airspace and regulations on how far away from airports twin-engine aircraft are allowed to operate when passing over the great oceans [Air International 2000]. A third example is that the choice of routings could be optimised as to avoid flying at altitudes and latitudes where aircraft emissions are considered to contribute most to global warming [Lee 2000].

6. Choosing a fuel with lower GHG emissions per available energy unit than the fossil jet fuel that is currently being used can reduce the emissions per distance travelled. An example could be a switch from fossil kerosene fuel to jet fuel produced from Biomass or liquid hydrogen produced on the basis of renewable energy sources [Brewer 1991] [Pohl 1995a]. However, there is uncertainty as to whether for example hydrogen is a less GHG intensive fuel than fossil kerosene when combusted at high altitude [Marquart et. al. 2001].

It should be noted that the theoretical options for reducing the emissions of greenhouse gases from commercial civil air transport described in figure 1.2 are to a large extent interdependent, and therefore not fully separable and addable, and furthermore to some extent counteractive. The possible benefits and drawbacks are discussed throughout the report. Most emphasis in this study has been directed towards studying possibilities for reducing the transport volume growth and for reducing the specific fuel consumption of aircraft. The other areas exemplified in Figure 1.2 are dealt with to a lesser extent.

1.4 Overall methodology and contents

The overall purpose of assessing the potential for reducing GHG emissions from commercial civil aircraft activities in the future is analysed by considering some social drivers and impeders of commercial civil air transport activities as well as some technical and operational possibilities to reduce the specific greenhouse gas emissions

of those activities. The body of the report (Chapters 2-5) is divided up into four main parts as illustrated in Figure 1.3:

<table>
<tr><td>
Part 1
Determinants of passenger air travel growth
- description of drivers and impeders
(Chapter 2)
</td></tr>
<tr><td>
Part 2
Energy and greenhouse gas intensity of air travel and freight
- present and future
(Chapter 3)
</td></tr>
<tr><td>
Part 3
Assessment of the possible future environmental
impact of a jet fuel tax
(Chapter 4)
</td></tr>
<tr><td>
Part 4
Proposal for a long-term normative scenario for environmentally
sustainable commercial civil air transport activities
(Chapter 5)
</td></tr>
</table>

Figure 1.3: Illustration of how the report is build up

The *first part* of the report (Chapter 2) analyses and describes some overall driving forces for the growth in passenger air travel:

- Immediate – or short term – driving forces generating the present air transport trends
- Societal background for the driving forces
- Attitudes and other social driving forces
- Options for changing trends in transport demand

The aim of this part of the project is to analyse and describe some overall economic, physical, social, and political determinants of passenger air travel development. The section focuses on the main drivers and impeders of growth. The purpose is to point out some potential strategies for impeding growth in the future.

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Few studies in this area give comprehensive insights as to how commercial civil air transport volume can be reduced in the future. Focus is most often dedicated to assessing possible technical and operational fixes to mitigate the environmental problems connected to the increasing demand for passenger air travel and airfreight. Most studies project that air traffic and the associated energy use and emissions will grow far into the future.

In most of these studies little attention is turned towards non-economic drivers for technical, social and life-style changes, such as changing work structures, changing family relations, changing age distribution in the population and changes in social norms, ethics and values and religious beliefs. Social sciences may be able to contribute with more comprehensive approaches to these non-economic drivers. Especially, they may give useful information to the questions of; a) the preconditions (technical, psychological and social) for the demand for air travel and airfreight, and what might change that demand; and b) the preconditions (possibilities and constraints) for technological change in the commercial civil air transport sector, and what might change these preconditions. This project studies some of these issues.

One aim is to study the determinants of passenger air travel growth. There seems to be a need for reducing growth, and this is especially true for the commercial civil air transport sector that generally grows faster than most other types of energy services [IPCC 1999]. Therefore, it has become increasingly important to draw on the social sciences to better understand the social implications of energy consumption, that is the social determinants of energy service growth [Christensen and Nørgaard 1976] [Schipper 1991] [Shove et. al. 1998] [Kuehn 1999]. Inspired by Rip and Kemp [1998] a main starting point for this description is to look into how commercial civil air transport's socio-technical system has been built up.

Passenger air travel cost reductions in combination with rising incomes are found to be some of the main drivers for passenger air travel growth. Passenger air travel growth also, however, relies on the building up of airport infrastructures and the development of ever-more efficient types of aircraft. The aerospace industry is a highly prestigious venture being supported by governments for achieving national prestige, military sovereignty and economic growth and for maintaining work places throughout the

commercial civil air transport industry. Economic growth is a main political goal furthering income rise. Other aspects such as market liberalisation, economic subsidies and airline marketing strategies further the reduction of airfares. Passenger air travel has become imbedded in modern culture and is a major symbol of status. Migration, population growth and globalisation of businesses, trade and social relations are also strong drivers. Conversely, environmental policies as well as planning initiatives to stop airport capacity expansions while improving rail capacity and the motor highway system impede passenger air travel growth.

Chapter 2 also identifies some possible future policies for reducing greenhouse gas emissions from commercial civil air transport and discusses barriers to their implementation. *Short-term policies* may be aimed at introducing standards for the maximum allowable amount of GHG emissions from aircraft considering all phases of flight and at introducing voluntary agreements with the aerospace industry on the average fuel-efficiency of new aircraft and at introducing agreements with airlines on aircraft scrapping schemes. Environmental NGOs may gain most by trying to push for environmental taxes and for stopping government subsidies for airports, airlines and aircraft producers as well as airport expansions and night flights. *On a wider perspective* alternative policies may aim at de-emphasising economic growth as a major political goal in the high-income regions of the world. Instead, policies may focus at introducing alternative ways of measuring progress and welfare than gross domestic product. This may help people in defining new less materialistic ways of life, for example by working and earning less while having more free time available for social relations.

The **second part** of the project (Chapter 3) gives a quantitative description of the *historic and present* energy intensity of commercial civil air transport. The main purpose is to discuss and establish an overview of the energy intensity of passenger air travel and airfreight for trips of different lengths and to put aircraft fuel use into perspective by comparing to other uses. Chapter 3 analyses and illustrates the parameters and their relationships listed below:

- Types of aircraft in use
- Vehicle energy intensities
- Load factors

- Emissions
- Environmental impact

This part of the project also describes some *future* technical and operational GHG abatement options. The aim is to estimate to which extent *"technical and operational fixes"* can contribute to reduce the specific greenhouse gas emissions from commercial civil air transport in the future. The section considers the five parameters listed below:

- Improved vehicle efficiency options
- Load factor optimisation potential
- Alternative transport mode options
- Improved operational procedures
- Alternative fuel options

The fuel intensity of passenger air travel and airfreight is found to vary significantly between airlines, mainly due to use of different types of aircraft and differences in route structures and passenger- and freight load factors. For example, some European charter carriers are found to be significantly less fuel intensive than scheduled airlines because they operate relatively new aircraft in high-density seat-configuration at relatively high passenger load factors.

New aircraft consume much less fuel than older types, and are at level or even better than the present stock of passenger cars when considering fuel use per passenger kilometre. However, due to the relatively long distance each person can potentially travel within a relatively short period of time, passenger air travel greenhouse gas emissions can contribute considerably to the yearly per capita emissions.

The fuel intensity of passenger air travel and airfreight has been reduced throughout the last decades but the yearly improvements are slowing down. Airline preference for increasing speed over fuel efficiency may lead to reduce the fuel efficiency improvement rate further in the future. On the longer-term commercial civil air transport is heading for becoming a major source of greenhouse gases because passenger air travel and airfreight grow stronger than most other energy services.

The **third part** of the project (Chapter 4) assesses the possible future environmental impact of a jet fuel tax.

Mainstream energy and environment studies tend to focus on the price of energy as the main determinant for society's willingness to reduce energy consumption, either by investing in more energy efficient end-use technologies or by substituting energy intensive activities by less energy intensive types. For example, by implementing a jet fuel tax, airline demand for more fuel-efficient aircraft may increase, while consumer preferences for other modes of consumption over passenger air travel and airfreight may grow[4]. Therefore, a discussion of the possible environmental impact of increasing jet fuel costs by introducing a fuel tax is given in Chapter 4.

Chapter 4 discusses the level of fuel tax that may be needed to achieve environmentally sustainable commercial civil air transport activities. The main conclusion of the chapter is that a rather high level of jet fuel tax may be needed if air traffic volume and the specific fuel intensity of aircraft are to be reduced enough to secure that global commercial civil air transport activities become environmentally sustainable in the future. That is, a tax that roughly increases the current jet fuel price by a factor of up to 10 may be needed to stabilise fuel consumption at the current level. If such a relatively high tax level cannot be agreed upon politically some other supplementary measures may be needed to reduce the environmental impact of commercial civil air travel.

The **fourth part** of the project (Chapter 5) discusses some of the major challenges facing the development of an environmentally sustainable energy system. The primary aim is to discuss the possible future role of commercial civil air transport within such a system and to propose a sustainability target for passenger air travel.

What is argued here is that mainstream studies tend to forecast the past into the future assuming that general mechanisms and structures will remain more or less unchanged. Such a methodology seems to be most comprehensive for forecasting developments in the near future. However, energy planning involves long-term planning, because

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[4] See for instance the following studies of the likely future impact of a jet fuel tax: [Barrett 1996] [OECD 1997] [Resource Analysis 1998] [Bleijenberg and Wit 1998] [NSN 2000] [Wickrama 2001].

infrastructures as well as some energy consuming technologies, such as houses and aircraft, have relatively long lifetimes and production cycles. For example, the phase of developing and testing new aircraft and engine designs may take decades, and the production phase of a single aircraft type may well last for several decades. Furthermore, aircraft may be in airline operation for more than forty years. The time perspective in aircraft production and usage cycles is therefore relatively long. Therefore, other instruments than forecasting may be more appropriate within long-term energy and environmental planning for the commercial civil air transport sector.

"Backcasting" is a methodology proposed in other energy [Robinson 1982a, 1982b and 1990] [Dreborg 1996] and transport future studies [Steen et. al 1997] that can be used when constructing normative scenarios for our energy system to be used in discussions on how to shape our future. The aim of using a "backcasting" methodology in this report is to construct a "desirable" picture of a future sustainable energy and transport system. The idea of "backcasting" is that the use of a long time horizon makes it possible to include major adjustments of present society. In a longer time horizon existing vehicles and infrastructures will be replaced and present power structures and lifestyles may be outdated. The "backcasting" approach allows the planner to suggest new types of environmentally and human desirable societies with consistent patterns of new norms, habits, life-styles, consumption levels, power structures, infrastructures, vehicle fleets, energy systems, etc. The concrete aim of creating scenarios in this study is to suggest new types of transport structures with environmental impact reduced to a level fulfilling future goals for reduction of GHG's.

Chapter 2

Determinants of passenger air travel growth[1]

For environmental reasons it may be necessary to reduce the growth in passenger air travel in the future. This chapter aims at giving an overview of some main determinants of passenger[2] air travel growth focusing on drivers and impeders. The intention is to summon some economic, physical; social and political determinants, and thereby to describe the background for the growth in the demand for passenger air travel in broader terms than what is often the case. The purpose of this description is to point out some potential strategies for impeding growth in the future.

2.1 Introduction – growth in civil air transport

Passenger air travel, measured in revenue passenger kilometres[3] (RPKs), has grown continuously from year to year since 1960 except for one year, namely 1991, see Figure 2.1. In 1991, the war in the Persian Gulf pressed up the oil price[4] leading to a general downturn in the economy and to some extent scared travellers from flying through fears of hijackings [Heppenheimer 1995] [Dings et. al. 2000b and 2000c]. From

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[1] Note that this chapter has also been published in a shorter version in the Journal "World Transport Policy and Practice", Issue 2, 2001 [Nielsen 2001].

[2] It should be noted that, on a global scale, around one third of the revenue weight carried by commercial civil aircraft can be attributed to freight transport whereas two thirds can be attributed to passenger transport, see Figure 2.12 or Appendix D for a further description of the distribution between passenger air travel and airfreight. Airfreight is growing faster than passenger air travel. Airfreight is closely connected with passenger services because passenger aircraft carry belly-hold freight. This chapter mainly focuses on describing determinants of passenger air travel. Further studies into the drivers for growth in airfreight have been excluded in this project due to time constraints.

[3] A revenue passenger kilometre is a measure for the amount of passenger air travel that is calculated by multiplying the number of revenue passengers (passengers that pay at least a certain percentage of the normal fare) to the distance flown in kilometres.

[4] For a description of the fluctuations in the jet fuel price over the last 30 years see Section 4.3 in Chapter 4.

1960 to 1998 the number of RPKs increased more than 20-fold from around 131 billions to around 2888 billions, corresponding around 44 RPKs per capita globally in 1960 and almost 500 RPKs per capita in 1998.

Figure 2.1: Passenger kilometres generated by the World's commercial airlines
Actual data 1960 – 1998 and Airbus' 1999 industry forecast to 2020 (5% yearly growth rate). Sources: RPKs are from [Boeing 1980] and [IATA 1994 and 1999], industry forecast is from [Airbus 1999 and 2000b].
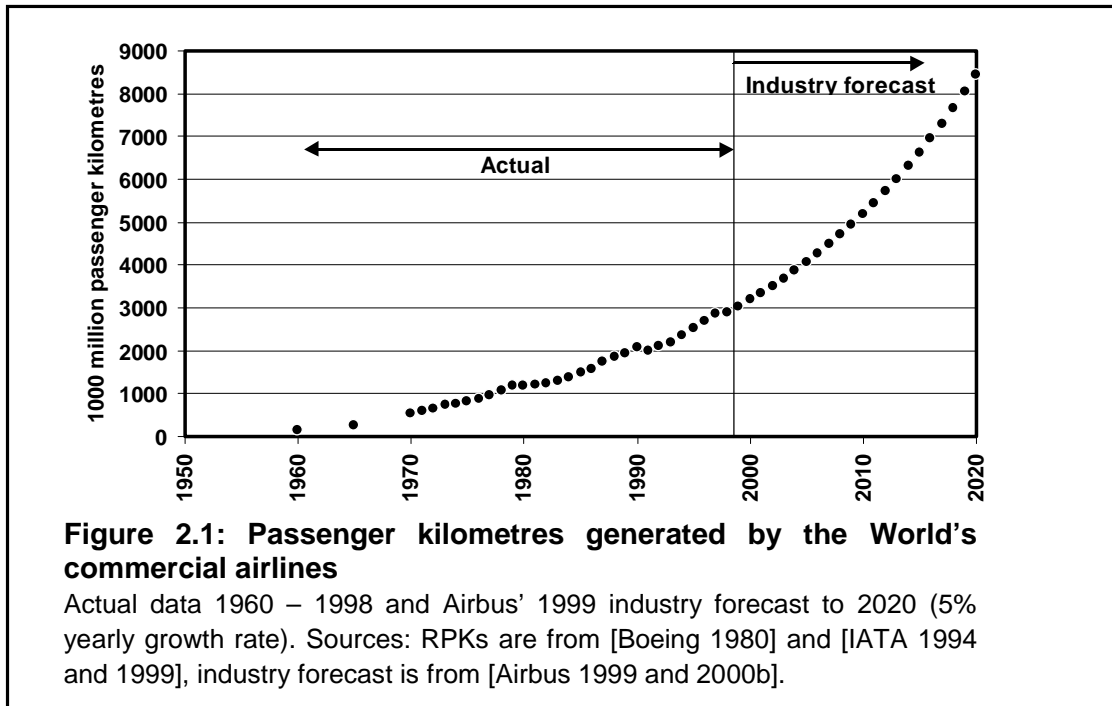
The yearly growth rate in global passenger air travel has fallen since the early days of commercial civil air transport, but passenger air travel is still envisioned by the aeronautical industry to continue growing at around 5 percent per year in the next decades [Airbus 1999 and 2000a]. In some markets growth seems to be levelling off somewhat suggesting that these markets might be on their way towards maturity after decades of strong growth. The best example of this is the United States, where the average yearly growth in revenue passenger kilometres in the 1990s was around 3,5 percent. This is quite low compared to average yearly growth rates of around 22,2 percent in the 1960s and around 7,2 percent in the 1970s and around 5,5 percent in the 1980s. As can be seen from Figure 2.2 the growth rate in airfreight, measured in revenue freight tonne kilometres[5] (RFTKs) is higher than the growth rate in passenger air travel, and this resembles the general trend on a global scale [Boeing 2000c and

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[5] Revenue freight tonne kilometres is a measure for the amount of freight transported by air that is calculated by multiplying the number of revenue freight tonnes transported to the distance flown in kilometres.

2000d]. In the 1990s passenger transport (RPKs) and airfreight (RFTKs) performed by scheduled airlines situated in North America grew by around 42 percent and 83 percent respectively [Air Transport Association 2000d]. It should be mentioned here that North America is the largest single market for passenger air travel today, representing some 39 percent of the worlds RPKs in 1996, see Figures 2.12 and 5.9 and Appendix D.

Figure 2.2: Yearly growth in available seat kilometres (ASK), revenue passenger kilometres (RPK) and revenue freight tonne kilometres (RFTK) for scheduled American air carriers 1930-1999
Sources: [Air Transport Association 2000c and 2000d].
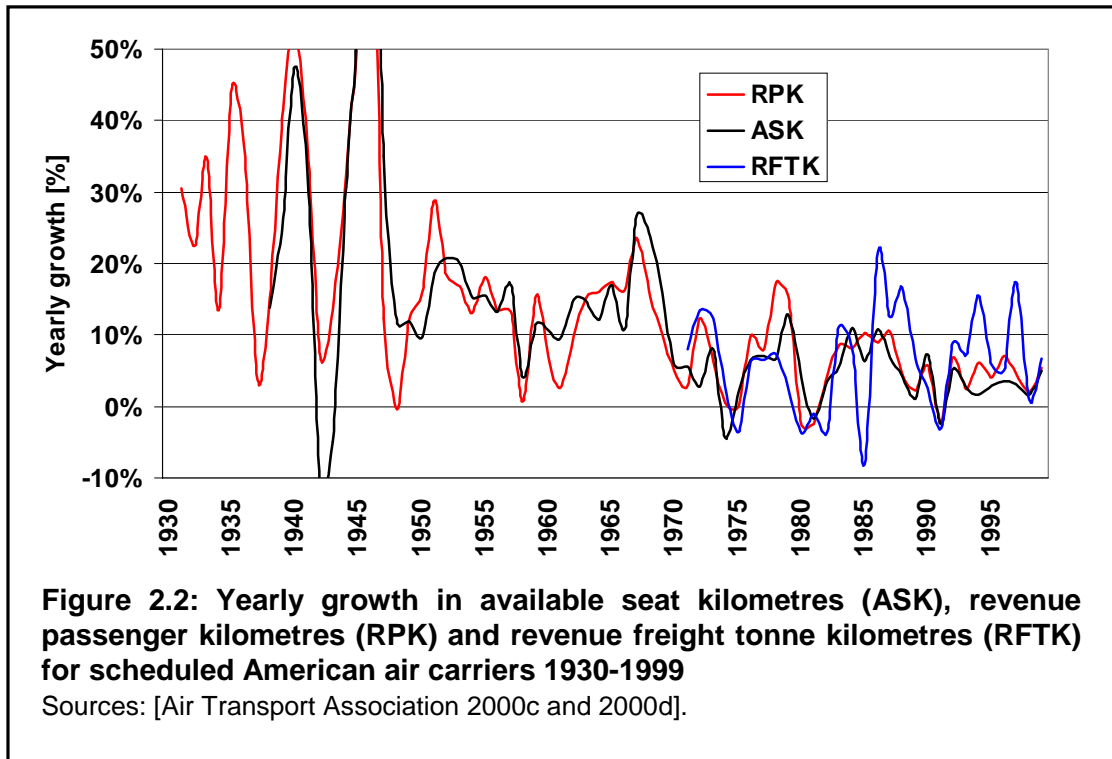
In the next decades, the fuel consumption related to commercial civil air transport is expected by the Intergovernmental Panel on Climate Change (IPCC) to grow by around 3 percent per year (see the Introduction for a further explanation of this issue) if the aeronautical industry's traffic forecast materialises (see the forecast in Figure 2.1) [IPCC 1999]. For environmental reasons, it therefore seems necessary to discuss the possibilities for reducing passenger air travel growth in the future. In this context, it becomes relevant to investigate the forces promoting and sustaining passenger air travel, as well as the impeding factors.

2.2 On lifestyles and social practices

Many countries throughout the world has set up schemes for reducing GHG emissions to reduce the risk of global warming due to the so-called "greenhouse effect". The main challenge for reducing GHG emissions seems to be that energy service levels grow faster than the technical reductions of the specific GHG emissions per unit of energy

service rendered. Life-style research has therefore in recent years become more widely used within energy studies because it is generally acknowledged that the current level of growth in energy services is environmentally unsustainable and that technical fixes will not be sufficient to match growth. There seems to be a need for reducing growth in energy services, and this is especially true for transportation that generally grows faster than most other types of energy services [IPCC 1996b]. Therefore, it has become increasingly important to draw on social sciences to better understand social implications of energy consumption, that is the social determinants of energy service growth [Stern 1986] [Schipper 1991] [Shove et. al. 1998] [Kuehn 1999].

Mainstream energy and environment studies focus much on the price of energy as main determinant for society's willingness to reduce energy consumption, either by investing in more energy efficient end-use technologies or by substituting energy intensive activities by less energy intensive types. For example, by implementing a jet fuel tax, airline demand for more efficient aircraft may increase, while consumer preferences for other (perhaps more environmentally benign) modes of consumption over air travel and freight may grow[6].

Such mainstream studies are criticised by some social researchers who, often grounded in social-psychological and sociological theories about human behaviour and social systems, find that mainstream energy studies tend to separate the social from the technical while often focussing on individual, technical and economical aspects instead of social or cultural aspects of energy consumption [Shove et. al. 1998, pp. 300-301] [Kuehn 1999]. Some of the critics suggest that seeing people as mere automata responding to pushes and pulls initiated by government, such as energy taxes and information about alternatives, is not always relevant, because people do not necessarily act according to cost-benefit projections or informative campaigns [Shove et. al. 1998, p. 300]. Rather, social context, that is social norms and cultural practices, has been found to also play a predominant role in the way people consume energy [Læssøe 2000] [Wilhite 2000].

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[6] A review of such mainstream studies of the possible impact of a jet fuel tax is given in Chapter 4 [Barrett 1996] [OECD 1997] [NEI 1997] [CAEP 1997] [Brockhagen and Lienemeyer 1999] [Resource Analysis 1998] [Bleijenberg et. al. 1998] [NSN 2000] [Wickrama 2001] [Olsthoorn 2001].

First of all, some energy analysts study differences in social practices connected to energy use in different countries and regions of the world. For example, a study compares Norwegian and Japanese household energy consumption, showing that Norwegians connect the use of energy intensive heating and lighting closely to creating "cozyness" while in Japan especially energy intensive bathing routines are socially significant [Wilhite et. al. 1996]. Another study compares determinants of automobile use in OECD countries, showing socially significant differences. For example, Americans tend to drive longer yearly distances and use larger cars than European and Japanese citizens on average [Schipper 1995a]. These differences can in part be explained by the low level of taxes on vehicles and fuels in the United States as compared to many European countries, and also relate to differences in urban planning, United States having much more urban sprawl and less public transport options [Schipper 1995b] [Newman and Kenworthy 1991]. However, much of the difference also relates to differences in the meaning of personal mobility, automobility being a socially significant aspect of American culture [Sachs 1992]. Some studies also emphasise that the car in itself can be seen as an artefact that has contributed to shape city planning, culture and the way we live [CEC 1993] [Tengström 1992, 1995a and 1995b] [Sørensen 1993a and 1993b].

Secondly, some studies focus on differences in energy consumption between individuals or groups of people within countries, also showing that other factors than technology and economy are important in the way we consume energy [Jensen 1997] [Kuehn 1999] [Carlsson-Kanyama and Linden 1999] [Hallin 1992]. Some of these studies tend to focus on differences between socio-economic groups, showing general differences connected to income, age, gender etc. For example, in Sweden, older generations generally travel less per capita than younger generations, leading researchers to suggest that these younger generations have been born into a "travelling culture" and may continue being on the move also when they get older. If this theory holds true it will lead to higher travel patterns in the future than what is seen today [Carlsson-Kanyama and Linden 1999] [Linden and Carlsson-Kanyama 1998]. Other studies tend to focus more on individual lifestyles or life-style groups, which are not necessarily tied to more traditional socio-economic characteristics. Rather, these studies focus on how individual wants, needs and desires are shaping energy consumption, explaining how individuals seek to fulfil their basic needs while positioning themselves in their social surroundings [Jensen 1997] [Kuehn 1999]

[Douglas et. al. 1998]. Such studies, focusing on individual lifestyles, can oftentimes point out the lifestyles that are less greenhouse gas intensive than the "average" lifestyle, and thereby be used for proposing alternatives to lifestyles that are relatively greenhouse gas intensive. However, these studies also often give insights into the difficulties facing planners wanting to persuade people to change their habits, because people's ways of life are often "tied up" by their socio-technical surroundings.

Furthermore, as technologies spread, large-scale socio-technical systems are built up around them, leading to promote the use of such technologies further. One example is the building up of large transport infrastructures contributing to "gridlock" society into sustaining and furthering flows of traffic. The passenger car made possible urban sprawl while the emergence of airport capacity and jet powered aircraft made air travel available and affordable to the broad public. The building up of infrastructures and vehicle production industries contribute to shape society and creates "mobile cultures" [Sørensen 1993a and 1993b] [Urry 1999] and facilitates and furthers globalisation of the market and the social sphere [Tengström 1995a] [Sachs et. al 1998] [Sachs 2000]. Such developments are to a large extent chosen by governments and the general public, that is technologies do not spread autonomously, but are shaped by and constantly shaping the social structure [CEC 1993] [Rip and Kemp 1998] [Bijker et. al. 1987].

Some studies also emphasise that the passenger car is a good example of how technological development can be "locked in". For example, the image of what types of performances a car should offer and what it should look like maintains car producers in designing steel based cars powered by internal combustion engines using primarily gasoline and diesel [Hård 1992] [Hård and Knie 1993] [Hård and Jamison 1997] [Elzen et. al. 1993]. The social meaning of automobility is a barrier to development of less GHG intensive alternative cars such as ultra-lightweight compact cars, as have for example been envisaged by Lovins et. al. [1993 and 1995], based on carbon fibres and fuel-cell or diesel hybrid-electrical drive systems and alternative fuels. Energy efficient technologies are not always considered socially or economically attractive [Schot and Elzen 1994]. A similar example from the *commercial civil air transport* industry is propfan engines for aircraft propulsion that have never reached the market and the preference for jet powered aircraft because they offer higher speed than propeller

aircraft[7] [DOT 1998] [IPCC 1999] [Dings et. al. 2000b]. That is, to some extent, lifestyle choices hinder the development of more environmentally benign technologies.

By often overlooking social factors energy studies often tend to oversimplify the determinants of energy consumption into merely a question of energy prices and technological possibilities. The element of public choice for shaping policies, social structures and social norms is thereby often not seriously considered.

Likewise, mainstream studies describing possibilities for reducing the GHG emissions from *commercial civil air transport* often tend to focus on technical possibilities to reduce the specific energy requirements and emissions per passenger kilometre. That is, studies tend to focus mainly on increasing the "eco-efficiency" by developing more fuel-efficient aircraft [Greene 1997] [Dings et. al. 1997 and 2000b] [IPCC 1999] or by using less GHG intensive fuels than current fossil jet fuel [Pohl 1995a and 1995b] [Pohl and Malychev 1997]. Such studies indicate that the technical GHG emission reduction potentials are relatively large, but are anyway likely to be eaten up by the forecasted growth in air travel. A study also looking into the possibility of reducing air travel – or at least curbing growth – therefore seems relevant. Therefore, this chapter deals with the question of what determines air travel growth, as to be able to point to a broader range of solutions for what may contribute to reduce aviation greenhouse gas emission growth than what is done in mainstream studies.

The enormous growth in global air travel over the recent decades is an expression of a significant change in lifestyles in the Western part of the world, and it also illustrates a large difference between the lifestyles in the Western world and the rest of the world. In a number of recent studies of the connection between life-style and transport different aspects and conceptualisations are presented and discussed [Carlsson-Kanyama and Linden 1999] [Christiansen 1998] [Læssøe 1998] [Urry 1999] [Jensen 1997] [Schipper 1995a and 1995b]. And, indeed, there are different definitions of the term "*lifestyle*", but the importance of these differences should not be overrated, since it is to a large extent a linguistic question. Rather, the main difference between the studies seems to be their different choices of focus, as will be explained in the following.

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[7] See sections 3.10.2 and 3.10.4 in Chapter 3 for a further discussion of the speed issue.

The diagram in Figure 2.3 is meant to give an aggregated overview of the relations around lifestyles in a system approach [Christensen and Nørgaard 1976]. In this simple model, the lifestyle is defined as people's set of practices or behaviour as they are manifested in physical, measurable actions. As indicated, the lifestyle is determined by people's individual attitudes, which again depend on their needs and values, but the lifestyle is constrained and driven also by the social structures and the physical environment. This definition of lifestyle implies that a certain pattern of behaviour, for instance in air travel, is an expression of a certain lifestyle, no matter whether this behaviour is shaped by people's attitudes or by the outer options or constraints. In other words, if someone only travels little by air, this behaviour illustrates the person's lifestyle no matter whether it is due to a low interest in flying (attitude) or it is caused by a low income or a lack of air travel facilities (social structure).

The model in Figure 2.3 illustrates the dynamic development in lifestyle as part of a large system, which includes feed backs, delays, etc. This demonstrates for instance that a lifestyle of today is both shaped by the values of the past, as well as it shapes the future values through the socialisation, artifacts, etc. The model can help to clarify some of the various perceptions or definitions of the concept lifestyle. Læssøe [2000] discusses this and distinguish between the view of two groups of researchers, namely social researchers and environmental/energy researchers.

Social researchers are usually focussing on the links to the left of lifestyle in Figure 2.3, that is the values, attitudes and other individual human background factors, and how they affect the way people behave. They would usually define lifestyle as an integration of the behavioural patterns and the human causes of the behaviour.

Energy planning researchers tend to focus on the impact people's lifestyles have on the environment and the social structure, that is the factors to the right of lifestyle in Figure 2.3. This development in using the lifestyle concept in energy analysis seems to originate in the recognition that energy demand is determined not only by technology, but also by people's behavioural pattern, termed lifestyles. This interpretation of the term lifestyle has been used by various energy analysts [Schipper 1989, 1991 and 1995b]. Not much investigation has been conducted, however, of the individual human factors, which actually gear people to the behaviour, and what could change it to achieve energy savings.

Figure 2.3: Influence diagram for lifestyle changes
Based on [Christensen and Nørgaard 1976, p. 413].
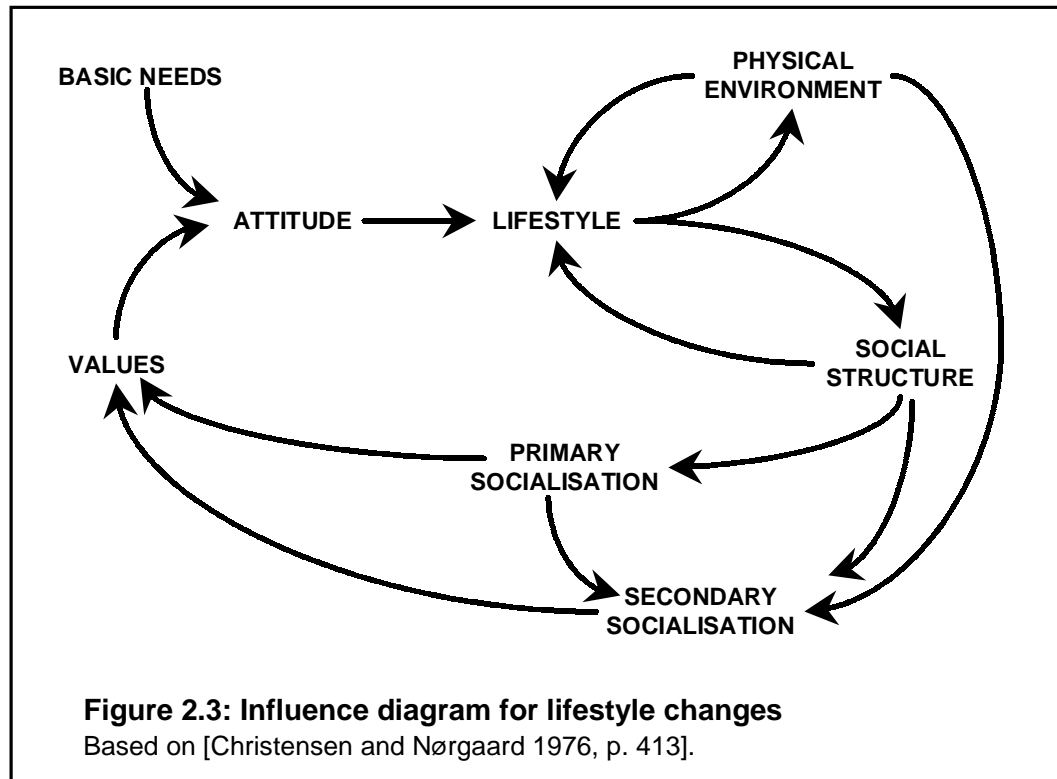
A more sociological approach by Spaargaren [1997] is illustrated by a diagram in Figure 2.4, modified to the present study of air travel. Spaargaren's model does fit into the overall pattern of the model in Figure 2.3, only with a slightly different use of the term lifestyle, which he interprets as integrated with people's personal attitudes, etc. What Spaargaren terms social practices is very much the same as what is called lifestyle in Figure 2.3, and like there it is determined by the individual's personal drive as well as by the physical environment and social structure.

actor/agent   human action   social practices   structures

sports
relaxation
dancing
sunbathing
eating
drinking
swimming
shopping
sight spotting
social contacts

reflexive
monitoring
rationalisation
motivation

conscious
----
unconscious

lifestyle

collective socio- material systems

rules
and
resources

Figure 2.4: Connections between lifestyles, social practices and collective socio-material systems.
Source: This figure is inspired by a similar model developed by [Spaargaren 1997, p. 144] describing connections between human action, social practices and collective socio-material systems within the domestic mode of consumption.

In the present report on air travel, the lifestyle aspects is defined more or less as the energy planners would normally do, namely as people's air travel pattern. In this context however, inspired by the works of the American and Danish physicists Lee Schipper and Jørgen Nørgaard, life-style is defined as the "activity pattern" of individuals in society [Schipper 1989, 1991 and 1995b] or behaviour pattern [Christensen and Nørgaard 1976]. The issue here is to quantify relations between activities and energy. But in order to avoid misunderstanding as to the meaning of the term "lifestyle" it has hardly been used in this report.

The models illustrated in Figures 2.3 and 2.4 are very broad, and can be adapted to most types of (energy) consumption. However, each mode of energy consumption may have very different characteristics connected to it, that is different perceptions and rules are connected to each type of activity, and these change in both time and space. Furthermore, one can choose to focus on various aspects of lifestyle developments. This Chapter sets out to identify some main determinants shaping global air travel

growth, as illustrated in Figure 2.5, some of the aspects being inspired by the studies mentioned in this Section.

2.3 Determinants of passenger air travel growth

Inspired by Michaelis [2000] the explanations sought of life-style development aim at describing technical, economical, political and social determinants of air travel in a broad model (see Figure 2.5). According to Michaelis drivers of consumption patterns can generally be seen to originate from economic and institutional development, technological change, and cultural shifts; as well as changes in demography and social structures and norms; and changes in individual needs, habits and motivations and religious beliefs etc. But only some of these issues are dealt with in this report. Inspired by Læssøe [1999 and 2000] the study focuses both on drivers and impeders because the identification of these makes it possible to point out potential strategies for impeding the current drivers as well as for strengthening impeders. Inspired by Doganis [1985], Hanlon [1996] and O'Connor [1995] the empirical examples of the current drivers and impeders primarily focus on economical aspects. Also inspired by [Heppenheimer 1995], Grübler [1998] and Rip and Kemp [1998] a main starting point is to look into how aviation's socio-technical system has been built up. Some social and cultural aspects of passenger air travel growth are also mentioned but because relatively few studies have been conducted in these areas the empirical examples mentioned in the following Sections are relatively scarce.

Some important economic, physical, social and political determinants of passenger air travel growth are illustrated in the diagram in Figure 2.5. The circle in Figure 2.5 illustrates the size of passenger air travel demand. The arrows pointing out from the circle represents elements that currently seems to drive passenger air travel growth, while the arrows pointing towards the circle centre are meant to represent current and potential impeders. Note that many of the current drivers could become impeders in the future, i.e. the current drivers are not necessarily per se going to continue increasing the demand for air travel in the future. One example is that one of the main current aims in the development of new aircraft technologies is to reduce the direct operating costs and increasing capacity, range and speed. However, it is possible that in the future the aircraft producers may for example introduce new types of GHG intensive supersonic passenger aircraft with focus on increasing the speed substantially. Another possibility is the introduction of radically improved and more environmentally benign

lower-speed subsonic aircraft that may for example feature blended wing body (BWB) fuselage shapes and the use of propfan engines (see Chapter 4 for a further discussion of these issues). Although these two typologies are radically different in their nature both concepts may feature higher direct operating costs over comparable next-generation conventional subsonic aircraft. The high-speed models may be more expensive to develop [Heppenheimer 1995] and will be more fuel intensive [IPCC 1999] while the low speed models might reduce the overall productivity due to the lower speed [Dings et. al. 2000b].

Figure 2.5: Determinants of passenger air travel growth
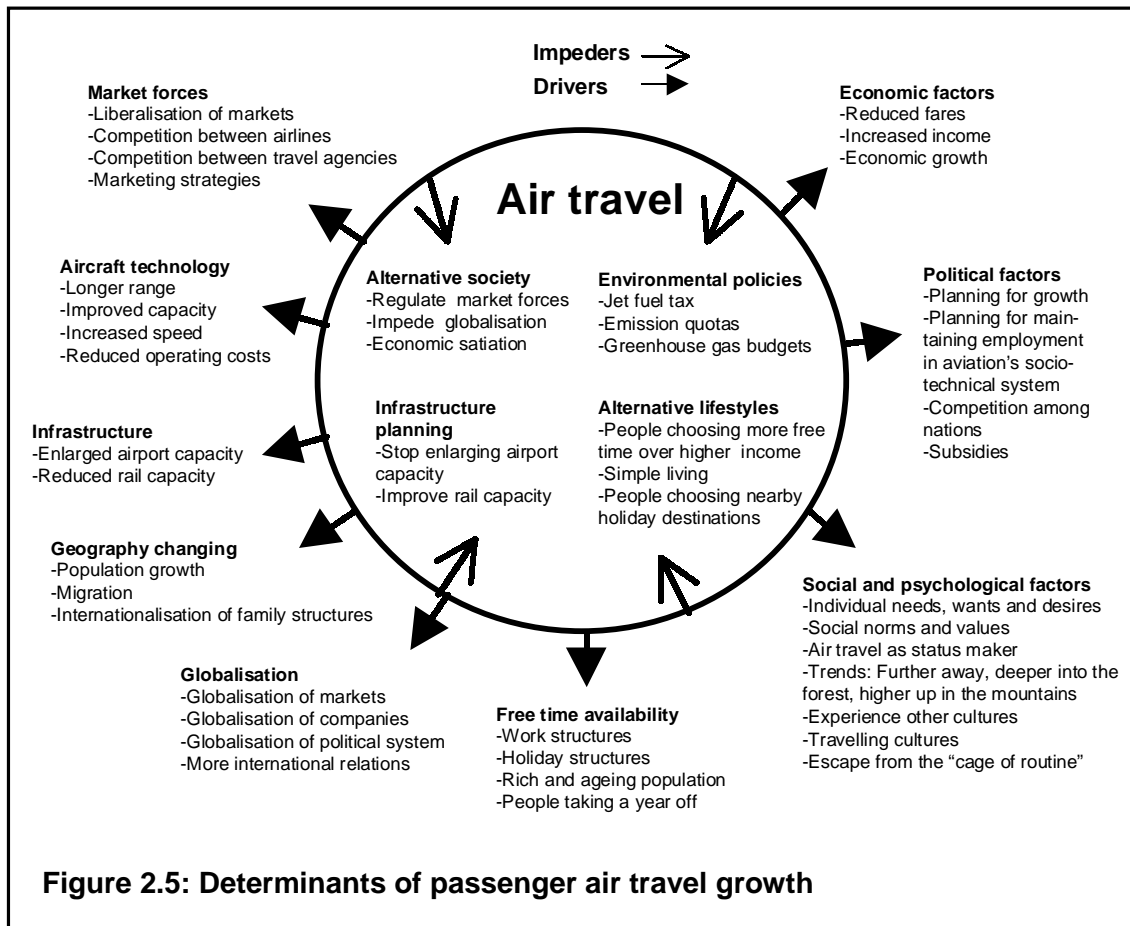
Some air travel is related specifically to leisure, to shopping, to visiting friends or to business activities, but much relate to several or all categories. People are driven towards travelling by personal desires to explore new territory and cultures and the wish to create new professional and social relations. A precondition for passenger air travel, however, is the availability of aircraft and airports and of the socio-technical system surrounding and governing these. Passenger air travel growth is furthered by constantly enlarging the physical capacity of commercial civil air transport's socio-

technical system and improving it's productivity while cutting real costs. Improved airline productivity brings reduced real airfares, and increasing income allows a higher number of people to fly. Economic growth in general as well as globalisation of economies, companies, markets, political systems and personal relations leads to the drive for travelling more often and over longer distances. Increasing migration, marriages across national borders and population growth are further aspects. Some of these drivers are described further throughout Section 2.4.

People are basically restricted from air travel by financial and time constraints as well as technology and geography. Financial constraints are mainly connected to airfares and personal incomes. Technology is an important constraint in the sense that aircraft speed, range and capacity limit the distance people are able to fly within the time available. Geographical characteristics also play an important part in the sense that the earth is a limited geographical area, and unless space-flight becomes available for a broad part of the population, there seems to be upper limits as to how far each person might want to travel in a year. Current impeders to passenger air travel growth are congested airports and airspace. In the future new environmental policies might emerge, and on the longer term a reduction or a saturation of world economic- and population growth could reduce air travel growth. These impeders are described further throughout Section 2.5.

2.4 Drivers of passenger air travel growth

First, we describe some of the drivers of passenger air travel growth that are illustrated by Figure 2.5 in the previous section. Thereafter, the impeders are described in Section 2.5.

2.4.1 Building up commercial civil air transport's "socio-technical system"

Global passenger air travel growth is accompanied and supported by the rise of a large "socio-technical system" surrounding commercial civil air transport, made up of aluminium, steel, plastic and fossil fuel (aircraft and jet fuel), concrete (roads, airports and runways), telephones, computers and satellites (for navigation, control, administration and ticket sales), law (traffic rules), and culture (the value and meaning of personal mobility). A "seamless web" combining very different elements (artefacts,

aircraft producers and suppliers, airlines, airports, travel agents, regulations, politicians, users, etc.) is build up[8].

Consumers have become accustomed to travel over ever-longer distances at ever-increasing speed and at lower costs. Commercial civil air transport contributes directly as well as indirectly to a relatively large share of global and local economies. Aircraft and airport production, maintenance and operation as well as travel agents, suppliers etc, comprise large amounts of work places, not to mention the importance of tourism to local economies and the importance of business travel for global business. Each part of the "seamless web" contributes to the shaping of commercial civil air transport's "socio-technical system".

Thereby users, the aeronautical industry, politicians, environmental non-governmental organisations (NGO's) and other actors connected in some way or another to the commercial civil air transport system contribute to promote, sustain and impede the rise of passenger air travel and the "socio-technical system". See Figure 2.6 for an illustration of commercial civil air transport's socio-technical system.

The building up of commercial civil air transport's socio-technical system is to a large extent supported by economic subsidies from governments seeing aerospace industries, airlines and airports as job-creation programmes[9] [Heppenheimer 1995] [FoE 1998 and 1999].

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[8] For a description of technological change and the building up of "Socio-technical systems" and "Seamless webs" see for instance [Rip and Kemp 1998], [CEC 1993] and [Bijker et. al. 1987].

[9] A very recent example is the British government's decision to back Airbus' plans to develop a new large-capacity aircraft, the A380, by offering cheap repayable loans for airframe and engine launch investments. One of the main arguments for backing the A380 project is the generation of an estimated 22000 jobs in the UK alone, 2000 at British Aerospace's (BAE's) factories and some 20000 jobs among the engineering firm's suppliers and subcontractors [The Times 2000a]. Airbus claims that the A380 will sustain some 145000 jobs in Europe [Aviation Week and Space Technology 2001c].

Figure 2.6: Commercial civil air transport's socio-technical system
The theoretical background for making this Figure is inspired by [Rip and Kemp 1998], [CEC 1993] and [Bijker et. al. 1987] and their ideas of how to describe "socio-technical systems" and "seamless webs" as important aspects of technological and social developments.
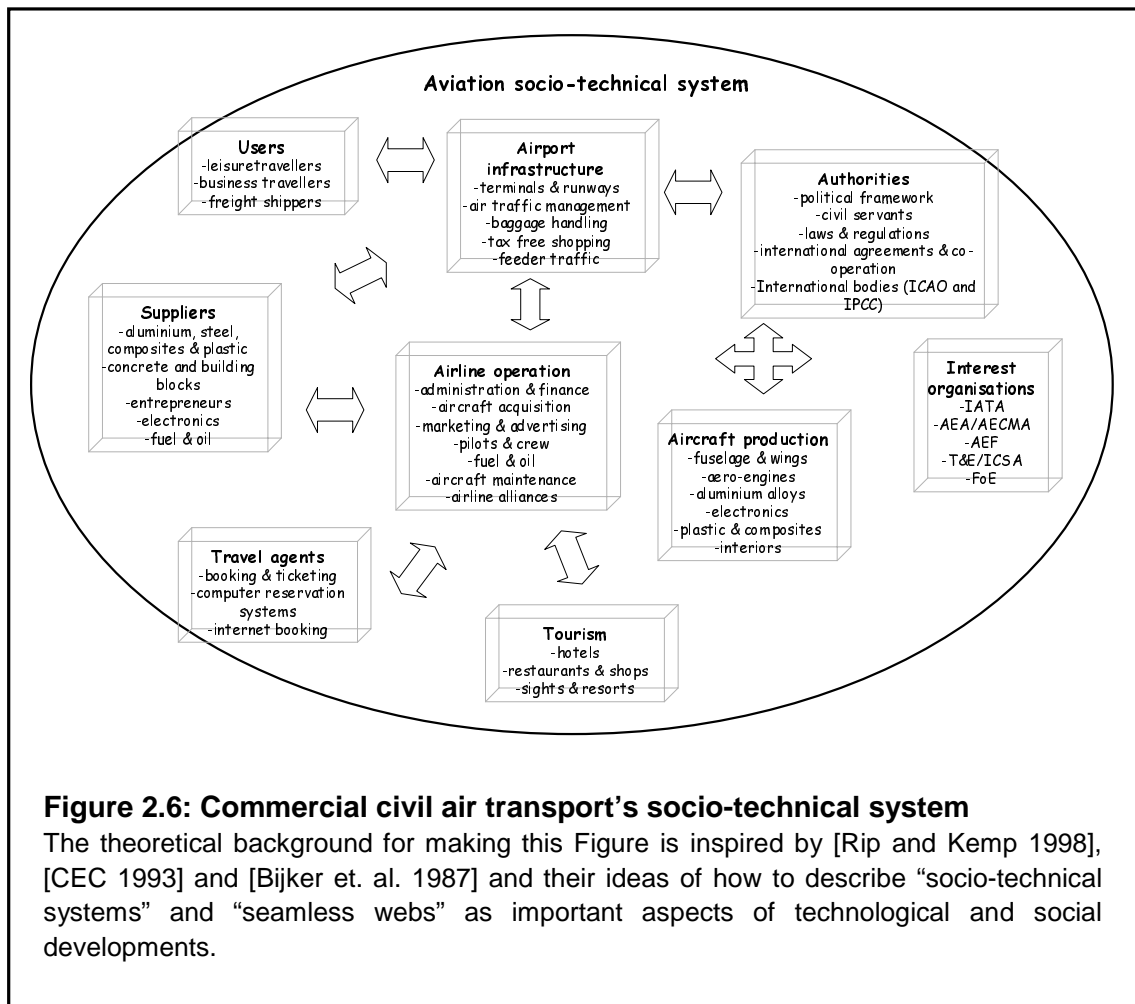
2.4.2 Technological change

Passenger air travel growth is furthered by constantly enlarging the physical capacity of the aircraft fleet while improving its productivity and cutting the real costs of air travel. By far the most important aspect in the historic improvement of airline productivity and the subsequent reduction in airline costs and fares is technological change [Doganis 1985]. Since the invention of powered flight aeronautical engineering has brought ever-improved aircraft offering higher productivity, that is higher payload, higher passenger capacity, greater range and higher speed, at ever lower operating costs per seat and freight capacity unit[10] [Heppenheimer 1995] [Jackson 1998] [Donald 1999].

As exemplified by Figure 2.7, the passenger productivity of large subsonic civil passenger aircraft, measured as the number of seats within an aircraft multiplied by the

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[10] Appendix H describes some historical developments in aircraft performance.

average speed of that aircraft, has been increased substantially. In the early days of commercial civil air transport the aircraft in use were using piston engines and propellers. The piston engine was taken over by fuel-efficient gas turbine powered turboprops in the early 1950s. The turboprop engine is still widely used for smaller short-haul and medium-haul aircraft because of its superior fuel-efficiency over jet engines. By the end of the 1950s[11] the turboprops were supplemented by turbojets, the latter evolving into low-bypass-ratio turbofans and later into high-bypass-ratio turbofans that are used by most large aircraft types today. The jump from piston engines to turboprops allowed for more fuel-efficient operation, whereas the introduction of jet engines allowed for a radical increase in speed over earlier models. The emergence of turbofan engines, featuring radically higher thrust ratios, also allowed for the construction of aircraft of ever increasing sizes [Heppenheimer 1995].

By the end of the 1960s the American aircraft producer Boeing introduced the wide-body B747-100 jumbo. The derivative B747-400 version introduced in 1989 still remains the largest model in use for civil passenger transport [Jackson 1998] [Donald 1999]. The emergence of the B747 and other high-capacity wide-body jets introduced by Douglas Aircraft Company (DC-10), Lockheed (L-1011) and Airbus (A-300) in the early 1970s brought the basis for growth in cheap passenger air travel over longer distances [Doganis 1985, p. 11-14] [Heppenheimer 1995]. Since the introduction of these subsonic wide-body jets the aircraft producers have concentrated their efforts on developing "families" of aircraft featuring a number of models of different sizes, each fitting into a special segment of the market

Future generations of very large capacity subsonic jets promise to increase the productivity further while also cutting the direct operating costs marginally [McMasters and Kroo 1998] [Cranfield College of Aeronautics 2000a]. For example, the next-generation A380-100 full double-deck jumbo-jet from Airbus will feature 555 seats in three-class seat-configuration and more than 800 seats in all-economy class seat-configuration and the following stretched A380-200 is envisaged to accommodate up to 1000 seats, see Picture A in Figure 2.8 [Airbus 2000a and Airbus 2001a]. For

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[11] It should be noted that the de Havilland Comet, which was introduced already in 1952, was the first civil aircraft to be powered by turbojets. However, the aircraft was removed from the market due to problems with fatigue. Therefore, the use of turbojets really took off by the end of the 1950s when Boeing introduced the B707 and Douglas introduced the DC-8.

comparison, the B747-400 accommodates around 580 seats in all-economy class seat-configuration normally and below 400 seats in three-class version [Jackson 1998]. The passenger productivity of the A380-100 is shown in the right part of Figure 2.7, together with a more futuristic advanced design flying wing BWB (Blended Wing Body) aircraft that is currently being studied by the aeronautical industry, see Picture B in Figure 2.8 [Cranfield College of Aeronautics 2000a]. The A380-100 will commence airline operation in 2006 whereas flying wings are still only on the drawing board.

Figure 2.7: Passenger productivity of selected long-range aircraft introduced from the 1920s and onwards
Note that the passenger productivity, measured as available seat kilometres (ASK) per hour, is calculated by multiplying aircraft cruising speed to the seating capacity. Examples here are for selected aircraft, primarily maximum (all-economy class) seat-configuration models. Derivatives of the same aircraft type will typically show lower passenger productivity in for example three-class seat-configuration. The figure does not take the freight capacity into account. But in maximum seat configuration the freight capacity would most often be relatively low.
Sources: Data for seat capacity and average speed are from [Doganis 1985], [Jackson 1998] and [Donald 1999].

In the late 1960s the Anglo-French supersonic Concorde took first flight and remains the only supersonic aircraft in use for civil air transport. When introduced, the Concorde was faced by concerns over sonic boom noise and high-altitude emissions that contribute to deplete the stratospheric ozone layer. Furthermore, the Concorde became an economic failure because of the aircraft's relatively high development costs, combined with its relatively low passenger capacity and its excessively high fuel consumption as compared to the relatively fuel-efficient wide-body jets that emerged in

the early 1970s. The oil price rise following the 1973 oil crisis left the Concorde economically unattractive to airlines. Eventually, only 14 Concorde aircraft came into airline operation and were virtually given away for free to Air France and British Airways [Owen 1997]. Thereby, the Concorde that was financed by British and French tax payers, even though remaining an engineering triumph and a symbol of national pride, became one of the biggest economic failures of commercial civil air transport [Owen 1997] [Heppenheimer 1995]. Therefore, since the late 1960s the quest for achieving higher speed[12] has been stalled. However, through the last decades there have been ongoing design studies both in Europe, the United States and Japan, for a future generation of supersonic aircraft for passenger transport, see Picture G in Figure 2.8 for an illustration of such a design study from Airbus.

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[12] All current civil subsonic aircraft cruise at below around 910 km/h being the maximum cruising speed of the B747 at 30.000 feet altitude [Donald 1999].
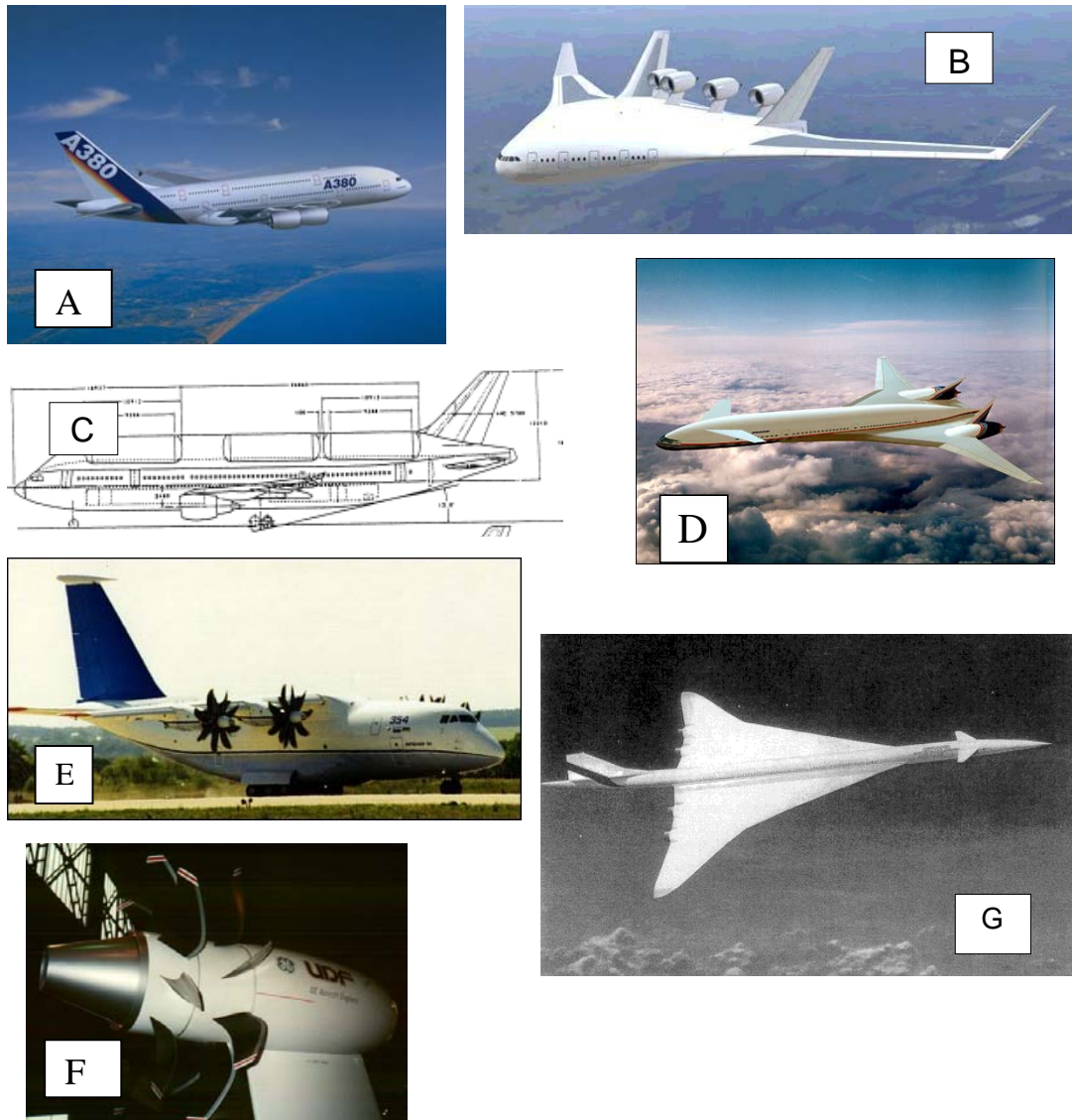
Figure 2.8: Design concepts for future passenger aircraft.
A) A380 next-generation very large sub-sonic airliner from Airbus to be delivered to a number of airlines from 2006. The A380-100 accommodates 555 seats in three-class version and up to 850 seats in all-economy version. Later to be followed up by the stretched A380-200 featuring 656 seats in three-class configuration and up to 1000 seats in all-economy configuration. Picture source: [http://www.airbus.com] B) Airbus futuristic design illustrating a Blended-Wing-Body (BWB) subsonic flying-wing airliner [Flug Revue 2001]. Picture source: [http://www.flug-revue.rotor.com/]. C) Design study for a medium-sized airliner fuelled by liquid hydrogen stored in tanks inside the upper part of the fuselage. Picture source: [Pohl 1995] D) Proposed subsonic delta wing sonic cruiser from Boeing being able to cruise at speeds very close to the speed of sound. May be launched within a few years and could be flying by 2006 or shortly thereafter. Picture source: [http://www.boeing.com]. E) Antonov AN-70 prototype military aircraft powered by counter-rotating propfan engines. Picture source: [http://www.russian.ee]. F) Prototype counter-rotating UDF engine presented by General Electric in the 1980s. G) Design study for a next-generation supersonic passenger airliner from Airbus [Flug Revue 2001]. Picture source: [http://www.flug-revue.rotor.com/].

2.4.3 Competition among nations

Aircraft production is a highly prestigious venture, and nations compete to produce the most efficient types and to gain market dominance [Lynn 1995] [McGuire 1997]. Some famous historical examples are the competition between British and American companies to introduce the first jet powered civil aircraft in the 1950s [Heppenheimer 1995] and the American, European and Russian competition to produce the first civil aircraft cruising at supersonic speed. Today, similar types of competition exists between nations aiming at developing the most efficient subsonic civil aircraft in all the size segments ranging from relatively small regional turboprops and jets to wide-body jumbo jets.

Currently, the production of large civil subsonic aircraft is divided between the American and European aircraft producers Boeing and Airbus[13] that compete to each produce a family of aircraft of different sizes ranging from around 100 to above 400 seats[14]. In the market for regional jets and turboprops there are a range of producers each offering families of aircraft of different sizes accommodating up to around 120 seats [DOT 1998] [DTI 1999] [Aircraft Economics 2000a]. One feature connected to this competition among nations is that governments accuse each other of favouring national manufacturers of aircraft and engines. For example by offering them economic subsidies [Lipinski 2000] [The Times 2000 and 2000a] [Sochor 1991] and by persuading airlines to buy certain models and makes [The Times 2001a] [Sochor 1991]. The competition among nations is also related to the prestige that is connected to operating national flag carriers. Many countries therefore favour their flag carriers in various ways [Hanlon 1996].

One of the latest examples of the competition between nations is the European Airbus consortium's successful launch of the A380 super jumbo-jet to compete with Boeing in

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[13] It should be noted that a number of aircraft producers in the Former Soviet Union have produced a substantial number of large civil aircraft. But since the economic recession began in the region in the early 1990s their production of large aircraft types has been reduced to rather insignificant numbers [DTI 1999]. Furthermore, a number of countries are in some way or the other involved in manufacturing parts for the aircraft produced by Boeing and Airbus.

[14] Appendix E contains a detailed description the specifications for Airbus' family of current and next-generation aircraft. Appendix B contains a list of the types of civil passenger jets above 80 This footnote continues on the next page.

the market for very large aircraft. The A380 has been ordered by a number of airlines while Boeing has had to cancel its plans for developing a larger version of its 747-400 due to lack of airline orders. The A380 may enable Europe to gain market dominance as well as the prestige connected to producing the largest passenger aircraft in the world.

However, the A380 only makes sense in a market with rapidly growing demand for air travel and Boeing seems to believe that Airbus' expectation for a future market for around 1500 very large jets until 2020 [Airbus 2000a] is an overestimate because the market may develop towards less hubbing and more direct flights in smaller aircraft. Boeing therefore only anticipates global sales of around 330 aircraft in the segment above 500 seats until 2020 [Boeing 2000a].

Airbus' success with the introduction of the A380 seems to have lead Boeing into launching the 100-300-seat family of so-called "sonic cruisers" being able to cruise around fifteen percent faster than current subsonic aircraft at a speed very near to the speed of sound. Thereby, the travelling time can be cut by up to three hours on ultra long-range Trans Pacific flights. The Sonic Cruiser is a delta wing aircraft that is envisaged to cruise several kilometres higher than current subsonic aircraft, being more fuel-intensive and polluting[15] more [Flight International 2001a], see Picture D in Figure 2.8 for an illustration of how the Sonic Cruiser may come to look like.

Thereby, the Europeans seem to continue the development of ever-larger and more fuel-efficient aircraft offering higher productivity and lower operating costs per seat. Boeing seems to have chosen a strategy focusing more on time savings in the belief that high-yield business travellers and others who can afford it will be willing to pay a premium for faster travel.

However, the point to be made here is that both the development of larger and faster aircraft are drivers for growth in passenger air travel. First of all, the increases in speed

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seats that are in use, in production, under development or planned. Appendix C contains a list of all civil turbine-engined aircraft of the world.

[15] Recently, the European Commissioner for Environment sent a letter to Boeing urging the company not to develop an aircraft that consume more fuel than current subsonic aircraft [Flight International 2001a].

offered by the Sonic Cruiser will allow passengers to travel longer distances within a given amount of time. Secondly, the use of ultra-large aircraft, such as the A380, will reduce the direct operating costs connected to passenger air travel and will give airlines increased incentive to sell a larger proportion of tickets at discounted prices to fill up those larger planes.

2.4.4 Government subsidies

The development of for example new aircraft technologies as well as new airport capacity (runways, terminals and air traffic management systems) and other infrastructures are important preconditions for passenger air travel growth. By developing more efficient aircraft and building new airport capacity air travel becomes cheaper and more widely available and this is all supported with public funding by governments [Heppenheimer 1995] [Kapur 1995] [Sochor]. Costs of technology and infrastructure are thereby not fully reflected in airfares. Furthermore, many airlines are national flag carriers owned partly or fully by national states. Most flag carriers have seen periods with very low profitability and even losses, and have often received government funding[16] [Hanlon 1996]. The political decisions to subsidise the commercial civil air transport industry leads to lower airfares than would have been possible if the industry was fully commercialised and functioning in a liberalised market without subsidies.

The subsidisation of commercial civil air transport's socio-technical system has been found to be appearing at many different levels and in many different ways, and it has therefore not been possible to create a total picture of the level of subsidisation in this report. However, some empirical examples can be given here to get an idea of the magnitude.

Firstly, the financing of new aircraft projects is a geopolitical matter where governments accuse each other of subsidising the development of all-new aircraft types [Lipinski 2000] [Sochor 1991]. Aircraft development is a risky business, since each new aircraft

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[16] Many of the World's scheduled airlines reported financial losses in the first half of 2001. After the terrorist hijackings in the US in September 2001 this situation is expected to worsen, and many airlines in the United States and Europe have therefore asked their governments for financial support [Financial Times 2001e and 2001f]. Although being a special situation of crisis this is the latest example of the aid that is given to airlines from time to time.

model has to be sold in relatively large quantities to repay investments. Historically, only few aircraft models have actually sold in such substantial numbers and aircraft are therefore often sold at artificially low prices to airlines [Aviation Week and Space Technology 2000] [Heppenheimer 1995] [Sochor 1991] or governments offer cheap loans to the airline customers[17]. Because of the substantial costs associated to the development of new aircraft and because of the relatively long lead-times from initial development to the point in time where the yields from aircraft sales break-even with the development costs some governments choose to offer cheap loans to aircraft producers [Heppenheimer 1995]. For example, according to the U.S. department of Commerce, Airbus has been granted over 30 billion US$ in state aid and cheap repayable state loans for their family of aircraft models. Airbus' American competitors therefore complain that if Airbus instead needed to raise capital in the private market the interest rates would be higher. Furthermore, the Americans claim that if the demand for Airbus' aircraft is lacking the company may not have to repay the loans [Lipinski 2000]. According to Airbus, the company's first model introduced, the A300, was granted 100% launch aid. Since then the aid for the later aircraft programmes has gradually been reduced over 90% for the A310, 75% for the A320, 60% for the A330/340 and less again for the estimated $11 billion[18] that it may cost Airbus to develop the A380[19]. Furthermore, Airbus claims that all the state aid plus interest will be paid back to governments [Airbus 2001b]. Furthermore, the development costs are also often indirectly subsidised because many aeronautical technologies are initially developed in military aircraft programmes, being paid by government funding [Heppenheimer 1995]. For example, according to Airbus, the B707 that enabled Boeing

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[17] For example, in the early 1990s, Airbus offered steep discounts to establish its A320 narrow-body planes in the North American market. Airbus sold A320s to Air Canada, America West, and Northwest, which received $500 million in soft loans as an inducement, raising the tensions between the European and American companies [Europe Magazine 1999].

[18] The initial development costs for the A380-100 has been estimated at roughly $9 billion and another $2 billion may be needed for developing variants of the A380 [Dow Jones Newswires 2000].

[19] It has not been possible for the author of this report to find the total figure for the state aid provided to the A380 programme. But for example Rolls Royce's engine division has received around $363 million in repayable state loans for developing their Trent 900 engine that is to power the A380 and BAE Systems is greeted around $770 million for their stake in the airframe development [Financial Times 2001a]. Likewise, the German government invests $912 million for the development costs of the A380 [Pethel 2000] while the French government is reported to offer 8 billion French Francs [Dow Jones Newswires 2000]. According to U.S. Congressman William Lipinski airbus' suppliers also receive government aid.

to enter the market for commercial civil jets in the late 1950s cost only around $180 million (in current US$) to develop because the military carried the burden of the development costs (estimated at $2billion in current US$), for a tanker version, the KC 135. Also, again according to Airbus, since 1994 the U.S. aerospace industry has received some $9 billion as non-repayable financial support from the U.S. government. Furthermore, aircraft are often sold at artificially low prices to launch customers, for example Airbus are reported to have sold the A380-100 at up to 40 percent below the list price [Newsweek 2001] [Aviation Week and Space Technology 2000]. Boeing officials therefore claim that Airbus does not make money on the launch orders [Perrett 2000]. Governments also accuse each other of offering cheap loans to airlines that purchase aircraft of a certain brand [Financial Times 2001b and 2001c].

Secondly, some airlines receive direct state aid from their national governments. For example, six European airlines (Sabena, Iberia, Aer Lingus, TAP, Air France and Olympic) received around 8 billion ECUs in subsidies and around 1,2 billion ECUs in state loans in the early 1990s [Hanlon 1996, p.26]. In the future, the Commission is set for not allowing new State aids, except for "truly exceptional and unforeseeable circumstances" [Van Miert 1998]. In the period between 1994-1996 average yearly European direct state aid for air transport amounted to more than 2 billion EURO, but fell to around EURO 1,1 billions per year in the period 1996-1999. The Commission expects the figure to drop further in a transitional period in the future, before phasing out state aid for air transport in the European Union entirely [CEC 2000c]. Furthermore, airlines are given indirect subsidies by not paying jet fuel tax, and by not paying VAT on tickets and jet fuel, and by being allowed duty-free sales. Environmental NGOs furthermore claim that airlines ought to pay environmental taxes to cover the external environmental costs associated to airline operation. For example, the environmental NGO Friends of the Earth claims that these indirect subsidies add up to at least 45 billion EUROs[20] per year in the European Union countries alone [FoE 1998].

Thirdly, according to a World Bank study [Kapur 1995], global investments for airport infrastructure, that is modernisation of existing capacity and construction of new capacity as well as new air traffic control (ATC) services and intermodal linkages, could

exceed $500 billions in the period between 1995-2010. A large part of these investments are likely to be financed by government funding. A study examining sources of airport funding in more than 60 countries has shown that two thirds of all airports receive some sort of government assistance. Recently, newly built major airports are reported to cost around $7 billion on average, though some major projects are excessively more expensive [Kapur 1995]. The environmental NGO Friends of the Earth (FoE) give some recent examples of the subsidisation of airports. According to FoE newly built airports in Malaysia and Hong Kong received in excess of fifty percent of airport investments as government funding. Such government funding adds to build up airport capacity cheaper than what would have been possible if only private investors were involved.

2.4.5 Economic growth policy

Historically, new innovations in technologies and production methods have brought forth ever-increasing improvements in productivity thereby allowing population and consumption to grow. Grübler [1998] estimate that, since the 18th century, the labour productivity in industry and agriculture has improved by at least factors of 200 and 20 respectively on a global scale. And economic growth of around three percent per year in the period has brought about a factor 200 higher economic activity.

Probably the most important aspect of passenger air travel growth is the political focus on economic growth, being a main political goal for most governments throughout the world [Michaelis 2000]. Economic growth contributes to rising travel for both business and leisure. Business travel is furthered by economic growth in the sense that increasing flows of products and money generates the need to communicate more and more. Rising disposable incomes, being a direct result of economic growth, further leisure travel by allowing people to choose to buy more luxurious goods and services, for instance passenger air travel. The propensity for leisure travel by air is highest for people living in high-GDP countries, see Figure 2.9, and also among the richest people within a country, see Table 2.1. Therefore, as long as economic growth is given top priority and continues to generate increased communication needs for businesses as well as real income rise, people seem likely to fly more.

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[20] Of these 45 billion EUROs FoE claims that some 17.5 billion EUROs are due to the exemption from paying jet fuel tax and some 6,5 billion EUROs are due to exemption from This footnote continues on the next page.

Figure 2.9: Yearly per capita Gross Domestic Product (GDP) versus passenger kilometres[21] per capita for selected countries
Sources: RPKs are from [ICAO 1998a], GDP is from [United Nations 2000a] and population is from [United Nations 2000b].
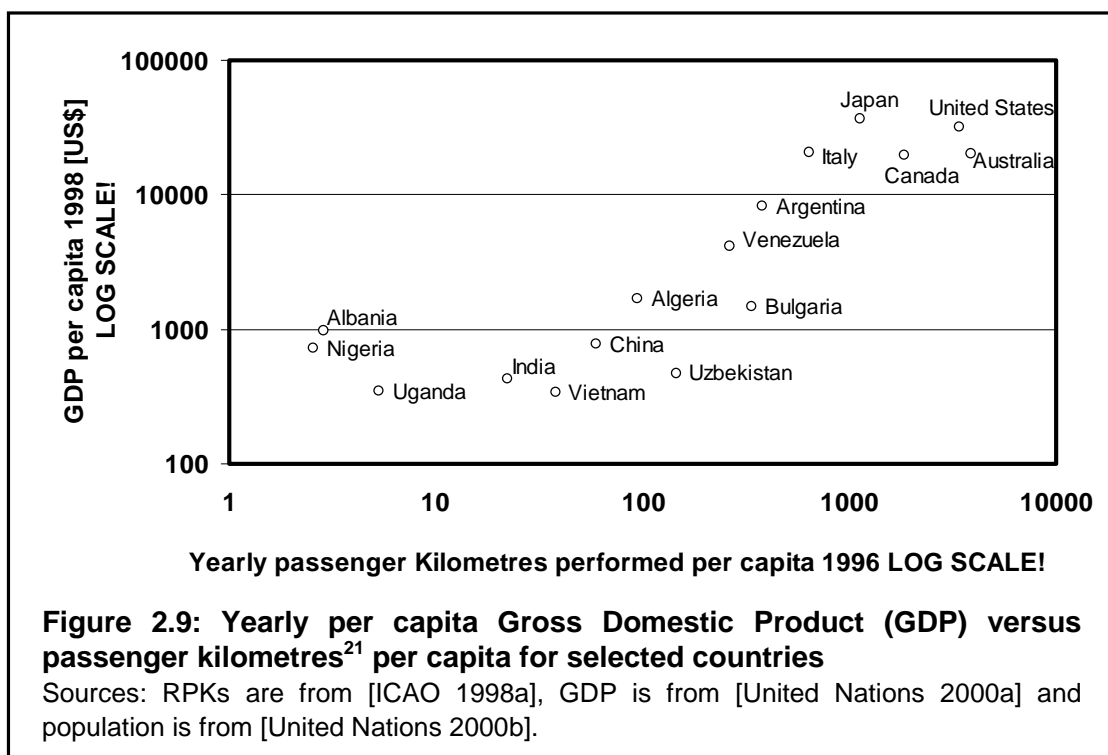
As shown in Table 2.1, in 1990, about 75% of people living in US households with income above $100000 travelled by air. However, when moving down through lower household income categories the use of air trips seems to decline [Pitt and Norsworthy 1999]. Similar tendencies are shown in surveys of Swedish, Danish and Norwegian citizens' use of air travel suggesting that high-income groups tend to fly more than low-income groups[22] [Carlsson-Kanyama 1999] [Transportrådet 2001]. Furthermore, according to the Danish survey, the wealthiest sixth of the Danish population,

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paying VAT on tickets.

[21] Note that the distribution of passenger kilometres per capita between countries that are shown in Figure 2.10 are based on airline reporting on passenger kilometres flown. These passenger kilometres have been distributed (by the author of this report) between countries by attributing them to the nations in which the airlines are based. There is a methodological problem connected to this procedure of distribution because the airline industry is a truly international business, and airlines of one country can transport passengers from another country. Thereby the estimate for passenger kilometres flown per capita may be overestimates for the countries in which the major hub airports are situated. The methodological problem arises because of the lack of reliable data on the nationality of airline passengers in the airline statistics published by ICAO and IATA.

[22] This tendency is even more significant for business trips than for leisure trips.

measured by personal income, performs around half of all air trips[23] [Transportrådet 2001].

Number of households (000)	Penetration	Income category [000 $]
4085	75%	100+
5100	68%	75-100
8437	56%	60-75
13859	45%	40-60
31461	31%	20-40
17287	18%	10-20
14085	11%	10 or less

Table 2.1: Penetration of household air travel by income class in the US, 1990 [Pitt and Norsworthy 1999].

2.4.6 Increasing income and reduced real airfares

The airlines' airfares are constantly reduced, when measured in real terms. This is one of the main reasons why the number of people who can afford travelling by air is rising, leading to increasing passenger air travel. Indices of the reduction of the real airline yield per revenue passenger kilometre (RPK) is shown in Figure 2.10 based on the average yield per RPK of the World's airlines and US scheduled airlines since 1960 and 1950 respectively. These data suggest that the real average airline yields have been reduced by something like a factor of four in the 50-year period. US airline yield per RPK only doubled in the period while personal disposable income per capita grew by a factor of 17, both measured in current US$, see Figure 2.10.

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[23] Note that the Danish travel survey cited here only provide data on the number of trips, but not their length. Therefore the distribution on income groups of the passenger kilometres and the related fuel consumption may be otherwise than the distribution of trips.

Figure 2.10: Development in average US airline yield per RPK and average US disposable personal income 1950-1999 and comparison to world average yield 1960-1997

Sources: Average US airline yield per RPK is from [Air Transport Association 2000b]. World average yield per RPK is from [DTI 1999]. US personal disposable income is from [US Economic Time Series 2001]. US consumer price index is from [US Bureau of Labour Statistics 2000]

In the commercial civil air transport sector's early days passenger air travel was an expensive privilege for the rich and a rather time consuming adventure. For example, when Pan American Airways opened the first passenger service from the US to the Philippines in the mid-1930s, using four-engine flying boats, it took six days and five intermediate stops on small islands along the way to get there. The 1936 round-trip fare to Manila was $1438 (corresponding to around 18000 US$ in 2000 if measured in real terms using the U.S. consumer price index), a years wage for a working man in that period [Heppenheimer 1995, p. 71]. Today, the average fare on international routes is around 8,2 US¢ per RPK but fares are much lower on intercontinental flights. For example, on routes across the North Atlantic the average fare is around 5,5 US¢ per RPK, and the cheapest economy-class tickets as well as the fares on charter flights are even lower[24] [ICAO 2000d]. This is why, for example in the spring 2000 it was possible to buy low-cost scheduled round-trip-tickets from London to the US at around

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[24] Note that these fares are for 1997.

$300 (corresponding 3 US¢ per RPK)[25]. The emergence of low-cost scheduled airlines has also made possible excessively cheaper flights[26] (as compared to the normal economy fares of scheduled flag carriers) on more local routes where there is competition between airlines. For instance, in autumn 2000, the lowest round-trip fare with British Airways' subsidiary GO, when flying between London and Copenhagen was as low as $59 (500Dkr), or around 3 US¢ per RPK[27].

On many routes established flag carriers dump their cheapest fares to be able to compete with the low-cost carriers, see Figure 2.13. These excessively cheap flights can hardly cover the average costs connected to airline operation[28], but are only possible because airlines can sell the last tickets at almost any price. This is because of the marginal increase in revenue that can be attained from filling up the seats that would otherwise be empty [O'Connor 1995]. A further discussion on the average costs and fares of airlines is given in Chapter 4.

2.4.7 Airline yield management systems

One important aspect in understanding the impact of fares on passenger air travel growth is that the airlines optimise their fare structures as to attract as much yield per flight as possible by using different yield management tools. Most notably, airlines often offer a range of different fares at each flight, business travellers generally paying a much higher fare than leisure travellers do. This is because business travellers are generally willing to pay higher fares, making business traveller demand less price- and income elastic than leisure travel [O'Connor 1995] [Hanlon 1996]. The last tickets sold for a given flight can in principle be sold at very low prices, as to optimise the revenue marginally. This is one important factor contributing to passenger air travel growth. Passengers travelling at reduced (discount) economy fares are thereby indirectly subsidised by business travellers and economy passengers travelling at full fare [Shaw 1983] [O'Connor 1995] [Hanlon 1996]. Furthermore business travel is in itself often

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[25] These prices were shown in adverts in the papers in the United Kingdom in the period in question.

[26] For an overview of the total operating costs per revenue tonne kilometre of low-cost scheduled and charter carriers as compared to scheduled flag carriers see Chapter 4.

[27] These prices were shown in adverts in the papers in Denmark in the period in question.

[28] For example, in 1997 Ryanair's (Ryanair being a no-frills low-cost carrier) average operating cost per revenue passenger kilometre has been estimated at around 12 US¢ [Mason et. al. 2000].

indirectly subsidised because companies can deduct travel expenses against taxes [Shaw 1983, p. 18].

Another important aspect is "frequent flier programmes" aimed at generating customer loyalty towards certain airlines, which are thereby able to sustain high-fare passengers. Customers earn "airmiles" that can later be exchanged into free or discounted tickets. Often "airmiles" are used for private leisure trips even though earned in business travel. In this way business travel indirectly generates and subsidises additional leisure travel [Shaw 1983] [Hanlon 1996].

Another aspect that is closely related to airline yield management is advertising creating additional demand for air travel by influencing peoples' preferences for air travel and holiday destinations. Advertising is also an important tool for informing people about discounted fares and last minute offers. Air travel advertising has become an important part of the media picture. Most newspapers advertise for air travel, and increasingly new media such as the Internet and Television Text is used. A special feature of the Internet is that it has become possible to book and buy tickets directly from personal computers at home or work, thereby to some extent substituting travel agencies and reducing airline costs. Increasingly, tickets are sold cheaper through the Internet than through travel agencies, as airlines seek the cost advantage.

2.4.8 Airline market competition

The competition between airlines leads to lower fares thereby generating more passenger air travel. Historically, the airline market has grown up with national flag carriers being dominating and enjoying more or less monopolistic status in many countries. In recent decades the United States and Europe have liberalised their domestic markets [Hanlon 1996]. Thereby new airlines have emerged, some of them offering low-cost no-frills service competing with established flag carriers pressing down fares on certain routes [Mason et. al. 2000] [Sull 1999] [Aircraft Economics 1999e].

For example, low-cost scheduled-only carriers have considerably lower operating costs on busy short-range European routes than traditional flag carriers. A number of studies estimate the operating costs of flag carriers at around two times the costs of their low-cost competitors on comparable routes [Mason et. al. 2000] [Sull 1999] [CAA 1998].

Therefore, on those routes where low-cost carriers have entered the market, fares have been reduced significantly. This is not only a consequence of the low fares of low-cost airlines, but also a consequence of flag carriers promoting cheap economy fares at almost the same low level to keep the new entrants out of market [Sull 1999]. In Europe, scheduled fares seem to mainly have been reduced on domestic markets on routes with competition and on dense intra-European routes [CAA 1998]. One consequence of the emergence of low-cost carriers has been a significant air traffic growth on dense European routes. For example, the number of scheduled airline passengers travelling between Dublin and London almost doubled from 1.7 million passengers in 1991 to 3.3 million passengers in 1996, after Ryanair entered that route. A demand increase said to have been dubbed the "Ryanair effect" by industry analysts [Sull 1999, p. 27].

Currently, no-frills scheduled carriers hold about 4% of the intra-EU market, but this share is envisaged to expand to between 12% and 15% over the next decade. Because there is much charter traffic within Europe[29] it is not expected that no-frills scheduled carriers will reach the same high level of the intra-EU market, as is currently the case in the US domestic market (40%) [Mason et. al. 2000, p. 91]. Costs and fares of passenger air travel may be reduced further in the future as airlines introduce new more efficient aircraft, thereby improving productivity, and cut labour- and other costs further. However, there are counter-acting tendencies such as increasing airport charges and limited airport capacity which lead to higher costs and lower productivity due to delays [Mason et. al. 2000]. Furthermore the possibility of governments introducing market-based measures to reduce the environmental problems connected to air traffic become increasingly apparent [FoE 2000b] [Wickrama 2001]. Another counteracting tendency may be the continuation of the increasing tendency of creating

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[29] Note that these European charter carriers operate at substantially lower costs than their low-cost no-frills scheduled counterparts. In 1997, the operating costs per RPK for European low-cost scheduled-only carriers was generally around 12 to 16 US¢ per RPK (Debonair 16 US¢/RPK, easyJet 15 US¢/RPK and Ryanair 12 US¢/RPK). Some European low-cost scheduled carriers (Air Europa, Spanair and Virgin Express) also perform in the charter market and therefore have operating costs per RPK in the order of 6 US¢. Charter-only carriers generally have lower operating costs per RPK than their scheduled low-cost counterparts, although there is considerable variation between carriers. The most efficient European charter carriers (Caledonian, Monarch and Air 2000) have average operating costs per RPK around 3 US¢ [Mason et. al. 2000, p. 67-69].

airline mergers and alliances that has been experienced in the last decade [Hanlon 1996].

Despite being a high growth sector, the global airline industry is generally not as profitable as other industries. The airline industry's yields are very close to costs and with significant losses in several periods, most markedly the early 1980s and the early 1990s, see Figure 2.11. This leaves the impression that if also taking account of government subsidies for commercial civil air transport's socio-technical system as such, the commercial civil air transport sector may not be profitable and therefore operating at "artificially" low prices, which again helps to generate and maintain passenger air travel growth.

Figure 2.11: Operating revenue and operating result of ICAO scheduled airlines[30] 1947-1999
Sources: [ICAO 1998c] and [ICAO 2000b].
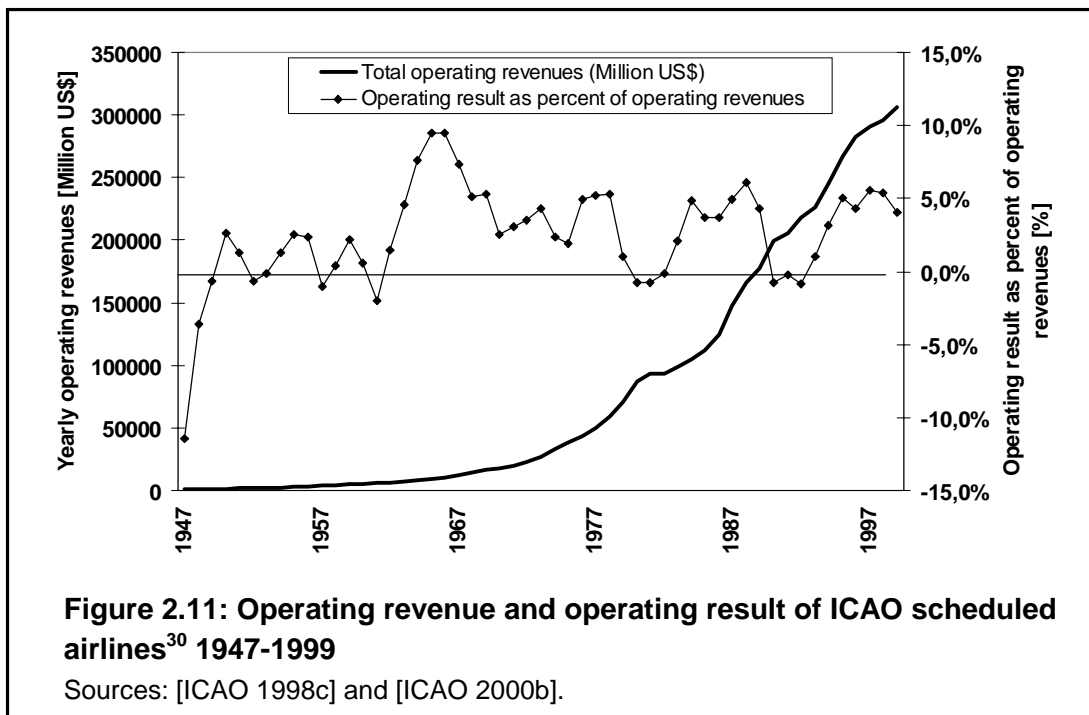
2.4.9 Globalisation

We live in a world that seems to be shrinking because jet powered aircraft makes it possible to travel over ever-longer distances at ever-reduced real costs. Furthermore, global communication networks facilitate real-time electronic communication over long distances thereby for instance disseminating news from around the World faster than

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[30] Note that these data do only include airlines reporting to ICAO.

ever. Also the financial market becomes increasingly global and governments seem to be loosing some of their sovereignty. Giddens [2000] has dubbed this phenomenon of globalisation "a runaway world" where for example global environmental problems and risks that cannot be solved at the national state level become more apparent and seems to call for more global collaboration between countries to regulate these global issues. The increasing globalisation thereby reshapes our political, technological, cultural and economical surroundings.

Increasingly, political forums and large business corporations become part of a global system. Liberalisation of markets and the creation of multinational trade agreements further globalisation of businesses. Alongside, political forums such as the World Trade Organisation (WTO), the European Union (EU) and United Nations (UN) are built up. The globalisation of businesses and political forums furthers the need for communication across national borders, thereby spurring passenger air travel growth. One further aspect of this is that an increasing amount of people are employed abroad thereby generating additional leisure travel for visiting relatives and friends in their home countries. Furthermore, networks of friends may become increasingly global, and more people may meet their spouse abroad, generating migration and new family ties across borders and over longer distances. Employees of business corporations as well as politicians and civil servants are typically high-yield customers travelling on business- and first class, thereby indirectly subsidising low-yield economy-class leisure travellers [Hanlon 1996] [O'Connor 1995]. Globalisation of trade, business corporations and political forums thereby become strong drivers for passenger air travel growth.

2.4.10 Population growth and distribution of wealth

The World's population doubled from three billions to six billions in the forty-year period between 1960 and 2000, and is projected to increase to nine billions by the middle of this century. Clearly, population growth is an important aspect of passenger air travel growth. Neither air travel or population growth is evenly distributed among countries. People living in highly industrialised countries generate the bulk of passenger air travel and airfreight (see Figure 2.12) [IATA 2000d] while the distribution of population growth is generally reversed [World Bank 2001]. The effect of population growth as a driver for passenger air travel growth is strongest when population is growing in industrialised countries. However, countries that are currently less industrialised may achieve stronger economic growth in the future, thereby generating passenger air travel growth.

For example, if people currently living in China and India flew as much per capita each year as Europeans currently do on average, they would alone generate almost as much air traffic per year as is currently generated globally[31]. Another driver is increasing migration leading to increased passenger air travel when immigrants visit friends and families in their previous home countries.

Figure 2.12: Major Traffic flows between regions of the world 1999 Scheduled services performed by IATA member airlines
Source: [IATA 2000d]

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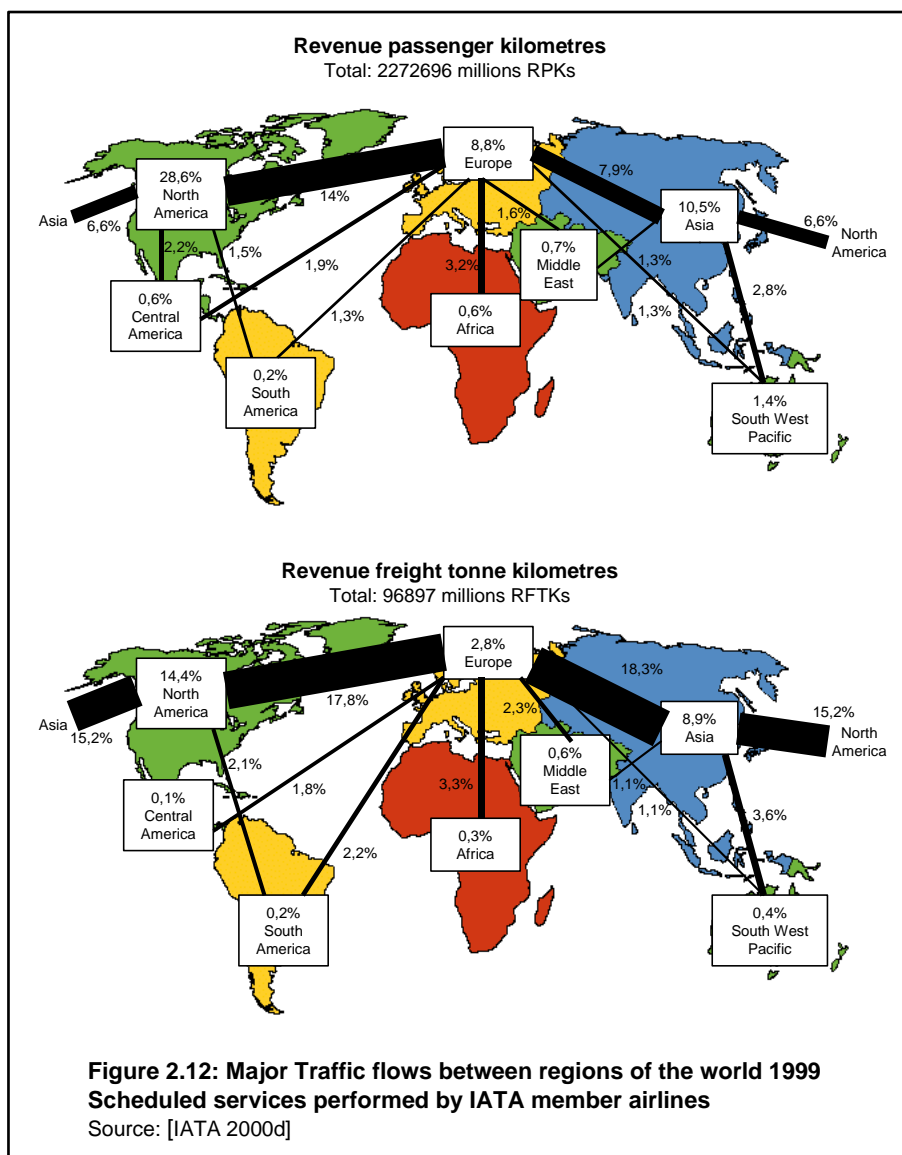
[31] Based on an estimate of the size of the populations in India and China of around 980 millions and 1239 millions in 1998 [World Bank 2000] and an average passenger air travel per capita of around 1200 kilometres per year in Europe in 1998, adding up to around 2700 billions of This footnote continues on the next page.

2.4.11 Other social factors

The modern western working culture can be seen as an important precondition for passenger air travel in industrialised countries by allowing employees to take time off for weekends and holidays. Before the industrialisation most people were, for several reasons, more or less bound to their homes, but today people have to some extend been disengaged from their homes and furthermore tend to have an increasing amount of free time available [Frändberg 1998]. Furthermore, a stressful working culture generates the need for people to take some time off, to escape the "cage of routine" [Frändberg 1998] [Læssøe 1999] [Corrigan 1997]. Another aspect of our working culture is that employees are typically encouraged to split up their yearly holidays into several small entities. Thereby, for example a two-week summer holiday can be supplemented by one-week holidays at other times of the year. For example, in Denmark, it is relatively common to travel to Southern Europe on skiing holidays in the wintertime or to go sunbathing in the Far East or in the Canary Islands. An almost overwhelming example of how cheap such off-season trips can be is illustrated by the ad to the right side of Figure 2.13 that has appeared in various versions in recent years. In this ad the travel agency offer seven days of Christmas shopping in Beijing for the price of 3995 Danish Kr including hotel accommodation and breakfast. This price corresponds to around $470[32]. The emergence of weekend trips to far-away places is a further development of this issue. For example, in Denmark, London has become a major short-stay leisure destination after GO and Ryan Air entered the route with low fares. The ad on the left-hand side in Figure 2.13 exemplifies that, to be able to compete with these low-cost carriers, the Scandinavian flag carrier SAS promotes cheap discount fares. Another example is that, in the spring 2000, British travel agencies advertised in various British newspapers for one-day whale spotting trips to Iceland. And at the other end of the scale we experience the emergence of an increasing amount of for example young people being able to take a year off from their work or educational occupation travelling around the globe with several stopovers.

The population is ageing in industrialised countries. Ageing populations may generate more passenger air travel, especially if elderly people who are retired from work have adequate resources for travelling by air. People on retirement generally have adequate

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passenger kilometres as compared to the approximately 3000 billion passenger kilometres transported by the World's airlines in 1998.

time for travelling, and many are also in a better economic situation than earlier generations. Therefore, ageing population may generate additional leisure travel in the future.

The demand for passenger air travel is generally not evenly distributed among age groups within a population. Younger to middle aged generations tend to fly more trips in a year than children and elderly people on retirement [Carlsson-Kanyama and Linden 1999] [Transportrådet 2001]. However, the current trend shows that younger generations tend to travel even more than what was the case for the previous generation at the same age. Some sociologists assume that air travel will grow in the future because each new generation tend to fly more than the previous generation, and because each generation is assumed to sustain the travelling culture as they become older [Carlsson-Kanyama and Linden 1999].

Figure 2.13: Examples of discount fares from Danish newspaper ads

Basically, holidays often fulfil many types of individual needs, wants and desires. Some common types of holiday purposes are relaxation, adventure, personal relations, education and so on. Some common types of activities performed through holidays are sunbathing, eating, drinking, talking, sight spotting, shopping, walking, driving, hiking,

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[32] Based on an exchange rate of 856 Dkr per 100 US$ in December 2000.

climbing, swimming, and so on. The list is endless. Travellers create new private or professional relations to people in other countries, while exploring foreign geographical sites and cultures. Another purpose is to visit family and friends and doing something together with travel companions. For instance, daily life routines may not allow parents to see their children much in everyday life. A holiday abroad gives the chance to be together while creating common histories to be remembered. In the early days of commercial civil air travel some 80 percent of passenger trips by air were business related, while leisure and holidays only accounted for approximately 20 percent [Hanlon 1996]. Today, this mix has been reversed and some 60-75% of the passenger kilometres flown by air relates to leisure- and holiday activities [Frändberg 1998].

People are driven by personal desires to explore new territory and cultures and create new professional and social relations. Individual needs, wants and desires are to a large extent shaped by social values and norms [Douglas et. al. 1998] [Kuehn 1999]. For example, passenger air travel is a significant social status maker, and choice of destination depends on what is fashionable and trendy. One such trend is a tendency to travel further away, deeper into the jungle and higher up in the mountains. Nearby holiday destinations that used to be popular are supplemented and to some extent substituted by far away places. Air travel has become an important part of peoples' identity creating "travelling cultures". Young generations in industrialised countries are born into a travelling culture finding it natural to travel by air [Urry 1999].

Studies into the sociology of consumption has shown that individuals seek to position themselves in their social surroundings by consuming [Douglas et. al. 1998] as for instance by choosing prestigious types of holidays and destinations [Corrigan 1997]. For example, backpackers often choose other types of travel and destinations than do mainstream charter tourists. Backpackers often seek new territories that have not yet been overtaken by charter travellers, and therefore considered more original. Backpacker travel and accommodation is often basic and cheap, and often acquires more available time for getting around than do mainstream charter travel. Likewise, high-yield leisure travellers tend to prefer types of travel, destinations and hotels that are more expensive and considered more luxurious or exotic than the cheaper mainstream mass-tourism resorts. Expensive Caribbean Sea cruises and Concorde flights between London and New York reigns among types of holiday travel that may be considered extremely luxurious and prestigious. To some extent people choose the

type of holiday that fits their general lifestyle and social class, some basic limitations being available time and economic and social resources.

2.5 Impeders to passenger air travel growth

After having described some of the drivers in the model in Figure 2.5 of the determinants of passenger air travel growth we now turn to describe some current as well as some possible future impeders.

2.5.1 The role of infrastructure planning

Many of the world's busiest airports are today congested. Long-term air travel growth therefore depends on the enlargement of airport infrastructure and on the implementation of new and more efficient air traffic management systems[33]. Especially in the US and Europe, many airports are now operating at their maximum capacity through peak-hours. Some airports wish to expand capacity, but find it increasingly difficult to get approvals for new runways and terminals, mainly because of environmental regulations or land-use constraints [Mulcahy 2001]. In Europe and the United States, a number of NGOs, most often established by citizens living in the vicinity of large airports, are opposing plans for enlarging the capacity [Mulcahy 2001] [HACAN 2000] [FoE 2000a and 2000b][34]. Planning initiatives to stop enlarging the airport capacity as well as strategies aimed at favouring alternative modes of travel such as rail, sea and road based transport may therefore in the future contribute to reduce air travel growth.

2.5.2 Alternative lifestyles, alternative society modes and catastrophes

Social factors, such as changing values and norms, may reverse trends in passenger air travel. The social acceptance of air travel may dampen if signs of climate change become more present. Other major changes or catastrophes, such as wars and economic downturns and oil supply crisis as well as for example an increase in the amount of hijackings, may also contribute to reduce the growth in passenger travel. Furthermore, as air travel reaches a higher penetration in the population, and more and

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[33] The use of bigger aircraft may also add to the capacity of airports.

[34] Some examples of European environmental NGOs that oppose expansions of the capacity of major airports are for example The Environmental Organisation of Copenhagen (Kastrup Airport), HACAN Clear Skies (Hethrow Airport), Coalition Against Runway 2 (Manchester This footnote continues on the next page.

more people can afford travelling to remote parts of the globe, the social prestige connected to air travel might well diminish. Long-term impeders to passenger air travel may be the emergence of alternative lifestyles and alternative society modes. New working structures, including fewer but perhaps longer-lasting holidays, might emerge as a first step. On the longer term changing values and preferences might emerge. People may choose more simple modes of living, implying for instance the choice of less labour work, more free time and less increase in income (than what may otherwise have happened). In such a scenario people may well reduce their travel patterns, for instance by choosing nearby holiday destinations. The stride for economic growth, and the current appraisal of market forces and globalisation may also be halted or slow down.

2.5.3 Possible future environmental policies

The commercial civil air transport industry has until now not been subject to international regulations aimed specifically at reducing aircraft greenhouse gas (GHG) emissions. Rather, standards issued by ICAO set limits for aircraft noise and engine emissions in and near airports [ICAO 1993 and 1998b]. However, the industry may soon be facing new environmental policies that can to some extent contribute to reduce the GHG intensity as well as the growth in passenger air travel. Some of the most commonly suggested policies are listed below:

♦ Economic means that reduces the demand for passenger air travel and airfreight and/or increases the airlines' incentive to reduce their emissions, i.e. a jet fuel tax[35], a passenger tax, landing charges, an emission tax[36] and/or emission trading schemes[37] for commercial civil air transport.

Airport), Notgemeinschaft der Flughafen-anlieger (Hamburg Airport) and Erzhäuser Bürgerinnen und Bürger gegen Fluglärm (Frankfurt Airport).

[35] See for instance Chapter 4 that describes the possible future effects of a kerosene tax.

[36] See for instance Bleijenberg et. al. [1998] for a discussion of the environmental effects of taxes on tickets, landings and emissions.

[37] E.g. the possibility for the commercial civil air transport industry to trade emission quotas either in a "closed" system within the industry or in an "open" system including trade with other industries. See for instance Wickrama [2001] and Hewitt and Foley [2000] for a discussion of how an emission trading system could function and what the possible effects may be for commercial civil air transport. See also Ott and Sachs [2000] for a discussion of the ethical aspects related to emissions trading.

♦ Voluntary agreements[38] with the aviation industry, i.e. certain reduction targets to be met by the commercial civil air transport industry such as targets for the future improvement of airlines' average fuel efficiency and targets for the future improvement of the fuel-efficiency of next-generation aircraft.

♦ Regulatory means for improving aircraft technologies and operational procedures, i.e. in-flight emission standards for new aircraft, speed limits, "old for new" aircraft scrapping schemes[39] and/or banning operation with the oldest aircraft[40].

♦ Regulatory means for reducing the demand for commercial civil air transport, i.e. personal passenger air travel emission quotas limiting individual mobility patterns[41] as well as promotion of railway infrastructure and restrictions to expanding airport capacity[42].

♦ Cancelling direct and indirect subsidies for the commercial civil air transport sector. That is, direct subsidies for producers of aircraft and engines and for airlines and airports as well as indirect subsidies such as the commercial civil air transport industry's exemption from paying VAT and kerosene tax and its allowance to maintain duty free sales[43].

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[38] A voluntary agreement on average aircraft fuel-efficiency may be one part of a solution in line with what has been agreed between the European Community and the car industry [CEC 1997b], see for instance CEC [1999a].

[39] "Old for new" scrapping schemes is a measure that has been suggested by representatives of British Airways. The suggestion is to let airframe producers buy back and scrap old fuel intensive aircraft each time they sell a new aircraft. Such a scheme could potentially secure earlier scrapping of old aircraft than what would else happen [Muddle et. al. 2000] [Cooper 2000].

[40] Such bans exist, but are primarily aimed at prohibiting the use of the noisiest aircraft [ICAO 2001d]. So-called Chapter 2 aircraft can be hush-kitted to apply to the Chapter 3 noise standard but in some cases this even increases the fuel intensity [IPCC 1999].

[41] A proposal for a sustainability target for GHG emissions from commercial civil air travel as well as a corresponding yearly budget for passenger air travel are suggested in Chapter 5 of this report.

[42] NGOs seem to mainly to focus on three aspects of the need to reduce the expansion of airport capacity namely on reducing the total number of flights and reducing the use of the oldest and most noisy aircraft and on banning night flights [FoE 2000b] [Mulcahy 2001].

[43] See for instance FoE [1998] and Lipinski [2000] for a discussion of the magnitude of government subsidies to commercial civil air transport.

- Cancelling indirect subsidies to business travellers, i.e. the ability of companies to deduct their travel expenses against taxes and the ability of frequent business fliers to use airmiles earned through frequent flier programmes for private trips.

- Support for research into and development of more environmentally benign aircraft technologies and new improved air traffic management systems.

- Institutional measures, e.g. the necessity of creating new institutions that can promote lifestyle changes or the need of creating a supranational organisation that can implement and police for example global agreements on GHG reductions or economic measures such as a global jet fuel tax[44].

- Behavioural measures, e.g. information campaigns that aim at enlightening the public on commercial civil air transport's possible impact on climate change as well as on giving information on possibilities for changing lifestyle in more appropriate directions[45].

- Other policies aimed at changing the driving forces behind transport growth through adapting policies in economics, labour, etc. towards transport patterns in appropriate directions. Some examples could be to aim policies at impeding globalisation or at reducing economic growth rates[46].

For example, a tax on kerosene or emissions will increase the price of passenger air travel, thereby reducing air travel growth, while also increasing airlines' incentive to operate more fuel-efficient aircraft and to optimise load factors and other operational features. The possible effect of a tax will obviously depend much on the level of tax applied. Most studies expect that the reduction of passenger air travel demand will be

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[44] See for instance Sandler [1997] for a discussion of the need for a supranational infrastructure for policing GHG reduction targets and for collecting and distributing global taxes.

[45] See for instance Christensen and Nørgaard [1976] and Linden and Carlsson-Kanyama [1998] for a discussion of the limitations of information and education and the importance of the primary socialisation, that is experiences from the pre-school age.

[46] See for instance Christensen and Nørgaard [1976], [Meadows et. al. 1972], Sachs [1998 and 2000], Bossel [1998] and Durning [1991] for a discussion of the need to shift focus from measuring wealth by economic GDP growth and material well-having towards focusing on material sufficiency and well-being.

rather insignificant because ticket prices will not rise much unless a rather high tax level is implemented[47]. This is discussed further in Chapter 4 that gives a review of a number of studies that have assessed the likely future environmental impact of a jet fuel tax. On the longer term however, some definite cap for the total allowable greenhouse gas emissions from commercial civil air transport might be needed, leading for instance to certain emission quotas per capita[48]. This is discussed further in Chapter 5 that discusses some of the main challenges facing an environmentally sustainable commercial civil air transport system and proposes some limits for the amount of air travel performed per capita within certain sustainability targets.

The implementation of any of these policies may likely slow down passenger air travel growth. However, no single policy seems to be appropriate for creating an environmentally sustainable commercial civil air transport system. Rather, a mix of some of the policies above seems to be needed. In section 2.6 the current status on the discussion of the possible future introduction of some of these policies is presented.

2.6 The current political setting

This Section explains in brief the positions of some of the actors on the political scene towards the environmental impacts of commercial civil air transport.

2.6.1 The position of the environmental NGOs

Around the World, a number of environmental NGOs and protest groups that are concerned specifically about the environmental problems connected to commercial civil air transport have emerged. Initially, citizens living in the vicinity of major airports founded most of these NGOs. Although many of these local NGOs are mainly focusing on the noise issue their campaigns have in the last few years been directed towards also focusing on other environmental problems such as climate change.

In Europe, the local NGOs co-operate in a network that has been organised by some European umbrella-NGOs such as the European Federation for Transport and

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[47] See for instance the following kerosene tax studies: [Barrett 1996] [OECD 1997] [Resource Analysis 1998] [Bleijenberg et. al. 1998] [NSN 2000] [Wickrama 2001] [NEI 1997] and [Brockhagen and Lienemeyer 1999].
[48] See for instance Spangenberg et. al. [1994] or [Wackernagel 2000] for a discussion of the limited consumption levels that would be appropriate within a "sustainable space".

Environment (T&E) [T&E 1998a and 1999], Friends of the Earth (FoE) [FoE 1996, 1998 and 1999], the Netherlands' Society for Nature and Environment [NSN 2000] and the Aviation Environment Federation (AEF) [AEF 1999a and 1999b]. This network have in the last five years intensified their pressure on governments to reduce the environmental impacts associated to commercial civil air transport [FoE 2000b].

In their various campaigns the NGOs pledge for European governments and the European Community to adopt stricter standards for noise and emissions, to ban night flights, to stop airport expansion, to ban hush-kitted aircraft[49], to introduce environmental taxes and charges and to stop direct as well as indirect economic subsidies to the sector, i.e. direct subsidies for aircraft and engine manufacturers, airports and airlines as well as indirect subsidies through exemptions from VAT, kerosene tax and duty free sales [FoE 2000b].

The European NGOs run campaigns at all the levels ranging from local communities and airports over national governments and authorities to political forums on the international level. On the local and national levels the NGOs for example arrange demonstrations and happenings at airports and send petitions and complaints to the local authorities[50]. At the international level the umbrella NGO's have run a series of campaigns focusing on national governments and the European Community[51] as well as the international climate negotiations in Kyoto and the further work in the United

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[49] A hush-kitted aircraft has been equipped with a noise muffler to apply to the current noise standard. However, hush-kitted aircraft are still considerably more noisy than the most modern aircraft. In some cases the muffler also increases the fuel intensity of the aircraft.

[50] For example, the Heathrow Association for the Control of Aircraft Noise (HACAN) has set up a so-called SkyWatch initiative where people suffering from aircraft noise can complain. This is intended to raise the number of complaints posted to British Airport Authorities [HACAN 2000]. Another type of local initiative has been initiated in the Netherlands where the organisation Vliegtax-strohalm request companies and air travellers to voluntarily pay jet fuel tax. The income is used by Vliegtax-strohalm to invest in environment-friendly energy supplies etc [Vliegtax-strohalm 2001].

[51] For example, Friends of the Earth Netherlands has published reports on the need for jet fuel taxes [FoE 1996] and on the need to abolish subsidies [FoE 1998] and on the need to stop the expansion of the capacity of airports [FoE 1999]. And the European Federation for Transport and Environment has published reports on the need for jet fuel taxes [T&E 1998a] and on the environmental impacts of commercial civil air transport [T&E 1999]. Furthermore, the network has arranged a series of campaigns such as "The right price for air travel" [The 'Right Price for Air Travel' Campaign 1999a] and the "Dialogue on aviation and the environment" [C&E 2000] and "Clear Skies" [FoE 2000b].

Nation's Framework Convention on Climate Change (UNFCCC) and in the Intergovernmental Panel on Climate Change (IPCC). Logos used for some of the campaigns run by NGOs is shown in Figure 2.14[52]. In recent years the NGOs have also stepped up their efforts to start up a dialogue between the green organisations, the decision-makers and the commercial civil air transport industry and a series of conferences have put air transport's environmental impact on the agenda [ECAC 1997] [Immelmann 2000] [SCAN-UK 2000] [C&E 2000].

Recently, the European environmental umbrella NGOs, in co-operation with NGOs from around the World, formed the International Coalition for Sustainable Aviation (ICSA)[53] to step up the international pressure for global initiatives. ICSA has been granted the role of observer in the International Civil Aviation Organisation's (ICAOs) Committee on Aviation Environmental Protection (CAEP) [T&E/ICSA 2001].

The campaigns run by European NGOs seem to have been quite effective in getting the subject of environmental impacts of commercial civil air transport on the agenda in the European countries [Vavrik 2000]. As explained in Section 2.6.3 many of the ideas of the NGOs have become part of some recent policy documents from European Governments [NMH 1995] [Luftfartsverket 1997] [DETR 2000] and the European Commission [CEC 1999a, 2000a, 2000f and 2001b].

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[52] For example, the 45 billion EURO cheque shown in Figure 2.14 was sent to European politicians as part of Friends of the Earth's (FoEs) campaign to stop subsidies. FoE calculated that European airports and airlines receive some 45 billion EUROs each year in direct and indirect subsidies [FoE 1998].

[53] As of January 2000 the membership of ICSA consists of the Aviation Environment Federation, the Centre for Clean Air Policy, the Coalition for Clean Air, the Dutch Society for Nature and Environment, Friends of the Earth Europe, the German League for Nature and Environment (DNR), Germanwatch, European Federation for Transport and Environment (T&E) and World wildlife Fund (WWF). Greenpeace International is in the process of joining.
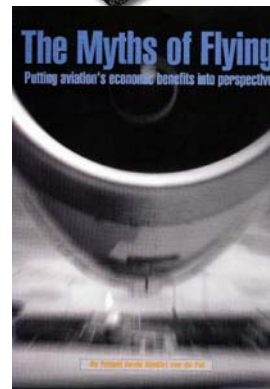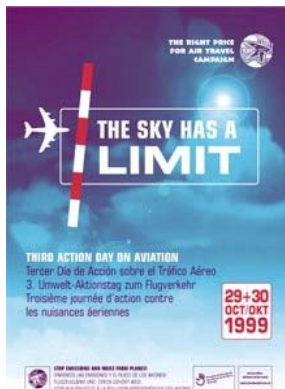
Figure 2.14: Environmental campaigns run by NGOs
Pictures are downloaded from the Internet at: Aviation Environment Federation
[http://www.aef.org.uk] and The Right Price for Air Travel Campaign
[http://www.milieudefensie.nl/airtravel/] and Aviation Conspiracy Newsletter
[http://pages.prodigy.net/rockaway/newsletter128.htm].

2.6.2 The position of the commercial civil air transport industry

The commercial civil air transport industry hopes to avoid taxes, and proposes instead the adoption of voluntary agreements for future emission reductions. Such proposals are brought forward by for example, the Association of European Airlines[54] [AEA 2000b] and the European Association of Aerospace Industries[55] [AEA and AECMA 1999], the British Air Transport Association [British Air Transport Association 2000] and the International Air Transport Association [ATAG 2000] [Dobbie 1999 and 2001] [IATA 2000a, 2000b and 2000c]. Some airlines have similarly adopted future efficiency targets, which are to be met mainly by continually buying new and more efficient aircraft [Lufthansa 1999] [All Nippon Airways 1999].

For example, the European commercial civil air transport industry has on several occasions demonstrated the view that voluntary agreements are preferable from economic measures such as jet fuel taxes. A 2000-proposal from the European Commission stated that Europe should aim at introducing a European jet fuel tax on domestic flights and bilaterally on international routes [CEC 2000a]. The Association of European Airlines (AEA) criticised the European Commission's proposal. "*Apart from the obvious anachronism of introducing bilateral agreements into the single market, the proposals give no suggestion that a fuel tax will be anything other than deeply damaging to the industry, while contributing next to nothing to the environment. For an industry which has gone from regulation to liberalisation, the concept of managed growth would be a backward step*" [AEA 2000a, p. II - 8]

However, the industry acknowledges that voluntary agreements on fuel efficiency improvements will not be sufficient to stabilise emissions from commercial civil air transport activities. For example, a 1999-proposal from the European Commission stated that a voluntary agreement with the European Aeronautical industry should aim to achieve 4-5% annual reductions in carbon dioxide emissions per passenger

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[54] AEA is the Association of European Airlines. Its members are Adria Airways, Aer Lingus, Air France, Air Malta, Alitalia, Austrian Airlines, Balkan, British Airways, British Midland, Cargolux, Croatia Airlines, CSA, Cyprus Airways, Finnair, Iberia, Icelandair, JAT, KLM, Lufthansa, Luxair, Malev, Olympic Airways, Sabena, SAS, Swissair, TAP Air Portugal and Turkish Airlines.

[55] AECMA is the European Association of Aerospace Industries. Its members are the national aerospace associations of all 15 EU member states - Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, The Netherlands, Portugal, Spain, Sweden and the United Kingdom - as well as the largest European aerospace companies.

kilometre by 2012 [CEC 1999a]. This proposal was met by a joint proposal from the European aviation industry stating that it will be more than a decade before the sector can exceed annual 1,1% reductions in carbon dioxide emissions per passenger kilometre performed on average. The proposal would lead to an improvement of the average fuel efficiency of some 22,4% by 2012 as compared to the 1990-level [AEA and AECMA 1999]. Some 14% of this reduction had already been achieved between 1990 and 1998 as the consequence of a considerable aircraft renewal programme carried out in recent years by AEA member airlines [British Air Transport Association 2000]. Furthermore, AECMA proposes to develop the technology needed to provide better fuel efficiency for the next generation of civil aircraft. The Aeronautics Programme under the 5th Framework Programme of the European Commission aims to develop technology that will allow 15-20% cut in CO_2-emissions per passenger kilometre by 2015 [AEA and AECMA 1999].

Parts of the airline industry is realising that the sector may in some way have to contribute more to reducing greenhouse gas emissions than what is proposed by for example AEA and AECMA. Increasingly, this part of the industry fear that if they do not come up with proposals for voluntary agreements or emission trading schemes, politicians will move on to implement measures such as kerosene taxes [Somerville 2000] [Muddle et. al. 2000]. A British Airways Chief Economist expresses it in this way: "*If airlines are to avoid taxes on aviation fuel, we need to come forward with constructive and workable proposals for voluntary agreements and emissions trading. That is British Airways' approach – and we are leading by example with our own efficiency target"* [Muddle et. al. 2000].

One example of a more radical scheme (than for example the one proposed by AEA and AECMA) for improving the fuel efficiency of the aircraft fleet is a trading scheme, dubbed "old for new aircraft", that has been suggested by British Airways. This proposal aim at making airframe producers buy back and scrap an old fuel intensive aircraft each time they sell a new and more fuel-efficient aircraft. Such a scheme could potentially secure earlier scrapping of old aircraft, leading to improved fleet efficiency and possible also to less excess capacity within the commercial civil air transport sector. The proposal is described as the "*most workable and least painful option on offer to the industry*" by British Airways representatives but has initially been received with less enthusiasm from aircraft producers who see the proposal as a constraint to

their growth. For example, Boeing acknowledges that emissions trading can produce optimal benefits for the environment at minimal economic cost, but only if it is implemented across various industry sectors, i.e. as an open trading system between sectors [Muddle et. al. 2000] [Cooper 2000]. For the longer time perspective British Airways representatives even call for more radical solutions such as a substitution of fossil kerosene by kerosene produced from biomass or the use of liquid hydrogen as fuel [Somerville 2000].

To sum up, the position of the commercial civil air transport industry is that technical measures to mitigate the emissions of greenhouse gases would be preferable from measures that are aimed at reducing demand.

2.6.3 The international framework and the role of the European Commission

The commercial civil air transport sector has until now not been subject to international regulations aimed specifically at reducing greenhouse gas (GHG) emissions from aircraft engines[56]. Rather, standards issued by the International Civil Aviation Organisation (ICAO) set limits for aircraft noise and engine emissions in and near airports throughout the so-called landing and take-off (LTO) cycle [ICAO 1993 and 1998b]. The ICAO standards will be subject to further negotiations and probably also gradual improvements. For example, the current standards are criticised by the European Commission [CEC 1998a, 1998b, 1999a] and European environmental NGOs [T&E 1998a, 1998b and 1999] [The 'Right Price for Air Travel' Campaign 1999a and 1999b], for not being strict enough and for not setting a standard for the specific fuel consumption of aircraft and the associated in-flight GHG emissions.

Following recent international commitments to reduce global GHG emissions, the aviation sector has come under increasing pressure to reduce energy use and GHGs[57].

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[56] Furthermore, national emission inventories currently only include domestic transportation sources. However, there are ongoing discussions within the IPCC and the United Nations' Framework Convention on Climate Change's (UNFCCC) Subsidiary Body for Scientific and Technological Advice (SBSTA) on how to allocate emissions from international air traffic between countries in national emission inventories [WIT 1996] [UNFCCC 1999a and 1999b] [ICAO 2000a] [IPCC 2000a] [DNV 1999].

[57] The international nature of commercial civil air transport has lead most governments to exempt international air traffic from national environmental and energy policy planning and related GHG reduction goals. However, a few countries, such as Sweden and the Netherlands, This footnote continues on the next page.

In the 1997 "Kyoto Protocol to the United Nations Framework Convention on Climate Change", it is stated that "*The Parties included in Annex I shall pursue limitation or reduction of emissions of greenhouse gases not controlled by the Montreal Protocol from aviation and marine bunker fuels, working through the International Civil Aviation Organization and the International Maritime Organization, respectively*" [UNFCCC 1997, article 2b]. This reflects that UNFCCC see ICAO as an intergovernmental organisation that may be an appropriate forum for negotiating possible global targets and measures to be implemented in the future.

In recent years, several European governments and the European Commission have expressed their interest in reducing the GHG emissions from commercial civil air transport, for example by implementing a tax on jet fuel or aircraft emissions[58]. One of the Commission's main strategies seems to be to commit ICAO to implement global measures. At the 32nd ICAO Assembly held in 1998, the European Commission aimed at committing ICAO to commission a working programme to assess technical and economical possibilities for implementing stricter standards for aircraft noise and emissions of nitrogen oxides as well as to investigate the possibilities to reduce GHG emissions [CEC 1998a]. At the Assembly, ICAO asked countries not to adopt any unilateral measures that might be harmful for the development of the global commercial civil air transport sector. However, ICAO did commit to a working programme for aircraft noise and emissions and on developing guidelines (to be ready by its fall 2001 33rd Assembly) for the introduction of emission charges by individual governments

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have published official policy plans for environmental sustainability [NMH 1995] [Luftfartsverket 1997] which are to be followed soon by a plan in the United Kingdom [DETR 2000].

[58] Several European governments has for some years been interested in levying taxes on aviation kerosene [T&E Bulletin March 1997 and November 1997], but international and bilateral air services agreements negotiated between countries prohibits countries to levy kerosene tax on international flights [Bleijenberg et. al. 1998]. European Union member countries are restricted from levying kerosene tax on domestic flights as well [CEC 1997]. Some countries and airports have introduced other types of environmental taxes and charges [Zurich Airport Authority 2000] [Luftfartsverket 1997] [Durand 2000]. In Sweden the airlines paid environmental taxes between 1989 and 1996, but these payments have been stopped [T&E Bulletin March 1999]. In 1999 the Norwegian Government promptly introduced a tax on kerosene. However, leading European airlines pressured the Norwegians to back down by refusing to pay the tax. The refusal was founded on bilateral air services agreements negotiated between countries. After two days the Norwegian Government agreed to exempt international airlines from the tax, making it in effect only a tax on flights within Norway. The Norwegian tax was set at NKr 0,25 per litre and was designed to be fiscally neutral as the government reduced its environmental levy on tickets [T&E Bulletin February 1999].

[CEC 1998b]. But ICAO wants all countries to avoid emission charges before these guidelines have been agreed upon [T&E Bulletin November 1998].

Since then, ICAOs Committee on Aviation Environmental Protection (CAEP)[59] has set down working groups which are assessing a range of possibilities for reducing noise and emissions. Among other things the groups consider market based measures to enhance development of more environmentally "sustainable" aircraft and to improve operational procedures as well as contributing to demand side management [Crayston 2000] [Rossell 2000].

In recent years, the European Commission has stepped up its efforts to put pressure on the other ICAO members for agreeing on measures to reduce the environmental impact of commercial civil air transport. Most notably, in a December 1999 Communication, the European Commission describes a list of measures that might be taken into consideration. The Commission proposes more stringent international standards and rules to reduce aircraft engine emissions and noise and for improving air traffic management efficiency. These should be accompanied by market incentives such as aviation charges, emission trading, voluntary agreements and research and development into new and more efficient aircraft technologies [CEC 1999a]. This Communication has since then been approved by the European Parliament and the European Council of Ministers [CEC 2000f]. Furthermore, in a Communication issued March 2000, the Commission states that the European Union member states, in co-operation with the Commission, should intensify their work within the ICAO framework for the introduction of taxation on aviation fuel and other instruments with similar effects [CEC 2000a].

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[59] ICAOs Committee on Aviation Environmental Protection is composed of experts who are nominated by States, major sectors of the commercial civil air transport industry and an environmental NGO umbrella group. Current members were nominated by Austria, Brazil, Canada, Egypt, France, Germany, Greece, Italy, Japan, the Netherlands, Norway, Poland, Russian Federation, Singapore, South Africa, Spain, Sweden, Switzerland, Tunisia, United Kingdom, United States, Arab Civil Aviation Commission (ACAC), Airports Council International (ACI), the European Commission, the International Air Transport Association (IATA), the International Business Aviation Council (IBAC), the International Co-ordinating Council of Aerospace Industries Associations (ICCAIA), the International Federation of Air Line Pilots' Associations (IFALPA), the European Federation for Transport and Environment (T&E), the United Nations Framework Convention on Climate Change (UNFCCC) and the World Meteorological Organisation (WMO) [Hupe 2001].

Besides focusing on a global jet fuel tax, some European countries as well as the European Commission and the European Parliament[60] are discussing the possibility of introducing a tax in Europe. In a 2000 Communication the European Commission pushes for the idea of a not yet adopted Commission proposal[61] to allow member countries to tax domestic and intra-EU flights [CEC 2000a]. The proposal is strongly backed by Germany, but opposition led by Spain has so far been enough to block the tax measures, which under EU rules require unanimity [Reuters 2000a]. By March 2000 the proposal was presented to European Union Finance Ministers that agreed only to tax jet fuel if there was an agreement at the international level [Reuters 2000b].

Therefore, the initiative to introduce measures for reducing greenhouse gas emissions from Commercial Civil Air Transport currently seems to be in the hands of ICAO.

2.6.4 The current work in ICAO

ICAOs Committee on Aviation Environmental Protection (CAEP) has been given the task to review a number of options for reducing noise and emissions. In January 2001 CAEP met to take decisions on which environmental rules and standards to recommend to the ICAO Council. These recommendations were introduced to those member states of ICAO that are not directly involved in the CAEP process at an international colloquium in April 2001. Since then, the ICAO Council has decided upon standards and proposals for resolutions to be considered by ICAOs 33rd Assembly in September/October 2001. Since this Assembly is to be held after the deadline for this report the final agreements unfortunately can not be described here.

At the January 2001 meeting CAEP agreed upon a more stringent new noise standard[62] to be applied to all new aircraft introduced after 2006 [Hupe 2001]. CAEP

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[60] In its treatment of the European Commission's December 1999 Communication on "Air Transport and the Environment - Towards meeting the Challenges of Sustainable Development" [CEC 1999a] the European Parliament added that, in the absence of international agreement on taxation of kerosene it would propose a community-wide charge. It further proposed that the revenue be invested in reducing the environmental damage caused by aviation [CEC 2000f] [Lucas 2000].

[61] The proposal was voted against by European Governments in 1997 [Airwise 2000a].

[62] The proposed Chapter 4-noise standard has been criticised by environmental NGOs and by the European Commission and the Airports Council International for not being strict enough. This footnote continues on the next page.

also reviewed how greenhouse gas emissions might be reduced through optimising operational measures and through laying down voluntary agreements on fuel efficiency improvements as well as through implementing market-based measures such as a global tax on kerosene or emissions and emission trading schemes. Concerning the market-based measures, CAEP concluded in its assessment report that an "*open emission trading scheme*" allowing the commercial civil air transport industry to buy emission quotas in other energy consuming sectors would be a better and cheaper solution (than a tax on emissions or fuel) [Wickrama 2001] [CAEP 2000a and 2000b]. "*This is because it appears that less costly reductions are possible in other sectors (the aviation sector faces higher abatement costs), and hence the potential savings from trading with other sectors would be substantial...compliance costs would be reduced by over 95 percent (compared to other options) if the aviation sector could participate in an "open" emissions trading regime with other sectors*" [Seidel and Rossell 2001].

The written comments posted by CAEPs members to the session at the January 2001 meeting dealing with market-based measures exemplifies that there is not common agreement on which strategies to propose to ICAO [CAEP 2000c and CAEP 2000d] [T&E/ICSA 2001] [IATA/ICCAIA 2001]. Some of the differences in views can be seen from the Boxes below describing the positions of the environmental NGOs (Box 2.1) and of the commercial civil air transport industry (Box 2.2).

One critique is that almost all existing production aircraft already today comply with the new noise standard. Another critique is that new noise standard does not consider the phasing out of some of the older and more noisy Chapter 3 aircraft [Airports Council International 2001] [CEC 2000f] [T&E Bulletin August/September 2001] [ICAO 2001d]. (Chapter 3 is the current noise standard that will function until 2006). On this background, the European Civil Aviation Conference states that "*...the new standard will not encourage the introduction of more advanced noise reduction technology and nor will it lead to a significant improvement in noise exposure as traffic grows in the longer term. The proposed new standard can only be a first step*" [ICAO 2001d, p. 2]. The United States, Russia and Brazil as well as some African States oppose the plans to impose operating restrictions on Chapter 2 aircraft that are hush-kitted to apply to the Chapter 3 standard [ICAO 2001e].

Box 2.1: The position of the International Coalition for Sustainable Aviation (ICSA) towards market-based options to limit or reduce emissions.

♦ CAEP has mainly been focusing on possibilities to reduce emissions of CO_2. ICSA therefore suggests that ICAO and CAEP should urgently develop a strategy that addresses all greenhouse gas emissions.

♦ Voluntary agreements are not considered sufficient to respond to the provisions laid out for commercial civil air transport in the Kyoto Protocol and ICAO is therefore urged not to develop this concept further.

♦ ICAO is furthermore urged to establish a CO_2 target that is consistent with the Kyoto Protocol and aiming at a reduction of 5% in the period 2008-2012 as compared to 1990 levels.

♦ ICAO should introduce an emission charge (on both the LTO and the cruise cycle) by its 34th Assembly at the latest. If the charge is not adequate for achieving the 5% reduction target, it should be supplemented by an emission-trading scheme that would begin no later than 2008.

♦ ICAO should establish a NO_x cruise standard and a market-based mechanism to control all emissions during the cruise phase, including potentially weighing CO_2 emissions to fully reflect the total radiative forcing.

♦ If no appropriate solutions are decided by at the next ICAO Assembly, COP7 of the UNFCCC should decide on a workplan and immediate implementation plan, by COP8 at the latest.

Source: [T&E/ICSA 2001].

One main disagreement between the NGOs and the industry is whether the total emissions of CO_2 from the commercial civil air transport sector should be allowed to grow or if they should be reduced in accordance to the goals set up in the Kyoto Protocol, as suggested by the NGOs. The industry seems to prefer voluntary agreements for improving the fuel efficiency and an open CO_2 emission-trading scheme that will allow the industry to buy emission permits in other sectors [IATA/ICCAIA 2001]. NGOs seem to prefer a tax that considers all types of emissions in all phases of flight. If no agreement can be reached the NGOs furthermore urge the UNFCCC to take over the obligation to introduce measures that can contribute to reduce emissions from commercial civil air transport [T&E/ICSA 2001].

At its January 2001 meeting CAEP recommended the continued development[63] of market based measures and the ICAO Council will report the further work to the 33rd ICAO Assembly in the fall 2001. It is therefore up to the ICAO Council and the ICAO Assembly to assess whether they can reach an agreement on a resolution calling for additional work with, for example, voluntary agreements and market based measures. Currently, voluntary agreements and an open emissions trading system seems to have more support from CAEP members than do for example a global CO_2 tax [Seidel and Rossell 2001]. In a September 2001 White Paper on the European transport policy the European Commission assesses that ICAOs 33rd Assembly will not agree upon a jet fuel tax [CEC 2001b]. 38 European countries, that are all members of the European Civil Aviation Conference (ECAC), now seem to accept that ICAO maintains its existing policy on charges and taxes [ICAO 2001b] but hopes for ICAOs acceptance of the implementation of stringent operating restrictions in Europe for the noisiest aircraft [ICAO 2001d]. However, the Europeans still encourage ICAO to investigate further

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[63] An important part of the additional analysis will consider the impact of market-based measures on developing countries and examine ways to ensure that their concerns are taken into account [Seidel and Rossell 2001]

(after the 33rd Assembly) the development of a trading system for aircraft emissions as well as the establishment of long-term technology goals [ICAO 2001c]. The ICAO Council notes that the establishment of a framework for setting up a scheme for emissions trading is a long-term process [ICAO 2001b], and no immediate actions are therefore to be expected.

Therefore, at least until the next ICAO Assembly in 2004, it seems unlikely that the 187 countries that are represented in ICAO will agree upon any global market based measures to reduce the GHG emissions from civil air transport. The focus seems to be directed towards agreeing upon a new noise standard as well as at studying further the possibility of setting up a regime for emissions trading. Furthermore, ICAO seems to be focusing on the necessity to improve operational practices. Both the reduction of noise and the improvement of operational procedures seem to be strategies that will allow air traffic to grow further. As will be discussed in Chapters 3 and 5, better operational procedures offer some reduction of the specific GHG emissions, but are likely by far to be overridden by growth in demand in a business as usual scenario.

Even the long-term emissions trading solution may most likely be constructed in a way that will allow passenger air travel to grow further, if emissions reductions are traded in an open system[64] between sectors with air transport as a net buyer. Some critics argue that a regime for emissions trading would have to consider not only the emissions of CO_2 from air transport, but also the emissions of water vapour and NO_x, because these gases contribute to climate change at high altitudes [Lee 2000]. Furthermore, the settlement on a cap for emissions and the distribution of quotas or emission permits between countries and airlines will pose challenges to CAEP [Wickrama 2001] [Hewitt and Foley 2000]. The possible impact of emissions trading is not discussed further in this report. Rather, Chapter 4 looks into the possible impact of a jet fuel tax. The reason for this choice of focus is that the aim of this project is to assess the possibilities for reducing the emissions from *commercial civil air transport*.

Since CAEPs January meeting, the European environmental NGO's have expressed disappointment with the ICAO process. Their hope for ICAO to agree upon a global tax

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[64] The opposite, a closed system, would only allow internal trading within the commercial civil air transport sector, see Hewitt and Foley [2000] for a further discussion of these issues.

on emissions or jet fuel does not seem to be realistically feasible in the near future. They therefore urge the European countries to go it alone by implementing measures to reduce the environmental impact of commercial civil air transport [T&E Bulletin August/September 2001].

2.7 The position of consumers and the need for common action

Besides focusing on the positions of NGOs, the industry and various governments towards the emission of greenhouse gases from commercial civil air transport it also seems relevant to focus on the role of the consumers of air transport. Consumer choices are constrained by economic and other structural factors, and governments and legislators can to a certain extent try to persuade individual consumers to adapt to, for example, more environmentally benign transport patterns and technology choices. However, ultimately, legislation decided upon by decision-makers in a democratic society will to a large extent have to be reflecting individual and collective preferences in that society. Thereby, the problem of individual preferences versus (the possible need for) collective choice becomes apparent. The problem is described in this way by Rayner and Malone [1998]:

"*The problem of collective choice has usually been framed as one of aggregation or of coercion:*

- *How to aggregate individual preferences into a collective preference, or*
- *How to persuade individuals to conform with normative requirements of corporations and governments, as implemented by the decision makers who are their officials.*

Arrow (1951) has famously demonstrated the impossibility of aggregating individual preferences into a collective one in a way that satisfies certain minimal conditions of rationality or transitivity. For Arrow, the dictatorial social welfare function is the only one possible. However, dictatorship is incompatible with democracy. We seem to be caught in a bind. But Arrow's analysis assumes that preferences are inherently individual. If we use another set of assumptions – for example, that preferences are inherently rational (that is, expressions of social solidarity) – we change the nature of the problem from being one of aggregating individuals to discerning the structure and dynamics of social solidarity, which in turn may open up a new solution space for the problem of collective action" [Rayner and Malone 1998, p. XVii].

To a certain extent, the above citation seems to express the core of the problem. Namely that agreeing upon certain potentially more environmentally benign life-styles, technology choices and consumption patterns would acquire collective choices that may differ from current individual preferences (which again have social and cultural dimensions) [Douglas et. al. 1998]. Individual consumers can be seen as actors performing a range of social practices driven by individual needs, wants and desires which are constantly shaped by and shaping (vice-versa) constraints opposed by the social material system [Spaargaren 1997]. Individuals do not necessarily behave as "rational" energy consumers in a social (economical or environmental) sense, but are motivated by individual needs, wants and desires, which are in turn shaped by social norms, ethics etc [Christensen and Nørgaard 1976] [Douglas et. al. 1998] [Michaelis 2000]. Therefore, an important precondition for achieving environmental sustainability seems to be to change those peoples' preferences towards mobility changes. The point to be made here is that such lifestyle changes seem to acquire changes in a number of the preconditions for common action, that is, the social norms and the rules and resources that make up the socio-material structures of our surroundings, see Figures 2.3 and 2.4.

2.8 Concluding remarks on determinants

If air transport continues growing at the current rate it may become a major source of greenhouse gas emissions within the next few decades. The availability of airports and aircraft are important preconditions for passenger air travel growth, and further enlargements of airport infrastructures seems to be needed to sustain long-term growth. Policies aimed at reducing air travel growth may therefore be directed towards not increasing airport capacity further as well as discarding subsidies for development of larger and faster types of aircraft. Therefore, governments could stop subsidising the largest and fastest aircraft, for example by discarding all plans for future supersonic aircraft, sonic cruisers and next-generation ultra-large super-jumbo jets. Furthermore, there is the possibility of promoting alternative modes of transport, for instance by enlarging rail capacity and by using fast train systems.

Some major drivers for passenger air travel growth seems to be the reduction of real fares as well as the tendency to sell leisure tickets at discounted prices. Air travel is currently not taxed to the same degree as other transport modes, not to mention other consumption. Furthermore, aircraft producers, airlines and airports are often subsidised

directly or indirectly by governments. Therefore environmental policies could be aimed at increasing prices by not subsidising the commercial civil air transport industry and by applying taxes to air travel. Other possibilities are to cancel the ability of companies to deduct their travel expenses from taxes as well as to stop frequent flier programmes.

Governments may also try to alter some of the structural determinants driving air travel growth. Much air travel relates to globalisation, changing geography, migration and population growth. Therefore any policy aimed at counteracting these factors may help in reducing air travel growth. Another way to reduce the demand for air travel is to promote alternative lifestyles and ways of life. If the social status connected to travelling far away diminishes people might choose nearby holiday destinations. Similarly, if people choose a less materialistic approach to life by working less, having more free time available as well as earning less, there is clearly potential for change. On the longer term, governments may seek to find alternative ways of measuring progress and growth than Gross Domestic Product, allowing nations to develop in more sustainable directions than when planning mainly to achieve economic growth.

Chapter 3

Energy intensity of passenger air travel and freight

This chapter analyses the energy intensity[1] of air transport. The main purpose is to discuss and establish an overview of the energy intensity of passenger air travel and airfreight for trips of different lengths and in different types of aircraft and to put the aircraft fuel use into perspective by comparing to other uses. The energy intensity of passenger air travel and freight is found to be typically higher than for other modes of passenger and freight transport when used over comparable distances. However, the comparison between modes is found to be relatively complicated because the energy intensity depends strongly on a lot of factors such as the type of vehicle in use and the load factor and the usage cycle on the route in question. For the passenger aircraft that carry belly-hold freight there is an additional methodological problem connected to the distribution of the fuel consumed between passenger travel and freight transport. Furthermore, because the emissions from aircraft engines per amount of fuel burnt at high altitude may contribute considerably more to climate change than emissions at sea level, the greenhouse gas intensity of air transport may be considerably higher than what is the case for other modes of transportation. The energy intensity of passenger air travel and freight is found to vary significantly between different airlines, mainly because they use different types of aircraft and due to differences in their route structures as well as differences in passenger load factors and in freight load factors[2]. Due to the relatively long distance each person can potentially travel by air within a relatively short period of time the greenhouse gas emissions associated to passenger air travel can contribute considerably to the yearly per capita emissions. The fuel intensity has been reduced throughout the last decades but the yearly improvements

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[1] By energy intensity of passenger air travel and airfreight is meant fuel use per revenue passenger kilometre (RPK) and per revenue freight tonne kilometre (RFTK).

are slowing down. Airlines' preference for increasing the speed over their preferences for improving the fuel efficiency may lead to reduce the fuel efficiency improvement rate further in the future. On the longer term, commercial civil air transport is likely to become a major source of greenhouse gases because passenger air travel and airfreight grow stronger than most other energy services.

3.1 Introduction - the CO_2 emissions from all transport

According to the Intergovernmental Panel on Climate Change (IPCC), the transport sector, including passenger travel and freight movements by road, rail, air and water, consumed about 25% of the World's primary energy use in 1990 and emitted about 22% of the CO_2 emissions that are related to the combustion of fossil fuels. Globally, transportation's fuel consumption is growing rapidly and is forecast by the IPCC to grow by between 50% and 200% between 1990 and 2025 [IPCC 1996b, p. 681].

The industrialised countries generate the bulk of the World's motorised transport activities, but motorised mobility is currently spreading to developing countries. There are distinct differences between countries in the amount of passenger travel and freight transport that is generated as well as there are differences in the modal split. For example, in most industrialised countries the main part of the motorised passenger travel is carried in private passenger cars whereas in some developing countries the public transportation modes are the most significant [Schafer 1998] [Schafer and Victor 1999]. In 1990, North American and European citizens travelled about 22400 kilometres and 10500 kilometres per capita per year respectively in motorised transport modes whereas people living in for example Sub Saharan Africa only travelled around 1600 kilometres per capita on average [Schafer 1998].

The amount of transport as well as the modal split is changing over time. For passenger travel the trend in most industrialised countries seems to be that passenger cars and aircraft increase their market share over other public modes of transportation [Schafer 1998] [Grübler 1998] [EEA 2001].

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[2] The passenger load factor is calculated as the ratio of revenue passenger kilometres to the available seat kilometres. The freight load factor is calculated as the ratio of revenue tonne kilometres transported to the available tonne-kilometres offered.

Air transport, being the fastest growing transportation mode, is currently a much smaller energy consumer than road transport, but may become a relatively large source in the future if the sector continues to grow at current rates [IPCC 1999]. In 1990, road transport emitted around 75% of the CO_2 emissions from transport activities, while around 12% was attributable to commercial civil air transport and 7% to international shipping and around 6% to rail and inland waterways [IPCC 1999].

In general, passenger transport typically accounts for some 60-70% of the energy use and the related emissions of CO_2 from transportation in the OECD countries. However, there are wide variations in the amount of CO_2 emitted per capita from transport in different countries. For example, United States citizens emitted approximately 3,8 tonnes of CO_2 per capita for passenger travel on a yearly basis in 1995, while for example Danish and Dutch citizens emitted around 1,3 tonnes and 1 tonne per capita respectively in that year. Likewise, for freight transport there are wide variations between countries. For example, in the United States, freight transport accounted for around 1,7 tonnes of CO_2 per capita in 1995. In West Germany this figure was only around 0,5 tonnes of CO_2 per capita while Danish citizens emitted some 0,8 tonnes on average (also in 1995) [Schipper and Marie-Lilliu 1999]. We note that these estimates do not consider the CO_2 emissions from international air transport and international marine traffic because such emissions are normally not allocated to specific countries due to the difficulties connected to agreeing upon how to allocate emissions[3]. However, the CO_2 emissions from domestic air transport is included, and in large countries like the United States and Australia the CO_2 emissions from domestic air transport represents around 11-13% of the total domestic transport emissions.

The differences between countries in the CO_2 emissions from passenger travel and freight transport can be explained by differences in a number of factors. First of all, the patterns of passenger travel and freight varies between regions and countries of the world. Secondly, there are distinct differences between countries and regions in the modal split [Schafer 1998]. Thirdly, the CO_2 intensity of the various modes varies between countries [EEA 2001] [Schipper and Marie-Lilliu 1999].

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[3] For example, the emissions could be allocated to the country in which the fuel is rendered, to the country in which airline is situated or to the home countries of the passengers. At present,

The CO_2 intensity of the different vehicles depends on a number of factors. The energy intensity per capacity unit varies between the different types of vehicles as well as between different types of usage cycles and the fuel consumption per passenger kilometre or per tonne kilometre is dependent on the actual load factors. For example, the average load factors in passenger cars is estimated to range from around 1,5 to 2,5 in various EU countries [EEA 2001, p. 43]. Furthermore, the CO_2 intensity depends on the mix of vehicles in the fleet that are powered by diesel, petrol, natural gas or electricity. For the electrical vehicles the CO_2 intensity depends on the types of primary energy, such as fossil fuels (oil, coal and gas) and nuclear and renewable (solar, hydro and wind) sources of primary energy that are used in the power production [Schipper and Marie-Lilliu 1999] [IPCC 1996b, pp. 689-691] [IPCC 1999, pp. 284-287] [Roos et. al. 1997].

The fuel intensity and the related CO_2 emissions of air transport are in focus throughout this chapter. The reason why this subject is found to be of interest is that an important aspect in reducing the growth in the CO_2 emissions from air transport may be to reduce the specific fuel intensity in the future (See Figure 1.2, chapter 1).

3.2 Purpose of this chapter

The main purpose of this chapter is to discuss and establish an overview of the fuel intensity of passenger air travel and airfreight. The specific fuel consumption per passenger kilometre[4] and per freight tonne-kilometre[5] of selected airlines and of different types of aircraft as well as of the world aircraft fleet[6] is quantified and some main determinants of aircraft fuel consumption are identified.

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no methodology has been agreed upon on how to allocate the emissions between countries [UNFCCC 1999a and 1999b] [DNV 1999].

[4] A passenger kilometre is a term describing when a passenger is transported one kilometre. The term "revenue passenger kilometres" refers to the distance travelled by revenue passengers. For some airlines only passengers that have paid a certain percentage of the normal fare are counted as revenue passengers. Examples of non-revenue passengers are the pilots and crew onboard as well as other passengers travelling for free.

[5] A freight tonne kilometre is a term describing when one tonne of freight is transported one kilometre.

[6] By the world aircraft fleet is meant all civil aircraft used for commercial purposes, that is scheduled and non-scheduled and charter airline traffic, excluding aircraft produced and operated in the former Soviet Union of which data are generally not available. Thereby aircraft used for military purposes as well as general civil aviation has been excluded from this study.

Section 3.4 describes the historical development in the patterns of air travel and the fuel intensity improvements since the early 1970s.

Sections 3.5 and 3.6 analyse and compare the specific fuel consumption of different types of aircraft that are in use on short-haul, medium-haul and long haul routes. Most studies in this area seem to focus on a few aircraft models and often neglect the relatively large differences between different types of aircraft. Therefore, this analyses includes a relatively large number of models and discusses some of the main reasons for the differences as to exemplify the potential for reducing the fuel consumption that are offered by choosing to use the most fuel-efficient types of aircraft. The section furthermore looks into some of the main determinants of aircraft fuel intensity, that is airframe size and engine, passenger and freight load factors and seat configuration, and flight distance.

Section 3.7 compares the average fuel intensity of a number of airlines and assesses the main reasons for the differences between these airlines. This part of the analysis focuses on the differences between low-cost charter airlines and scheduled flag carriers and also makes comparisons between regional carriers that mainly operate at short haul routes, and truly international carriers operating mainly at intercontinental long-haul routes.

Section 3.8 gives a detailed analysis and discussion of the distribution of the fuel consumption of aircraft and airlines on passenger air travel and airfreight. Most studies analysing the fuel intensity of aircraft and airlines seem to neglect such an analysis. Rather, the total fuel consumption of the airlines is most often attributed to the transport of passengers even though all passenger aircraft carries both revenue passengers and revenue belly-hold freight. Therefore, one aim of this analysis is to estimate the fuel consumption that is attributable to freight in passenger aircraft, see Section 3.8. Another part of the analysis focuses on the fuel consumption of all-cargo carriers that operate dedicated freighter aircraft, see sections 3.6.2 and 3.7. Thereby, it also becomes possible to compare the fuel that is consumed for freight transport in passenger aircraft to that of all-cargo freighters.

The chapter also gives a brief comparison of the fuel intensity of aircraft and other alternative transport modes that may potentially substitute aircraft (see Section 3.9).

This part of the chapter focuses on the fuel intensity of modes that are used for transporting passengers over short distances, as this is one area where a substitution of air transport by more fuel-efficient modes seems feasible.

Finally, in section 3.10, the chapter gives a brief description of the future prospects for reducing the fuel intensity of the aircraft fleet through phasing out the oldest aircraft models as well as by introducing more fuel-efficient next-generation aircraft and by improving the operational procedures. Furthermore, a brief discussion of the longer-term prospects for reducing the fuel intensity of future aircraft models is given. The aim is to discuss the potential of "technological fixes" for reducing emissions in the next decades.

3.3 Description of the main sources of information

The main sources of information that are used in this chapter are airline operational statistics that typically contain information on the yearly average fuel intensity of different airlines and of the different aircraft in their fleets. The information on the specific fuel consumption is typically given as the fuel consumed per aircraft kilometre[7] or per available seat kilometre (ASK)[8] produced and per revenue passenger kilometre (RPK) transported or per available tonne kilometre (ATK) offered and per revenue tonne kilometre (RTK) transported or per revenue freight tonne kilometre transported (RFTK). The data material covers a broad range of scheduled airlines and charter carriers that are situated in Europe, in Asia and in the United States.

Most of the data for the European and Asian airlines are taken from their yearly environmental statements[9] and from some overall operating statistics that are

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[7] The data for the number of aircraft kilometres flown are typically for the shortest great circle distance between the airports in question. That is, the aircraft actually often fly longer routings. Therefore, there is a potential for reducing the specific fuel consumption per ASK and RPK by flying more direct routings.

[8] The term available seat kilometre is a measure for transporting one seat one kilometre. The number of available seat kilometres produced by an aircraft is calculated by multiplying the number of seats available in that aircraft by the number of kilometres flown. Available seat kilometres is thereby a measure for the passenger capacity (i.e. the number of passenger kilometres that could be produced at the maximum passenger load factor) of a given flight.

[9] Most notably, such yearly environmental statements are published by airlines such as British Airways, Lufthansa, Lufthansa Cargo, Lufthansa Condor, Lufthansa City Line, SAS, Swissair, Balair, Premiair, Air France, Finnair, Braathens, All Nippon Airways, Japan Airlines and Cathay Pacific Airways.

published by the Association of European Airlines (AEA)[10] but much additional material have been requested directly from the airlines. Most notably, Lufthansa, All Nippon Airways and British Airways as well as the European charter carriers Premiair and Air 2000 have kindly assisted the author in getting access to detailed information on the specific fuel consumption of the aircraft in their fleets as well as the passenger load factors and the freight load factors and other operating statistics. Furthermore, some older studies of the fuel intensity of Lufthansa in 1989 and 1990 [Reichow 1990 and 1992] and of all the British Airlines in the 1980s [Martin and Shock 1989] are included to be able to compare today's average operating statistics to those of earlier years.

Most of the data used for describing the fuel-intensity of the American air carriers have been requested from the United States Department of Transportation (DOT) that maintains a detailed statistical database describing the operating characteristics of American air carriers. For decades, the air carriers situated in the United States have reported their operating statistics to the DOT in the so-called "form 41" arrangement. These data cover most aspects that are interesting for an analysis of the fuel consumption of the different aircraft and airlines. Most of the operating statistics for the American air carriers that are used here have been kindly provided in Excel spreadsheets[11] from the DOT. These data describe the average overall fuel intensity of a number of American air carriers in selected years from 1982 to 1999. Furthermore, quite detailed data have been provided on the airlines' operating statistics in 1999. The 1999-data contains specific information on the fuel burn, the aircraft kilometres, the available seats, the average stage distances and the average passenger load factors by type of aircraft for all the aircraft types that are operated by the US air carriers. Furthermore, some additional form 41 data that describe the fuel consumption of the aircraft that were operated by the Major[12] US air carriers in 1998 are taken from some

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[10] Most notably, some information from the Statistical Appendixes to Association of European Airlines' (AEA) Yearbooks [AEA 1998, 1999, 2000c and 2001] are included. These statistics include operating statistics on the amount of cargo carried in the passenger aircraft that are operated by AEA member airlines.

[11] These data are referred to in the text as [DOT 2001] describing the fuel cost and consumption and other operating statistics of the American Majors, Nationals and Regional airlines in selected years from 1982 to the present.

[12] In 1999 there were 13 Major US scheduled airlines with annual revenues of over $1 billion. Three of these, DHL, FedEx and United Parcel Service, are all-cargo carriers. The ten passenger carriers are Alaska, America West, American, Continental, Delta, Northwest, Southwest, Trans World, United and U.S. Airways. By January 2000 American Eagle and American Trans Air also became Majors [Air Transport Association 2000a].

recent articles published in the Journal "Aircraft Economics". The data for 1998 describe the fuel intensity and the productivity of all-cargo aircraft [Aircraft Economics 1999d] and of narrow-body passenger aircraft [Aircraft Economics 1999c] and of wide-body passenger aircraft [Aircraft Economics 1999f]. These data are furthermore supplemented by some statistical sources from the American Air Transport Association (ATA)[13] and by some overall statistics from the United States Department of Transport[14] [DOT 1999 and 2000] and the United States Department of Energy[15] [Davis 1995 and 1999]. Additionally, an older analysis of the "form 41" fuel consumption data that describes the impact of the 1973 and 1979 oil crisis' on the operating economics of the Major American air carriers is included [Sarames 1984] as to be able to compare today's fuel intensity by type of aircraft to that of the early 1970s.

It is likely, that there are some inconsistencies in the data material that describes the specific fuel consumption of different aircraft and airlines. For example, the airlines may use different methodologies for calculating the weight of the passengers and the freight that they are transporting. Furthermore, the information on the amount of freight that is carried in passenger aircraft is most often relatively scarce or non-existent in some of the statistical sources used here. It has therefore been necessary to use different types of estimates to be able to distribute the fuel consumption of passenger aircraft between the passengers and the belly-hold freight that they are transporting. There are also inconsistencies in the way the airlines attribute their fuel consumption to passenger and freight transport. Furthermore, there are differences in the way the airlines report their amount of revenue passengers transported. Some airlines may count all passengers whereas others exclude the passengers that are paying below a certain percentage of the normal fare. These inconsistencies are likely to be greater in cross-comparisons between the operating statistics of the European, the Asian and the American airlines

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[13] The operational statistics published in Air Transport Association's yearbook [Air Transport Association 1999, 2000e and 2001] are used to derive information on the amount of freight that is carried in passenger aircraft.

[14] Information on the overall yearly traffic performance (aircraft kilometres, average seats, available seat kilometres and revenue passenger kilometres) and the total fuel consumption, divided on domestic and international operations, of the American air carriers since 1973 are taken from the National Transportation Statistics that are published by the US Department of Transport [DOT 1999 and 2000].

[15] Information on the overall yearly traffic performance (aircraft kilometres, average seats, available seat kilometres, revenue passenger kilometres and revenue freight tonne kilometres) and the total fuel consumption of the American air carriers since 1973 has been taken from the

than what is the case when only comparing the data for the American air carriers that are reported to the US Department of Transportation in the same format. The data for the US air carriers are therefore internally consistent. Because the operating statistics of the American air carriers cover a large number of aircraft and airlines these data are used for most of the analysis' that makes cross-comparisons between a number of airlines. Some of the data inconsistencies are discussed further throughout this chapter.

The airline information is supplemented by various other sources, such as material from the aircraft producers and data from two modelling studies that gives information on the average fuel consumption according to the stage distance flown for a number of generic aircraft types [Gardner et. al. 1998] [Falk 1999]. Another modelling study that is mentioned briefly describes the increase in the specific fuel consumption per aircraft kilometre when the load factor increases [Daggett et. al. 1999]. These studies are drawn in because the data for the average yearly fuel consumption by type of aircraft does most often not offer insights to the fuel consumption connected to single trips of a specific length or with a specific load factor. Rather, the main part of the data reported by the airlines are average yearly data, that is, for example, averages for an airline or a number of airlines that are operating on a number of routes in a certain year. Additionally, a rather large amount of new regional jets and turboprops are currently emerging at the market. Some data for their specific fuel consumption at short-haul trips are drawn in as to be able to assess their likely impact on the specific fuel intensity of short-haul passenger air travel in the future [Aircraft Economics 2000a, 2001a and 2001c]. Most of these regional aircraft have only recently been introduced into airline operation or are planned to be introduced within the next few years, and are therefore generally not yet included in the airline reporting for the recent years.

The section that describes the future prospects for improving the fuel efficiency of next-generation aircraft is based on estimates found in the literature as well as information from the aircraft producers [Vincendon and Wrede 1999] [Airbus 2000a] [ATR 2001]. The section on the long-term possibilities to improve the fuel efficiency of aircraft as well as the brief discussion of alternative fuels draws extensively on other sources such as the recent report from the Intergovernmental Panel on Climate Change "Aviation

Transportation Energy Data Book that is published by the US Department of Energy [Davis 1995 and 1999].

and the Global Atmosphere" [IPCC 1999]. The brief mentioning of the possible contribution of aircraft engine emissions to climate change is also primarily drawing on the conclusions of this recent report.

Finally, the section that compares the fuel intensity of passenger air travel to that of other transportation modes draws on a number of studies of the fuel intensity of passenger cars [Færdselsstyrelsen 1999] [Schipper and Marie-Lilliu 1999] [EEA 2001] and trains and buses [IPCC 1996b] [Roos et. al. 1997] [DSB 1998] [Jørgensen 1999].

3.4 Evolution of the fuel intensity of passenger air travel

The fuel intensity per passenger kilometre of commercial civil air transport has been reduced by approximately 50% since the early 1970s. The use of more fuel-efficient jet engines and the introduction of bigger aircraft accommodating more seats per aircraft in combination with an increase in the average stage distances has reduced the fuel use per available seat kilometre (ASK). The improvement in the specific fuel consumption has furthermore reduced the necessary amount of fuel that has to be carried on flights of comparable distances leading to additional fuel savings. Furthermore, the operation at higher passenger load factors have contributed to reduce the fuel use per revenue passenger kilometre (RPK)[16]. The trend in the average specific fuel consumption per revenue passenger kilometre in commercial civil air transport is illustrated in Figure 3.1 that plots a number of different estimates that are given in the literature for all the US airlines [Davis 1999], for British Airways [British Airways 1999a], for all the UK airlines [Martin and Shock 1989] for the World's scheduled fleet [Greene 1990] [Balashov and Smith 1992] [Gardner et. al. 1998] and for the IATA fleet [Dobbie 2001]. We note that the estimates that are shown here include the total amount of fuel consumed by the airlines in question. The major part of this fuel is attributable to the carriage of passengers, but some is related to freight transport. Thus, the estimates for the average fuel consumption per passenger kilometre that are shown in figure 3.1 can be said to be somewhat overrated. Sections 3.7.1 and 3.8 of this chapter discusses the relative importance of freight in passenger airline activities and analyses how the fuel consumption can be distributed between passenger and freight transport weights respectively.

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[16] For a further description of these improvements see for instance [Sarames 1984] [Martin and shock 1989] [Grieb and Simon 1990] [Balashov and Smith 1992] [ETSU 1994] [Greene 1997] [Dings et. al. 1997] or [IPCC 1999].

Figure 3.1: Fuel intensity per revenue passenger kilometre (RPK) of passenger air travel according to various sources

Note that these estimates are biased because the total fuel consumed for passenger and freight transport is included. The impact of freight is explained further throughout this chapter. The estimates are furthermore for various groups of airlines that operate at different routes at varying passenger load factors and freight load factors using fleets of various aircraft mixes.

Sources: [Davis 1999], [Martin and shock 1989], [Balashov and Smith 1992], [Greene 1990], [Gardner et. al. 1998], [British Airways 1999a] and [Dobbie 2001].

A major part of the reductions in the fuel intensity per revenue passenger kilometre is due to the introduction of new and ever-more efficient aircraft that contributes to constantly enlarge the aircraft fleet. The seat capacity, measured in available seat kilometres offered, of the world's fleet of commercial jets and turboprops that are used for civil airline services tripled between 1978 and 1998 (see Figure 3.2). The lifetime of commercial civil aircraft is relatively long and many of the aircraft introduced in the 1960s and 1970s are still operating, although the rate of utilisation is typically highest for the newest aircraft in the fleet [AEA 1998] [DOT 2001]. Today, some 5000 operating jets are more than 23 years old, representing around 40% of the world's jet fleet [DTI 1999].

Figure 3.2: Seat capacity of the world's scheduled airlines (excluding the former Soviet Union)
Source for data: ICAO Statistics that are taken from [DTI 1999].
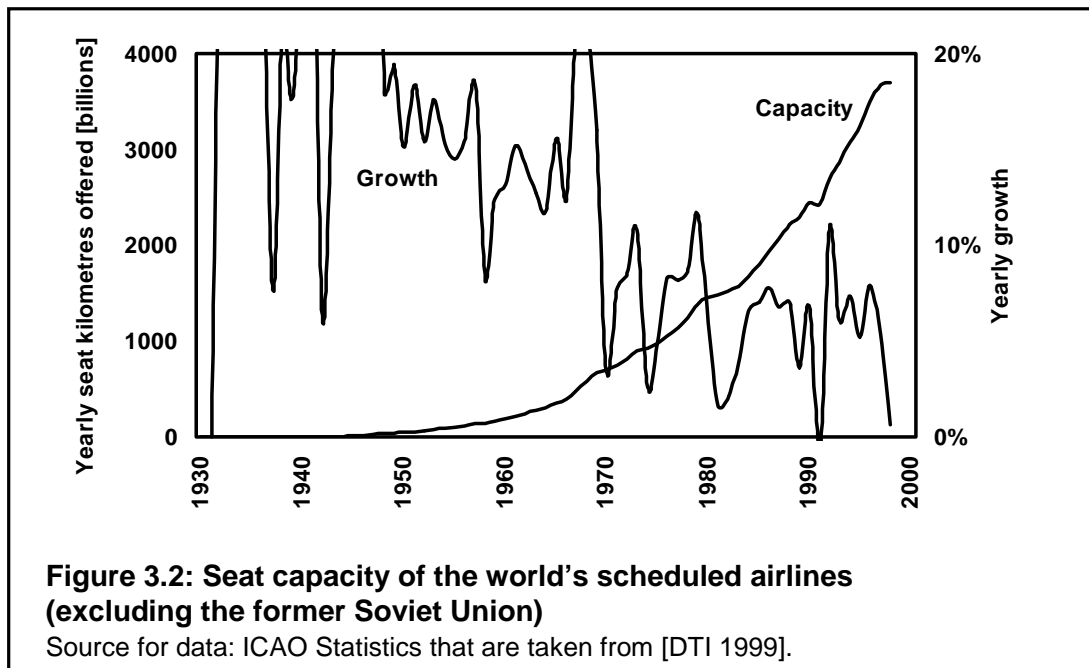
The growth in the volumes of passenger air travel and airfreight makes possible the enlargement of the fleet. But on the other hand the volume growth is speeded up as a consequence of the growing fleet capacity because the use of more efficient aircraft reduces the direct operating costs (DOC) per available seat kilometre (ASK) and per available tonne kilometre (ATK) offered [Aircraft Economics 1999a, 1999b, 1999c, 1999f, 2000a, 2001b and 2001c]. Furthermore, the airlines introduce cheap fares to fill up better their planes [Heppenheimer 1995] [Doganis 1985]. The efficiency gains attained are thereby to a large extent dependent on and furthering the growth in the transport volume. The reduction of the aircraft fleet's fuel intensity has not reduced the total fuel use because the efficiency gains are overridden by volume growth. For example, the fuel consumption of the American air carriers grew by a factor of 1,7 between 1973 and 1997 while the amount of revenue passenger kilometres (RPKs) and revenue freight tonne kilometres (RFTKs) grew by factors of 3,6 and 4,6 respectively, leading to an increase in the total amount of revenue tonne kilometres (RTKs) by a factor of 3,8. Freight transport and passenger transport have grown at average yearly rates of around 6,5% and 5,4% since 1973. While the yearly growth rate in passenger air travel has slowed down in the second half of the period freight transport has grown faster in these later years than in the first half, see Figure 3.3 [Davis 1999].

Figure 3.3: Some main developments for the US air carriers 1973-1997
Note that the fuel consumption indexes per available seat kilometre (ASK), per revenue passenger kilometre (RPK) and per revenue tonne kilometre (RTK) should be read at the left y-axis. The indexes for the fuel consumption, for the available seat kilometres (ASKs), for the revenue passenger kilometres (RPKs), for the revenue tonne kilometres (RTKs) and for the revenue freight tonne kilometres (RFTKs) should be read at the right y-axis. The number of RTKs have been calculated by using an average weight factor of 100 kilograms per revenue passenger inclusive baggage.
Source: [Davis 1995 and 1999].

The reduction of the specific fuel intensity of the American air carriers is attributable to technical changes as well as to operational changes. Between 1973 and 1997, the average passenger load factor of the American air carriers increased from around 54 percent to around 70 percent, thereby contributing to reduce the specific fuel consumption per revenue passenger kilometre (RPK) by some 15 percent. The specific energy intensity per available seat kilometre (ASK) was reduced by some 37% due to the introduction of larger and more fuel-efficient aircraft that operate over longer average distances[17]. However, the specific fuel intensity per revenue tonne kilometre (RTK), that is the total weight of the passengers and the freight transported, was reduced more (55%) than the specific fuel intensity per RPK because the amount of freight transported grew faster than the amount of RPKs. This exemplifies, that the

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[17] It should be noted that the specific fuel consumption of aircraft is also affected by a number of operational factors such as the actual usage cycles etc.

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specific fuel consumption per ASK and per RPK has been greater than what is suggested by Figures 3.1 and 3.3 when the fuel consumption that is attributable to freight transport is taken into account. In 1973, freight accounted for 26% of the total revenue weight. The freight weight share was gradually reduced to around 20% in 1980 and has increased since then to around 31% in 1997. This subject is discussed further in Sections 3.7.1 and 3.8.

As can be seen from Figure 3.3, a major part of the reduction of the specific fuel intensity of the US air carriers was achieved between 1973 and 1983. In this ten-year period the fuel consumption per revenue tonne kilometre (RTK) was reduced by 38%. In the same period, the specific fuel consumption per available seat kilometre (ASK) and per revenue passenger kilometre (RPK) was reduced by 33% and 41% respectively. The main explanation for these reductions is that new fuel-efficient wide-body jets, such as B747s, DC10s and L1011s were introduced into the fleet offering a substantial increase in the seat capacity (but also a reduction in the average passenger load factor as compared to the 1960s) as compared to the earlier narrow-body jets. The average number of seats per aircraft increased by approximately 43% in the period[18]. Since 1983, the yearly reduction in the fuel intensity has been lower. The specific consumption per RTK, per RPK and per ASK was reduced by 38%, 20% and 6% respectively in the fourteen-year period between 1983 and 1997. The major part of the reduction of the specific fuel consumption per revenue passenger kilometre between 1983 and 1997 has emerged due to the increase in the average passenger load factor from around 60% in 1984 to around 70% in 1997. Some explanations for the lower yearly reduction of the specific fuel consumption in the second part of the period is that the yearly fuel-efficiency improvements of the new types of aircraft that were introduced decreased over the period and that these new aircraft perform an ever-decreasing share of the total traffic because the old aircraft are kept in operation [IPCC 1999]. Furthermore, the average number of seats per aircraft declined by 11% in the second period and the average passenger trip length increased less (7%) than in the first period (11%). It should be noted that a number of other factors that are not mentioned here may have influenced the fuel-intensity improvement rates.

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[18] This estimate is calculated as the ratio of available seat kilometres to the revenue aircraft kilometres [Davis 1995 and 1999].

3.5 Fuel intensity of different types of aircraft

This section analyses the specific fuel intensity of different types of aircraft, based on recent information from some European and Asian airlines' yearly environmental audits[19] as well as some recent operating statistics for the American air carriers that are submitted to the US Department of Transport and some information from a number of academic studies that analyse the fuel intensity of aircraft in some earlier years (see section 3.3 for a description of the sources of information used).

Figure 3.4 plots the average specific fuel consumption per available seat kilometre (ASK) and per revenue passenger kilometre (RPK) for a range of different aircraft types for the average stage lengths at which they are used. Most of the data refer to the use in recent years, but a few older data are included as well (see the notes to Tables 3.1 and 3.2 for a further description of the data that are included in Figure 3.4. The data includes subsonic jets and turboprops in operation in various years from the beginning of the 1970s and onwards. The data for the fuel consumption per ASK and per RPK for each aircraft type refers to the usage cycle for a specific airline, or a number of airlines, in a specific year, including the specific load factor and the average stage distance flown by type of aircraft in that year.

Some data for the older aircraft types are derived from academic studies analysing 1970s and 1980s fuel intensity of a number of American and British airlines by aircraft type and are summarised in Table 3.2. The data for the aircraft types that are currently in use are summarised in Table 3.1 and represents data for use in the period between 1998-2000 of airlines that are situated in the United States, in Europe and in the Asia/Pacific region[20]. It should be noted that the different airlines may use different

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[19] For some of the European airlines (SAS and Lufthansa) that do not report their average stage distances in their yearly environmental reports these data are taken from the operating statistics that they are reporting to the Association of European Airlines [AEA 1999].

[20] The airlines included in this study are: **European** - Air 2000, AirBaltic, Balair, Condor, Lufthansa, Lufthansa City Line, Norwegian Air Shuttle, Premiair, SAS, Swissair. **Asia/Pacific** - All Nippon, Cathay Pacific, Japan Airlines. **American** - Air Wisconsin, Airtran / Frontier, Alaska Airlines, Aloha Airlines, America West Airlines, American Airlines, American Eagle/Simmons, American Trans Air, Atlantic Southeast Airlines, Champion Air, Continental Airlines, Continental Express, Continental Micronesia, Delta Air Lines, Eastwind, Emery Worldwide, Executive Airlines, Express. One Intl/Jet East, Federal Express, Frontier Airlines, Hawaiian Airlines, Horizon Air, Laker Airways, Mesaba Aviation, Miami Air Int'l, Midway Airlines (New), Midwest Express Airlines, National Airlines, North American Airlines, Northwest Airlines, Omni Air Express, Pro Air, Reno Air, Ryan Int'l Airlines, Southwest Airlines, Spirit Air Lines, Sun Country

methodologies for calculating the specific fuel consumption per passenger kilometre. For example, Lufthansa subtracts the fuel which is attributable to lifting the belly-hold freight in the company's passenger aircraft. Therefore, the further analysis' in the following sections primarily concentrate on comparisons of data between airlines or groups of airlines for which the data are consistent, unless otherwise is mentioned.

Figure 3.4: Specific fuel consumption per ASK and RPK versus stage distance for different types of aircraft

For an explanation of the data included see the explanations for Tables 3.1 and 3.2.
Data sources: [Premiair 2001] [All Nippon Airways 1999, 2000a and 2000b] [Lufthansa 1999 and 2000] [Lufthansa City Line 1999] [Swissair 1999] [SAS 1999b and 2000] [Sarames 1984] [Air Baltic 2001] [DOT 2001] [Norwegian Air Shuttle 2001] [AEA 1999]

The fuel use per revenue passenger kilometre (RPK) is higher than the fuel consumption per available seat kilometre (ASK), due to non-optimal passenger load factors. Aircraft that are used for short-haul regional flights are typically operating at load factors below average and are typically quite fuel intensive, as compared to aircraft that are used at medium-haul and long-haul, using normally around 50-90g per RPK (see Table 3.1 and Figure 3.2). The most fuel-intensive subsonic passenger aircraft that are currently in use (among the airlines studied here) are low-capacity regional turboprops and jets using up to 119g per RPK[21].

Airlines, Sun Pacific, Tower Air, Trans States Airlines, Transmeridian Airlines, United Air Lines, USAir, USAir Shuttle, Vanguard Air Express, World Airways.

[21] Note that these data only include jets and turboprops in airline operation. Aircraft dedicated for business- and general aviation are not included, and these may use more fuel per

Aircraft type	Average stage distance [km]	Fuel [g/ASK]	Fuel [g/RPK]	Seats	No. of Airlines
Bae jet stream 31**	231-245	60-66	119*	19	2
Bae jet stream 41**	390	52	96	30	1
Embraer 120**	359-411	45-52	86*	30	2
Dornier 328**	385	43	65	32	1
Saab 340B**	304-338	46-52	84*	34	2
Embraer 135	567-613	37-64	83*	37	2
De Havilland DHC 8-100**	259-272	45	76*	37-39	2
ATR 42**	235-365	39-47	70*	46-48	5
Saab 2000**	456	41	66	47	1
Fokker 50**	278-368	30	48-76	46-50	4
Embraer 145	513-796	40-47	72*	50	3
ATR 72**	295-399	30-36	56*	64-68	6
Fokker 28	512-585	50-59	81-94	65-75	2
De Havilland DHC 8-Q400**	500	36	58	72	1
AVRO RJ 85	532-661	63*	89^L-112	69-80	2
Canadair jet 100/145	621-1107	32 –63	46-87	48-50	4
DC-9-10	640-1040	65-68	107*	60-78	3
Bae 146-300	513	39	60	89	1
Fokker 100	494-961	41-54	66*	97-98	3
DC-9-30	552-1181	33-58	77*	83-117	8
B737-100/200	229-1250	28-64	62*	95-123	13
DC-9-40	782-1390	38-54	69*	100-127	3
B737-500	604-1274	37-39	57*-72^L	103-122	4
MD-87	741-852	38-44	61-64*	110-125	3
B717-200	759	23	33	119	1
DC-9-50	203-743	48-61	80*	115-134	3
A319	808-2131	28-32	42-53^L	120-126	5
B737-300/700	685-2525	24^C-36	46*-59^L	120-155	12
B727-100	2062	37	79	170	1
B727-200	319-1887	36-83	66*	95-179	15
MD-80 & DC-9-80	855-1790	31-40	51*	114-160	10
A320-100/200	696-2700	16^C-38	18^C -52	110-183^C	14
MD-90-30/50	645-1340	29-40	48*-53	141-150	4
B737-400	630-2257	24-33	46*	140-170	6
B737-800	1126-3848	26-36	38*-58	146-179	4
A321	763-787	16^C-24	18^C -40	182-220^C	3

Table 3.1: Recent airline reporting on specific aircraft fuel consumption 1998-2000

(Table 3.1 continues on the next page…)

passenger kilometre because they are generally designed for accommodating fewer passengers than similar sized aircraft in scheduled airline operation.

B757-200	1600-3617	17^C -29	19^C -38*	158-233^C	14
A310-300	994-3401	27	37-52^L	222	2
B757-300	NR	NR	25^{CL}	252	1
B767-200/200ER	941-5746	23-37	46*	168-264	6
A300-600	1333-2705	30*	40-47^L	228-270	2
A300B4-120	2794	27^C	27^C	298^C	1
B767-300/300ER	796-5387	19^C -32	21^C -52	188-322^C	9
L-1011-500	1776	42	56	244	1
DC-10-10	2073-3702	21-42	48*	267-379	7
A330-200/300	3081-3169	19^C-21^C	20^C-28	196-409^C	3
A340-200/300	7393	NR	29 –36^L	212-291	2
DC-10-30	4085-6023	29^C -45	34^{CL}-46*	229-370^{CL}	7
MD-11	4384-7150	23-41	31-60*	232-376	5
L-1011-100/200	2021-2998	30-37	43*	299-361	2
B777-200/300	870-7888	18^D -36	27^D -56	202-477^D	7
B747-200/300	589-6817	23-52	32-108	310-389	5
B747-100/100SR	921-5735	28^D-33	40-46	447-536^D	4
B747-400	970-7883	24^D -34	37^L -53	343-569^D	6

Table 3.1 continued…

* US airline average

** Turboprops

NR Not reported by any of the airlines

[C] In charter all-economy class configuration

[D] In domestic all-economy class configuration

[L] lufthansa

Note that the data that are shown here are generally for the total fuel consumption in passenger aircraft, including the fuel used for lifting belly-hold freight. However, for the aircraft that are operated by Lufthansa the fuel consumption related to freight transport in passenger aircraft has been subtracted and the figures for the fuel consumption per RPK are therefore lower than for similar aircraft that are operated by other airlines. Lufthansa's figures are marked with an [L]. In the case of the B747-400 Lufthansa reports the lowest fuel consumption per RPK because this type of aircraft carry much belly-hold freight. Lufthansa and Cathay Pacific Airways do not report their fuel consumption per ASK. For the aircraft operated by Lufthansa Condor, Japan Airlines, Cathay Pacific and Air 2000 it has not been possible to get data for the average stage distances, and their aircraft are therefore not included in Figure 3.4. For the American air carriers, the specific fuel consumption per ASK and RPK of each type of aircraft that is operated is shown as the average for all carriers.

Data sources: [Condor 2000] [Premiair 2001] [Air 2000 2001] [Cathay Pacific Airways Limited 2000] [All Nippon Airways 1999 and 2000] [Japan Airlines 2000] [Lufthansa 1999, 2000a and 2000b] [Lufthansa City Line 1999] [Swissair 1999] [SAS 1999b and 2000] [Air Baltic 2001] [DOT 2001] [Norwegian Air Shuttle 2001] [AEA 1999]

Aircraft type	Average stage distance [km]	Fuel [g/ASK]	Fuel [g/RPK]	Seats	Year	Airline
Shorts 360**	-	51	87	36	1986	British airline's average
Fokker 27**	-	46	85	44	1986	British airline's average
Vickers Viscount**	-	80	94	60	1986	British airline's average
BAC 1-11	-	57	78	65-99	1986	British airline's average
B707 (all)	1587	62	119	129	1973	US airline average
DC-9-30	538	64	123	90	1973	US airline average
DC-9	-	41	67	85-110	1986	British airline's average
B737 (all)	496	59	114	94	1973	US airline average
B737 (all)	-	32	34	106-149	1986	British airline's average
DC-8-10/50	1416	73	141	127	1973	US airline average
DC-8-60/70	1580	54	103	169	1973	US airline average
B757-200	-	30	37	189-225	1986	British airline's average
B767-200	-	23	23	273	1986	British airline's average
L-1011	1907	49	95	222	1973	US airline average
L-1011	-	46	55	226-234	1986	British airline's average
DC-10	1577	44	85	233	1973	US airline average
DC-10	-	39	52	233-379	1986	British airline's average
B747 (all)	2799	43	84	332	1973	US airline average
B747 (all)	-	39	55	370-475	1986	British airline's average
Concorde	-	175	313	100	1986	British airline's average

Table 3.2: Examples of 1970s and 1980s airline reporting on specific aircraft fuel use

**Turboprops

Note that the figures for British airlines in 1986 do not give information on the average stage distances and are therefore not included in Figure 3.4.

Sources: [Martin and shock 1989] [Sarames 1984].

The aircraft used at medium-haul typically use around 30-50g/RPK, but the most fuel-efficient types consume less than 20g/RPK. However, the old DC9s operating in the medium-capacity market use up to around 111g per RPK on average when operated on short-haul routes at below average load factors.

Aircraft that are used for long-range flights normally consume around 40-50g/RPK. The most fuel-efficient long-range aircraft consume below 30g/RPK whereas the least

efficient types consume up to 60g/RPK[22]. The supersonic Concorde, that has not been included in Figure 3.4, is in a class of its own among the long-range aircraft, using 175g/ASK and 313g/RPK. That is, the Concorde use about ten times as much fuel per revenue passenger kilometre as do the most efficient subsonic long-range jets. Furthermore, the Concorde cruise at much higher altitude (18 kilometres) than subsonic aircraft (typically around 10-12 kilometres), leading potentially to a more severe environmental impact per kilo of fuel burned than aircraft cruising at lower altitudes[23].

3.6 A further look into the specific fuel intensity of aircraft

This section identifies some of the main determinants of aircraft specific fuel consumption, that is airframe characteristics and engine technology, passenger and freight load factors, stage distances and seat-configuration. Other factors, such as the choice of speed and altitude, flying indirect routings, stacking above congested airports, weather conditions, engine deterioration, fuel tankering, weight of aircraft seats and other interiors, and additional weight of in-flight meals etc., are not considered here, but are also determinants in aircraft fuel use.

3.6.1 Airframe size and engine

The main part of the reduction in the specific fuel consumption per available seat kilometre that has been achieved over the past decades are due to the use of more fuel-efficient engines and the use of bigger aircraft on average.

As for engine technology, turboprops are the most fuel-efficient (see Section 3.6.3 and Figure 3.14), but are mainly used for small- to medium-sized regional aircraft. The main reasons for not using turboprops for larger aircraft is that they cannot generate the same level of thrust and speed as can turbojets and turbofans. In recent years, regional jets have seen strong sales whereas turboprops have to some extent become out of fashion, partly due to consumer preferences for jets over turboprops[24].

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[22] We note that the fuel consumption per ASK and RPK of long-range aircraft will typically be much lower than this if taking account of the fact that these aircraft carry much belly-hold freight. This is explained further in Section 3.8.

[23] For an introduction to the possible impact of aircraft engine emissions on the global atmosphere see [IPCC 1999].

[24] For a further introduction into the emerging role of regional jets in the US see [DOT 1998].

Jet engines have seen large improvements since the first civil turbojets were introduced in the early 1950s. The introduction of low-bypass turbofans in the 1960s and later high-bypass turbofans in the 1970s and third-generation turbofans in the 1980s reduced the specific fuel consumption per amount of thrust produced as compared to the early turbojets [IPCC 1999] [Birch 2000]. Basically, the reduction in the specific fuel consumption has been achieved by improving the thermal efficiency of the combustion chamber while increasing the propulsive efficiency of the fan. The thermal efficiency improves as the temperature and the pressure in the engine's combustion chamber increase while the propulsive efficiency improves as the engine's bypass-ratio increases[25]. However, counteracting tendencies have to some extent reduced the overall environmental improvements. One example is that when the bypass ratio of turbofan engines increases the engine's weight and drag increases. Another example is that when the combustion temperature increases the emissions of NO_X per amount of fuel burnt also increases. NO_x is a GHG precursor when emitted at cruise altitude. However, new types of low-emission combustion chamber technologies can to some extent reduce the NO_x emissions while also reducing the specific fuel consumption [IPCC 1999].

It should also be mentioned here that the newest high-bypass turbofan engines are less noisy than the earlier versions [IPCC 1999]. Although there are no government standards for the specific fuel consumption and gaseous emissions at cruise altitude from aircraft engines, some ICAO regulations put out standards for the maximum allowable engine noise and gaseous emissions (soot, unburned hydrocarbons, carbon monoxide and nitrogen oxides) through the so-called landing and take off (LTO) cycle. A part of these regulations requires the airlines to phase out or re-engine or hushkit the oldest aircraft models, the so-called chapter 2 certificate aircraft, to apply to the current chapter 3 standard that is applicable to all aircraft in operation from 2002. Re-engine schemes may make the old aircraft more fuel efficient whereas hushkits may increase their specific fuel consumption while a phasing out may allow for the introduction of newer and more fuel-efficient aircraft types [IPCC 1999].

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[25] The term bypass-ratio is a measure for the amount of air surpassing the combustion chamber through the duct surrounding the engine core over the amount of air passing through the combustion chamber.

As for airframe technology the main part of the reductions in the specific aircraft fuel consumption is attributable to increases in the aircraft size and thereby the seat and freight capacity. However, some other main features are the improvements in the lift and drag performance as well as the use of advanced lighter and stronger airframe materials (aluminium alloys and composite materials) leading to weight reductions [IPCC 1999].

A look at the data presented in Tables 3.1 and 3.2 reveals the impact of the technological improvements to some main aircraft models that were operated by the American air carriers in 1973 and 1998 respectively. For example, in 1973 the B737s consumed around 59g of fuel per ASK on average and had 94 seats on average. For comparison, the B737-500s that are operated by American major airlines in 1998 use 37g of fuel per ASK and have 110 seats on average. A second example for comparison is the long-range B747. In 1973 the B747s used 43g per ASK and had 332 seats on average. In 1998 the B747-400s use 32g per ASK and have 383 seats on average. A third example for comparison is that the 233-seat DC-10 tri-jet introduced in the early 1970s used around 44g per ASK while the 290-seat B777-200 twinjet introduced in the mid-1990s consume around 28g per ASK [Sarames 1984] [Aircraft Economics 1999f and 1999c]. Many airlines are today replacing their current aircraft by bigger types and this makes it possible to operate at lower specific fuel consumption. For example, SAS estimates that by replacing their current 169-seat B767-300ERs that were introduced on SAS' intercontinental routes in 1989 by 261-seat A330-300s and A340-300s the fuel consumption per ASK is reduced by 10-20% [SAS 2001].

It should be noted however, that even though the fuel efficiency increases when using large aircraft, the total fuel consumption from aircraft operations also increases. That is, large aircraft still consume more fuel per aircraft kilometre even though they consume less fuel per seat offered (when comparing aircraft of the same generation). Thereby, the introduction of new and ever-larger aircraft adds to the rebound effect[26]. That is, by introducing large-capacity fuel-efficient jets airlines can operate at lower direct operating costs per seat kilometre offered making it possible to reduce the airfares and thereby spurring additional demand. Airlines may furthermore have an increased

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[26] The term "rebound effect" is often used within energy studies for describing to which extent fuel efficiency gains makes energy services cheaper, thereby allowing users to acquire even more energy services, and thereby driving energy consumption upwards.

incentive to sell a certain proportion of the tickets at discounted prices to fill up those larger aircraft.

3.6.2 Passenger and freight load factors and seat configuration

Generally, the average yearly passenger load factors of commercial air carriers have been improved through the last decades from around 50 percent in the early 1970s to around 70 percent currently [ICAO 1999a]. The low load factors in the early 1970s was a direct result of the over-capacity resulting from the introduction of very large wide-body aircraft. Today, the passenger load factors on domestic scheduled services are slightly lower than on international scheduled services [ICAO 1998a].

There are considerable differences among airlines concerning load factors. Passenger load factors are reported from around 50% to above 75% by scheduled airlines, although most major airlines operate above 65% [ICAO 1998a] [AEA 1998]. European charter carriers generally operate at above average passenger load factors, some of them close to the optimum, one example being Premiair reporting a passenger load factor of 98% in 1999 [Premiair 2001].

The weight load factors, that is the weight of passengers and their baggage plus the weight of the freight transported as belly-hold over the available capacity (measured as available tonne kilometres, are generally lower than the passenger load factors. The share of freight in total scheduled traffic range from less than 10% to above 40% for some airlines [Cranfield College of Aeronautics 2000b]. Freight's share of the total weight transported is generally higher on long-haul routes than on medium-haul while being almost insignificant on short-haul, see Section 3.8 for a further discussion of this issue [AEA 1999] [DOT 2001].

The fuel use per revenue passenger kilometre and per freight tonne kilometre is generally reduced at higher load factors. However, the total aircraft fuel use increases as the load factor increases, because of the weight that is added to the aircraft when carrying additional passengers and freight and this is also reinforced by the aircraft carrying more fuel. The connection between load factors and the fuel-burn per seat vary according to the aircraft type and the distance flown. A recent study proposes, that for modern medium- to large-capacity aircraft such as B747-400, B777-200, B757-200 and B737-700, the additional fuel burn at high load factors is rather small. For example,

an increase in the passenger load factor from 70% to 100% is suggested to generally lead to an increase of less than 5% in the total fuel use on trips of average lengths for those aircraft [Daggett et. al. 1999]. For smaller short-haul aircraft as well as for some older medium-capacity jets the fuel consumption increase considerably more than what is suggested for modern medium-haul and long-haul jets [IPCC 1999, p. 280].

An example of the importance of the freight load factors for the fuel consumption per revenue freight tonne kilometre transported by all-cargo carriers is illustrated in Figure 3.5. In 1998, the main types of aircraft used by the three major US all-cargo carriers (UPS, DHL and FedEx) operated at weight load factors of between 47% and 67%. The fuel consumption per revenue freight tonne kilometre is therefore around 1,5 to 2 times as high as the fuel consumed per available tonne kilometre, that is the available capacity[27]. The aircraft shown to the left in Figure 3.5 are operating at short distances with average revenue loads of between 10-30 tonnes and those to the right are long-haul aircraft with revenue loads of up to 65 tonnes.

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[27] These all-cargo carriers use old jets for some of their short haul and medium-haul operations. Because the utilisation rate is often low in such operations it may be relatively expensive to use new aircraft with high capital costs even though these would have lower fuel costs. For example, some 40% of the freighter fleet that is operated by the three largest US all-cargo carriers (UPS, FedEx and DHL Airways) consists of relatively old DC8s, DC9s, B727s and DC10s, some of them dating back to the 1960s and the 1970s [Aircraft Economics 1999d].

Figure 3.5: The specific fuel consumption of the main aircraft models operated by the three major US all-cargo carriers in 1998
Source: [Aircraft Economics 1999d]
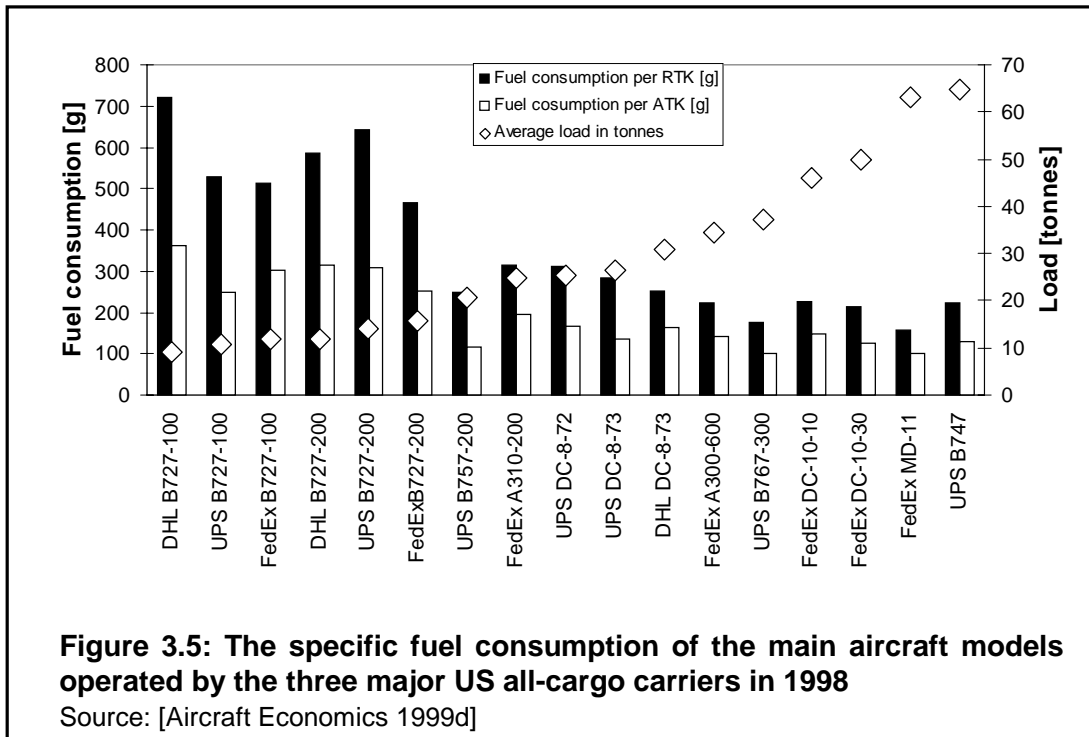
An example of the link between the passenger load factors and the fuel use is given in Figure 3.6 that illustrates the specific fuel consumption per available seat kilometre (ASK) and per revenue passenger kilometre (RPK) of the aircraft in All Nippon Airways' fleet in 1998. All Nippon Airways' fuel use for different aircraft operated at domestic routes is generally between 35-46g per RPK, when excluding the 108g/RPK used by the B747-200LR long-range low-density seat-configuration[28] aircraft[29]. On international long-range operations All Nippon Airways' aircraft consume 46-61g/RPK on average. The fuel use per RPK is generally 1,4-1,8 times higher than for ASK because of average yearly specific load factors by aircraft type of some 55% to 73%.

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[28] Medium- and long-range aircraft types are produced in a range of versions offering different seat configurations. Three-class seat-configuration offers seats in first class, business class and tourist class. Two-class seat-configuration offers seats in business class and tourist class. One-class seat-configuration features tourist class only. Seats at first class and business class are the most spacious while tourist class seats acquire much less space. What is here referred to, as high-density seat-configuration aircraft are those equipped mainly with tourist class seats whereas three class seat-configured aircraft are referred to as low-density seat-configuration aircraft.

[29] It should be noted that All Nippon only used the B747-200LR on a total flight distance of 23560 kilometres in domestic operations in 1998, almost negligible as compared to the total flight distance of around 270 million aircraft kilometres performed by the carrier in that year.

Figure 3.6: The specific fuel use by aircraft type for All Nippon Airways' passenger fleet in 1998

Data source: [All Nippon Airways 2000]
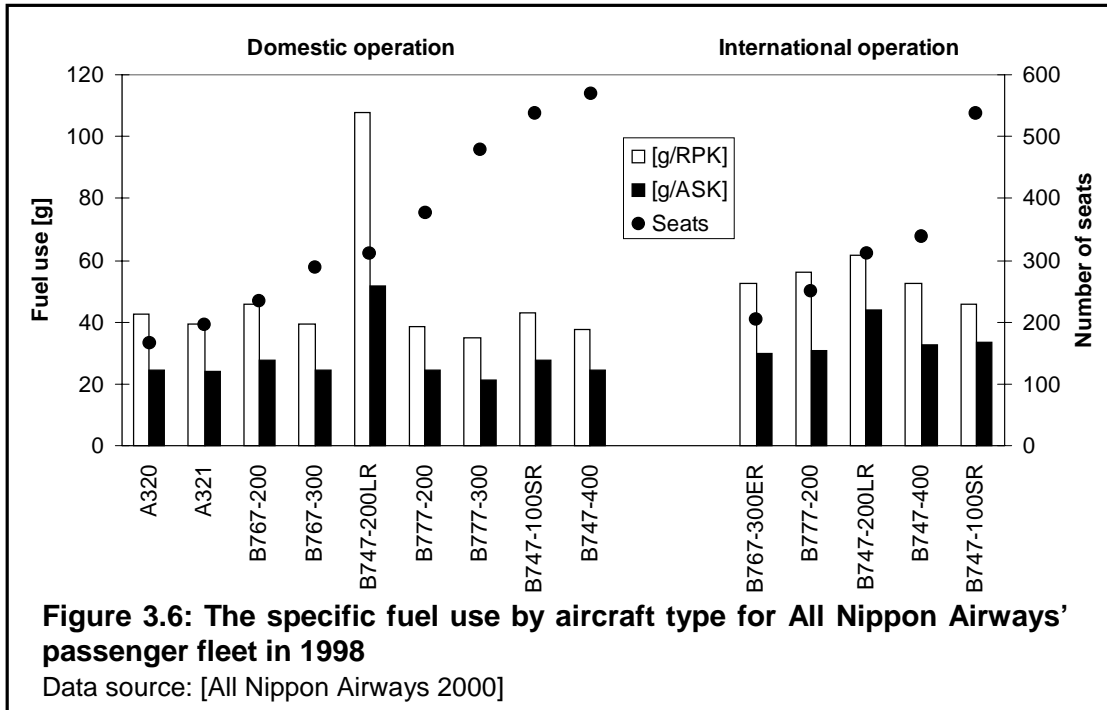
Figure 3.6 also indicates that All Nippon's fuel use is generally higher on international routes than in domestic mode. A part of this difference is due to the higher freight load factors on international routes. Around one third of All Nippon's revenue weight transported in passenger aircraft on international routes is freight while passengers and baggage weigh around two thirds. In domestic passenger operations the freight weight only accounts for around 13% of the total revenue weight. However, the main explanation for the differences between the specific fuel consumption in domestic and international operations is that all-economy class high-density seat-configuration aircraft are used on domestic routes while three-class low-density seat-configuration aircraft are used on international flights. For instance, All Nippon's B777-200s accommodates 376 passengers in all-economy seat-configuration but only 250 in the three-class international version, while the B747-400 accommodates 569 passengers in the all-economy seat-configuration and only 337 in three-class mode.

Similarly, European charter carriers and many low-cost scheduled carriers generally use high-density seat-configuration aircraft, thereby operating at lower fuel consumption per available seat kilometre than scheduled flag carriers. Many examples can be drawn from the data shown in Table 3.1, showing considerable differences in the seat-configurations, especially in the segment for long-haul aircraft. For example,

the European charter carrier Premiair operates A330-200s and A330-300s accommodating 30% and 50% more seats respectively than similar aircraft types operated by Swissair and Cathay Pacific respectively. A similar comparison in the medium-range segment shows that the European charter carrier Air 2000 operates A320s and A321s with 20-25 percent more seats than Lufthansa's aircraft. The operation at above average passenger load factors and the negligible amounts of freight loads[30] combined with the use of new-generation aircraft in high-density seat-configuration, explain why the fuel intensity of Premiair and Air 2000 is around half of the global average for the world fleet.

However, another not yet mentioned major feature of the specific fuel consumption of aircraft is revealed in Figure 3.6, showing the B747-200LR to have considerably lower specific fuel consumption per seat kilometre on international routes than on domestic routes. This is mainly due to the fact that the specific fuel consumption depends on the actual flight distance, as will be explained in the next section.

3.6.3 Flight distance

A European modelling study, "*Abatement of Nuisances Caused by Air Transport*", gives further insights into the effect of flight distances for the fuel consumption per aircraft kilometre, as exemplified in Figure 3.7 [Gardner et. al. 1998] [Falk 1999]. The aircraft fuel use per kilometre is generally reduced the longer the stage length, because a rather large amount of fuel is consumed during the takeoff and climb to the cruising height, whereas less fuel is consumed per time unit in high altitude cruising mode. However, for the long-range aircraft the fuel use per kilometre begin increasing slightly around 5000 to 8000 kilometres, depending on the aircraft in question [Falk 1999]. This increase mainly occurs because the weight of the additional fuel load needed for extended range outweighs the gains from extended cruising distance. The graphs in Figure 3.7 illustrate the fuel use per aircraft kilometre for some selected aircraft types. The examples shown are for generic aircraft models that are supposed to represent the most used types of aircraft. Each generic model represents an average over a range of models, with differences in the fuselage length, the seat configuration, the types of engines fitted and the maximum take-off weight and range etc. The curves in Figure

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[30] On charter flights the amount of freight carried is normally negligible. According to Roos et. al. [1997, p. 25] there is often too little time to load and unload cargo in charter operations and the relatively high amount of passengers and baggage leaves only a little residual room available.

3.5 should therefore merely be used to illustrate the tendency towards lower fuel use per aircraft kilometre and ASK at increasing stage length, and the increase after a certain point for long-range aircraft.

Long-range aircraft

Short- and medium-range aircraft

Figure 3.7: Generic aircraft fuel use versus stage distance
Data source: [Falk 1999]
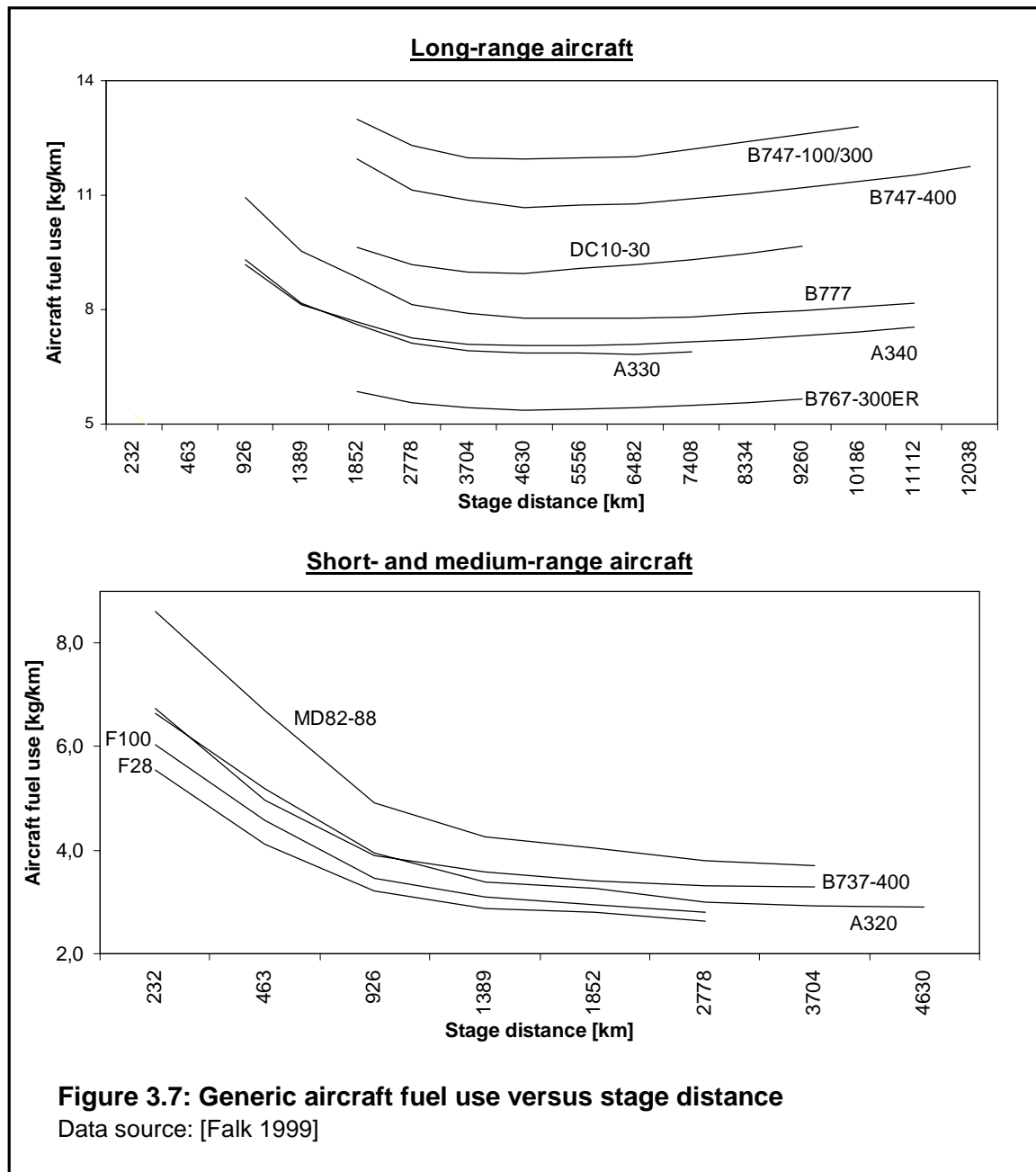
The fuel consumption per aircraft kilometre and ASK rise sharply at low sector lengths for all aircraft types. In the case of the Boeing 747-400, the point at which the fuel use per ASK starts to rise sharply is at distances below about 1400 kilometres, with the fuel consumption per ASK at 500 kilometres being about double that at 2000 kilometres. For smaller jets, such as B737s and A320s the fuel consumption per ASK seems to

start increasing at sector lengths of less than 800 kilometres with the doubling in fuel consumption per ASK occurring at around 200 kilometres.

In most cases, turboprop aircraft (not shown in Figure 3.7) are more fuel-efficient than similarly sized jets for short-haul air transport, the specific fuel consumption being less than one third higher at sector distances of 185 kilometres as compared to sector distances of around 700 kilometres[31] [Norwegian Air Shuttle 2001]. This is one reason why turboprops are likely to remain dominant for use at flight distances shorter than approximately 400 kilometres. At the other end of the market, in the segment for long-haul aircraft, the fuel consumption per revenue load increases more than the increase in the fuel consumption per aircraft kilometre that is shown in Figure 3.7 at flight lengths that are longer than the maximum payload range[32], because payload is removed to accommodate the extra fuel, and this effect becomes extreme once full-tank range[33] is reached [Aircraft Economics 1999a].

The data reported to the US Department of Transportation for the average fuel burn per ASK and per RPK by aircraft type of American air carriers in 1999 are shown in Figure 3.8. Figure 3.8 indicates that the fuel use per ASK is generally highest on short-haul, while being lowest on medium-haul and on long haul. However, when also considering that the load factors are below the average on short-haul, the fuel consumption per RPK on those distances is considerably higher than on medium-haul and long haul. The 65-seat ATR-72 turboprop is the least fuel intensive aircraft that is used on average stage distances of around 365 kilometres using about 33g per ASK on average. According to information from the manufacturer the newest derivative, the 68-seat ATR 72-500 should be even more fuel-efficient than the older –200 version [ATR 2001]. At average stage distances of about 750 kilometres, the 119-seat B717-200[34] jet

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[31] This estimate is based on data for the specific fuel consumption of Fokker 50s according to stage distance at various load factors, speeds and cruising heights that has been kindly provided by a Norwegian regional airline [Norwegian Air Shuttle 2001].

[32] The maximum payload range is a term that expresses the range of an aircraft flying with the maximum allowable payload weight.

[33] The full-tank range is a term that expresses the range of an aircraft that takes off with filled-up fuel tanks.

[34] The brand-new B717-200 was only in use by one single American air carrier in 1999, making this estimate less statistically certain than for most of the other models. The B747-400 was only operated by two airlines. The B737-800 was operated by three airlines, the B777 by four airlines, the ATR 72 by six airlines, the A320 by eight airlines and the B757-200 by twelve airlines.

is the least fuel-intensive aircraft using about 23g per ASK. At stage distances of around 2000-3000 kilometres the 148-seat A320, the 186-seat B757-200 and the 149-seat B737-800 jets are the least fuel-intensive aircraft using around 26-27g per available seat kilometre. At average stage distances of over 5000 kilometres the 274-seat B777 and the 376-seat B747-400 are the least fuel intensive using about 30g and 33g per ASK respectively. That is, if comparing the most efficient types described here, the fuel intensity per ASK is slightly lower on medium-haul than on long-haul (but this difference is smoothed out if also taking into account that long-range aircraft typically transport more freight than medium-haul aircraft, see Section 3.8).
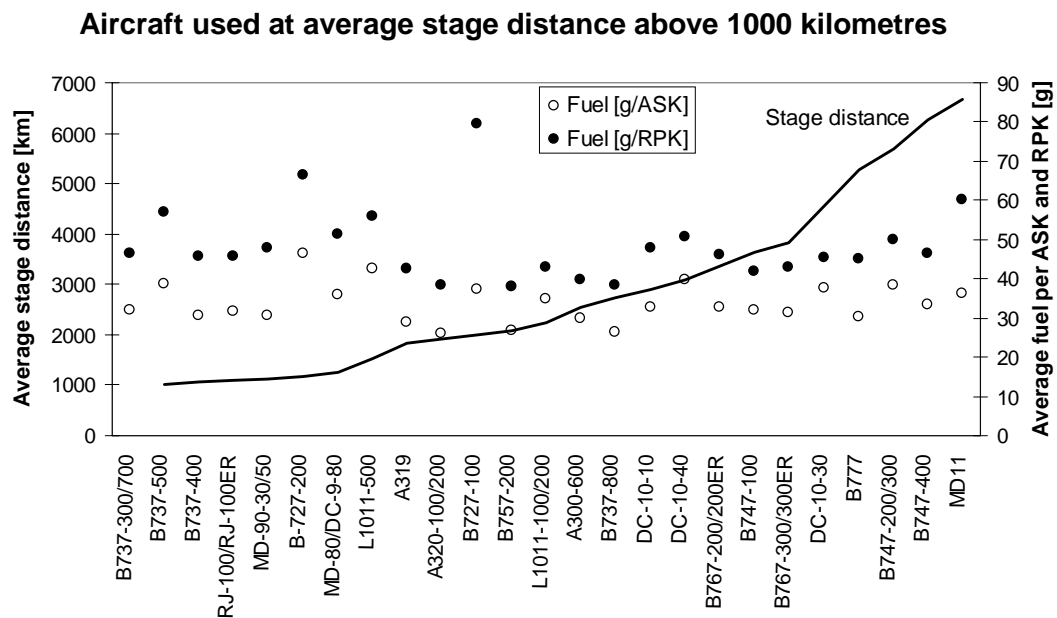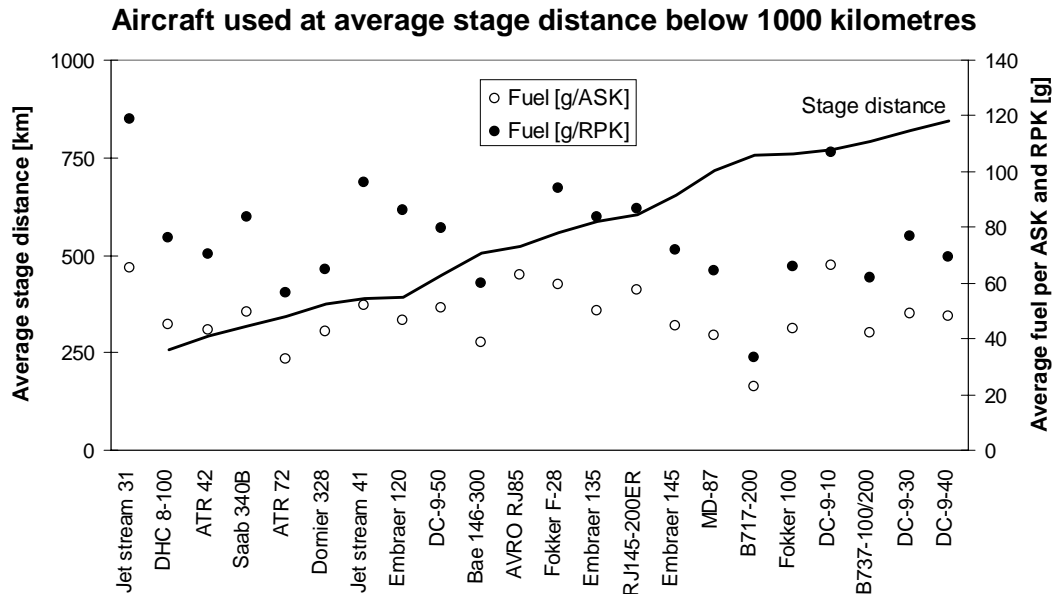
Figure 3.8: US major airlines' average specific fuel use and the average stage distances for different types of passenger aircraft 1999

Note that these data are for the total fuel consumption in passenger aircraft. That is, these data also include the fuel consumed for lifting belly-hold freight. Large-capacity long-range passenger aircraft generally carry a relatively high proportion of freight. Therefore, it could be argued that the fuel consumption figures for passenger transport in long-haul aircraft are somewhat overrated in the Figure (see Section 3.8).

Data source: [DOT 2001].

3.7 A comparison of the average fuel intensity of airlines

Some airlines publish environmental reports giving estimates for their fleets' average yearly fuel intensity. Such data are compared in Tables 3.3 and 3.4 for a number of airlines.

The airlines represented in Table 3.3 report average fuel-burns of between 24-46g/ASK, and between 26-81g/RPK. European charter airlines are generally the most fuel-efficient. Scheduled airlines that are operating relatively old aircraft mainly at short- and medium-haul routes, such as SAS[35] in 1998, are more than twice as fuel intensive as the most efficient charter airlines. Commuter- and regional airlines, like Lufthansa City Line, which often operate at below average load factor at short-range routes, generally use around twice as much fuel per passenger kilometre than do the major scheduled airlines.

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[35] It should be noted that SAS has embarked upon a major fleet renewal scheme by introducing the newest types of B737s to substitute its DC9s and Fokker F-28s, and A330/340s will replace SAS' B767-300Ers. Furthermore, A321s will supplement SAS' MD90s. SAS' specific fuel consumption is therefore likely to be reduced in the coming years [SAS 2001].

	Fuel [g/ASK]	Fuel [g/RPK]	Fuel [g/ATK]	Fuel [g/RTK]	Passenger Load factor %	Freight weight share in passenger aircraft
Lufthansa average****	30	39	-	-	75	-
Lufthansa Scheduled	-	(37)* 42	-	-	-	17%
Lufthansa City Line	46	81	-	-	57	-
Lufthansa Condor***	-	28	-	-	81	-
KLM	-	-	227	298	77	-
SAS	40	62	285	479	66	-
British Airways	35	(35)* 49	248	370	67	30%
Braathens	38	70	-	-	-	-
Finnair 1997	30	44	-	377	72	-
Swissair	-	35	390	-	-	-
SairLines**	-	38	-	-	-	-
Air France	-	(42)* 49	-	-	-	-
All Nippon Airways	30	47	-	-	64	22%
Japan Airlines	-	-	246	-	69	-
Cathay Pacific	-	35	-	-	-	-
Delta Airlines 1999	-	47	-	-	-	-
American Airlines 1999	34	-	-	-	-	-
American Eagle 1999	43	-	-	-	-	-
Premiair*** 1999	24	26	-	-	98	-

Table 3.3: The average specific fuel consumption of passenger airlines[36]

All data are for 1998 except when anything else noted.

*The figures in brackets represent airline estimates where fuel used for lifting belly-hold freight in passenger aircraft is subtracted. Note that the three airlines that give such estimates for the fuel which is attributable to belly-hold freight all use different methodologies in the calculation

**(Swiss Air, Crossair, Balair/(CTA) altogether).

***European charter carriers.

****Average for Lufthansa Scheduled, Lufthansa City Line and Lufhansa Condor.

Sources: [Lufthansa 1999 and 2000a] [Lufthansa City Line 1999] [Condor 2000] [KLM 1999] [SAS 1999a and 1999b] [British Airways 1999a and 1999b] [Braathens 1998] [Finnair 1998] [Swissair 1999] [Air France 2000] [All Nippon Airways 1999] [Japan Airlines 2000] [Cathay Pacific Airways Limited 2000] [Delta Airlines 2000] [American airlines 2000] [Premiair 2001].

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[36] It should be noted that these yearly averages are constantly changing. For example, British Airways nearly halved its specific fuel intensity in the period between 1974 and 1999, see

Similarly, Air France and Lufthansa Cargo report their average fuel use per revenue freight tonne-kilometre (RFTK) performed. These are averages over the fuel consumed for freight transport in their all-cargo freighters and the fuel that is attributable to lifting the belly-hold freight in their passenger aircraft. According to these estimates from Air France and Lufthansa Cargo around five times as much fuel is consumed for transporting one tonne of freight one kilometre as is used per passenger kilometre on average. However, this is an average over a number of different aircraft models that operate at different stage lengths. The specific fuel consumption of airfreight on short haul in passenger aircraft can be more than twice as high as the average. Furthermore, the fuel consumption per RFTK in some of the all-cargo aircraft that are operated by Air France, Lufthansa Cargo, KLM, UPS, FedEx and DHL are shown in Table 3.4. These data show that the specific fuel consumption in all-cargo freighters range from around 165g per RFTK to around 644g per RFTK. The lowest figures reported are for long-haul MD11s that operate at average loads of above 60 tonnes while the highest figures represents old B727s that operate at average stage distances of around 500-1300 kilometres carrying average loads of around 10-20 tonnes, see Figure 3.5. The average specific fuel consumption of the operations performed by the three Major US all-cargo carriers in 1998 can be estimated from the data described earlier in Figure 3.5 at around 237g per revenue freight tonne kilometre (RFTK) transported and some 138g per available tonne kilometre (ATK). Note that these data do only cover the most used types of aircraft by the carriers in question [Aircraft Economics 1999d].

Figure 3.1. This is representative for the general historic trend reported by most major scheduled airlines.

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	Average	Medium-haul passenger aircraft	Long-haul passenger aircraft	Medium-haul freighter	Long-haul freighter
	Fuel g/RFTK	Fuel g/RFTK	Fuel g/RFTK	Fuel g/RFTK	Fuel g/RFTK
Air France	232	360[a]	215[a]		245
Lufthansa cargo 1999	210	160-550[d]	165-212[d]		165[f]-204[e]
KLM 1999	-	-	-		262[c]
UPS	-			176-644[d]	224[b]
FedEx	-			215-513[d]	158[f]
DHL	-			250-721[d]	

Table 3.4: The specific fuel consumption of airfreight
[a] Average over a number of models, [b] B747-F, [c] B747-300F, [d] various aircraft models,
[e] B747-200F, [f] MD-11.
Sources: [Air France 2000] [Lufthansa 2000b] [Lufthansa Cargo 2000] [KLM 2000]
[Aircraft Economics 1999d]

The fuel intensity estimates for the different airlines that are presented here are not directly comparable between airlines because of the differences in reporting methodologies. One example is that some airlines subtract a part of the fuel consumption which is attributable to freight transport in passenger aircraft, whereas others include this use in the estimate for the specific fuel use per revenue passenger kilometre. All airlines carry both passengers and freight. Some freight is carried in freight-only freighter aircraft, some in combi-aircraft where a freight section replaces a part of the passenger section, while some is carried as belly-hold freight in standard passenger aircraft.

For airlines that carry much freight in passenger aircraft the fuel used for lifting the freight can contribute to a rather high proportion of the total fuel consumption. For example, British Airways'[37] average fuel consumption per RPK is 49g for the whole passenger fleet on average, but if taking freight into account the efficiency improves to 35g per RPK (see the figure in brackets in Table 3.3) [British Airways 1999b, p. 21].

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[37] Freight amounted to around 30% of the revenue weight transported by British Airways in 1998.

Similarly, Lufthansa's[38] and Air France's Scheduled services uses 42g and 49g per RPK respectively, but the numbers are reduced to around 37g and 42g when subtracting the fuel used for lifting belly-hold freight. The fuel consumption figures for scheduled airlines can be more realistically compared to charter carriers if using estimates for the fuel consumption where the fuel use which is attributable to freight is subtracted, because charter carriers generally transport negligible amounts of freight.

The division of fuel use between passengers and freight is not straightforward. For example, British airways attributes 30% of their fuel use to freight because around 30% of its revenue load is freight [British Airways 1999b, p. 21]. Other airlines argue, that transporting one tonne of freight requires less fuel than transporting one tonne of passengers and luggage. For example, Lufthansa attributes 1,7 times as much fuel to passenger weight than to freight weight [Lufthansa 2000b, p. 51] while Air France uses a factor of 1,4 for medium-haul aircraft and up to a factor of 2 for some long-haul jets [Air France 2000, p. 9]. These ratios are supposed to account for the weight and space within an aircraft that is acquired for in-flight passenger services such as seats, galleys, flight crews, catering supplies etc. Only three of the airlines mentioned in Table 3.3 have reported specifically on both the passenger load factors and the freight loads in their passenger aircraft.

Another example of the differences in reporting methodologies between airlines is the use of different assumptions for the average weight of passengers and their baggage when calculating the ratio between the weight that is attributable to passengers and freight respectively.

Yet another example of the differences in airline reporting methodologies is that for some scheduled airlines the passenger load factor refers to passengers that have paid a certain percentage of the normal fare. Children oftentimes get discounts or travel for free, as do frequent flyers having earned bonus points. The actual load factor is therefore sometimes higher than seen from the statistics and the fuel use per passenger may be somewhat lower.

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[38] Freight represented around 17% of the total weight carried by Lufthansa in passenger aircraft in 1998 [Lufthansa 1999].

3.7.1 A closer look at the American air carriers

This section takes a closer look at the specific fuel consumption of the American air carriers. The data material shown here covers the overall traffic performance of all the US carriers in the years 1982 and 1999. These data are not biased by the fuel consumption of all-cargo carriers that was included in the overall data shown in Figures 3.1 and 3.3. However, the data still include the fuel consumption that is attributable to belly-hold freight in passenger aircraft. The data describes the fuel consumption per ASK on domestic routes (Table 3.5) and on routes to Latin America (Table 3.6) as well as on Atlantic (Table 3.7) and Pacific routes (Table 3.8). Furthermore, the passenger load factors are available for each airline in 1999. These data exemplify the differences in the specific fuel consumption among the various airlines in the different markets. Figures 3.9 and 3.10 exemplify the variations in the specific fuel consumption of a number of US air carriers.

Figure 3.9: Illustration of the specific fuel consumption per ASK and RPK of American air carriers in domestic operations in 1999
Source: [DOT 2001]
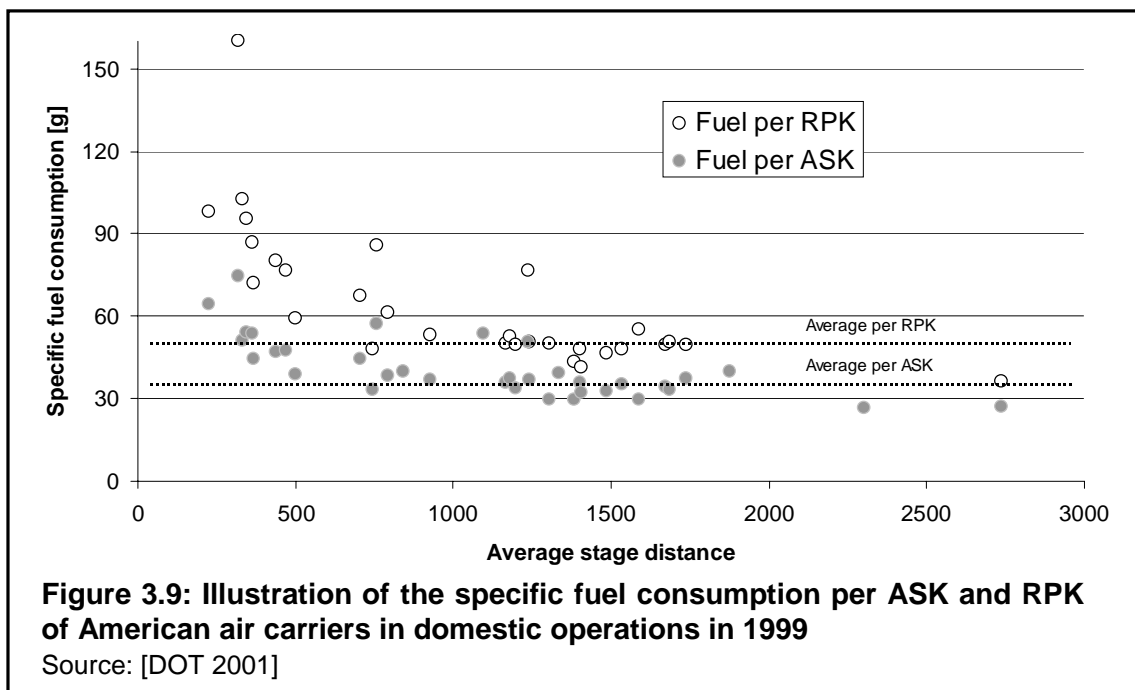
Figure 3.9 shows the average yearly specific fuel consumption per ASK and per RPK of US air carriers on domestic routes in 1999. The specific consumption varies between 27g and 64g per ASK and between 36g and 102g per RPK, if excluding a single carrier that uses some 74g per ASK and 160g per RPK. Among the Major US airlines that performed around 90% of the domestic revenue passenger kilometres in the United States in 1999 the specific consumption ranges between 30-37g per ASK and 44-53g

per RPK. The large regional carriers, such as American Eagle and Continental Express, typically use around 50% more fuel per ASK and per RPK than the Major air carriers do. The overall average specific fuel consumption on domestic routes is around 35g per ASK and 50g per RPK. In 1982 the average specific consumption per ASK was about 43g suggesting a reduction of approximately 8g per ASK in the period or about 19%.

Figure 3.10: Specific fuel consumption of US air carriers on Domestic, Atlantic, Pacific and Latin America routes in 1982 and 1999
Source: [DOT 2001]
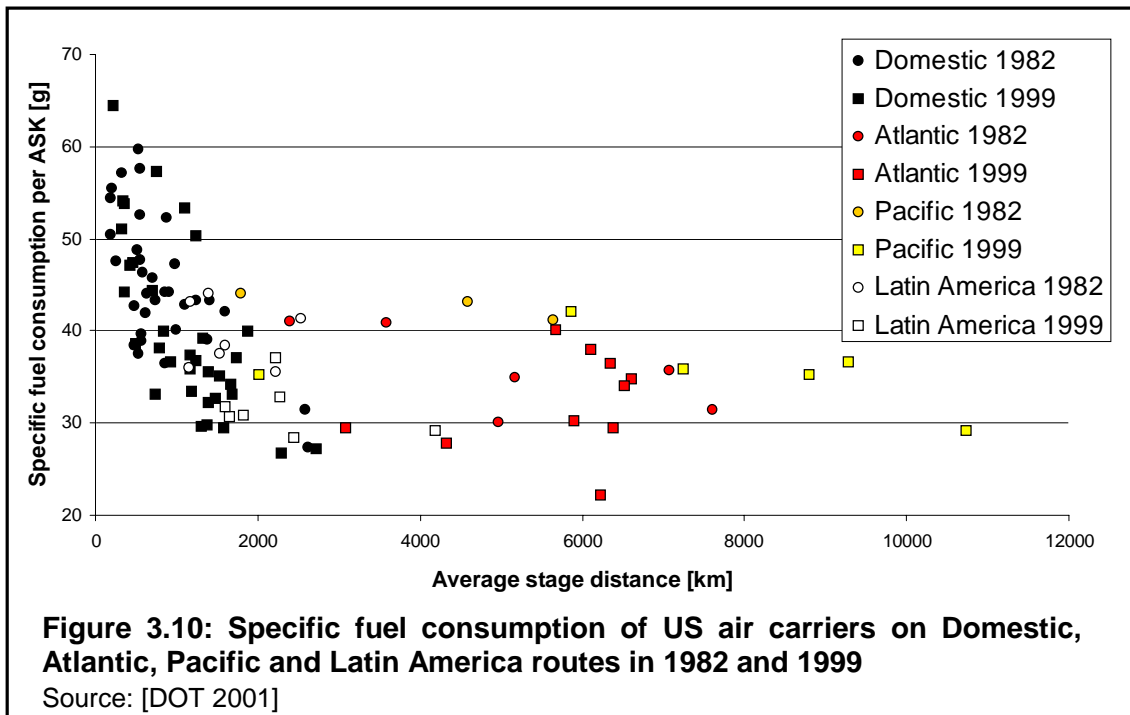
Figure 3.10 illustrates the specific fuel consumption per ASK on Domestic, Atlantic and Pacific routes and on routes to Latin America in 1982 and 1999. On routes to Latin America, the average specific fuel consumption is about 32g, representing a reduction of some 7g per ASK or about 17% as compared to 1982. In the Atlantic traffic the average specific fuel consumption is about 33g per ASK, representing a reduction of some 5g or some 13% in the period since 1982. In the Pacific traffic the specific consumption is about 38g per ASK, representing a reduction of 4g or some 10% in the period since 1982. That is, the fuel intensity per ASK is lowest on routes to Latin America and on Atlantic routes and a little higher on domestic routes and highest on pacific routes. These patterns fit with the trends illustrated in Figures 3.4 and 3.7 with the highest specific fuel consumption on short-haul routes and slightly higher fuel consumption on long haul than on medium-haul. The reductions since 1982 have been greater in the medium haul segments than in the long-haul segments.

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	1999					1982			
	g/ASK	g/RPK	Avr. dist [km]	% of ASKs			g/ASK	Avr. dist [km]	% of ASKs
Domestic						*Domestic*			
United Air Lines	33	47	1486	12,2		United Air Lines	39	1387	14,2
Delta Air Lines	36	50	1166	11,9		American Airlines	43	1417	10,2
American Airlines	34	50	1672	11,7		Delta Air Lines	44	868	10,1
Northwest Airlines	37	53	1182	6,4		Eastern Air Lines	44	917	9,5
Continental Airlines	35	48	1537	5,7		Trans World Airlines	43	1241	5,9
Southwest Airlines	33	48	747	5,6		Republic Airlines	48	546	3,8
US Airways, Inc	37	53	927	5,6		Northwest Airlines	47	985	3,5
Trans World Airlines	37	50	1241	3,3		Continental Airlines	43	1112	3,3
America West Airlines	30	44	1384	2,7		Western Air Lines	40	1008	3,2
Alaska Airlines	33	49	1199	1,7		Pan Am. World Airw.	42	1605	3,0
American Trans Air	32	41	1405	1,2		US Airways, Inc	52	549	2,5
Hawaiian Airlines	37	49	1741	0,6		Piedmont Aviation	49	511	1,6
Airtran / Frontier (Old)	40	-	843	0,6		Airtran / Frontier (Old)	42	626	1,3
American Eagle/Simm	44	72	368	0,5		Southwest Airlines	43	477	1,1
Continental Express	47	76	469	0,4		Pacific Southwest Airl.	39	565	1,1
Frontier Airl. (New)	30	50	1307	0,4		Ozark Air Lines	46	589	0,9
Sun Country Airl.	33	50	1686	0,4		Texas Intl. Airlines	43	736	0,7
Spirit Air Lines	36	48	1401	0,3		Braniff	44	636	0,7
Midwest Express Airl.	50	76	1239	0,3		Air California	40	566	0,6
Tower Air	27	36	2737	0,3		People Express Airl.	36	860	0,6
Reno Air	38	61	796	0,3		Alaska Airlines	52	884	0,5
Mesaba Aviation	54	95	348	0,3		Wien Air Alaska	57	332	0,3
Atlantic Southeast Airl	47	80	440	0,3		Midway Airlines (Old)	46	714	0,3
Horizon Air	54	87	365	0,2		New York Air	37	531	0,3
Air Wisconsin	39	59	502	0,2		Capitol Intl. Airways	31	2593	0,2
Midway Airlines (New)	57	86	760	0,2		Hawaiian Airlines	50	188	0,2
Champion Air	40	-	1877	0,2		TranStar Airline	38	477	0,1
Totals	**35**	**50**	**1287**	**74,1**		**Totals**	**43**	**1102**	**80,4**

Table 3.5: The fuel consumption per ASK of the American air carriers in 1982 and per ASK and RPK in 1999 in domestic operations[39]

Source: [DOT 2001].

	1999					1982			
	g/ASK	Avr. dist [km]	% of ASKs				g/ASK	Avr. dist [km]	% of ASKs
Latin America						*Latin America*			
American Airlines	33	2280	2,7		Pan Am. World Airways	41	2539	1,4	
Continental Airlines	37	2225	1,0		Eastern Air Lines	36	1158	1,0	
United Air Lines	29	4192	1,0		American Airlines	38	1605	0,8	
Delta Air Lines	28	2454	0,4		Western Air Lines	36	2230	0,3	
Alaska Airlines	31	1830	0,2		Braniff	44	1401	0,2	
					Delta Air Lines	37	1535	0,2	
Totals	**32**	**2589**	**5,41**		**Totals**	**39**	**1856**	**3,9**	

Table 3.6: The fuel consumption per ASK of the American air carriers in 1982 and 1999 in traffic to Latin America[40] Source: [DOT 2001].

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[39] Note that only those airlines performing more than 0,14% of the total ASKs (performed by all American airlines on all routes in 1999) within each segment, that is Domestic, Atlantic, Pacific and Latin America are shown in tables 3.5-3.8. This choice has been taken to limit the use of space for the Tables.

[40] See footnote above.

1999	g/ASK	Avr. dist [km]	% of ASKs	1982	g/ASK	Avr. dist [km]	% of ASKs
Atlantic				Atlantic			
Delta Air Lines	35	6618	2,4	Pan Am. World Airways	41	2401	4,1
United Air Lines	29	6394	2,3	Trans World Airlines	35	5177	3,4
American Airlines	34	6528	2,1	Northwest Airlines	41	3592	0,5
Continental Airlines	38	6117	1,5	Delta Air Lines	36	7087	0,3
Northwest Airlines	36	6359	1,3	American Airlines	31	7616	0,2
US Airways, Inc	22	6236	0,6	Capitol Intl. Airways	30	4979	0,1
Trans World Airlines	30	5903	0,5				
Tower Air	40	5679	0,4				
American Trans Air	29	3086	0,3				
World Airways	28	4327	0,3				
Totals	33	6236	11,8	Totals	38	3882	8,5

Table 3.7: The fuel consumption per ASK of the American air carriers in 1982 and 1999 in Atlantic traffic[41]

Source: [DOT 2001].

1999	g/ASK	Avr. dist [km]	% of ASKs	1982	g/ASK	Avr. dist [km]	% of ASKs
Pacific				Pacific			
United Air Lines	36	7257	3,3	Pan Am. World Airways	41	5640	2,7
Northwest Airlines	42	5868	2,9	Northwest Airlines	43	4593	2,1
Delta Air Lines	35	8798	0,5	Continental Airlines	44	1793	0,3
American Airlines	37	9281	0,5				
Continental Micronesia	35	2027	0,5				
Continental Airlines	29	10731	0,3				
Totals	38	6810	7,9	Totals	42	4957	5,1

Table 3.8: The fuel consumption per ASK of the American air carriers in 1982 and 1999 in pacific traffic[42]

Source: [DOT 2001].

As it was mentioned in Section 3.4, the overall fuel consumption figures coupled with the overall figures for the amount of ASKs and RPKs transported in 1997 suggest that the US air carriers consume around 39g per ASK and 56g per RPK (see Figures 3.1 and 3.3). However, the data provided by the US Department of transport on the operating statistics of all the US air carriers makes it possible to deduct the fuel consumed by the all-cargo carriers [DOT 2001]. The Grand totals that are shown in Column 2 in Table 3.9 are estimates for the specific fuel consumption per ASK including the all-cargo carriers, while the totals in Column 3 in Table 3.9 are estimates

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[41] See footnote above.

[42] See footnote above.

that excludes the fuel consumed by the all-cargo carriers. The fourth column in Table 3.9 shows how much the Grand totals are reduced when subtracting the fuel that is consumed by the all-cargo carriers. Column 5 in Figure 3.9 shows the passenger airlines' share of the total fuel consumption. Our calculations suggest that the specific fuel consumption per ASK that is shown in Figure 3.3 is reduced by 3 percent in 1982 and this share increases over the years to 12 percent in 1999 because the all-cargo carriers consume an increasing share of the total consumption. Thus, the specific fuel consumption per ASK of all US passenger carriers is around 35g in 1999. If taking an average load factor of around 71% [DOT 2000, p. 258] into account, the overall specific fuel consumption per RPK is about 49g (as compared to the 56g when including the all-cargo carriers).

The data used for these calculations do not allow for calculating the specific fuel consumption of all the all-cargo carriers because the data used for these calculations do not include information on the revenue freight tonne kilometres (RFTK) transported [DOT 2001].

	Grand totals incl all-cargo	Totals excl all-cargo	Difference between Grand totals and Totals	% of fuel consumed by these carriers included in the totals
	[g/ASK]	[g/ASK]	[%]	[%]
1982	43,2	41,8	-3	96,9
1985	41,1	39,3	-4	97,5
1990	41,2	38,3	-7	92,7
1995	39,6	35,5	-10	89,5
1999	39,8	35,0	-12	87,6

Table 3.9: Correction of the specific fuel consumption of American carriers taking into consideration the amount of freight that is carried by all-cargo operators[43]**.**
It should be noted that these data are calculated (by the author of this report) on the basis of data provided by the US Department of Transport on the fuel consumed and the ASKs produced by all American air carriers in a number of years.
Source: [DOT 2001]

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[43] Note that the author of this report has revised the 1985 data because United Airlines' fuel consumption was not reported in the spreadsheet data received from the United States Department of Transport. United Airlines carried some 12% of total ASKs in 1985. The fuel

3.8 A closer look at the weight share of freight in passenger aircraft

This section quantifies how much freight that is transported as belly-hold in passenger aircraft by different aircraft and airlines and discusses how much of the fuel that is attributable to passenger and freight revenue weight respectively on different routes.

Currently, freight and passengers account for around 30% and 70% respectively of the total number of revenue tonne kilometres that is performed by the World's airlines[44]. However, some of this freight is carried in all-cargo aircraft. In 1999, 29 billion revenue freight tonne kilometres (RFTKs) were transported by the American air carriers [DOT 2000, p. 326]. Eight all-freight carriers alone carried more than half of this total[45]. That is, less than 13 billion RFTKs were carried by the passenger airlines, representing some 18% of the total amount of RTKs transported[46]. The average weight share of freight is therefore less than 18% for the US passenger carriers. Similarly, in Europe, around 44% of the freight that is carried by the scheduled airlines is transported in passenger aircraft and the residual in all-cargo aircraft. The freight's weight share in the total scheduled passenger services is 23%. The share is 29% in international long-

efficiency of United Airlines in 1982 has been used (by the author of this report) to calculate United Airlines' approximate fuel consumption in 1985.

[44] In 1999, the World's airlines transported around 1,6 billion passengers over an average passenger trip length of around 1792 kilometres thereby generating approximately 2834 billion revenue passenger kilometres (RPKs). Similarly, the airlines also transported around 124 billions revenue freight tonne kilometres RFTKs [Air Transport World 2000]. The RPKs corresponds to around 283 billions revenue tonne kilometres (RTKs) at an average weight of 100 kilograms per passenger inclusive baggage (see Appendix D for further details) [Air Transport World 2000].

[45] FedEx 6,9 million RFTKs, United Parcel Service 4,1 million RFTKs, Emery Worldwide 1,1 million RFTKs, Polar Air Cargo 0,8 million RFTKs, Evergreen Int'l 0,8 million RFTKs, Airborne Express 0,6 million RFTKs, DHL Airways 0,4 million RFTKs and Atlas Air 0,6 million RFTKs [Air Transport Association 2000e]. The statistical sources used here do not contain detailed information on the amount of freight that is carried by the residual all-cargo carriers. However, 22,7 billions RFTKs are transported by the Major airlines [DOT 2000, pp. 325-326] and of these the 11,4 billions RFTKs are carried by all-cargo carriers [Air Transport Association 2000e]. That is, the Major passenger airlines carry some 11,3 billions RFTKs. The US National carriers carry around 5 billions RFTKs and the large regional carriers carry around 0,9 billion RFTKs [DOT 2000]. At least 3,9 billions RFTKs of the 5 billions carried by the US Nationals is carried by all-cargo carriers [Air Transport Association 2000e].

[46] In these US statistics the weight of a passenger plus baggage is set at 100 kilograms [DOT 2000, p. 325].

haul[47] scheduled passenger services, 10% in international short/medium haul[48] scheduled passenger services and around 4% in domestic scheduled passenger services [AEA 2001]. In Japan, All Nippon Airways report the weight shares of freight in their passenger aircraft at 13% on domestic routes and at 36% on international routes [All Nippon Airways 2000b]. These data suggest that, as a general rule of thumb, Asian carriers transport the highest shares of freight in their passenger aircraft while the US passenger airlines transport a lower share of freight than the European passenger airlines do. This is probably due to the large share of domestic traffic performed by the US air carriers that accounts for around two-thirds of all the RTKs and about three fourths of all the RPKs [DOT 2000, p. 323].

Generally, the overall statistics mentioned above suggest that the freight share is higher in long-haul traffic than in medium-haul and short-haul. A look at some statistics on the freight weight shares in individual aircraft confirms this picture, see Table 3.10.

As was touched upon briefly in Section 3.7 the airlines use different methodologies for the allocation of their fuel consumption on passengers and freight. Most airlines attribute all the fuel consumed to their passenger services. Some airlines attribute the same amount of fuel to a tonne of freight as to one tonne of passenger weight (including their baggage). Other airlines multiply the passenger weight with a factor of between 1,4 and 2 to account for the weight that is attributable to a number of in-flight passenger services (see Section 3.7 for a further description of this issue).

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[47] AEA longhaul is the sum of traffic between Europe and North Atlantic, Mid Atlantic, South Atlantic, Sub-Saharan Africa, Far East/Australasia and other long haul routes [AEA 1999, 2000c and 2001].
[48] International short/medium haul is the sum of traffic between countries in Europe and between Europe and North Africa and the Middle East [AEA 1999, 2000c and 2001].

	US air carriers 1998-1999-2000		All Nippon Airways 1999	Lufthansa 1990
	Avr.	*Passenger aircraft only*	*Passenger aircraft only*	*Passenger aircraft only*
B747-100		11%		
B747-400		25%	16% (domestic only)	38%
B747-200/300		22%		29%
B-777	36%		13% (domestic only)	
DC-10-40	18%			
DC-10-30		30%		38%
MD-11		39%		
A310				29%
A300-600		19%		32%
B767-300ER	37%		12% (domestic only)	
B767-200ER	26%		11% (domestic only)	
B757-200	13%			
B727-200	4%			11%
MD-80/90	4%			
A320-100/200	6%		4% (domestic only)	9%
A321			6% (domestic only)	
B737-300	4%			10%
B737-1/2/4/5/800	3%			8%
DC-9-30/40/50	4			
F-100	2%			

Table 3.10: Estimates of the freight weight as percentage of the total revenue weight in passenger aircraft

It should be noted, that these freight weight percentages are calculated (by the author of this report) on the basis of data for the cargo payload in tonnes as well as the passenger load factor and the average number of seats in different passenger aircraft for the United States air carriers 1998-2000 and for All Nippon Airways in 1998 and for Lufthansa in 1990. These factors may change from year to year and are different from airline to airline. The estimates for the average over each model for the US air carriers (Column 2) is for all aircraft, not only passenger models, and may include some all-cargo models

Sources: [Air Transport Association 1999, 2000e and 2001], [All Nippon Airways 2000b] [Reichow 1990 and 1992].

The average revenue of the World's airlines per tonne of freight is around 60% lower than the average revenue for a tonne of passengers (see Table 4.3 in chapter 4) [ICAO 1996c and 2000d]. We argue that this factor should also be taken into account in a discussion of which methodology that could potentially be used for the allocation. Therefore, if the fuel is distributed between freight and passenger loads according to their revenue shares, the weight of the passengers should be multiplied by a factor of around 2,5.

LONG HAUL B-747	Factor pass:freight	Fuel per RPK [g]	Fuel per RFTK [g]	Total fuel per aircraft km [kg]
All is allocated to passengers	1:0	46 (48)	0 (0)	12,6 (12,9)
Equal weight distribution	1:1	35 (31)	349 (315)	12,6 (12,9)
Correction for the weight of in-flight passenger services	1,7:1	39 (37)	228 (216)	12,6 (12,9)
Distribution according to the revenue per tonne	2,5:1	41 (40)	164 (159)	12,6 (12,9)

Table 3.11: Comparison of the fuel that is attributable to freight and passengers in a B747-400 on a long-haul flight when using the four different allocation methodologies

The figures outside the brackets are for an average B747-400 that is operated by the US air carriers. The freight weight is 9 tonnes, the aircraft accommodates 376 seats, the passenger load factor is 72%, 271 passengers are onboard and their weight (inclusive baggage) is 27 tonnes. Thereby, the freight weight share is 25%.

The figures in brackets are for a B747-400 operated on long-haul routes by Lufthansa in 1990. The freight weight is 14 tonnes, the aircraft accommodates 384 seats, the passenger load factor is 70%, 269 passengers are on-board and their weight (inclusive baggage) is 27 tonnes, the freight weight share is 35%)

Sources: [DOT 2001], [Air Transport Association 1999, 2000e and 2001] and [Reichow 1992].

The four different methodologies for distributing the fuel between freight and passengers are illustrated in Tables 3.11 and 3.12 and Figure 3.11. Not surprisingly, the most extreme difference in the estimate for the specific fuel consumption per revenue passenger kilometre appears between the methodology where all the fuel is attributed to passenger transport and the methodology where the fuel is distributed evenly between passengers and freight on an equal weight basis. In the latter case the specific fuel consumption per RPK is reduced by around 24-35% for long-haul trips in a B747-400 and by around 5-13% on medium-haul trips with B757s and A320s. The implication of this finding is that the figures for the specific fuel consumption of aircraft and airline operations that includes the fuel which is attributable to freight (for example those figures that are shown in Figures 3.6, 3.8, 3.9 and 3.10) would typically be reduced by 5-13% on medium range and by 24-35% on long-haul. We note that these are rough estimates and may differ between airlines and between different types of aircraft (see Tables 3.11 and 3.12 and Figure 3.11)

MEDIUM-HAUL B-757 and A320	Factor pass:freight	Fuel per RPK [g]	Fuel per RFTK [g]	Total fuel per aircraft km [kg]
All is allocated to passengers	1:0	38 (38)	0 (0)	5,0 (3,8)
Equal weight distribution	1:1	33 (36)	329 (361)	5,0 (3,8)
Correction for the weight of in-flight passenger services	1,7:1	35 (37)	204 (217)	5,0 (3,8)
Distribution according to the revenue per tonne	2,5:1	36 (38)	143 (149)	5,0 (3,8)

Table 3.12: Comparison of the fuel that is attributable to freight and passengers in B757-200s and A320s operated on medium-haul distances when using the four different allocation methodologies

The figures outside the brackets are for an average B757-200 that is operated by the US air carriers. The freight weight is 2 tonnes, the aircraft accommodates 186 seats, the passenger load factor is 71%, 132 passengers are onboard and their weight (inclusive baggage) is 13 tonnes. Thereby, the freight weight share is 13%.

The figures in brackets are for an average A320 that is operated on medium-haul routes by the US air carriers. The freight weight is 0,6 tonnes, the aircraft accommodates 148 seats, the passenger load factor is 68%, 101 passengers are on-board and their weight (inclusive baggage) is 10 tonnes, the freight weight share is 6%)

Sources: [DOT 2001] and [Air Transport Association 1999, 2000e and 2001].

The selected aircraft shown in Figure 3.11 are arranged with the most fuel-efficient aircraft, measured in fuel consumption per RTK, on the left hand side of the figure. The B767-300/300ER is the most fuel efficient when considering the fuel consumption per RTK and therefore also per RPK when distributing the fuel consumption on an equal weight basis between passengers and freight (methodology 2). The relative difference between the specific fuel consumption figures of methodology 1 and 2 is greatest for the MD-11s, the B767s and the B777s. For these aircraft RPK2 is between 35-38% smaller than RPK1. For the DC-10s, the 747s, the B767-200s and the A300-600s RPK2 is between 18-30% smaller than RPK1. That is, if comparing the specific fuel consumption figures of these long haul aircraft to the most fuel-efficient medium haul aircraft (B757-200s, A320s and B737-800s) they are at level or even more fuel-efficient if using methodology 2.

Figure 3.11: The variation in the specific fuel consumption per RPK when using four different methodologies for attributing fuel to freight

RPK1 represents the methodology where all the fuel is attributed to passenger transport. RPK2 represents the methodology where the fuel is distributed equally between passengers and freight on a weight basis. RPK3 represents the methodology where the weight of the passengers is multiplied by a factor of 1,7 before distributing the fuel consumption between the weight of passengers and freight. RPK4 represents the methodology where the weight of the passengers is multiplied by 2.5. The examples here are for selected aircraft operated by American air carriers in 1999. The average passenger loads factors as well as the average freight weight may vary considerable between airlines and may change from year to year.

Sources: Fuel consumption from [DOT 2001] and freight loads from [Air Transport Association 1999, 2000e and 2001].

3.9 Comparison to other modes of transportation

Road, sea and rail transport can be viable alternatives to the transport of passengers and freight by air over certain distances, and are oftentimes less energy intensive. Due to the potentially relatively high contribution to climate change of aircraft emissions at altitude alternative modes are generally also less GHG intensive than aircraft. But air transport is by far the fastest transport mode, and a shift to other modes will most often be more time consuming, at least when comparing transport over long distances. The substitution potential for passenger and freight transport is therefore dependent on the willingness of travellers and freight shippers to use slower modes of transport. Other considerations are the availability of alternative transport modes and the associated prices connected to those types of transport. For passenger transport there are many

examples of intra-European and intra-American routes where air transport is relatively cheap as compared to rail and bus. This section does not consider these economical and infrastructure aspects but merely compares the fuel intensity of air transport to other modes. The focus chosen is to study short-distance and medium-distance (up to a few thousand kilometres) passenger travel in aircraft, passenger cars, buses and trains.

First of all, it has to be mentioned that comparisons of the environmental impact of different transport modes are problematic, as each mode of transport generates different kinds of environmental problems. Additionally, the environmental impact is often site specific. For instance car exhaust creates other problems in cities than it does in rural areas, and it is difficult to compare health problems in cities created by exhaust from cars, buses and trucks to high altitude aircraft emissions contributing to climate change. Furthermore, a wide variety of vehicles with different characteristics makes it difficult to establish average pollution indexes for each mode of transportation. This has been exemplified in the earlier sections of this chapter that show the marked differences in the fuel intensity of old and new aircraft as well as differences between small short haul aircraft and larger medium-haul and long haul aircraft types. Another problem in such comparisons is the variability in the fuel consumption and emissions related to differences in the usage cycles for vehicles. For example, the fuel efficiency of aircraft depends strongly on the actual stage distance. For trains, one important factor to take into account is the number of stopovers at a given trip, while for passenger cars the fuel efficiency varies strongly between city and highway driving. Another factor is the level of traffic on roads and rails and in airports where congestion is often a problem for the flow of traffic. Furthermore, the actual load factor of passenger cars, buses, trucks, trains and aircraft plays an important role. A special feature of aircraft is furthermore that they most often fly more direct routings than for example road traffic. When comparing the fuel intensity per passenger kilometre this factor also has to be taken into account. Therefore, the average estimates given here should merely be taken as examples.

Most of the major scheduled airlines emit between 125-175g of CO_2 per revenue passenger kilometre (RPK). The most efficient European charter airlines emit around 109g of CO_2 per RPK on medium-haul routes while the least efficient short-haul regional scheduled carriers emit more than 250g of CO_2 per RPK. That is, the 109g of

CO$_2$ per RPK represents the minimum emissions from holiday travel over distances of at least 2000 kilometres whereas the 250g represents the maximum emissions from scheduled flights over short distances.

Figure 3.12 illustrates the mileage of different car models available for sale in Denmark in 1998 according to their energy labelling that is based on test data for an average European standard driving cycle. In 1999 and 2000, some more fuel-efficient models have been introduced, most notably the VW LUPO 3L TDI rated at 33 kilometres per litre of diesel. We note that such test data may overestimate the mileage because the actual driving cycle may be more fuel intensive [Schipper and Marie-Lilliu 1999]. The fuel efficiency of passenger cars is very much dependent upon the weight of the car. Light cars generally drive longer per litre of fuel than heavier cars [Færdselsstyrelsen 1999].

Figure 3.12: Fuel efficiency rating of passenger cars for sale in Denmark 1998
Source: [Færdselsstyrelsen 1999]
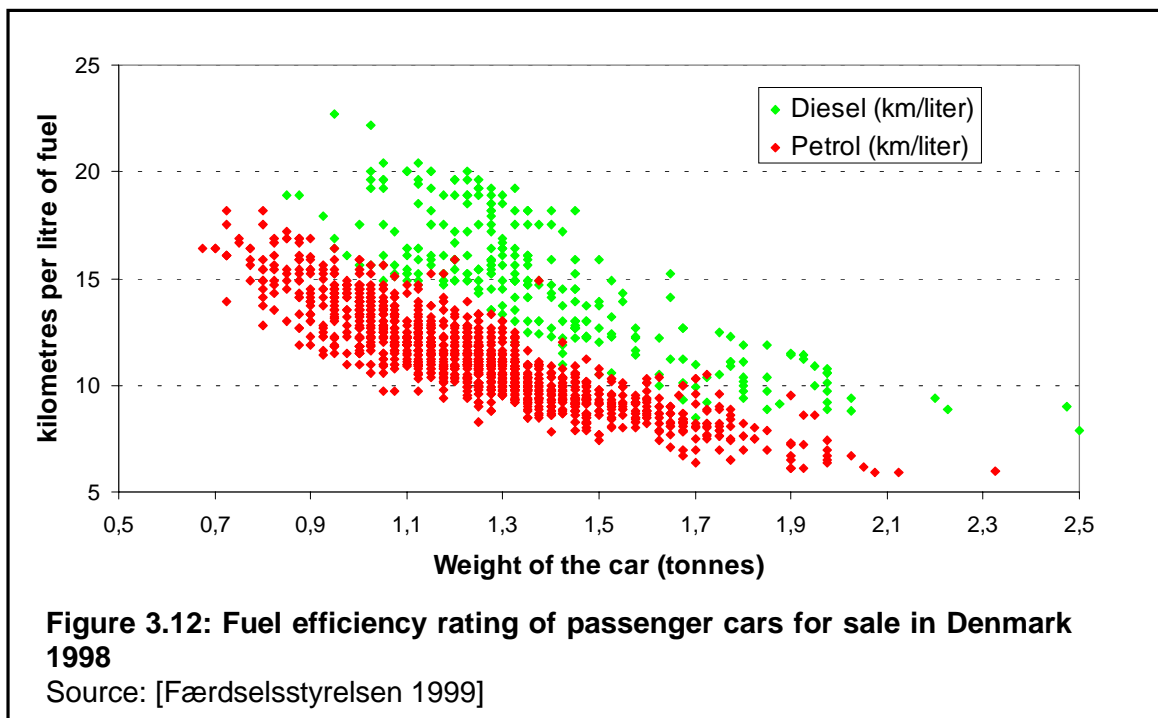
The average on the road CO$_2$ intensity of passenger cars differs widely between countries. For example the average United States passenger car emits around 272g CO$_2$ per vehicle kilometre whereas for example the average Dutch car emits around 193g[49]. These differences are largely due to differences in the fleet mix as well as driving cycles [Schipper and Marie-Lilliu 1999]. The CO$_2$ intensity per passenger

kilometre of a given trip furthermore depends on the load factor. The average passenger load factors are found to vary from country to country [Schipper and Marie-Lilliu 1999] [IPCC 1996b, 693] [EEA 2000 and 2001] and tends to be higher in for example European holiday traffic than in average everyday traffic [Roos et. al. 1997]. According to Roos et. al. [1997, p.26] the total fuel consumption per vehicle kilometre of a small car with four occupants may be around 14% higher than for a similar car with one occupant (larger cars are less sensitive in this respect). When used for long-distance travel most passenger cars may drive longer on each litre of fuel than in an average European driving cycle. Furthermore, if the car carries a caravan, the fuel consumption per kilometre may increase by 50-100% [Roos et. al. 1997]. Additionally, a comparison to aircraft should take into account that cars drive longer distances between destinations than aircraft and that passenger cars may have to cross waters by ferry to reach the destination. A study of the specific fuel consumption of passenger cars and other modes on distances between eight European city-pairs takes these factors into account. The study concludes that an average car with two occupants is typically as fuel-efficient as modern turboprops (Fokker 50s) and jets (B737-400s) that operate at these specific distances. This study thereby indicates that at passenger load factors of three or more persons the passenger car is typically more fuel-efficient than aircraft [Roos et. al 1997].

A number of studies from around the World have found that trains and coaches are generally less fuel-intensive than passenger cars and aircraft [IPCC 1996b] [Roos et. al. 1997] [IPCC 1999, p. 285]. For example, a long haul coach with a 70% occupancy rate typically emits around 20-30g of CO_2 per passenger kilometre or around 80% less than an average two-occupant passenger car [Roos et. al. 1997, p. 82] [Jørgensen 1998]. The emission of CO_2 per passenger kilometre of electrical trains depends on the primary fuel used for the power production and on the overall efficiency of the production and transmission system. High speed electrical trains, such as the German ICE and the French TGV emit 41g and 7g of CO_2 per passenger kilometre respectively[50]. However, if the TGV train had used electricity produced by the electrical system in for example Denmark (in 1996) where the fuel mix is based mainly on coal

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[49] These estimates are for 1995.

[50] Based on an average consumption of 78,9Mje/km, 51% load factor and 159g CO_2 emissions per MJ electricity produced for the German ICE train. Based on an average consumption of 68,5Mje/km, 65% load factor and 31,3g CO_2 emissions per MJ electricity produced for the French TGV train [Roos et. al. 1997, p. 101].

and other fossil fuels, the CO_2 emissions from the TGV train would be around 7 times higher [Roos et. al 1997, p. 101]. Likewise, the Danish inter-city electrical and diesel trains emit around 13-21g of CO_2 per available seat kilometre or around 26-42g at a load factor that is comparable to that of the German ICE train [DSB 2001].

3.10 Energy intensity of passenger air travel in the future

A number of airlines around the World have committed to certain goals for reducing their fuel intensity in the future. Lufthansa's passenger airline aims at reducing the specific fuel consumption per revenue passenger kilometre by 35% in 2012 as compared to 1991. This goal acquires that Lufthansa reduces its specific fuel consumption by around 18 percent between 1999 and 2012[51] [Lufthansa 2000b]. British Airways has similarly committed to reduce the specific fuel consumption per passenger kilometre by 30% in 2010 as compared to 1990, corresponding a reduction of some 16% as compared to the 1999-level[52] [British Airways 1999a and 1999b]. Likewise, in 1998, the Scheduled Airlines Association of Japan, that represents ten Japanese airlines, has committed to the target of reducing the emissions of CO_2 per available seat kilometre (ASK) by 10% in 2010 as compared to 1990 [All Nippon Airways 1999, p. 5]. The airlines that are members of the International Air Transport Association (IATA) are planning to reduce their specific fuel consumption per RPK by 10% in 2010 as compared to 2000 [Dobbie 2001]. These targets may reflect the magnitude of the fuel efficiency improvements that can be expected in the next decade.

In Europe, the reduction of the fuel intensity due to the introduction of new aircraft may be relatively modest, because many airlines have already carried through some major fleet renewal programmes. The current average age of the European aircraft fleet is estimated at 9 years. The European aeronautical industry does not expect to exceed annual reductions in the specific fuel consumption of more than 1.1% per RPK on the average until 2012. Only a part of that reduction is expected due to introduction of new aircraft, while some may come from improved load factors and operating procedures [AEA and AECMA 1999]. In the US, airlines generally operate older fleets, suggesting that the fuel-efficiency potential may be higher than in Europe.

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[51] Lufthansa has already achieved a reduction of 21.6 percent in 1999 as compared to 1991 due to an extensive fleet renewal programme [Lufthansa 2000b].

3.10.1 The potential effect of replacing the oldest aircraft

The aircraft fleet that was operated by American air carriers in 1998 consists of a wide variety of aircraft models in a range of sizes that are used for passenger- and freight transport at different distances ranging from short-range commuter traffic to long haul intercontinental flights. Figure 3.13 illustrates the distribution on different types of aircraft of the revenue passenger kilometres that were carried by the Major US airlines in their total domestic and international traffic in 1998. Note that Figure 3.13 does only include the most commonly used aircraft that performed some 90 percent of the total amount of RPKs in 1998. The data in Table 3.13 contains all the aircraft types in operation.

Figure 3.13: The distribution of the revenue passenger kilometres transported by Major American air carriers on aircraft types in 1998
Source: [Aircraft Economics 1999c and 1999f]
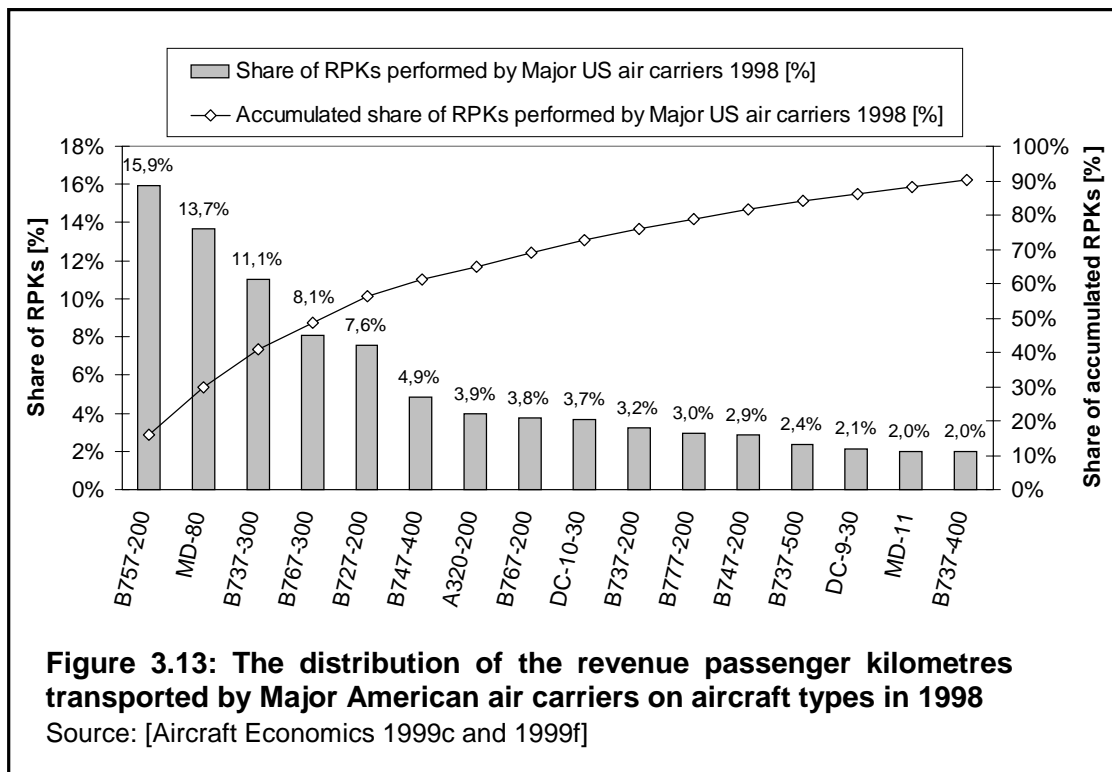
As can be seen from Table 3.13, the relatively fuel-efficient B757-200s, B767-300s, B747-400s, A320-200s, B777-200s, MD90s, B747-100s and B737-400s carry some 39% of all the ASKs and RPKs using about 32% of the fuel. Their average fuel consumption is about 28g per ASK. Likewise, the relatively fuel-intensive DC-9s, B737-200s, Fokker 100s, B727-200s, L1011-500s, DC10-40s, DC-10-30s and B747-200s

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[52] British Airways has already cut its specific fuel consumption per revenue passenger kilometre by some 17% between 1990 and 1999 [British Airways 1999a, p. 18].

carry about 23-24% of the ASKs and the RPKs and consume some 30% of the fuel. Their average fuel consumption is about 38g per ASK. These figures give an idea about the potential for reducing the average specific fuel consumption of the fleet that is operated by the Majors if these last mentioned seven relatively fuel-intensive aircraft types were replaced by the most fuel-efficient types in their classes. The average specific fuel consumption of the Major airlines on all domestic and international routes is about 35g per ASK and 48g per RPK in 1998 (see Table 3.9). A substitution of the fuel intensive types mentioned above with more modern types (B717s, A320s and B777s) could reduce the specific fuel consumption at these operations to about 26g per ASK. This would reduce the average specific fuel consumption of the Majors from the current 35g per ASK to about 31g, a reduction of approximately 3,9g per ASK or some 11%. This is based on the assumption that the DC9s, the Fokker 100s and the B737-200s are replaced by B717s using 23g per ASK on average and that the B727-200s are replaced by A320-200s using 26g per ASK and that the L1011-500s and the DC-10s and the B747-200s are replaced by B777-200s using 28g per ASK. It should be noted that these estimates are rough calculations made by the author to get an idea of the potential of substituting the most fuel-intensive of the aircraft that are currently in operation. The calculations are not based on any real-world plans for scrapping old aircraft.

	Stage dist	Seats	Fuel	RPKs	Load factor		Fuel per RPK		Fuel per ASK	
						Diff over avr		Diff over avr		Diff over avr
	[km]		[%]	[%]	[%]	[%]	[g]	[%]	[g]	[%]
DC-9-10	604	77	0,3	0,1	60	-16	111	+130	66	+93
DC-9-50	734	122	0,8	0,5	65	-8	74	+52	48	+40
DC-9-30	747	100	3,5	2,1	65	-9	79	+63	51	+49
DC-9-40	787	108	0,2	0,2	66	-7	75	+55	50	+44
B737-200	805	113	4,1	3,2	69	-3	62	+28	43	+24
Fokker 100	826	97	1,5	1,3	69	-3	59	+22	41	+18
B737-300	978	132	10,7	11,1	69	-3	47	-4	32	-7
B737-500	1038	110	2,7	2,4	66	-7	56	+15	37	+7
B737-400	1056	142	1,7	2,0	70	-2	42	-14	29	-16
B727-200	1128	148	10,4	7,6	71	0	67	+38	48	+38
MD-90	1241	150	0,3	0,4	67	-5	42	-12	29	-17
MD-80	1305	140	14,0	13,7	70	-1	50	+3	35	+2
A320-200	1917	147	3,1	3,9	69	-3	38	-22	26	-25
L-1011	2031	300	1,4	1,5	78	+9	46	-4	36	+4
B757-200	2070	186	12,4	15,9	70	-1	38	-22	26	-23
L-1011-500	2137	234	0,8	0,7	78	+10	55	+14	43	+25
A300-600	2342	245	1,4	1,5	72	+2	45	-7	33	-5
DC-10-10	2475	275	1,9	1,9	75	+6	48	-1	36	+5
DC-10-40	3399	285	1,2	1,2	78	+10	51	+4	39	+14
B767-200	3713	180	3,7	3,8	73	+3	48	-2	35	+1
B767-300	3932	214	7,1	8,1	73	+3	43	-12	31	-9
B747-100	4295	447	0,5	0,7	76	+8	40	-17	31	-10
B777-200	4826	290	2,4	3,0	73	+3	39	-20	28	-18
DC-10-30	5319	261	4,0	3,7	77	+9	53	+10	41	+19
B747-200	5578	366	3,0	2,9	77	+8	50	+4	39	+12
MD-11	6882	243	2,1	2,0	75	+6	51	+5	38	+11
B747-400	7889	383	4,5	4,9	72	+2	45	-8	32	-6
Average					71		48,4		34,5	

Table 3.13: Domestic and international passenger traffic performed by the Major US air carriers in 1998

Sources: [Aircraft Economics 1999f and 1999c].

3.10.2 The fuel intensity of next-generation aircraft types

The two major aircraft producers, Boeing and Airbus, are constantly developing new derivatives of their existing aircraft types, while from time to time introducing new models. The most recent derivatives of each model tend to offer better fuel-efficiency than the earlier models. It is beyond the scope of this report to assess the fuel efficiency improvements of each new model. Rather, some trends that may influence the fuel efficiency such as increasing the size and the speed of the aircraft is discussed, focusing on the market for long-haul wide-bodies and the market for short-haul regional turboprops and jets.

Airbus currently devotes much effort to developing the next-generation double-deck ultra-large long-range A380 (see Figure 2.8, picture A) to be introduced around 2006 to

compete with Boeings somewhat smaller B747. Today, a B747-400 that is configured for long-haul operations typically accommodates around 330-360 passengers. The A380-100 and the A380-200 are planned to accommodate 555 and 656 passengers respectively in long-haul three-class configurations and up to 1000 passengers in all-economy configuration [Airbus 2000a]. The largest version, the A380-200, is envisaged by Airbus to burn up to 20% less fuel per ASK than the 747-400 [Vincendon and Wrede 1999]. Also in the other segments Airbus is introducing a number of aircraft that accommodates more passengers than the earlier versions that they are intended to replace. Airbus thereby seems to follow the traditional path of developing larger aircraft that burns less fuel per seat.

Boeing is also still following this path of introducing stretched derivatives of the different models in its family of aircraft. Boeing has for some years tried to sell its concept of a larger version of the B747-400 to the airlines, but currently seems to refrain from developing that aircraft due to lack of airline demand. It seems, that Airbus' A380 has drawn the attention of the airlines and several airlines have already ordered that aircraft [Aviation Week and Space Technology 2001a]. Instead, as also mentioned in chapter 2, Boeing has recently announced plans to develop a new family of delta-wing "sonic cruisers" (see Figure 2.8, picture D) designed for Mach 0,95 cruising speed over ultra-long range (above 16000 kilometres) seating 150 to 300 passengers. This type of aircraft is envisioned to cut flying time by up to three hours on Trans-Pacific flights and could enter the market before 2010. Even though reliable information on the specific fuel-burn of the still on the drawing board "sonic cruiser" is not available at the time of writing, this relatively low-capacity aircraft cruising at high speed is likely to have a considerable fuel-burn penalty over current long-range subsonic aircraft. Therefore, Boeing seems to be about to leave the tradition of continuing the incremental improvements in aircraft design by increasing the size in favour of developing a radically different type of aircraft.

Also in the segment for aircraft up to around 120 seats, the new next-generation regional jets offer fuel-efficient operation compared to the older types. Airbus is about to introduce the A318 and Boeing has already introduced the B717. In this segment Airbus and Boeing are supplemented by a range of producers of turboprops and regional jets, such as Bombardier, Embraer, Fairchild, British Aerospace and Aero International. A substitution of the old DC9s, Bae 1-11s and B737s that are currently

used mainly at regional distances by new relatively fuel-efficient regional jets could bring fuel efficiency gains. However, in many cases, the fuel intensity of short-haul passenger air travel could be improved further by choosing turboprops instead of regional jets (see Figure 3.14). Even though the new regional jets that are shown in Figure 3.14 are more fuel-efficient than their predecessor jets, they are not able to compete with turboprop fuel-economy at short-haul distances [Aircraft Economics 2000a, 2001a and 2001c] [ATR 2001]. Speed has become a main point of competition also in the short-range market. The travel time of the slowest modern turboprops is up to 25 minutes longer on a 550-kilometre trip when comparing to the fastest regional jets, but the fuel consumption is around 20-40 percent lower per available seat kilometre (ASK) [Aircraft Economics 2001a and 2001c]. Therefore, the operation of turboprops on short-haul routes is generally a little more time consuming, but more fuel-efficient[53]. Furthermore, the direct operating costs per seat kilometre are lower for turboprops than for similar sized jets on distances of around 400-900 kilometres [Aircraft Economics 2001a and 2001b]. Only a few major producers, such as ATR and Bombardier are still engaged in developing new types of turboprops. Other producers, such as Saab, Fokker, Embraer, Fairchild/Dornier and British Aerospace, recently left this market sector, the latter four concentrating mainly on developing new regional jets [Avmark Aviation Economist 2000]. The future reduction in the fuel intensity in the regional airline market will therefore depend on whether airlines choose turboprops or jets, the latter being increasingly popular by regional operators [DOT 1998], and whether the airlines will substitute some of the old fuel-intensive jets that are currently used for short-haul air transport.

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[53] It should be noted that there are differences in the fuel-efficiency of the different turboprops available. The 68-seat ATR72-500 is more fuel-efficient than the faster 74-seat De Havilland Dash-Q8-400. Conversely, the 56-seat De Havilland Dash-Q8-300 is more fuel-efficient than the faster 50-seat ATR42-500 [Aircraft Economics 2000a].
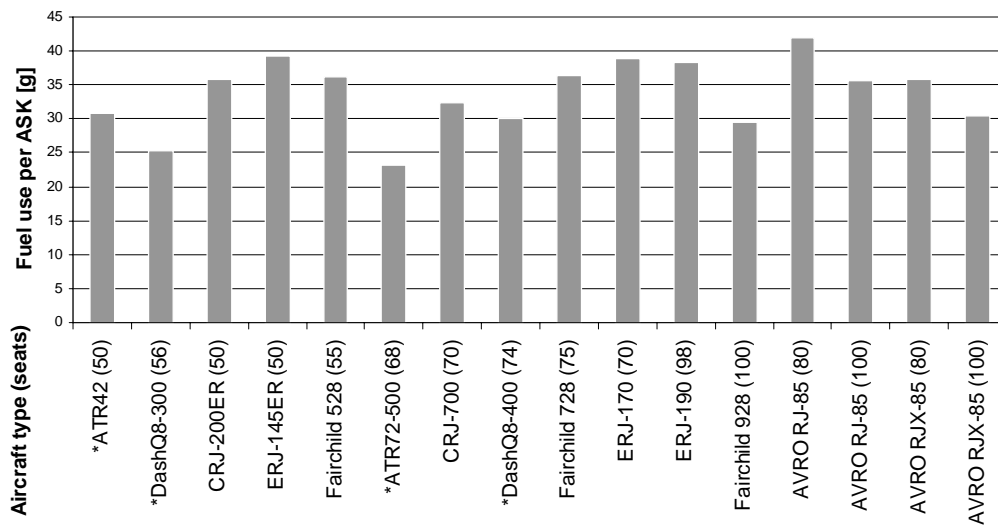
Figure: 3.14 Regional Aircraft fuel Use on a 550-kilometre trip
These data are based on European operating conditions. Aircraft marked by * are turboprops and the residual aircraft are jets. The figures in brackets are the number of seats.
Source: [Aircraft Economics 2000a]

3.10.3 Operational possibilities to reduce the specific fuel intensity

Other factors that are connected to the operation of aircraft, such as the choice of cruising speed and -altitude, the idling/taxiing in airports, delays, non-optimal choice of flight corridors and "stacking" (queues) above airports, also influence the aircraft energy use [British Airways 1999b] [Lufthansa 2000b]. Studies suggest that there is some potential for reducing the fuel consumption of aircraft through improving the air traffic management[54] system and the operational procedures. Estimates for the potential gains varies between sources. The Intergovernmental Panel on Climate Change estimate that the overall fuel intensity could be reduced by around 6-12% from the use of improved communications, navigation and surveillance (CNS) systems and air traffic management (ATM) systems [IPCC 1999, p. 273]. A similar study from ICAO suggests that the specific fuel burn of the World fleet could be reduced by 5% in 2015

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[54] Air traffic management plays a role in aircraft fuel consumption for several reasons. For example, aircraft often fly longer distances than the shortest great circle distance, some reasons being that twin-jets are not certified to fly directly over oceans and that some airspace is restricted for military usage. Another example is that, due to congestion and delays at airports, aircraft are "stacking" above airports waiting for permission to land while aircraft waiting for permission to take-off keep engines running at idle condition.

due to the introduction of CNS/ATM systems. Though, a recent IATA study concludes that a faster introduction of such systems (than assumed in the ICAO study) could lead to a reduction of around 9% by 2010 [Dobbie 2001]. Furthermore, there is still an additional potential for improving the load factors, and thereby also for reducing the specific fuel consumption per revenue passenger kilometre (RPK) [Daggett et. al. 1999]. Furthermore, a future growth in the market share of low-cost airlines that operate high-density aircraft may also bring some fuel-efficiency gains.

3.10.4 Long-term possibilities for reducing the GHG intensity of aircraft

On the longer term, after 2015, there is still scope for technical improvement of aircraft fuel efficiency and GHG reductions over currently envisaged next-generation aircraft. Examples of incremental improvements are more efficient versions of existing turbofan- or turboprop engines and stretched (longer, bigger aircraft, double-deck configurations) versions of existing airframes, use of light weight materials to reduce the weight per seat. Examples of more uncertain long-term, but potentially viable, radical improvements are advanced techniques for improving the aerodynamic performance[55] and a substitution of current fossil kerosene fuel by alternative fuels such as liquid hydrogen[56], liquid methane or synthetic kerosene produced from biomass. The combustion of methane and hydrogen increases the emissions of water vapour, and may therefore not be an environmentally viable solution [IPCC 1999] [Marquart et. al. 2001]. Other uncertain solutions is the substitution of current turbofan engines by radically different types such as propfans[57] or fuel cells (for use in the cruising phase) or use of radically different airframe design (and sizes) such as blended wing body aircraft[58].

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[55] For example, Airbus currently investigates the possibility of using an active laminar flow system where air is sucked through tiny holes that has to be drilled in wings, fuselage and engine nacelles, improving the aerodynamic performance of the aircraft [Vincendon and Wrede 1999]. This is a feature that has been studied by various researchers for many years, but there seems to be technical problems connected to the application [Greene 1997].

[56] See Figure 2.8 picture C, for an example of how liquid hydrogen could be stored in fuel tanks inside the fuselage [Pohl 1995b].

[57] See Figure 2.8 picture F for an example of a prototype counter-rotating profan-type engine presented by General Electric in the 1980s. General Electric name their engine UDF (un-ducted fan). Picture E in Figure 2.8 furthermore illustrates a Russian military prototype aircraft powered by counter-rotating propfan engines.

[58] See Figure 2.8 picture B, for an example of a blended wing body flying-wing shaped aircraft. For a further description of a blended wing body BWB aircraft proposal see [Cranfield College of Aeronautics 2000a]. The idea of introducing BWB aircraft is for example supported by the Society of British Aerospace Companies' Foresight Action Office [AEG 2000].

Some studies have proposed that aircraft should in the future be designed to operate at lower speeds and lower altitudes [Barrett 1994] [Dings et. al. 2000a, 2000b, and 2000c]. Lowering the speed would reduce the aircraft's fuel consumption and furthermore allow for using advanced high-speed turboprops or propfan engines, while cruising at lower altitude may reduce the overall contribution of aircraft engine emissions to climate change. However, the current trend towards replacing turboprops by regional jets, as well as Boeing's plans to launch sonic cruisers, are examples pointing towards flight at higher speeds and altitude in the future.

It should be mentioned that a new advanced generation of supersonic airliners has also been suggested[59], even though for the moment their possible emergence seem rather uncertain due to uncertainty over their high operating costs and due to environmental concerns over aircraft noise, climate change and ozone depletion. Such a new generation of supersonic passenger aircraft would anyway be substantially more GHG intensive than current modern subsonics [IPCC 1999]. Another uncertain but still technically feasible technology is freighter airships cruising at slower speed and altitude using less fuel than current jet freighters [Flight International 2000a] [Jensen 2000].

The Intergovernmental Panel on Climate Change (IPCC) estimates that on the medium term (2015) new aircraft could be 20% less fuel intensive than current production models. On the longer term (2050) new aircraft could be 40-50% less fuel intensive than current production models, but if engines are designed with greater emphasis on NO_x reduction, the reduction in fuel intensity is envisaged to be more modest, around 30-40% [IPCC 1999, pp. 219-266]. These estimates reflect that the improvement rate for the reduction of the fuel intensity of new aircraft types may slow down as compared to the last three decades (see Figure 3.3). Furthermore, due to the relatively long lifetimes of aircraft, typically around 30 years for passenger aircraft and up to 40 years for freighters, the improvement rate for the whole fleets' average fuel efficiency may slow down even further. This is because a large share of the improvements rely on fleet enlargement, unless new legislation emerges that forces the airlines to phase out the oldest aircraft earlier than currently expected. Current aircraft types may well be in

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[59] See Figure 2.8 picture G for an illustration of design studies for a future advanced supersonic transport from Airbus.

production for decades, and next-generation aircraft, such as A380s, may well still be operating by the middle of this century.

3.11 Data problems and areas that need further research

This chapter mainly focuses on the fuel intensity of passenger air travel and airfreight for a number of American air carriers and for some selected European and Asian airlines that have published environmental reports or made fuel consumption data available to the author. However, currently most European and Asian airlines do not publish such environmental audits, and among the airlines that do publish their environmental data the methodologies used for establishing those data differ, making comparisons rather difficult. Airlines in other parts of the World, such as Africa, Australia, Russia, Eastern Europe, Latin America, South America, China and India, are not included either. American carriers have for decades reported their operating statistics to the United States Department of Transportation, and those data are consistent in the reporting methodology and therefore have been used as a main basis for some of the analysis in this chapter. Further studies may aim at including fuel efficiency data of more airlines than what has been done here. Furthermore, a study of the total World fleet would be interesting.

General aviation and business jets are not included in this study, the latter being rather fuel intensive as compared to other passenger aircraft because the seat density and the load factor is often low. Likewise, military aircraft are not included even though the military consumes a rather large share of the world's jet fuel. For example, Gardner et. al. [1998] estimate that the military consumed around 11% of all jet fuel globally in 1992.

Of special interest is that civilian aircraft in the former Soviet Union are not included in this study either. Around 3500 Russian built jets are still in service or store, but due to low utilisation consume considerably less fuel per aircraft than Western built jets. The main reason for the low utilisation rate is the sharp drop in Russian passenger air travel following the collapse of the Russian economy in 1990. Domestic passenger air travel in Russia dropped from around 225 billion RPKs in 1990 to around 40 billion in 1998, while international Russian passenger air travel has been growing steadily to around

28 billion RPKs[60]. Some sources expect that most of the Russian built jets that are currently in use or store will be phased out of service soon because of their poor operating economics leaving room for a possible substitution by Western built jets [DTI 1999].

Besides studying the fuel use and the related CO_2 emissions it would be most interesting to also include other engine emissions as well, such as H_2O, NO_x, sulphate and soot, which are believed to act as GHG's or GHG precursors when emitted at high altitude in the aircraft's cruising phase. Water vapour emissions are directly related to the fuel consumption, but the emissions of NO_x per kilogram of fuel burned differ between engine types [Gardner et. al. 1998, p. 22] [IPCC 1999]. Some airlines already report specific emissions of some of these gases and particulate matter per ASK according to aircraft type, but data are too limited to include them here. If including such emissions, it would also be beneficial to know at which altitude and latitude they are emitted and the time of year to have a better idea of their possible impact on climate change. Some European studies are currently conducting such measurements of in-flight emissions from aircraft engines [Lufthansa 2000b]. Further comparisons of all types of emissions to other modes of transportation would also be interesting. Such comparisons are complicated by the lack of information on the actual aircraft engine emissions through all phases of flight and the methodological problems of comparing the different modes of transport and the different types of environmental problems [Roos et. al. 1997] [COWI 1999].

Another subject that is not dealt with in much detail in this chapter is the importance of the specific types of engines that are used by the aircraft. Because old aircraft can be re-engined with more fuel efficient types it would have been interesting to also consider this, but the limited time available for studying this issue has not allowed for including such an analysis in this project. The main reason is that the information on the specific engine types are not available in a rather significant share of the statistics that have been used here and this information would therefore have to be requested from airlines and the US DOT.

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[60] For comparison airlines situated outside Former Soviet Union performed around 3000 billions RPKs in 1999.

Further studies may also consider other types of energy use connected to the socio-technical system that is built up around the commercial civil air transport sector. Such studies could include the production of aircraft and fuel, as well as the construction, operation and maintenance of infrastructure such as airports, feeder roads and rails, and the energy spent by travel agents, advertising, regulatory authorities and so on. In such a perspective, of course, the environmental impact of commercial civil air transport could be quantified in a more comprehensive manner considering other factors than the operation of aircraft.

Chapter 4

Assessing the possible environmental impact of a global jet fuel tax

- A review of existing studies in the area

This chapter discusses the possible impacts of a global jet fuel tax on airline operating costs, airline fuel-efficiency, airfares and the demand for air travel and freight. A literature review of a number of studies[1] on the possible future impact of a global jet fuel tax is presented. The review shows that most studies agree that a rather high tax rate may be needed to stabilise the CO_2 emissions from commercial civil air transport. The studies use models derived from statistical analysis of historical trends for forecasting the future demand reduction. Assumptions on the future economic (GDP) growth and airlines' reaction by increasing the fuel-efficiency as well as estimates of the likely demand elasticity[2] have marked impact on the findings of the studies.

4.1 Introduction

The background for this chapter is that the current growth in commercial civil air transport activities does not seem to be compatible with an environmentally sustainable development. Currently, there are discussions, especially in Europe, on the possibility of introducing a global kerosene tax to reduce the growth in the environmental impact

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[1] Studies reviewed for this chapter: [Barrett, M. 1996], [OECD 1997], [NEI 1997], [CAEP 1997], [Resource Analysis 1998], [Bleijenberg et. al 1998], [Brockhagen and Lienemeyer 1999], [DIW 1999], [Wickrama 2001] and [Olsthoorn 2001].

[2] The demand elasticity is a term describing the connection between two variables. The issue here is to discuss to which extent an increase in airfares causes a reduction in the demand for air transport. The price elasticity describes the percentage change in the demand over the percentage change in the price. The price elasticity is estimated from historical trends. The studies reviewed here use historical data on airfare developments versus demand developments to establish a price elasticity estimate. For example, if the price elasticity is –2, the demand may be reduced by 2% (over a business as usual scenario) for each percent the price increases. The assumption used in the kerosene tax studies is that consumers may react to price increases in the same way as they have done in the past.

of commercial civil air transport (see chapter 2 for a further discussion of the current political setting).

A jet fuel tax will increase the airline's costs and fares, thereby presumably contributing to reduce air travel growth while giving airlines increased incentive to improve their environmental performance. This chapter discusses what level of tax that may be needed to achieve environmentally sustainable commercial civil air transport[3]. Note that the discussion focuses on a global kerosene tax applied to all jet fuel sold to commercial civil air carriers worldwide.

Section 4.2 explains the expected environmental impacts of a kerosene tax. Section 4.3 describes the historical development in the airlines' fuel expenses showing the impact of fuel-efficiency improvements and fuel cost fluctuations. Sections 4.4 and 4.5 assess the potential impact of a kerosene tax on the airline's operating costs and fares. Section 4.6 assesses the likely consequences of a kerosene tax for the demand for air travel and freight and for the fuel-efficiency of airlines. Section 4.7 gives a concluding discussion of the fuel tax studies that have been reviewed.

4.2 Consideration of the impact on airlines of a kerosene tax

Section 4.2 explains some expected environmental impacts of a kerosene tax. The main purpose of this section is to set up a model describing some important determinants and outcomes, as illustrated in Figure 4.1.

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[3] This chapter focuses solely on what may be an environmentally sustainable level of greenhouse gas emissions from commercial civil air transport.

Figure 4.1: Some possible environmental consequences of a kerosene tax
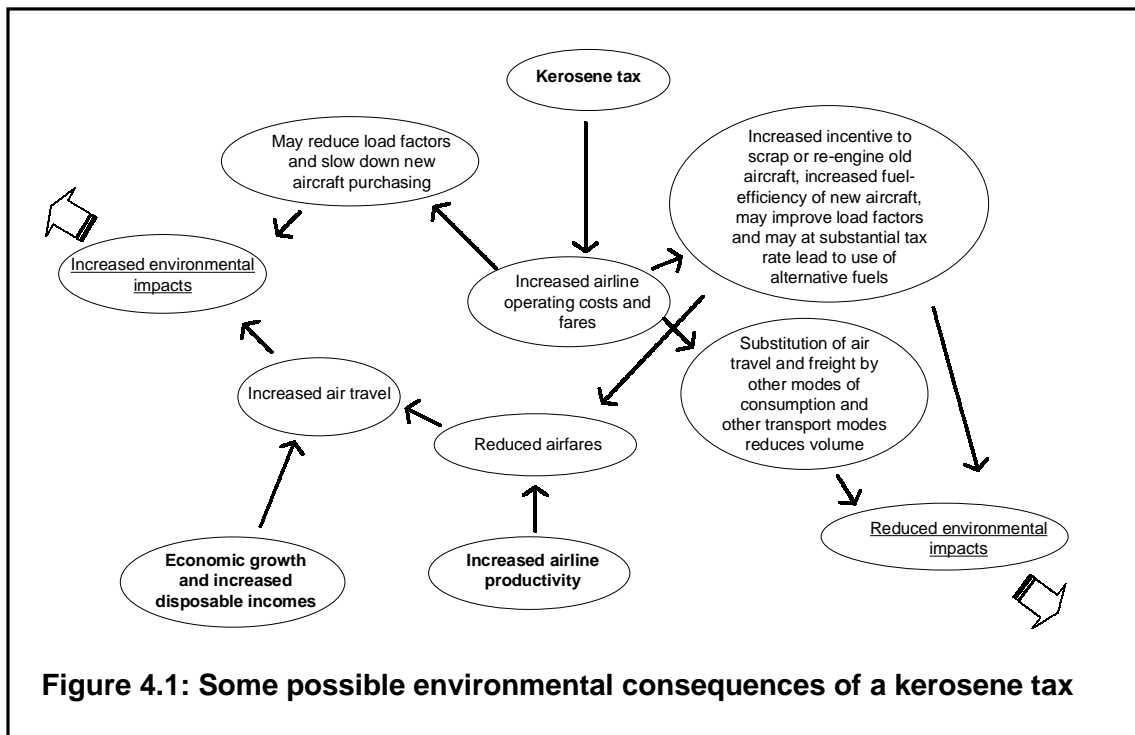
Figure 4.1 illustrates that, by raising the fuel price and adding to the overall airline costs, a kerosene tax may give the airlines a higher incentive to improve their fuel-efficiency. The airlines have the possibility to increase their load factors and to improve their operational procedures and to speed up their scrapping- and re-engine schemes for the oldest fuel-intensive types of aircraft. On the longer term, a kerosene tax may increase the commercial civil air transport industry's incentive to speed up the development of new and more fuel-efficient aircraft types and engines. At a substantial tax rate the development of radically new aircraft configurations[4] and engine types[5] might become economically attractive, as well as alternative fuels[6] based on renewable sources of primary energy, if they are made tax-free.

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[4] For example, the aircraft producers are studying so-called blended-wing-body (BWB) aircraft featuring advanced fuselage configurations resembling a flying wing. Such fuselage shapes may to offer savings in the specific fuel consumption per amount of revenue load carried as compared to the current state of the art subsonic aircraft [Cranfield College of Aeronautics 2000a].

[5] For example, the engine producers are studying new types of aircraft engines, so-called propfans, that can substitute the current types of turbofan engines [IPCC 1999].

[6] For example, the aircraft producers are studying possibilities for substituting fossil kerosene by liquefied hydrogen [Pohl 1995a and 1995b].

However, the operational and technical improvements that are on the horizon for the foreseeable future do not promise to close the gap between the efficiency improvement and the ever-rising air travel volume (see for example Figure 3.3 for an illustration of this gap). Thus, the environmental impacts of commercial civil air transport are set to increase. It is therefore an interesting question to which extent a kerosene tax will contribute to increase airline costs and fares thereby slowing down air travel growth. In general, people can be expected to travel less by air than they would have done in a situation without a kerosene tax, because air travel and freight may then, to some extent, be substituted by other modes of consumption. For example, some potential leisure travellers may choose to do without low-fare charter holidays or choose more nearby destinations. On commuter- and short-haul routes rising airfares might give travellers an incentive to substitute air travel by alternative, and perhaps more environmentally viable, modes of transportation, that is rail-, sea- and road traffic.

Additionally, it should be mentioned that a kerosene tax might have some counteracting effects, as also illustrated in Figure 4.1. For example, the rate of technological efficiency improvement may slow down when airlines improve their load factors and operational procedures to improve the fuel-efficiency per passenger kilometre because they will need fewer new aircraft. Also, in a situation where air travel growth is reduced, the implementation rate of new fuel-efficient aircraft capacity is likely to slow down. Likewise, all measures taken by airlines to reduce their specific fuel consumption will, to some extent, counteract the airfare increases that are to be an expected outcome of the fuel price increases, thereby eroding the demand reducing effect of a kerosene tax.

4.3 The impact of a kerosene tax on the airlines' fuel costs

As can be seen from Figure 4.2, jet fuel constitutes a major component in the airlines' operating costs. The actual fuel price is fluctuating, following crude oil spot prices. In the period from the early 1970s, before the 1973 oil crisis, and until the second oil price shock in 1979 the real jet fuel price rose by a factor of five. Following the second oil crisis in 1979 the fuel costs peaked at around 30% of the total airline operating costs [Jenkins 1999] and above 50% of the direct operating costs [Dings et. al. 2000b]. Throughout the 1980s the real fuel price plummeted (Except for a short peak in 1990 due to the Iraqi war in the Gulf) and fuel costs reached a historical low of 12% of the total airline operating costs in 1998. This left the real kerosene price at 18 US¢ per

kilogram, which is comparable to the pre-1973 level when measured in constant 2000$. In 2000, the jet fuel price peaked again above 30 US¢ per kilogram[7], see Figure 4.2.

Figure 4.2: Jet fuel price development 1967-2000 in current and constant 2000$ and jet fuel costs as percent of total airline operating expenses

Yearly averages have been used except for 2000 using the average for January to August. Current price has been converted into constant 2000 US$ using the US consumer price index.

Data sources: Fuel costs from [Jenkins 1999] except for jet fuel cost data for 1999 and 2000 which are taken from [Air Transport Association 2000a].

The fuel costs per revenue tonne kilometre (RTK) and per revenue passenger kilometre (RPK) and per revenue freight tonne kilometre (RFTK) of air traffic depends on other factors than the fuel price, namely those affecting the specific fuel consumption (as described in detail in chapter 3). One such factor is the length of haul. Medium-haul[8] and long haul[9] aircraft are generally more fuel-efficient than aircraft used at short-range[10]. Therefore, the specific fuel consumption diminishes the longer the

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[7] Note that the jet fuel price varies between geographical regions, airports and airlines. The fuel prices referred to in this text are global averages.

[8] Some examples of medium-haul aircraft are Boeing's B737s and B757s and Airbus' A320s that are typically operated at distances of between 800 and 3000 kilometres.

[9] Some examples of long-haul aircraft are Boeing's B747s and B777s and MD11s and Airbus' A330s and A340s that are typically operated at distances above 4000 kilometres.

[10] The airlines typically use turboprops at distances below 500 kilometres and tend to use regional jets at distances below 1000 kilometres. Turboprops come from a number of producers

stage distance. Another factor affecting the specific fuel consumption is of course the fuel-efficiency of the aircraft types used. Finally, the load factor has a significant impact on the specific fuel consumption and hence on the fuel costs. These matters are exemplified further in the following.

Table 4.1 shows examples of the fuel costs per revenue passenger kilometre (RPK) under different assumptions. The information in Table 4.1 exemplifies the average fuel consumption (Column 3) and fuel cost (Columns 4 and 5) of different airlines and of different types of aircraft. Furthermore, the fuel cost increases for three levels of kerosene tax are exemplified in columns 6, 7 and 8, as discussed later.

Column no. ⇒							
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Row no. ⇓		*Fuel use* *[g/RPK]*	*Fuel cost '98* *[US¢/RPK][e]*	*Fuel cost '00* *[US¢/RPK][e]*	*Fuel cost increase at* *fuel tax of (per kg)*		
					30 US¢	*87 US¢*	*126 US¢*
1	*Average for the US air carriers in 1999*		-	-	-	-	-
2	*Least fuel-efficient major scheduled airlines 1998*	62	1,2	1,9	1,9	5,4	7,8
3	*Most fuel-efficient major scheduled airlines 1998*	35	0,7	1,1	1,1	3,0	4,4
4	*Most fuel-efficient charter airlines 1999*	21	0,4	0,6	0,6	1,8	2,6
5	*Old long-haul aircraft 1998[c]*	50	1	1,5	1,5	4,4	6,3
6	*Modern long-haul aircraft 1998[c]*	36	0,7	1,1	1,1	3,1	4,5
7	*Old medium-haul aircraft 1998[b]*	76	1,4	2,3	2,3	6,6	9,6
8	*Modern medium-haul aircraft 1998[b]*	30	0,6	0,9	0,9	2,6	3,8
9	*Old short-haul aircraft 1998[a]*	120	2,3	3,6	3,6	10,4	15,1
10	*Modern short-haul aircraft 1998[a]*	72	1,4	2,2	2,2	6,3	9,1

Table 4.1: Fuel use and fuel costs per revenue passenger kilometre (RPK) under different assumptions

[a] load factor assumption 50%, [b] load factor assumption 60%, [c] load factor assumption 70%, [d] jet fuel price 1998 19US¢ per kilo, [e] jet fuel price August 2000 30US¢ per kilo. Source for fuel use per RPK is chapter 3 of this report, while source for jet fuel price 1998 is [Jenkins 1999] and source for jet fuel price in August 2000 is [Air Transport Association 2000a].

such as Saab, Avions de Transport Régional (ATR) and Bombardier and examples of regional jet producers are Bombardier and Embraer.

The current differences in airline[11] fuel-efficiency and thereby the fuel cost per RPK is revealed by comparing Rows 1-4, showing the most fuel-efficient major scheduled carriers to operate at around 44% lower fuel costs per RPK than the least fuel-efficient scheduled carriers. Furthermore, the most fuel-efficient European charter carriers operate at 40% lower fuel intensity and fuel cost than the most fuel-efficient scheduled carriers. Rows 5-10 show the specific fuel use to be generally lowest for medium-range and long-range aircraft and around twice as high for short-haul aircraft. As can be seen from Table 4.1, new aircraft operate at lower fuel costs than the oldest models in operation. The effect of variations in the jet fuel price is also significant. Table 4.1 compares the relatively low jet fuel price in 1998[12] to the higher price in August 2000[13] in Columns 4 and 5 showing a fuel cost rise of approximately 50% in the period.

Jet fuel consumed by international air traffic is not taxed unlike gasoline and diesel used for domestic car- and truck transport in many industrialised countries. If, for example, a kerosene tax is set to approach the tax level that is currently applied to road based transport in Europe[14] the airline fuel costs will increase significantly as discussed in the following.

Three levels of fuel tax are considered here, namely 30, 87 and 126 US¢ per kilogram of kerosene, see Table 4.1. The lowest tax level of 30 US¢ per kilogram corresponds to the minimum tax level for road diesel fuel in European Union countries. At this level of tax, the airline fuel costs would double if comparing to the relatively high fuel price in August 2000. The medium tax of 87 US¢ per kilogram corresponds to the current road diesel tax in the United Kingdom (having the highest diesel tax level among the European Union countries) and would roughly quadruple the airlines' fuel costs, again

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[11] Based on data for average fuel consumption per revenue passenger kilometre of the following airlines: Lufthansa Scheduled, Lufthansa City Line, Lufthansa Condor, KLM, SAS, British Airways, Braathens, Finnair, Swissair, Air France, All Nippon Airways, Japan Airlines, Cathay Pacific and Premiair and all the American air carriers as discussed in chapter 3.

[12] The yearly average jet fuel price in 1998 was 19US¢ per kilogram.

[13] The jet fuel price in August 2000 was 30 US¢ per kilogram.

[14] The tax levels on road fuels in European Union countries as of March 2000 amount to between US$309 and US$649 per 1000 litres of gasoline, the lowest tax in Greece and the highest in the UK. Similarly, diesel tax levels range from US$245 to US$691. EU minimum rate fuel taxes are set at US$278 and US$237 for petrol and diesel respectively. These figures are based on a petrol tax in Greece of 319 ECU and 670 ECU in the UK and a diesel tax of 253 ECU in Luxembourg and 713 ECU in the UK and EU minimum rate tax set at 287 ECU and 245 ECU for petrol and diesel respectively [Kaageson 2000, p. 25]. Furthermore based on Exchange currency as of 1 March 2000 at 0,9689 EURO per $.

as compared to the fuel price in August 2000. The highest tax of 126 US¢ per kilogram may be justified because of aircraft's relatively high impact on global warming per litre of kerosene-burn at high altitude when comparing to fuel burned at sea level[15]. At this relatively high tax level the airlines' fuel costs would be roughly five times higher than in August 2000.

4.4 The impact of a kerosene tax on airlines' operating costs

In this section the impact on airlines' operating costs of a kerosene tax is discussed. The aim is to quantify how much the airlines' costs may be raised by applying different levels of tax.

The increases in the real fuel costs, that followed the two major oil crises in the 1970s, were to some extent counteracted by technical and operational improvements. The relatively large improvements in the airlines' average fuel-efficiency and load factors as well as the productivity increases that followed from the introduction of large-capacity wide-body jets (see Figure 2.7) allowed the airlines to continue reducing the real airfares throughout 1978. The average real airfares only rose for a short period of time in the early 1980s (see Figure 2.10). Therefore, the fuel rises did not lead to such substantial increases in the real airfares as to affect a decline in the amount of passenger air travel[16]. In the future, the airlines will not to the same extent be able to improve their fuel-efficiency and productivity. This is because the improvements of next-generation aircraft are foreseen to be of a more incremental character than earlier [IPCC 1999] and because the load factors are relatively high today as compared to the early 1970s [ICAO 1998a]. Therefore, as a first order effect, future increases in the fuel costs are likely to be passed on to the total airline operating costs. In this section this first order effect is assessed.

Airlines' operating costs can be subdivided into direct and indirect costs. The **direct operating costs (DOC)** refer to expenses incurred directly in the operation of a particular aircraft type and include [a]flying expenses[17], [b]Maintenance and overhaul[18]

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[15] See [IPCC 1999] for an introduction to aviation's impact on the global atmosphere.

[16] Only in one of the last 30 years the amount of revenue passenger kilometres declined as compared to the previous year, namely in 1991, due to the Iraqi war in the Persian Gulf region.

[17] Flying expenses can be subdivided into flight crew salaries and expenses, fuel and oil, airport and en-route charges, aircraft insurance, rental of flight equipment and crews.

and [c)]aircraft depreciation (including cost of spares), see Figure 4.3. The **indirect operating costs (IOC)** refer to expenses which are not directly related to operating a particular type of aircraft and include [a)]station and ground costs, [b)]passenger services, [c)]ticketing, sales and promotion and [d)]general administration [Cranfield College of Aeronautics 2000b] [Mason et. al. 2000] [ICAO 2000d].

The rest of this section concentrates on assessing the impact of a kerosene tax on [a)]**aircraft direct operating costs** (section 4.1) and on [b)]**airlines' total operating costs** per revenue tonne kilometre and per revenue passenger kilometre (section 4.2).

4.4.1 The impact of a kerosene tax on airlines' direct operating costs

In 1997, the direct operating costs (DOC) accounted on average for around forty percent of the total costs of the world's scheduled carriers [ICAO 2000d, p. 14][19]. Figure 4.3 compares the major US air carriers' fuel costs to their **direct operating costs (DOC)** per available seat kilometre (ASK) in 1998 according to the average stage distance flown for different aircraft types[20]. First of all, Figure 4.3 exemplifies that the direct operating costs are lower on medium-haul and long haul than on short-range flights. This is mainly due to the higher productivity of large aircraft and due to a better utilisation rate for long-haul aircraft and its pilots and crew. Another reason is that the fuel cost per revenue tonne kilometre is generally lower on medium and long haul than on short haul flights [Aircraft Economics 1999a, 1999c and 1999f] [O'Connor 1995].

The two lower curves in Figure 4.3 compare the average fuel costs in 1998 to what these would have been at the average kerosene price paid by the US air carriers in August 2000. Furthermore, the three upper curves in Figure 4.3 suggest what the direct operating costs would amount to if a kerosene tax of 30, 87 or 126 US¢ per kilogram were put on top of the August 2000 fuel price. At these tax levels, the fuel cost would increase from 28US¢/kg to 58, 115 and 153US¢/kg respectively. See section 4.3 for an explanation why these levels of tax were chosen as examples. Note that the yellow

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[18] Maintenance and overhaul costs can be subdivided into labour costs, materials used and maintenance overhead.

[19] Note that wide variations in the ratio between direct and indirect operating costs are apparent amongst airlines [Comité des Sages 1994, p. 51].

[20] Figure 4.3 is based on data reported by the US Major air carriers to the US Department of Transportation [Aircraft Economics 1999c and 1999f]. Note that Figure 4.3 does not include regional jets and turboprops and that the average yearly kerosene price per kilogram varies by aircraft type between 17-21 US¢/kg.

curve in Figure 4.3 exemplifies the average stage distance at which the aircraft are used.

At the lowest fuel tax level, the American air carriers' direct operating costs connected to operating different types of aircraft increase by some 1-3US¢ per available seat kilometre as compared to the situation in 1998 at a fuel price of around 19US¢/kg on average. This corresponds to increases of around 2-6US¢ per revenue passenger kilometre at current load factors. At the highest fuel tax level, the direct operating costs increase by some 3-6 US¢ per available seat kilometre and some 4-12 US¢ per revenue passenger kilometre depending on the type of aircraft in question.

On average, the highest fuel tax that is suggested here would roughly increase the direct operating costs (DOC) by a factor of around 2,5. The high kerosene tax would totally change the distribution structure of DOC, fuel becoming the most dominant single cost item. In 1998, fuel costs generally amounted to between one third and one fourth of the direct operating costs for larger aircraft types operated by the major American air carriers. The high kerosene tax would turn this around, with fuel constituting generally from around half and up to four fifth of DOC.

For the fuel-efficient aircraft the increase in the direct operating costs would be less than for the oldest models. For example, the high fuel tax would raise the direct operating costs (DOC) of new fuel-efficient B777s by some 3,4 US¢ per available seat kilometre, whereas the increase for older DC10-30s would be around 4,7 US¢. The airlines would therefore have increased incentive to operate the newest and most fuel-efficient aircraft and to scrap or re-engine the oldest relatively fuel-intensive types. When acquiring new aircraft for the short-range market, turboprops may be favoured from jets and in the long-haul market fuel-intensive supersonics and sonic cruisers would be less economically attractive to airlines than at the current fuel price. Furthermore, the incentive to improve the operational procedures and to achieve higher load factors would be greater.
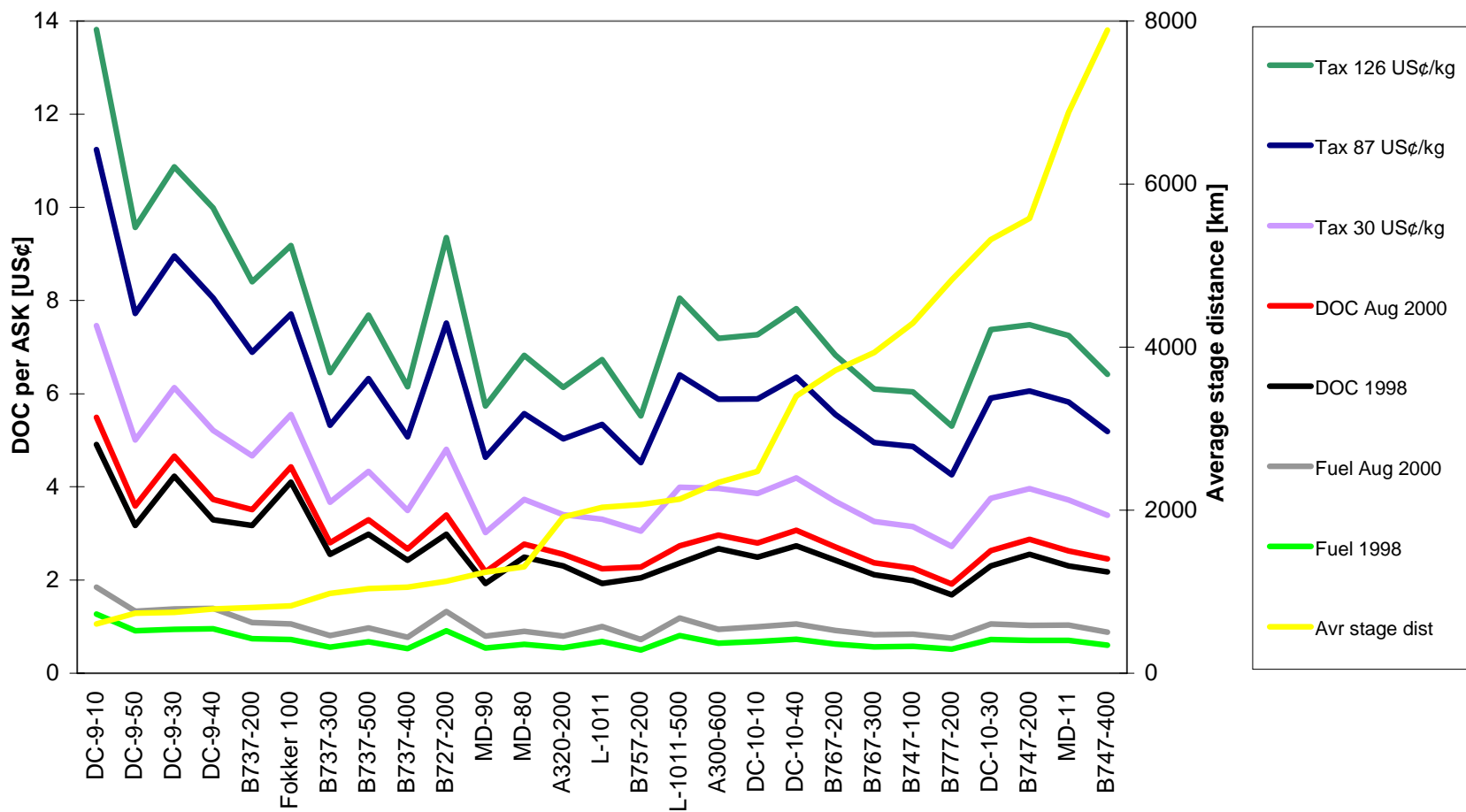
Figure 4.3: Impact of a fuel tax on the direct operating costs per available seat kilometre (ASK) by type of aircraft operated by the US major airlines in 1998

Sources for US air carriers' direct operating costs and stage distances flown by type of aircraft are [Aircraft Economics 1999c and 1999f].

4.4.2 The impact of a kerosene tax on the airlines' total operating costs

As can be seen from Figure 4.4 the effect of a kerosene tax on the airline's total operating costs will be different from airline to airline[21]. The total costs of major[22] scheduled airlines situated in Asia, the United States and Europe ranged between 26-99 US¢ per available tonne kilometre (ATK) and between 38-166 US¢ per revenue tonne kilometre (RTK) in 1998. The average operating costs per revenue tonne kilometre of major scheduled carriers is around 55 US¢ in Europe, 45 US¢ in North America and 38 US¢ in Asia [Cranfield College of Aeronautics 2000b, p. 121-144].

Figure 4.4 also exemplifies that low-cost scheduled airlines and charter carriers situated in Europe are operating at relatively low costs. Some of these airlines operate at costs that are comparable to low-cost scheduled airlines in Asia. It should be noted that the data in Figure 4.4 cover costs for all revenue load carried, that is both passengers and freight. Therefore, Figure 4.4 underplays the cost advantage of European low-cost scheduled airlines and charter carriers, because these typically carry insignificant loads of low-yield freight whereas typically around 40% of the revenue weight carried by the major scheduled carriers in Asia is freight [Cranfield College of Aeronautics 2000b, p. 122]. That is, the operating costs per revenue passenger kilometre (RPK) of European charter airlines are probable some of the lowest in the global airline industry [Mason et. al. 2000] [Aircraft Economics 1999e].

The impact on the airlines' operating costs of introducing a kerosene tax of 126 US¢ per kilogram can be seen from the horizontal lines in Figure 4.4. The lower lines suggest the fuel cost increase for the most fuel-efficient scheduled airlines and charter carriers today at around 38US¢ per RTK and 25US¢ per RTK respectively[23]. The higher lines suggest the fuel price increase for the least fuel-efficient scheduled- and charter

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[21] The total airline operating costs per revenue tonne kilometre (RTK) vary considerably between airlines (see Figure 4.4). The reason for the differences in cost structures lie in a number of different parameters connected to airline operations. For example, large deviations are seen in the passenger load factors and the freight load factors and in the in route- and demand structures. There are also differences in the average length of haul and in the types and sizes of aircraft used as well as there are differences in the aircraft utilisation rate. Further aspects are differences in aircraft productivity and labour productivity as well as wage structures and monetary exchange rates and fees and charges for take-off and landings etc.

[22] The airlines referred to here as majors are the three groupings of Asian, American and European scheduled airlines that are shown to the left in Figure 4.4.

carriers at 63US¢ per RTK and 44US¢ per RTK respectively[24]. Kerosene tax levels of 87 US¢ and 30 US¢ would lead to lower cost base increases as indicated in Table 4.2.

kerosene tax per kg	*30 US¢*	*87 US¢*	*126 US¢*
Most fuel-efficient charter airlines 1999	6 US¢	17 US¢	25 US¢
Most fuel-efficient scheduled airlines 1998	9 US¢	26 US¢	38 US¢
Least fuel-efficient scheduled airlines 1998	15 US¢	44 US¢	63 US¢

Table 4.2: Cost base increases per RTK induced by fuel tax of 30, 87 and 126 US¢ per kg
Source for fuel use per RTK is chapter 3.

At a fuel tax of 126 US¢, the major scheduled airlines would see their cost base increase by some 30-100%. For example, the 1998 cost base of SAS, being a relatively fuel-intensive high-cost carrier, would be increased by around 60US¢ per RTK corresponding to an increase of about 38 percent[25]. Conversely, a low-cost fuel-efficient Asian carrier like Cathay Pacific would have to pay around 38 US¢ kerosene tax per RTK, thereby almost doubling its total operating costs[26]. The fuel-efficient European charter carriers would see their cost bases increase by 60-80 percent[27].

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[23] Based on estimates for the specific fuel consumption for the most fuel-efficient scheduled carriers of 300g per RTK and 200g per RTK for the most fuel-efficient charter carriers, see chapter 3.

[24] Based on fuel consumption of 500g per RTK for the least fuel-efficient scheduled carriers and 350g per RTK for the least fuel-efficient charter carriers, see chapter 3.

[25] Based on SAS' 1998 operating at costs of 166 US¢ per RTK [Cranfield College of Aeronautics 2000b, p. 142] and average fuel consumption of 479g fuel per RTK (see chapter 3).

[26] Based on Cathay Pacific's operating costs of 43 US¢ per RTK [Cranfield College of Aeronautics 2000b, p. 126] and an average fuel-intensity of 300g of fuel per RTK.

[27] Based on Premiair's operating costs of 55US¢ per RTK [Aircraft Economics 1999e], and an average specific fuel consumption of around 260g of fuel per RTK (see chapter 3).
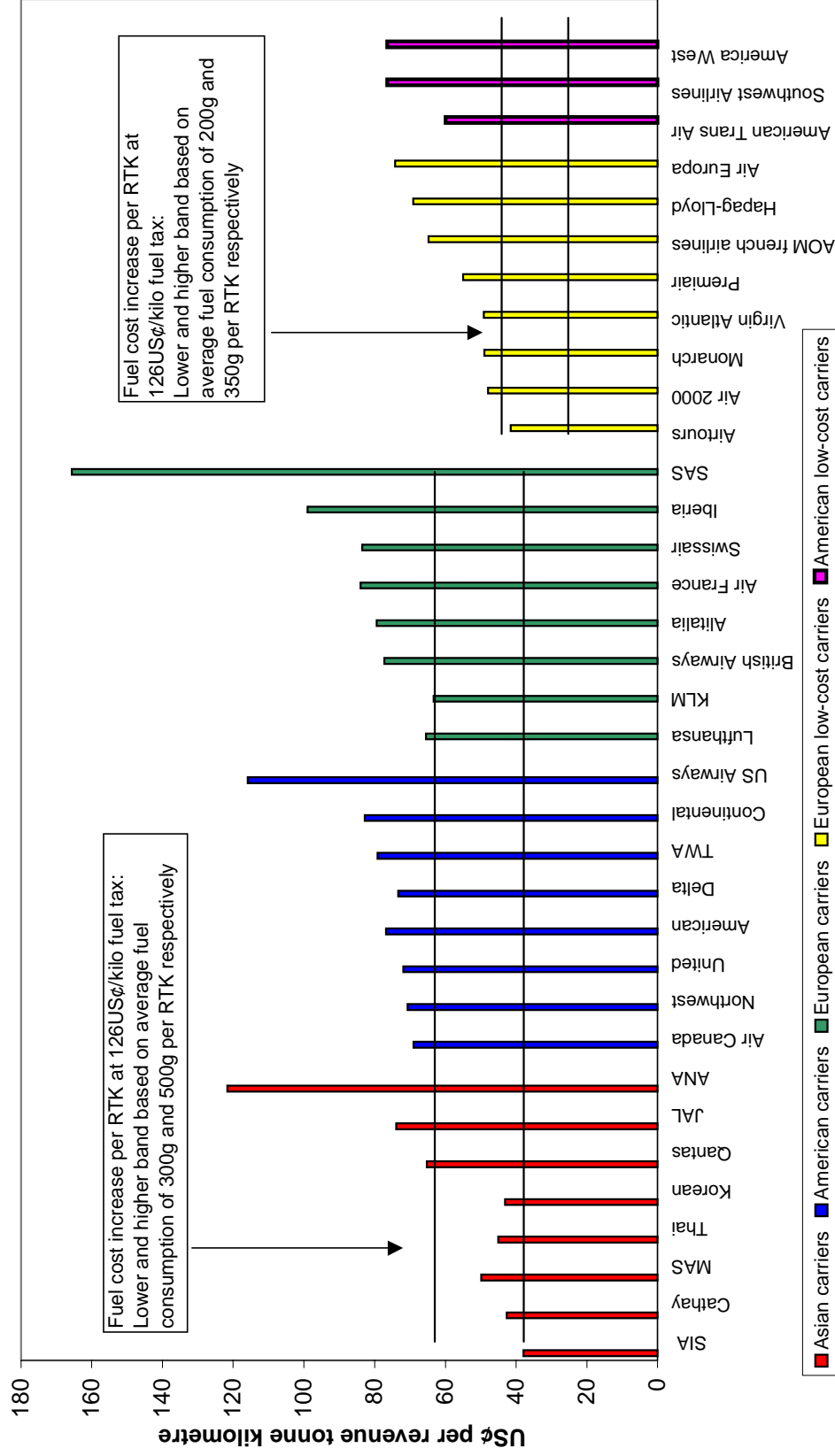
Figure 4.4: Comparison of the total operating costs per revenue tonne kilometre of different airlines in 1998 and examples of the fuel cost increases at a fuel tax of 126US¢ per kilogram

Note that the figures for the operating costs per revenue tonne kilometre are for the combined total of passenger load and freight load. The data sources for costs are [Cranfield College of Aeronautics 2000b, pp. 121-144] and [Aircraft Economics 1999e] while the fuel intensity ranges are based on chapter 3 of this report.

4.5 Impact of a kerosene tax on airfares

The average airline fares are not much higher than the average costs. Therefore, the average airline profits are relatively low (see Figure 2.11) leaving the average fares almost comparable to the average costs [ICAO 1986, 1996c and 2000d]. This situation is not a short-term problem for airlines, but has been evident throughout the last decades where airlines have even seen losses in the early 1980s and early 1990s following periods with economic recessions and high fuel costs. On this basis, as a first order effect, the average fares are likely to increase when fuel costs rise, because the airline industry is generally not likely to be able to reduce its profit margins. Some scheduled airlines might choose to distribute the fuel cost increases unevenly among high-yield business travellers and low-yield leisure travellers and freight. This is not taken into consideration here.

Global statistics from the International Civil Aviation Organisation (ICAO) estimate the over-all weighed world average[28] revenue per revenue passenger kilometre (RPK) for scheduled international passenger traffic, without distinction between class of travel or fare type, at 8,20 US¢ in 1997[29] [ICAO 2000d]. At an average fuel use of about 49g[30] per RPK the fares would increase by around 6 US¢ if implementing the high fuel tax of 126 US¢ per kilogram. The variation among route groups range from a low of 5,5 US¢ across the Mid-Atlantic to a high of 17.3 US¢ in local Europe[31]. On routes across the

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[28] It is generally difficult to get an overview over airline fares because these differ between airlines, routes, and airport city-pairs, and vary by season, day of week and time of day. Fares also vary substantially between passengers and freight, and passenger fares differ by class of travel (for example first, business, economy, and discount). Furthermore, tickets on each class deviate in price according to flexibility of the ticket (for example, duration of journey, ticket expiry date, ability to change flight-date or flight-hour, ability to refund ticket and so on). Generally, airline fare structures are composed as to optimise revenue by filling in as many passengers per aircraft as possible, with emphasis on attracting as much high-yield passenger- and freight volume as possible. Through yield management, airlines try to achieve the highest possible revenue per flight while at the same time keeping the lowest fares down as to attract price-sensitive leisure travellers and to stay competitive compared to other airlines [Doganis 1985] [O'Connor 1995]. This highly complex fare structure makes it difficult to estimate the impact on airfares of a kerosene tax.

[29] However, there are large differences in the average revenue among airlines and between different routes, see Table 4.3.

[30] Represents the average for the American air carriers in 1999, excluding all-freight but including belly hold freight, see chapter 3.

[31] Similarly, the average revenue per revenue tonne kilometre varies between routes, from a low of 22.9 US¢ on routes across the North/Mid Pacific, to a high of 80 US¢ on routes within Europe.

Atlantic the fares may increase by some 5,5 US¢[32] (a doubling). The fare increases will be less significant (relatively) on the more expensive routes.

	Percentage of the available seat kilometres in the world's international traffic	Revenue per passenger kilometre	Revenue per freight tonne kilometre
	[%]	[US cents]	[US cents]
Between North America and Central America/Caribbean	1.9	8.4	23.9
Between and within Central America and Carribbean	0.1	-	42.8
Between Canada, Mexico and the United States	3.8	7.9	36.8
Between North and Central/South America/Carribbean	3.8	8.2	38.2
Local South America	0.7	12.2	48.9
Local Europe	11.3	17.3	80
Local Middle East	0.7	15.2	35
Local Africa	0.4	-	44.5
Between Europe and Middle East	3.1	9.7	34.4
Between Europe/Middle East and Africa	3.5	7.4	30
North Atlantic	18.5	6.6	23.9
Mid-Atlantic	3.4	5.5	23.5
South Atlantic	2.5	6.6	26.1
Local Asia/Pacific	14.2	8.7	31.8
Between Europe/Middle East/Africa and Asia Pacific	16.8	6.8	26
North and Mid-Pacific	12.9	5.8	22.9
South Pacific	2.4	5.9	23.2

Table 4.3: Average revenue per passenger kilometre and freight tonne kilometre in international air traffic on geographical regions
Note that these data are for international traffic only. Source: [ICAO 2000d].

4.6 Impact of a kerosene tax on the demand for air travel and on fuel-efficiency

As can be seen from Figure 2.10 airfares rose from less than 5 US¢ per revenue passenger kilometre in the 1950s to around 8 US¢ in the 1990s, when measured in current US$. When measured in real terms, US airline revenue per RPK has been reduced by a factor of almost four in the 50-year period, showing that air travel fares have increased less than prices on other modes of consumption in general. The US consumer price index rose 6,9 times between 1950 and 1999. In the same period airfares per revenue passenger kilometre (RPK) only doubled, when measured in

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[32] Based on the average fuel consumption of the American air carriers of 33g per ASK on routes across

current prices, while average yearly personal disposable income in the US rose by a factor of 17 from around $1363 in 1950 to around $23946 in 1999, when also measured in current prices. When taking account of inflation, US disposable personal income increased threefold in the fifty-year period, while real airfares were reduced by almost a factor of four (see Figure 2.10). These are probably some of the main determinants of air travel growth.

As can be seen from Figures 2.1 and 3.3 air transport has grown at relatively high growth rates although slowing down somewhat in the last decades. One question to be addressed in this section is to which extent a kerosene tax will raise airfares thereby reducing consumers' access to air transport and changing their preferences towards other modes of consumption. Another question is to which extent a jet fuel tax will give the aircraft producers and airlines increased incentive to develop and introduce more fuel-efficient aircraft in the future.

The future demand reduction due to introduction of a kerosene tax can by its nature not be foreseen. The impact will to a large extent depend on economic growth, rise in real income and improvements in airline productivity reducing real airfares as well as consumer preferences for air travel over other modes of consumption. These determinants therefore have to be forecasted to give a reasonable estimate of the possible effect of a future kerosene tax. For that purpose a literature review has been carried out to study assumptions used in other studies in this area.

Studies assessing the likely future demand impact of a kerosene tax generally use a methodology based on projecting the future demand growth in a so called "business as usual" (BAU) forecast. BAU forecasts are most often based on assumptions on future economic growth and income rise as well as increasing airline productivity reducing real airfares. Studies furthermore use demand elasticity estimates indicating how consumers might react to the airfare increases. Note that the studies base their projections on statistical analysis of historical time-series data. The studies reviewed have varying results because of different assumptions on key parameters, see Table 4.4[33].

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the Atlantic (see chapter 3) an assumed passenger load factor of 75%.

[33] Note that there are distinct differences between studies in the time frames and the geographical regions under study as well as there are differences in the assumptions used. The

As a rule of thumb, most studies conclude that the environmental effectiveness of a kerosene tax will be rather small unless a quite substantial tax rate is applied. The main reason for this is the that studies assume that, in a business as usual scenario, economic growth and income rise will continue at current rates leading to a tripling of global demand for air travel and freight within a twenty-year time period. Some studies even forecast higher growth rates [Barrett 1996] [OECD 1997] (see indexes for demand in Table 4.4)[34].

Study	Region	Fuel tax [US¢/kg]	Base year	End year	RPK index over base year	RFTK index over base year	RTK index over base year	Fuel efficiency Yearly reduction of fuel intensity	Demand elasticity applied	Fuel use index over base year
Barrett 1996	World	BAU 15	1990	2030			8,8 8,2			
OECD 1997	World	BAU 10	1992	2020	3,7-7,5 3,2-6,5	3,8-5,3		1,1% p.a.	-0,66 to –2,1	2,8-4,1
NEI 1997	World	BAU 10	2000	2010					-0,8	1,3 1,25
CAEP 1997	World	BAU 30	1992	2005			2 1,8	1% p.a.	–0,1 to –1[b]	
Ress. Anls 1998	EU	BAU 33[d]	1998	2005	? -4%	? -6%		1% p.a.		? -2,4%
Bleijenberg 1998	EU	BAU 20 80-130[c]	1992	2025	4,6		26%*	0,63(-37%) 73%[a]	-0,4 to –0,5	3 2,1 1
Bleijenberg 1998	World	BAU 30	1992	2015			3,4 2,8			1,93 1,6
Brockhagen 1999	World	BAU 43[e]	1999	2020	2,7 2,4-2,5				-0,8	
DIW 1999	EU	BAU 65[f] 231[g]	1995	2020	2,7 2,6 2,2	4 3,8 3				2,2 2 1,5
Wickrama (CAEP) 2001	World	BAU 23 50 180	1990	2010	2,8	4,3	3,4 3,1 2,9 2,3	New aircraft 1% p.a.	-0,6 to -0,9	1,6 1,42 1,28 0,95

Table 4.4: Results of kerosene tax studies and main assumptions used
a. 73% of reduction in CO_2 emissions due to increased efficiency, 23% due to demand reduction.
b. Business –0,1, leisure –1, average passenger –0,83, freight –1.
c. Tax of 80-130 US¢/kg needed to stabilise CO_2 emissions from commercial civil air transport at current level if emissions are set to grow by 3% per year in a business as usual scenario. Tax of up to 286 US¢/kg would be needed at 4% growth in CO_2.
d. 0,245 EURO/l. Based on annual average exchange currency rate 1999 at 1,06 EURO per $.
e. 0,32 EURO/l. Based on annual average exchange currency rate 1999 at 1,06 EURO per $.
f. 1,2DEM per kg. Based on annual average exchange currency rate 1999 at 0,54DEM per $.
g. 4,25DEM per kg. Based on annual average exchange currency rate 1999 at 0,54DEM per $.

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main differences are connected to the price elasticities used and the expectations for growth of air travel and freight and for fuel-efficiency improvement rates.

[34] Note that some studies indicate a demand index for the end-year in revenue tonne kilometres whereas others use indexes for revenue passenger kilometres and revenue freight tonne kilometres.

In general, most of the studies expect that the demand growth will be reduced by little less than one percent over the business as usual scenario for each percent the tax raises airfares, while most studies expect new aircraft to become approximately 1% more fuel-efficient per annum. At tax rates of around 20US¢/kg studies generally expect growth in demand for air travel to be reduced by some 10% as compared to a business as usual scenario, because such a tax level is expected to raise average fares by around 10%. One study suggests that at current growth rate of 3% in CO_2 emissions from commercial civil air transport a kerosene tax of some 80-130US¢/kg may be needed to stabilise global emissions at current level [Bleijenberg et. al 1998]. Another study calculates that to reduce fuel use by 5% in 2010 as compared to 1990 a tax rate of around 180 US¢/kg might be needed [Wickrama 2001]. A main explanation for the difference between these two studies is that the latter study has lower expectations for fuel-efficiency improvement. Another study [DIW 2000] anticipates that even if implementing a 231US¢ per kg fuel tax in Europe the fuel consumption may increase by 50% within 20 years, see Table 4.4. Yet another study [Olsthoorn, X. 2001], which has not been included in Table 4.4, estimates that to stabilise commercial civil air transport CO_2 emissions at the current level in 2050 a fuel tax of at least 150 US¢/kg would be needed. This is for a BAU scenario where CO_2 emissions are only forecast to increase by a factor of 2,9 within the next fifty years. Within this same study it is concluded, that CO_2 emissions may grow by between a factor of 2,9 and 6,1, and a much higher kerosene tax than 150 US¢/kg may therefore be needed to stabilise CO_2 emissions at current level.

4.7 Discussion of the fuel tax studies reviewed

The studies reviewed suggest that at current growth rates in air travel and freight a relatively high level of kerosene tax would be needed to stabilise the CO_2 emissions from commercial civil air transport. Some studies suggest that a fuel tax of some 80-180 US¢/kg may be adequate, whereas other studies indicate that tax may have to be even higher. For comparison, EU minimum fuel tax for road diesel fuel is around 30 US¢/kg, but some countries levy higher taxes, up to 87 US¢/kg in the United Kingdom.

The potential environmental effects of a certain jet fuel tax are difficult to quantify. Some main parameters of crucial importance are the future developments in the economy (GDP), airline productivity and airfares as well as consumer income and consumer preferences for air travel over other modes of consumption.

Most studies reviewed here anticipate as a basis quite high growth rates in air travel and freight, mainly basing it on forecasting historical trends. Forecasts are based on the assumptions that continuing economic growth and increasing income combined with reductions in real airfares will allow such demand increases. Furthermore, studies seem to assume that adequate airport infrastructure will be provided to meet the rising demand. This is another crucial assumption considering that it is becoming increasingly difficult for airports to get approvals for enlarging their capacity in many industrialised countries. The studies reviewed tend to extrapolate historical trends in air travel and freight volumes without taking into consideration that some factors like economic satiation, environmental problems or resource scarcity, may on the longer term reduce the business as usual growth. Sooner or later the commercial civil air transport industry may reach a stage of maturity and therefore some sort of gradual reduction of the growth rates may be a reasonable assumption. A lower growth rate assumption would reduce the level of tax needed to reach a certain reduction target for demand. Chapter 5 discusses further the issue of growth versus environment. The key issue here seems to be that current growth rates in commercial civil air transport are not compatible with environmentally sustainable development.

The choice of demand elasticity assumption is another crucial parameter affecting the calculations. The demand elasticity estimates, based on previous experiences, may not adequately take into account that the real price of air travel and freight has never before increased for a longer period of time. In fact, the average real fares have been reduced almost continuously ever since the early days of commercial civil air transport, see Figure 2.10. Therefore, the demand elasticity may be higher than expected if real airfares rise substantially (as will be the case if a fuel tax of for example 126 US¢/kg is promptly introduced).

The knowledge on the long-term effects of fuel price increases on the fuel intensity is relatively poor. One reason is that the previous fuel price rises have lasted for a relatively short period of time. Another reason is that other factors than the fuel price have influenced the real airfares and the airlines' fuel-efficiency, some main parameters being the introduction of relatively fuel-efficient high-productivity wide-body jets in the early 1970s and increasing load factors. Future gains in these parameters are likely to be of a more incremental character.

Concerning the possible development of radically more fuel-efficient aircraft and engines and alternative fuels the lead-time can be relatively long because of the large investments required and the time needed for research and development and because of need for testing of new technologies due to concerns over safety and other issues like noise and emissions. If looking at specific technologies, like for instance aircraft fitted with propfan[35] engines or high-speed turboprops cruising at slower speed and altitude than turbofans, the kerosene price increase will have to outweigh the airline cost increases induced by time losses due to lower speed. Such specific areas are generally not discussed in detail in the studies reviewed. However, one study [Bleijenberg et. al. 1998] has a higher expectation for the fuel efficiency improvements than for example CAEP's study [Wickrama 2001]. One of the main differences is that Bleijenberg et. al. [1998] expect that propfan engines will be introduced throughout all size categories of the fleet and that lower operating speeds will be deployed. This assumption has been criticised by various sources for not taking adequately into account the costs barriers connected to operating at lower speeds [Dings 2000b, Annex VIII, pp.1-6]. Another critique raised is that the technological barriers to meeting airworthiness and the potential problem of fan blade containment and the increased cabin and ground level noise of propfan engines may disfavour the technology compared to turbofan engines [Wickrama 2001, p. 57] [Dings 2000b, Annex VIII, pp.23-31]. Thus, the lower estimates given by Bleijenberg et. al [1998] for the level of kerosene tax needed to stabilise the CO_2 emissions from commercial civil air transport (80-130 US¢/kg) may be too low if such radically improved technologies do not emerge.

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[35] A propfan engine is an advanced type of turboprop engine featuring highly swept blades than can rotate at higher speeds than current turboprops. For example, General Electric presented and tested a so-called UDF (un-ducted fan) prototype counter-rotating propfan engine in the 1980s.

Chapter 5

The future role of commercial civil air transport in a sustainable energy system

This chapter discusses the challenges confronting the global energy and transport systems if these are to become environmentally sustainable[1] in the future. The main purpose is to discuss the possible role of commercial civil air transport in an environmentally sustainable energy system. On the basis of this discussion a sustainability target for commercial civil air transport is suggested. We note that this chapter is not intended to predict what is going to happen, but rather to exemplify what may be required for achieving environmentally sustainable commercial civil air transport activities in the future.

Firstly, section 5.1 presents and discusses some of the main challenges confronting the global energy system as such. The main focus areas are the expectation for future population growth and the current uneven distribution of resources between regions of the world as well as the expectation for growth in energy services and energy consumption patterns and the related emissions of CO_2 to the atmosphere. In this perspective a sustainability target for the future energy system is proposed focusing mainly on the need to reduce the greenhouse gas (GHG) intensity of energy services through using more energy-efficient end-use technologies and less GHG intensive sources of primary energy. On this basis a scenario for a possible future environmentally sustainable European energy system is suggested. The aim of section

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[1] Note that the sustainability requirements discussed in this report merely focus on the need to reduce global emissions of greenhouse gases from combustion of fossil fuels and the need to redistribute the allocation of energy services equally between the world's citizens. Other studies focus on other types of environmental problems or other aspects of sustainability than environmental ones such as economic sustainability or social sustainability (for a further discussion of these issues see for instance [Gudmundsson 2000]).

5.1 is to exemplify that an environmentally sustainable energy system may require a substantial reduction of the world's GHG emissions as well as a redistribution of the current allocation of the world's resources between developing and industrialised nations.

Secondly, section 5.2 discusses the implications for commercial civil air transport of the proposed requirements for a future sustainable energy system. Also here, the main focus areas are the current uneven distribution of air traffic volume between regions and countries of the world and the expectations for future growth in air traffic and the expectations for the future GHG intensity of commercial civil air transport. The aim of section 5.2 is to exemplify the main challenges posed to commercial civil air transport if the sector is to become environmentally sustainable. The main challenges in the future will be to reduce the growth in air traffic while at the same time reducing the specific GHG intensity of the aircraft fleet. Some scenario calculations are used to exemplify the importance of each of these factors.

Thirdly, section 5.3 proposes a sustainability target for passenger air travel being based on the sustainability requirements that are discussed throughout chapter 5.

5.1 Challenges facing a future environmentally sustainable energy system

Before discussing specifically the greenhouse gas emissions from commercial civil air transport in section 5.2, this section describes the global CO_2 emissions from the combustion of fossil fuels and the challenges facing an environmentally sustainable global energy system. The reason for using this approach is that we emphasise that a target for environmentally sustainable commercial civil air transport activities must include considerations on the direction in which the whole energy system should be heading.

As can be seen from Figure 5.1 the global consumption of primary energy has risen ever since the beginning of the industrialisation. Primary energy use has risen from an estimated 256 Mtoe[2] in 1850 to around 8846 Mtoe in 1995. At the same time the world population rose from around 1,3 billions to around 5,7 billions. Thereby, the yearly

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[2] Mtoe is an abbreviation for million tonnes of oil equivalent that is sometimes used to compare the energy content of different types of energy.

primary energy use per capita rose from around 0,2 toe[3] to around 1,6 toe. Even though the use of more or less CO_2 neutral primary energy sources such as wood, hydro dams[4] and nuclear energy has risen in the period, the use of fossil fuels (coal, oil and gas) have grown faster to become the main sources of primary energy. Arnulf Grübler [1998] describes the cyclic nature by which wood, coal and oil have risen to each become the main primary source for a period of time, to be later taken over by other sources. However, the total use of each source has risen throughout the period. The main challenges ahead seem to be fears over the possible impact of CO_2 emissions on the global temperature and the exhaustion of fossil and nuclear reserves on the longer term. Therefore, renewable and nuclear sources of primary energy may take over as main sources in the longer term as fossil reserves are gradually nearing exhaustion or if governments decide to substitute fossil fuels for environmental reasons.

Figure 5.1: World yearly primary energy use from 1850 to present in million tonnes of oil equivalent (Mtoe)
Source: [Grübler 1998].
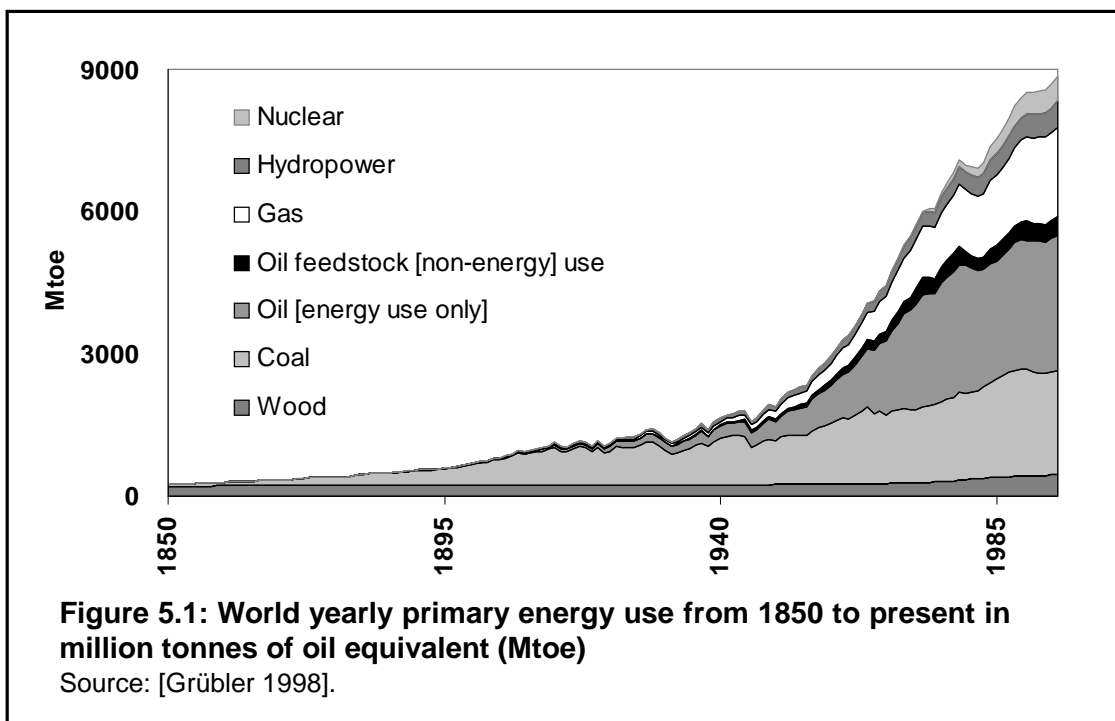
The CO_2 intensity of the energy services provided has been reduced throughout the period, by improving the efficiency of end-use technologies while reducing the losses

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[3] Tonnes of oil equivalent, see footnote above.
[4] We note that primary electricity based on renewable energy can not be compared to fossil primary fuels directly, because the conversion of coal, oil and gas into usable heat- and

connected to producing and distributing secondary energy and by increasing the share of less CO_2 intensive primary energy sources. Examples are the rise in use of oil, and later gas, nuclear and renewables, being less GHG intensive than coal. However, the demand for energy services has by far overridden these achievements leading to increasing emissions of CO_2 from the energy system. As can be seen from Figure 5.2, the global yearly emissions of CO_2 grew from around 6 giga-tonnes in 1950 to around 22 giga-tonnes in 1994. The yearly energy consumption growth rates have been reduced at the end of the period, most markedly in the early 1980s and in the early 1990s, following some major oil supply crisis' resulting in rising energy prices and downturns in the global economy.

Figure 5.2: World yearly CO_2 emissions 1950-2000 and three scenarios for future development
Source for historical data for the global CO_2 emissions 1950-1994 is [Marland and Boden 2000].
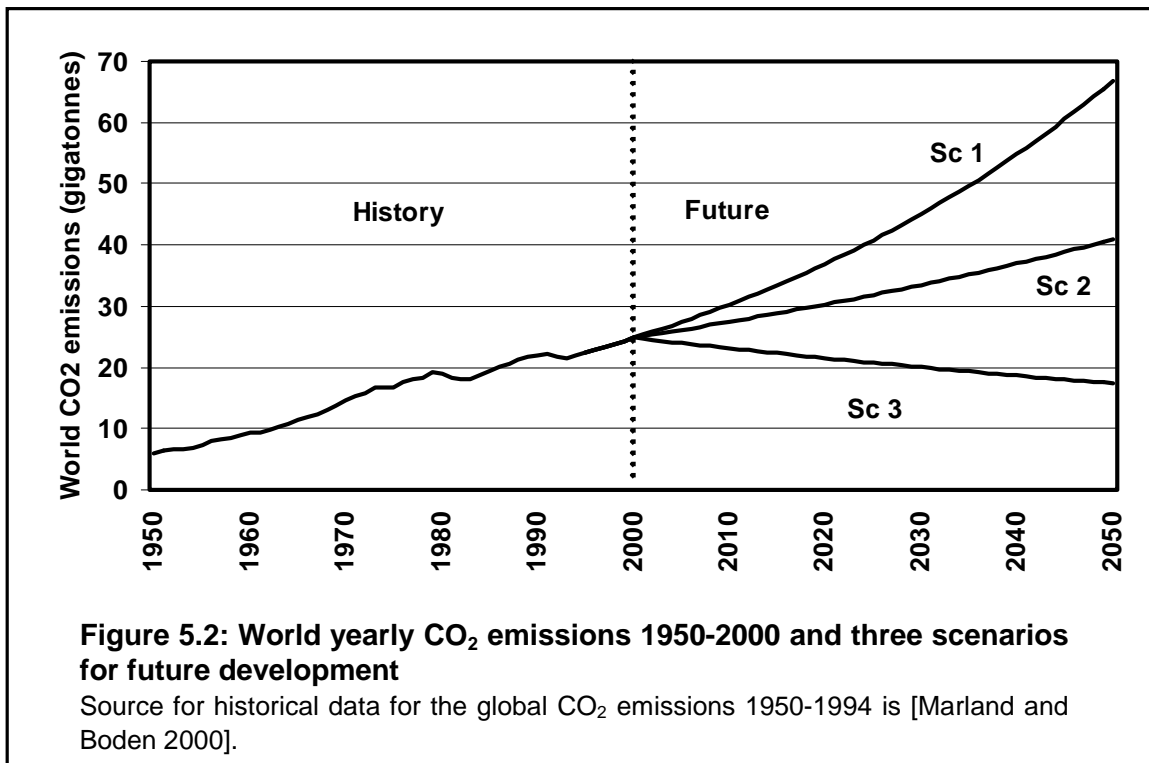
Depending on what actions are taken by governments and producers and consumers of energy the global emissions of CO_2 may be allowed to continue growing. However, if appropriate actions are taken to reduce the growth in energy services and to improve the end-use energy efficiency while reducing the losses connected to producing secondary energy and to increase the share of less CO_2 intensive sources of primary energy, the emissions of CO_2 may decline. The scenario calculations shown in Figure

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electrical energy imposes losses. Thereby, the renewable electricity's share of the useable energy for end-use purposes is higher than suggested by Figure 5.1.

5.2 exemplifies that if the CO_2 emissions are allowed to grow by two percent per year on average the result will be a tripling of the yearly CO_2 emissions in 2050 as compared to 1994 (scenario 1). Similarly, if CO_2 emissions are allowed to grow by one percent per year on average the result will be almost a doubling (scenario 2). However, what may be needed for the energy sector to develop in a more sustainable direction is something like a 30 percent reduction in 2050 as compared to today, exemplified by scenario 3 in Figure 5.2. And further reductions may be needed thereafter.

The sustainability target exemplified by scenario 3 in Figure 5.2 is inspired by a reduction scenario for the global emissions of CO_2 that is presented by the Intergovernmental Panel on Climate Change (IPPC) in its second assessment report. IPPC's reduction scenario aims at stabilising the concentration of CO_2 in the atmosphere at 450 ppmv[5] by 2075 [IPCC 1996a, pp. 13-26][6]. According to the IPCC the atmospheric concentration of CO_2 would reach 500 ppmv by the end of the 21st century if the global yearly emissions of CO_2 were maintained at the 1994-level. However, because the yearly emissions of CO_2 are most likely to increase in a business as usual scenario the concentration of CO_2 in the atmosphere is heading for much higher levels. The IPCC has presented a range of reduction scenarios for the global emissions of CO_2 leading to a stabilisation of the concentration of CO_2 in the atmosphere at between 450 ppmv and 1000 ppmv. For comparison, the pre-industrial concentration is estimated at around 280 ppmv and the concentration level in 1994 is estimated at around 358 ppmv. All the IPCC reduction scenarios imply that the yearly CO_2 emissions would have to be reduced substantially on the very long-term. The main differences between the various IPCC reduction scenarios are:

- the choice of a stabilisation target for the concentration of CO_2 in the atmosphere
- the future year in which the yearly emissions of CO_2 is set to stop growing
- the pace at which the yearly reductions are achieved thereafter

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[5] Parts per million by volume.
[6] In the scenario presented by the IPCC that aims at stabilising the atmospheric CO_2 concentration at around 450 ppmv the base year used is 1994. In this scenario the emissions of CO_2 should be reduced to around 75% of the 1994-level by 2050 and by around 60% by 2100. Furthermore, the scenario anticipates CO_2 emissions to increase by some 40% between 1994 and 2015 and thereafter to be reduced by some 43% over the 2015-level by 2050.

The IPCC scenarios thereby exemplify that the pace at which we begin reducing emissions of CO_2 is of marked importance for the resulting future concentration levels. For each year the yearly emissions continue rising the targets for needed reduction for reaching a certain stabilisation level for the concentration of CO_2 in the atmosphere also rise. We note that the IPCC does not attempt to suggest what concentration level governments should aim for. The reduction target that is suggested here is therefore merely a normative choice made by the author of this report, being inspired by the most drastic scenario for reduction of the yearly CO_2 emissions that is presented by the IPCC.

One major problem is how to agree upon national reduction goals for the nations of the world because the global CO_2 emissions are currently distributed unevenly between countries. We argue that in an environmentally sustainable world such differences would have to be smoothed out. As can be seen in Figure 5.3 the emissions of CO_2 per capita in the world on average increased from around 2,3 tonnes in 1950 to around 4 tonnes in 1970, and have remained fairly constant since then.

Figure 5.3: World average CO_2 emissions per capita 1950-2000 and scenarios for future development
Source for historical data for global CO_2 emissions 1950-1994 is [Marland and Boden 2000. Source for global population data is [US Census Bureau 2000].
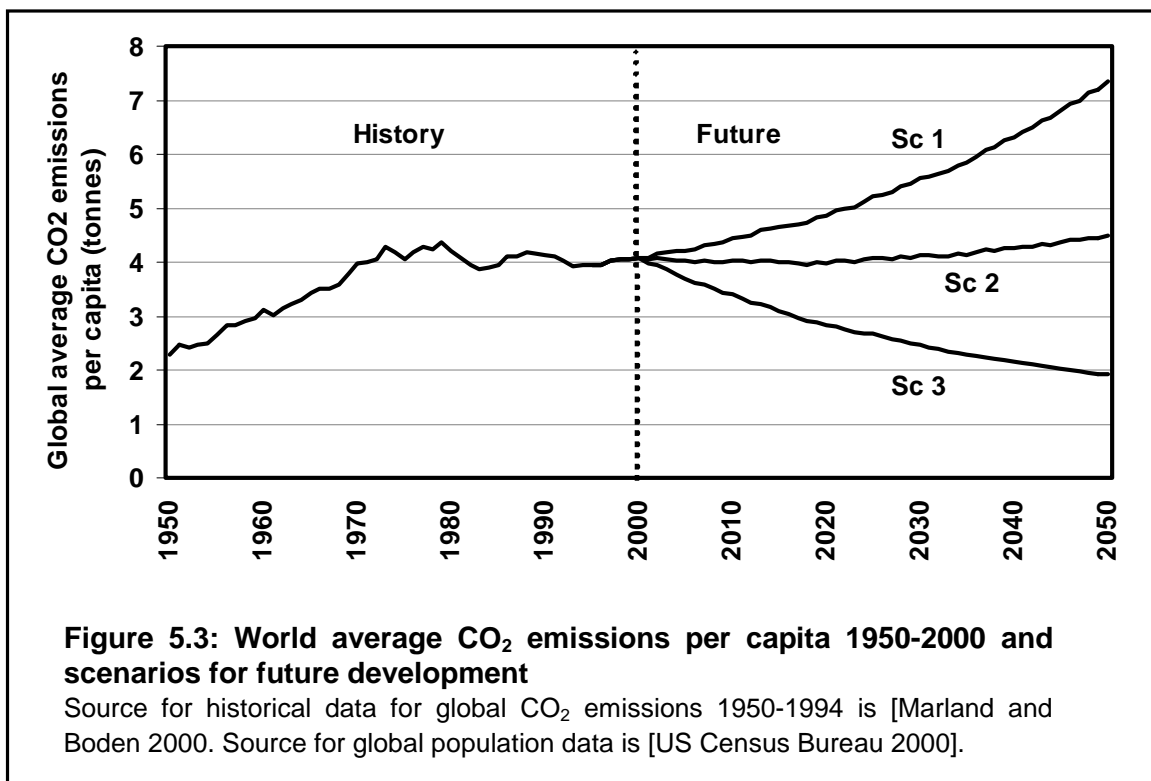
The world's population is currently envisaged to grow from approximately 6 billions today to around 9 billions in 2050 [US Census Bureau 2000]. If taking this population growth into account the reduction goal of scenario 3 in Figure 5.2 seems even more ambitious, as it requires a reduction of some 50 percent of the average current CO_2 emissions per capita on a global scale, see Figure 5.3 (scenario 3). Similarly, a one-percent yearly growth in the global CO_2 emissions requires for a stabilisation of CO_2 emissions per capita (scenario 2, Figure 5.3). A two-percent yearly growth in global CO_2 emissions would allow the average CO_2 emissions per capita to increase to more than seven tonnes in 2050, as compared to 4 tonnes currently (scenario 1, Figure 5.3).

Historically, the industrialised countries have contributed by emitting around 84 percent of the total global accumulated emissions of CO_2 from combustion of fossil sources of energy while developing countries have emitted only 16 percent, see Figure 5.4. In the future it may be that currently developing countries will seek to raise their energy service levels trying to catch up with currently industrialised countries. The biggest challenge seems to be for the industrialised countries to reduce their per capita emissions more than the fifty percent required on average globally by 2050, to allow for currently developing countries to raise their current yearly emissions per capita. Such a development seems to pose radical technical and economical challenges for the currently industrialised countries. For example, the United States, where the average American citizen emits around twenty tonnes of CO_2 per year, would have to cut emissions by around 90 percent if that country is to reach the global average needed in 2050 of around 2 tonnes of CO_2.

Figure 5.4: Accumulated shares of CO$_2$ emissions from combustion of fossil sources of energy 1800-1988 for different regions of the world
Source: [Nakicenovic 1993].
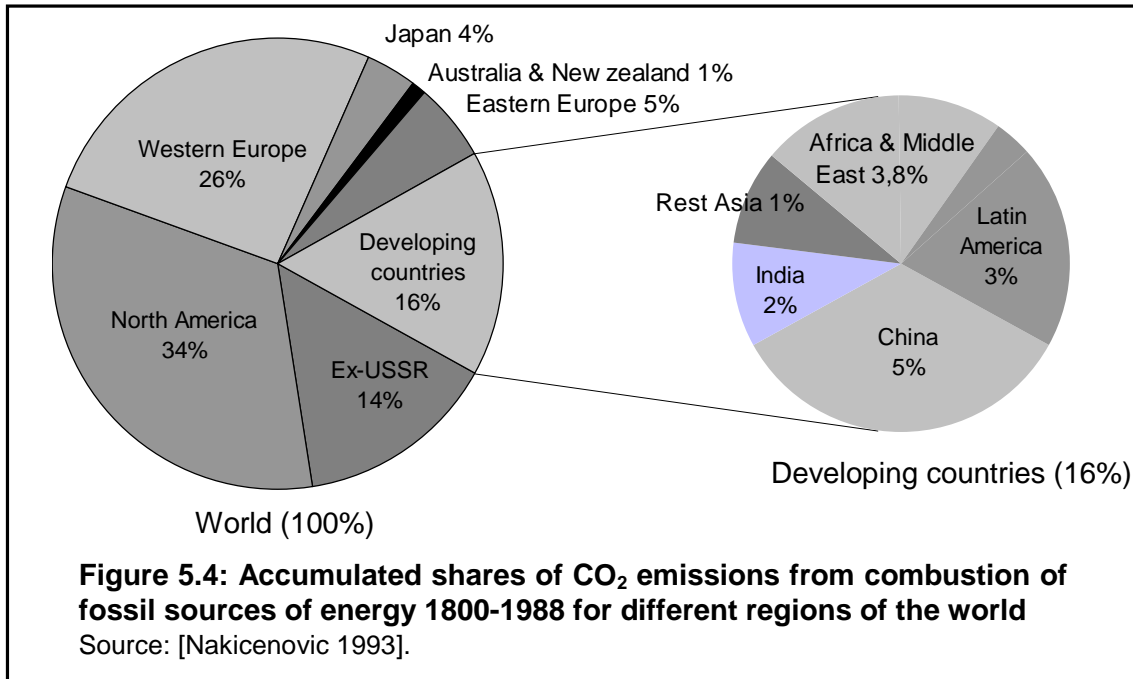
A reduction of the CO$_2$ emissions per capita in the industrialised countries in the order of magnitude described above could be achieved in many ways, but acquires major changes in the ways we produce and consume energy. First of all, the end-use conversion of useable energy into energy services can be much more efficient than what is currently the case, and would acquire for a substitution of the current electrical appliances, houses, cars, trains, aircraft etc. by much more energy-efficient models. Secondly, the energy losses in extraction and conversion of primary energy into secondary energy could be reduced. Some main examples would be the substitution of condensing power plants by combined heat and power (CHP) production plants and the use of electrical engines for transportation purposes in stead of internal combustion engines. Thirdly, less GHG intensive sources of primary energy, such as biomass, renewables and nuclear energy, could substitute fossil fuels, or emissions of CO$_2$ from combustion of fossil fuels could be removed from the stack gases and pumped into underground caverns or into the deep sea to avoid emissions into the atmosphere. Fourthly, the industrialised countries could consider reducing their energy service levels, or at least try to reduce the growth in the most energy intensive types of activities. One such energy intensive activity being commercial civil air transport.

5.1.1 Example of a sustainable energy system

A number of studies have shown that, at least technically, it may be feasible to reduce the CO_2 emissions of industrialised countries by more than 80 percent within the next fifty years. A short summary of one such study for the European Union (current 15 countries) energy system is given in Figures 5.5 and 5.6.

Fair market scenario for the energy system of the European Union (15 members) in 2050 (TWh/y)

Primary energy | Biomass conversion and storage cycles for electricity from renewable energy | Storage and transmission losses | Energy conversion by CHP and heat pumps | Demand/ energy quality | End use

Solar thermal heat — 387
Biogas — 258
Biomass residues — 384
Biomass from plantations — 2117
PV electricity — 699
On-shore wind electricity — 573
Offshore wind electricity — 610
Hydro power electricity — 269
Add. small hydro power el. — 222
Solar thermal electricity — 421
Oil for aircraft and ships — 540
Non-energy uses — 1013
Environmental heat — 269
Total primary — 7762
% fossil — 20%

Gasification/Biomass to hydrogen — 1877 | 939
Methanol plant — 623 | 274
Reversible fuel cells hydrogen input — 671 | 602; Heat 189; Electricity 413
Reversible fuel cells electricity input — 1397 | 1254

District heat pipeline — 398 | 299
Gas store/pipeline — 258 | 219
Hydrogen store/pipeline — 2149 | 1827
Solar heat storage space heat — 325 | 196
Solar heat storage hot water — 62 | 45
Electric grid — 2137 | 2019
Car batteries — 911 | 455

CHP using hydrogen — 418 | 335; Heat 209; Electricity 125
Heat pumps — 90 | 359

Industry
Heat pumps 45 | Electricity 384
Add low temp 65 | Fuels 924
Electricity 384
Hydrogen/gas 814

Households
Solar heat 241 | Electricity 318
Heat pumps 185 | Space heating 485
Add. low-T heat 116 | Water heating 57
Electricity 342 | Non-elec.cooking 24

Service sector
Electricity 293
Add low-T heat 117 | Electricity 293
Heat pumps 129 | Other uses 247

Transport sector
Electricity 511
Biogas 180 | Road 911
Methanol 274 | Rail (electricity) 54
Aircraft fuel 493 | Air 493
Ship fuel 87 | Waterways 87

Total 4275 | Total 4275

Hydrogen import 1
Electricity import 204

Figure 5.5: Proposed energy system for the European Union (current 15 countries) in 2050 based mainly on renewable primary sources of energy and use of advanced efficiency end-use technologies
Source: [Nielsen and Sørensen 1998].

Figure 5.5 illustrates the composition of a proposed future energy system for the fifteen European Union countries that has been proposed by Nielsen and Sørensen [1998]. The future energy system combines a number of renewable energy production technologies such as hydro dams, wind turbines, photovoltaics, solar thermal electric plants and solar thermal heat collectors with electrical heat pumps utilising the environmental heat of the surroundings and CHP stations fired mainly by residues, traditional biomass residues and biomass from large-scale energy-crop plantations and energy forests. Land based transportation is almost entirely based on electric motors, either in battery-electric vehicles or in fuel-cell electric vehicles using hydrogen stored on-board in pressurised fuel tanks or using methanol which is reformed into hydrogen on-board. However, air and ship transport still utilises conventional fossil fuels. The

system also contains an advanced reversible fuel cell system delivering CHP that utilises electricity overload from intermittent renewable sources (wind turbines, photovoltaic panels, solar thermal electric plants) to produce hydrogen which is stored in underground caverns and pressurised tanks. Hydrogen is also stored in buildings, passenger cars, trucks, buses and trains. At times when the electric load is low stored hydrogen is used for CHP production. Other energy storage options in use are vehicle batteries and pumped hydro. Biomass and biogas are used as back-up fuels, and are also used to produce methanol for transportation purposes. Furthermore, the system is based on large bulks of electricity and hydrogen being exported and imported internally between the 15 countries. And Europe as a whole is dependent on some imports of electricity and hydrogen that could be produced for example in sunny Northern Africa, where vast quantities of land could be available for large-scale centralised photovoltaic installations. Finally, the system is based on using advanced efficiency end-use technologies. Examples of such technologies in use in the transport sector are carbon-fibre ultra-light and aerodynamic fuel-cell battery-electric hybrid vehicles and ultra-large low-drag lightweight flying-wing shaped airliners powered by advanced propfan engines. Furthermore, the current electric appliances, motors etc. are considered fully substituted by advanced efficiency versions, and buildings are much better insulated offering substantially better thermal efficiency. The remaining part of the existing building stock has been retrofitted with additional thermal insulation and efficient glazing while new buildings have been built with emphasis on thermal efficiency and passive solar. Also industrial processes are assumed to be more efficient using less raw materials and energy per unit produced.

The energy system described in Figures 5.5 and 5.6 seems technically feasible in a long-term perspective, because the current energy system, as well as many infrastructures and a major part of the end-use technologies will have to be replaced within the next fifty years. But the implementation of such a system will depend much on the willingness of Europe to invest in energy efficiency and renewable energy technologies. The main arguments for building up such a system would be environmental concerns over pollution and global warming and long-term resource issues, such as exhaustion of fossil reserves. The main driver for implementing such a system is anticipated by Nielsen and Sørensen [1998] to be that the price of fossil energy is taxed to a substantial degree as compared to the current situation. This

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would allow the relatively expensive energy producing technologies that are based on renewable types of primary energy to be introduced into the market.

Figure 5.6 shows, from left to right, the flow of energy from primary energy supplies over conversion, storage and transmission to delivered energy and end-use conversion in the proposed energy system. In 1990 the primary energy supply was based primarily on fossil fuels, that is coal, oil and gas, and nuclear and hydro power (the latter two being primary electricity). By 2050 nuclear is assumed to have been phased out in Europe while the main part of the fossil sources have been substituted by renewable sources, that is wind power, solar thermal, solar electric, biomass, hydro and environmental heat (from electrical heat pumps).

Figure 5.6: Overview of European energy system in 1990 and comparison to a scenario for 2050
Source: [Nielsen and Sørensen 1998].
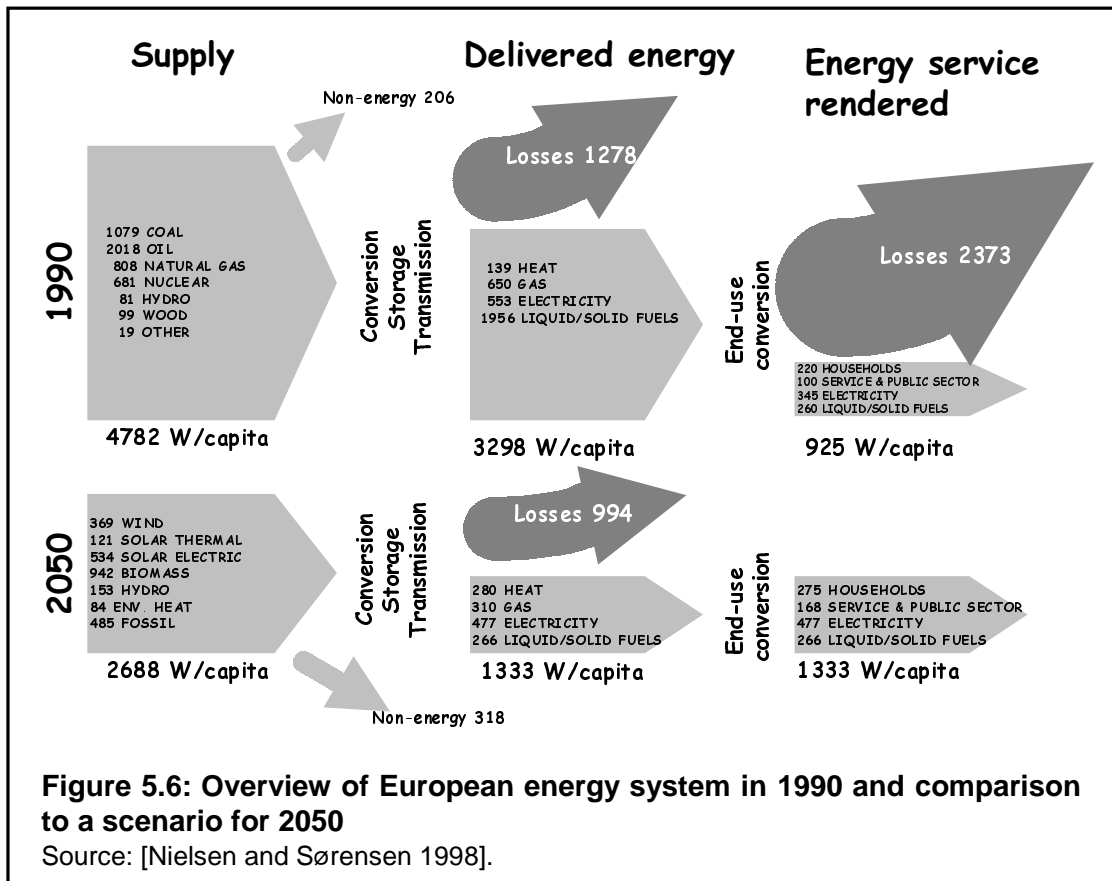
Figure 5.6 illustrates in broad terms the differences between the European energy system in 1990 and the proposed system for 2050. As can be seen from the illustration, the total amount of energy delivered to the consumers has been cut by almost 60 percent even though the end-use energy service level is 44 percent higher than today,

because much more energy efficient end-use technologies are in use. Similarly, the amount of primary energy needed to fulfil those needs is only about 56 percent of what is needed today, mainly because half of the primary electricity produced from renewables is being transmitted directly to consumers without considerable losses. The other part of this electric production is converted into hydrogen that is being stored for later use and thereby incurring some energy losses. Furthermore, the use of renewable sources of energy has allowed for phasing out most uses of fossil fuels.

In the proposed energy system commercial civil air transport still remains one of the few users of fossil fuels, using about 12 percent of the final energy consumption in Europe and 6 percent of the primary consumption, which equals 91 percent of the total remaining fossil uses, excluding non-energy uses. Note that these figures are based on the assumption that the specific fuel intensity of the global aircraft fleet has been reduced by 50 percent as compared to today while Europeans are assumed to only travel three times as much by air as in 1990. Three times more passenger air travel in Europe in 2050 as compared to 1990 is a relatively low figure as compared to what is currently envisaged by the commercial civil air transport industry itself. The latest industry forecast suggests that global passenger air travel might triple already in 2020 as compared to 1999 [Airbus 1999]. If air traffic continues to grow at the current pace in Europe the sector might well consume at least three to five times as much jet fuel in 2050 as what is envisaged in the European scenario suggested here for 2050. Thereby, commercial civil air transport may be using up to more than 50 percent of the total final energy use and up to around 30 percent of the total primary uses.

5.2 Challenges for commercial civil air transport

There seems to be two main challenges for a sustainable commercial civil air transport system, see Figure 5.7. The first major challenge is that passenger air travel and airfreight are growing strongly, when measured in passenger kilometres and freight tonne kilometres performed. The second major challenge is that the improvements in aircraft technology and operational measures that contribute by reducing the specific emissions per passenger kilometre or freight tonne kilometre are not sufficient to counteract the growth in commercial civil air transport activities. Each of these major challenges will be explained in sections 5.2.1 and 5.2.2 respectively.
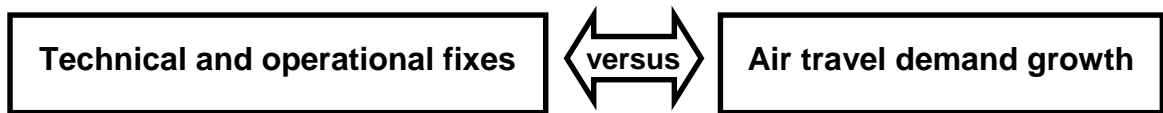
Figure 5.7: The two major challenges for reaching a sustainable commercial civil air transport system

5.2.1 Global air traffic growth versus environmental sustainability

A major challenge for developing a sustainable commercial civil air transport system is the current growth in passenger air travel and airfreight. Figure 5.8 exemplifies the challenges posed to the commercial civil air transport system by growth in passenger air travel. From 1960 to 1998 total passenger air travel, measured in RPKs, increased more than 20-fold from around 131 billions to around 2888 billions, corresponding around 45 RPKs per capita in 1960 and around 490 RPKs per capita in 1996, that is, an 11-fold increase per capita.

Figure 5.8: World passenger air travel 1970-1998 measured in revenue passenger kilometres performed and scenarios for future development
Sources for global RPKs: 1960-1975: [Boeing 1980] and 1976-1998: [IATA 1994 and 1999]. Global population data are from [US Census Bureau 2000]. Industry air travel forecast to 2020 from [Airbus 1999].
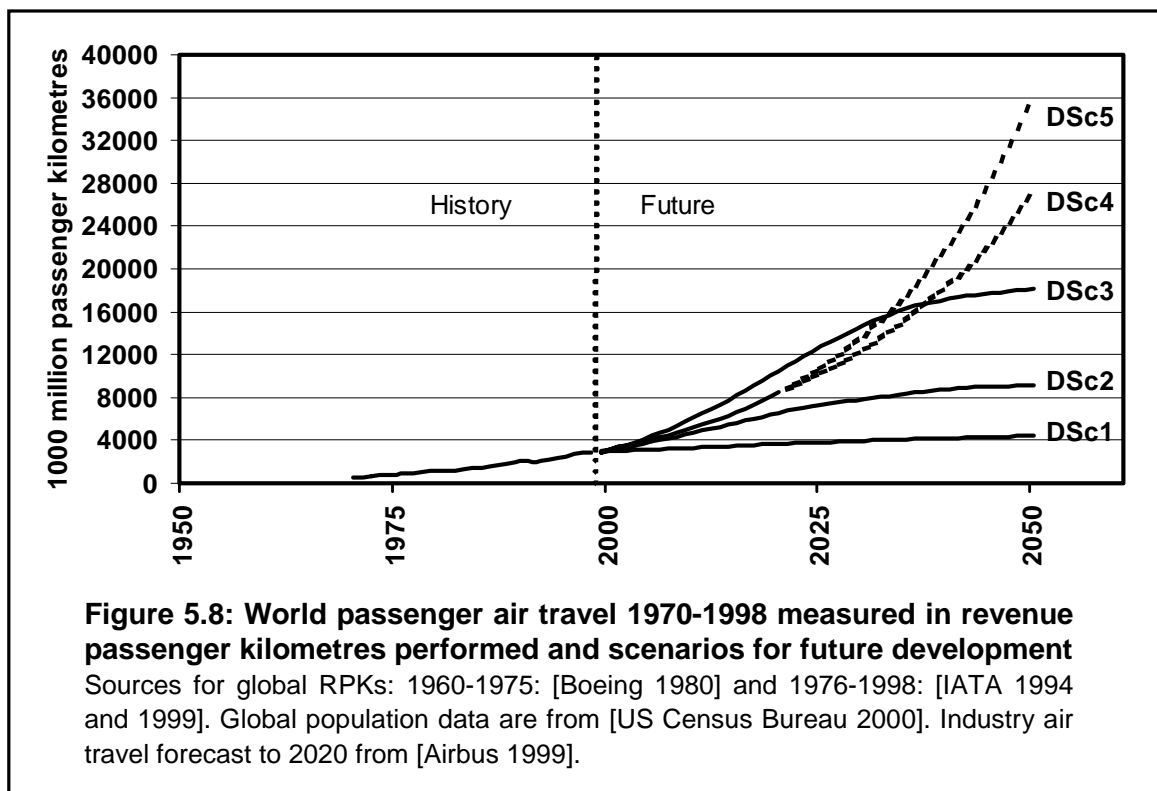
Scenarios four and five in Figure 5.8 are based on a recent aerospace industry forecast predicting that the world's RPKs will grow by 5 percent through the next two decades, thereby leading to a tripling of passenger air travel in 2020. The differences between scenarios four and five is that after 2020 growth is assumed to continue at 5 percent

and 4 percent until 2050 in scenarios five and four respectively, the period after 2020 being shown by dotted lines. In scenarios four and five world passenger air travel has grown nine-fold and twelve-fold in 2050 as compared to 1998. Scenario one illustrates that even if the average per capita passenger air travel in 1996 of around 490 RPKs is "frozen", the anticipated population growth would anyway lead to around 50 percent more passenger air travel. Scenarios two and three illustrate that passenger air travel volume would triple or six-double by 2050, if the average global per capita passenger air travel grows from 490 to 1000 or 2000 kilometres respectively. Even 2000 kilometres per capita, leading to a 6-fold increase in the global passenger air travel, is less than the amount of air travel in some industrialised countries today (e.g. the United States and Australia).

Currently, people living in industrialised countries perform the main share of the world's passenger air travel and airfreight. As indicated in Figure 5.9, airlines situated in North America, Europe and the Asia-Pacific regions performed around 90 percent of the world's revenue passenger kilometres (RPKs) in 1996. Therefore, on the longer term, the prospects for passenger air travel growth seem almost insatiable, if people living in developing countries begin flying more.

Figure 5.9: World air travel by geographical region 1975 and 1996
Sources: [ICAO 1986 and 1996a].
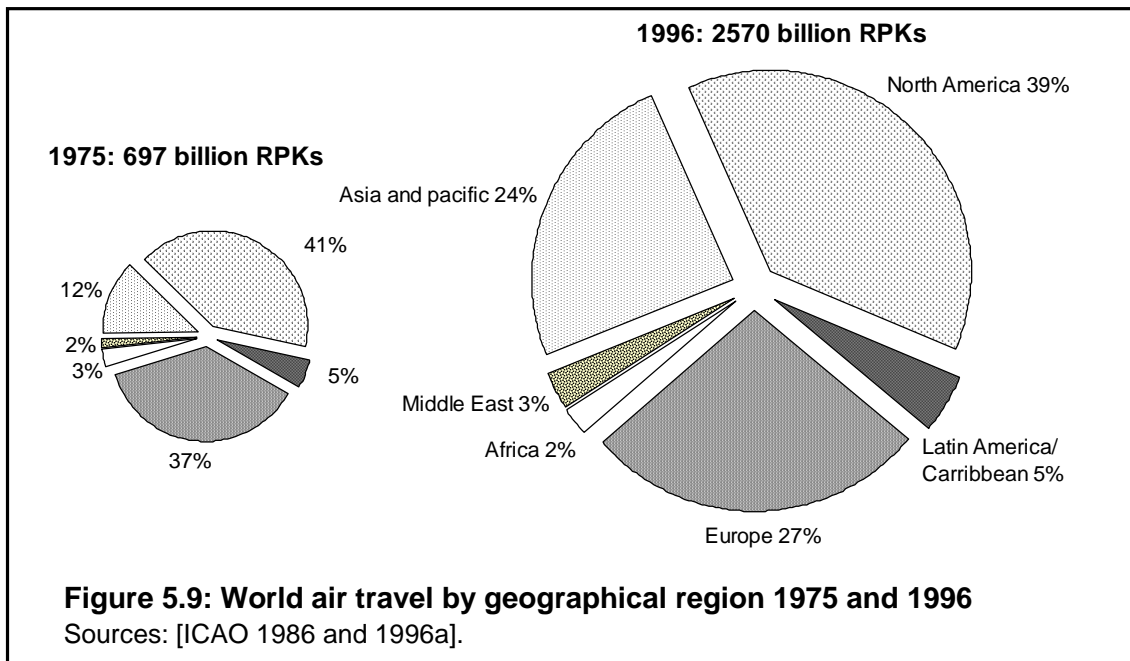
Before being able to suggest what may be adequate goals for the future level of air traffic volume in an environmentally sustainable commercial civil air transport system it

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will be necessary to evaluate to which extent the specific GHG emissions per passenger- and freight-tonne kilometre can be reduced in the future.

5.2.2 Technical and operational fixes versus growth

A major challenge for the commercial civil air transport system is to try to de-couple the growth in GHG emissions from the growth in air traffic volume by reducing the specific greenhouse gas emissions per passenger kilometre and per freight tonne kilometre performed. First of all, the specific GHG intensity per capacity unit of the aircraft fleet can be reduced by introducing more efficient new aircraft and by scrapping the oldest and most inefficient models. Secondly, improvements in operational procedures, such as improving average load factors and reducing stacking above airports can reduce the specific GHG intensity of the aircraft fleet. Finally, choosing fuel with lower GHG emissions per available energy unit than current fossil jet fuel can reduce emissions per distance travelled (see Figure 1.2). An example could be a switch from kerosene to liquid hydrogen fuelled aircraft.

As shown in Figure 5.10 the global aircraft fleet's specific CO_2 emissions per passenger kilometre performed has been reduced substantially since the 1970s. However, the fuel efficiency gains have been levelling off in the last decades as compared to earlier (see also Figure 3.3). The tendency for the fuel efficiency gains to slow down is expected to continue in the future. As an example, the European Aerospace Industry envisages that the yearly reductions in the European fleet's specific CO_2 emissions will not exceed 1,1 percent throughout the next decade [AEA and AECMA 1999].

Scenarios for the future specific CO_2 emissions of the world fleet until 2050 are illustrated in Figure 5.10. The scenarios are based on yearly reductions of the fuel intensity of 1,1 percent throughout the period in specific fuel scenario 1 (SFSc1); and starting at 2 percent and thereafter gradually levelling off to less than a half percent by the end of the period in specific fuel scenario 2 (SFSc2); and 2 percent throughout the period in specific fuel scenario 3 (SFSc3) respectively. The average fuel-burn per passenger kilometre is reduced by 43 percent in scenario one (SFSc1), by 46 percent in scenario two (SFSc2) and by 64 percent in scenario three (SFSc3). SFSc1 illustrates a business as usual development in Europe but is probably rather conservative if considering the global fleet. SFSc2 represents a more rapid introduction of new

advanced technology aircraft and improved operational procedures in line with what is anticipated by the IPCC in its central forecast for the global fleet for the next two decades. SFSc3 probably represents a minimum for what is technologically achievable concerning fuel intensity reduction.

Figure 5.10: Specific CO_2 emissions per revenue passenger kilometre (RPK) of the world civil passenger aircraft fleet and scenarios for the future
Source for historic specific fuel burn is chapter 3.
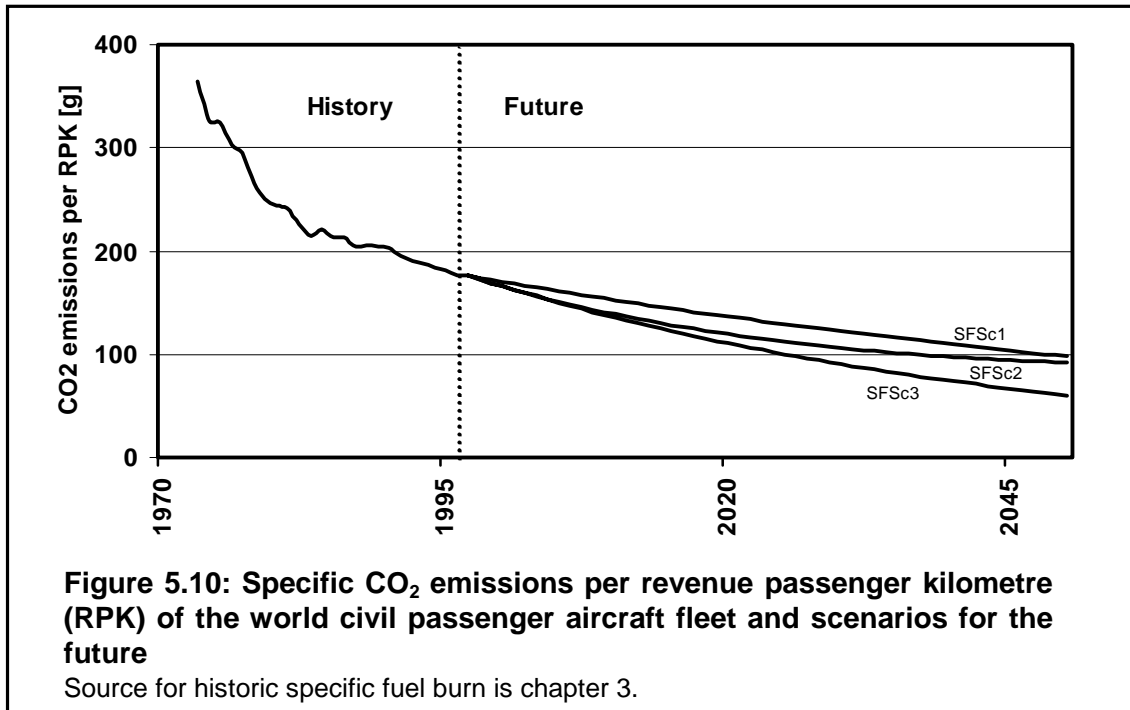
Figure 5.11 illustrates some scenarios for the world's civil aircraft fleet's future CO_2 emissions as compared to 1999. These scenarios combine the demand scenarios for passenger air travel that are illustrated in Figure 5.9 with the scenarios for the specific CO_2 emissions that are shown in Figure 5.10 and exemplifies the dominant role commercial civil air transport might possibly come to play in a future sustainable energy system. The thick curves in Figure 5.11 illustrate demand scenario five (DSc5) combined with specific CO_2 scenarios one (SFSc1), two (SFSc2) and three (SFSc3). This is meant to illustrate that if the air traffic volume grows by a factor of twelve, while the specific CO_2 emissions are reduced by 43 percent, 46 percent and 64 percent respectively, the CO_2 emissions from the world's civil aircraft fleet will grow by factors of 7.1, 6.8 and 4.5 respectively. Demand scenarios one (DSc1), two (DSc2), and four (DSc4) are only shown in combination with specific CO_2 emission scenario one (SFSc1). Demand scenario three (DSc3) is combined with scenarios one (SFSc1) and two (SFSc2) for specific CO_2 emissions. Among the scenarios shown here only the

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combination DSc1 * SFSc1 allows for reduced yearly CO_2 emissions from commercial civil air transport in 2050 as compared to 1999. This is under the assumption that air traffic volume per capita is kept constant at the 1996 level, while the specific CO_2 emissions are reduced by some 43 percent.

Figure 5.11: Scenarios for future CO$_2$ emissions from world civil aircraft fleet until 2050 (index 1999=1)
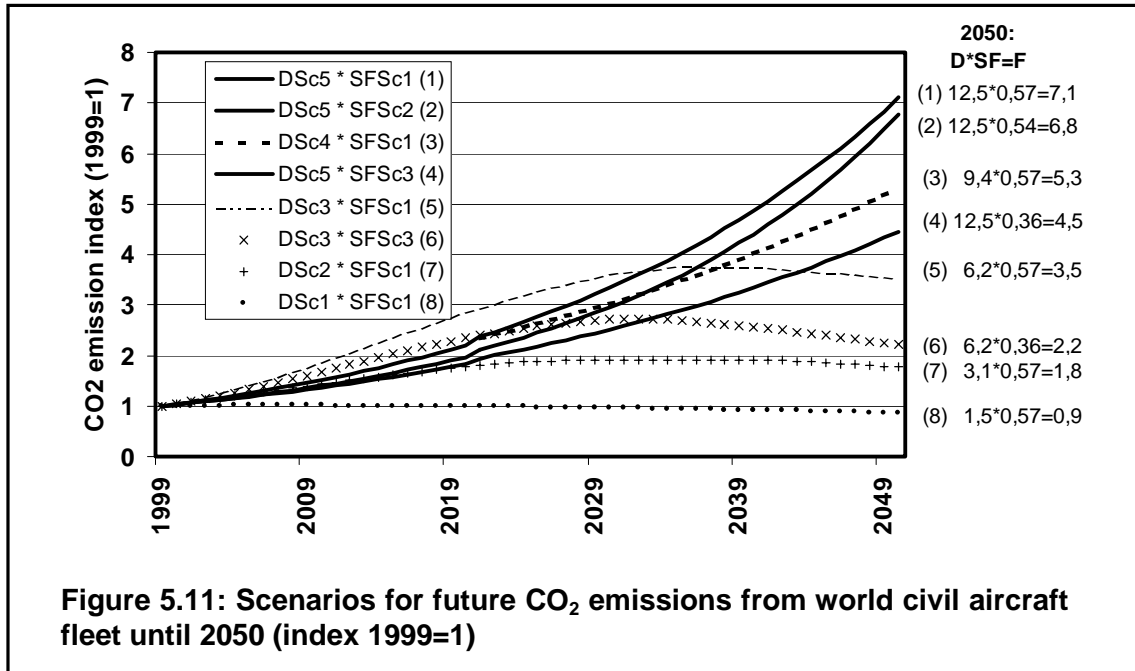
5.3. Proposal for a long-term sustainability target for civil air transport

On the basis of the information presented on the fuel intensity of passenger air travel in chapter 3 this section discusses the CO_2 emissions and the total greenhouse gas emissions from air traffic in relation to the total energy consumption and related emissions of greenhouse gases on a per capita basis.

Figure 5.12 exemplifies the GHG emissions from passenger air travel, measured as tonnes of CO_2-equivalent, according to the distance travelled under the assumption that the CO_2 emissions from aircraft engines contribute with 37%[7] of the overall positive radiative forcing affected by all aircraft emissions[8]. The upper curve in Figure 5.12

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[7] Aircraft pollutants emitted at high altitudes may contribute 2-4 times as much to global warming than CO_2 alone, although there are considerable uncertainties connected to current knowledge on global warming impacts [IPCC 1999].

[8] Assumptions used in figure 5.12: Based on an estimated fuel use per revenue passenger kilometre of 55g [Gardner et. al. 1998] corresponding 173g CO_2 in 1992. This figure includes the fuel that is attributable to freight. Furthermore, the figure is based on the assumption that CO_2 only contributes with 37% [IPCC 1999] of the total positive radiative forcing affected by aircraft

suggests the amount of GHG emissions when flying at airline operations at the average GHG intensity in 1992 (including the fuel that is attributable to freight), and thereby suggests how much GHGs would be emitted to the atmosphere if flying a certain distance. The lower curve represents a scenario for how much GHGs may be emitted in 2050, based on the assumption that the average GHG intensity of the global aircraft fleet is halved as compared to 1992[9].

Figure 5.12: GHG emissions from passenger air travel by distance in comparison to global per capita CO_2 emissions and sustainability targets
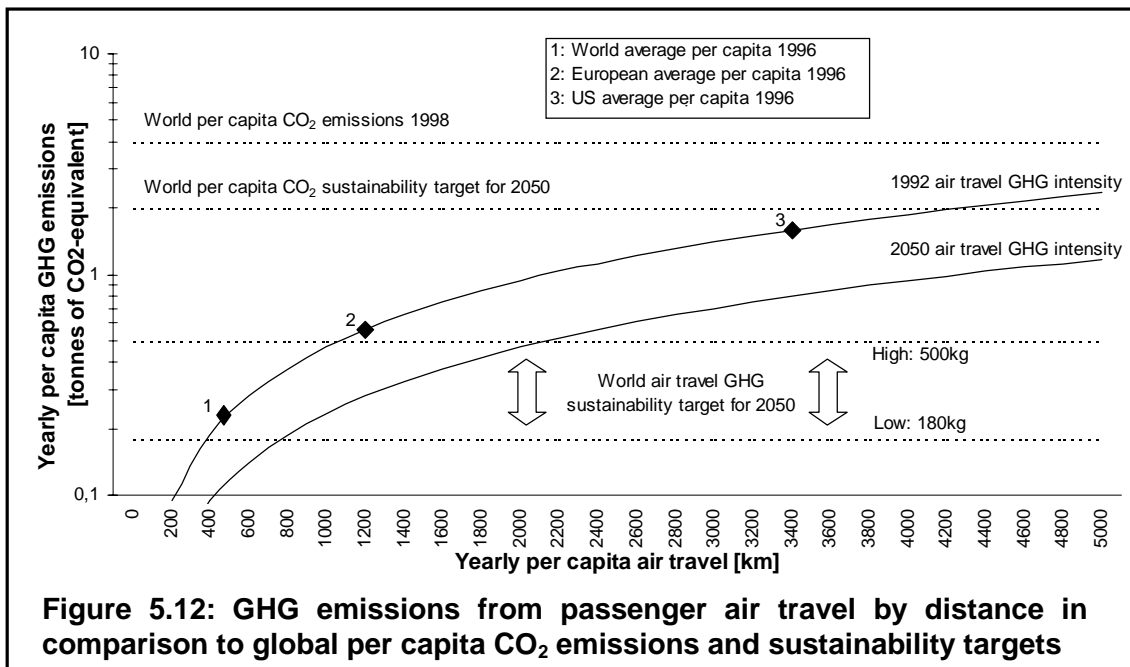
The two curves for GHG emissions from passenger air travel according to the distance flown in 1992 and 2050 shown in Figure 5.12 are compared to the average global per capita CO_2 emissions in 1998 of around 4 tonnes. Furthermore the curves are compared to a world per capita sustainability target for CO_2 emissions from combustion of fossil fuels in 2050 of around 2 tonnes. This sustainability target is based on the assumption that the current global CO_2 emissions may have to be reduced by 30 percent by the middle of this century, and distributed evenly among an expected 9 billion inhabitants (see scenario 3, Figures 5.2 and 5.3). Finally, the two curves in Figure 5.12 are compared to two suggestions for sustainability targets for passenger air travel GHG emissions in 2050 of 180 kg and 500 kg of CO_2-equivalent respectively.

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emissions, leading to the assumption that the 1992 global aircraft fleet emit 468g CO_2-equivalent per revenue passenger kilometre on average. We note that there is considerable uncertainty connected to current knowledge on the contribution of aircraft emissions to global warming [IPCC 1999].

[9] We note that there is considerable uncertainty connected to estimating the future greenhouse gas intensity of air travel.

These suggested sustainability targets for passenger air travel GHG emissions are based on the simple assumptions that passenger air travels' future contribution to the total emissions of greenhouse gases (measured in CO_2-equivalent) should not exceed 9% and 25% respectively of the global per capita CO_2 sustainability target of 2 tonnes. We note that these assumptions are made by the author of this report and are merely suggested for use in a political discussion of how much greenhouse gases commercial civil air transport may be allowed to emit in an environmentally sustainable energy system. In principle, commercial civil air transport can be allowed to emit any share of the GHG emissions from combustion of fossil fuels, but the higher the share the more emphasis will have to be made to reduce GHG emissions elsewhere in the energy system. Because aircraft emissions at high altitude may contribute considerable more to global warming than emissions at ground level, any increase in aircraft fuel consumption would have to be met by a comparatively higher reduction of the fuel consumption at ground level.

Point 1 at the upper curve in Figure 5.12 illustrates that the current global per capita passenger air travel at little less than 500 revenue passenger kilometres (RPKs) leads to emissions of around 230 kilograms of CO_2-equivalent per capita (85 kilograms of CO_2). This already exceeds the low sustainability target, but is well below the 500-kilo high sustainability target for passenger air travel GHGs. Point 2 at the upper curve illustrates that Europeans currently travelling on average around 1200[10] RPKs per capita per year emit around 560 kilograms of CO_2-equivalent (207 kilograms of CO_2). Point 3 at the upper curve illustrates that US citizens travel around 3400[11] RPKs per capita per year emitting around 1,6 tonnes of CO_2-equivalent (592 kilograms of CO_2). That is, the GHG emissions from passenger air travel of average Europeans and Americans may already today exceed the high sustainability target suggested here for GHG emissions from passenger air travel in 2050.

Figure 5.12 also suggests that even if the global aircraft fleets' GHG intensity would be cut in half within the next fifty years the average level of passenger air travel performed

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[10] Note that this figure is based on RPKs performed by airlines situated in Europe. These airlines also transport passengers of other nationalities. Likewise Europeans can travel with airlines situated in other parts of the world, and the figure is therefore a rough estimate.

[11] Note that this figure is based on RPKs performed by airlines situated in the United States, and the figure is therefore a rough estimate connected with a rather high uncertainty, see footnote above.

by American citizens today on a yearly basis would not be allowed within the high sustainability target. Rather, the high sustainability target only allows each person to travel around 2100 kilometres by air in 2050, while the low target allows each person to fly around 800 kilometres per year. That is, the current average global level of passenger air travel per capita may be within the low sustainability target for 2050, whereas the current European level may be within the high sustainability target. We note that these estimates are highly uncertain. One of the major uncertainties is connected to the estimate of the greenhouse gas equivalents. First of all, there is uncertainty about the impact of NO_x and water vapour on climate change. Secondly, if the climate impact of high-altitude emissions is considered severe, the aircraft could be designed to cruise at lower altitude, thereby reducing the impact. Therefore, if the sustainability targets were set to only consider the emissions of for example CO_2, the yearly allowable limits would be almost three times as high as what is being suggested by Figure 5.12.

Conclusions and recommendations

♦ **How energy intensive and GHG intensive is air travel and freight?**

The specific consumption of jet fuel per revenue passenger kilometre and per revenue freight tonne kilometre has been found to vary much between different types of aircraft. Old aircraft are typically more fuel intensive than newer types and aircraft used at short-haul are generally significantly more energy intensive than those used on medium-haul and long haul. For example, the energy consumption on short haul often exceed 80g of jet fuel per passenger kilometre and 500g per revenue freight tonne kilometre while on long haul these figures are most often below 50g and 270g respectively. However, for long haul passenger aircraft the specific fuel consumption per passenger kilometre and per revenue tonne kilometre depend much on the method used for allocating the fuel consumption to passengers and cargo respectively. For instance, the fuel consumption per aircraft kilometre flown by a B747-400 is typically around 12,5-13 kilograms per kilometre. At typical passenger load factors and freight loads the fuel consumption per revenue passenger kilometre is around 46-48g if all the fuel is attributed to passenger transport. However, if distributing the fuel consumption on an equal weight basis between the weight of passengers and freight respectively, this figure is reduced to around 31-35g per revenue passenger kilometre, while the fuel consumption per revenue freight tonne kilometre is around 315-349g. The most fuel-efficient medium-haul and long haul passenger aircraft use less than 20g per revenue passenger kilometre while the most fuel-efficient long-range all-freight aircraft use around 160g per revenue freight tonne kilometre.

The airlines studied in this report estimate their average yearly fuel intensity per revenue passenger kilometre and per freight tonne kilometre at around between 26-81g and 210-237g of jet fuel respectively. The deviations in airlines' average fuel intensity can be explained mainly by differences in the types of aircraft used as well as differences in route structures and passenger load factors and freight load factors as well as differences in methodologies for calculating the specific fuel consumption (especially the allocation of fuel between passengers and freight seems to be of importance). Among the airlines studied in this report European charter carriers are the

ones using the least amount of jet fuel per revenue passenger kilometre. Thus, currently European charter air travel seems to be the most fuel-efficient way of travelling by air. Conversely, commuter- and regional airlines are the most fuel-intensive.

Our analysis of the American air carriers indicates that the average CO_2 intensity of passenger air travel in the US (including belly-hold freight but excluding all-cargo) in 1999 is around 154g of CO_2 per revenue passenger kilometre. If also subtracting the fuel used for transporting cargo (on an equal weight basis) this figure is reduced to around 127g of CO_2. For comparison, the average American passenger car emits around 272g of CO_2 per vehicle kilometre. The most fuel-efficient European charter airlines emit less than 80g of CO_2 per passenger kilometre, and are thereby more fuel-efficient than an average Danish passenger car with two occupants emitting around 89g of CO_2 per passenger kilometre. On the other hand the least fuel-intensive diesel car currently available on the market (VW LUPO 3L) emits around 80g of CO_2 per vehicle kilometre and is therefore significantly more fuel-efficient than charter aircraft when the car transport more than one person. However, a comparison between cars and aircraft over short distances is more realistic if using the fuel-intensity of small turboprop aircraft that are typically used on short-haul routes. Such aircraft typically emit around 250g of CO_2 per revenue passenger kilometre. It should be noted that such comparisons between cars and aircraft are complicated by all the parameters connected to calculations. Some main examples are the differences in actual distances between destinations (aircraft fly more direct routings than cars), differences in passenger load factors (for aircraft this is further complicated by freight load factors), differences in the fuel-intensity of different types of vehicles (there are distinct differences in the fuel-intensities of different vehicle models and there are operational differences related to driving cycles of cars and air traffic management for aircraft), etc. Furthermore, comparisons of greenhouse gas emissions from a trip will also have to take into account that aircraft emissions at high altitudes contribute more to global warming than emissions at ground level.

♦ **What role does commercial civil air transport currently play as an energy consumer and a GHG emitter?**

Within the transport sector road transport is by far the most important energy consumer and source of greenhouse gas emissions, but air transport has grown to become the second largest energy consumer with higher annual activity growth rates than road transport. The Intergovernmental Panel on Climate Change (IPCC) estimates that commercial civil air transport emitted approximately 12% of the CO_2 emissions from the transportation sector in 1992 [IPCC 1999, p. 284]. According to the IPCC, current knowledge about commercial civil air transport's overall contribution to climate change suggests that the total positive radiative forcing (warming) effect might be 2-4 times higher than that of CO_2 emissions from aircraft alone [IPCC 1999, p. 7]. Note that a rather large uncertainty is connected to this estimate. In this perspective commercial civil air transport may already today account for not only the 12% of the transport sector's direct CO_2 emissions, but also around 30% of the sectors' total GHG budget. Air traffic is heading for becoming a much bigger source of GHG emissions in the future because air traffic volume currently grows stronger than the fuel-efficiency improvements.

Air travel and freight are relatively fuel-intensive activities as compared to other types of energy services because much fuel can be consumed within a relatively short period of time. One air trip can contribute considerably to the yearly per capita CO_2 emissions. For example, almost half a tonne of jet fuel may be consumed per passenger on a return trip between Copenhagen and New York emitting around one and a half tonnes of CO_2. If also taking account of emissions of NO_x and water vapour the greenhouse gas emission budget, measured in CO_2-equivalent, may correspond to the emission of some four and a half tonnes of CO_2 from sources at sea level. This exceeds the yearly per capita emission of CO_2, related to the combustion of fossil fuels, on a global basis. For comparison, Danes emit around 3 tonnes [Danish Energy Agency 2000] of CO_2 per capita per year from all domestic transportation sources and an average Danish car would have to drive around 26000 kilometres to emit four and a half tonnes of CO_2, corresponding to the GHG budget of the roundtrip Copenhagen-New York.

- **What is the scope for reducing the energy intensity and the GHG intensity of passenger air travel in the future?**

Modern aircraft are considerably more fuel-efficient than older types so if airlines replace old aircraft by current generation and next-generation aircraft models much fuel can be saved. Additional fuel can be saved if load factors are improved. Improvements in operational procedures allowing aircraft to fly more direct routings and easing congestion at airports can also save fuel.

Aircraft producers and airlines are likely to continue introducing more fuel-efficient aircraft. Near-term developments are introduction of ultra-large long-range super-jumbos and derivatives of existing models in the smaller segments. But also in the market segment for regional jets seating from around 30 and up to 120 passengers a number of new models are being introduced. These developments are likely to lead to a further reduction of the average fuel intensity of air travel in the future.

The prospect for introducing ultra-large capacity aircraft is an important development for the average fuel-intensity because large long-haul aircraft consume a rather large share of all jet fuel (around 40% in 1992 [Gardner et. al. 1998]). Airbus' A380-200 is envisaged to burn up to 20 percent less fuel per revenue passenger kilometre than Boeings' B747-400. However, it should be noted that larger aircraft still consume more fuel per aircraft kilometre even though they burn less fuel per seat kilometre. Introduction of new more efficient aircraft adds to the rebound effect, that is by introducing large-capacity fuel-efficient jets airlines can operate at lower operating costs per seat kilometre offered, lowering airfares thereby spurring additional demand. Airlines furthermore have the incentive to sell a larger proportion of tickets at discount prices to fill up those larger aircraft.

On the longer term the Intergovernmental Panel on Climate Change estimates that new aircraft may be 30-40 percent less fuel intensive by the middle of this century [IPCC 1999]. The fuel intensity of new aircraft could probably be reduced even further if governments push for aircraft producers to develop radically new types of aircraft shapes, such as blended wing body aircraft [Cranfield College of Aeronautics 2000a], and radically more efficient types of engines, such as propfans [Dings et. al. 2000b]. Also on the longer term the reduction in GHG intensity could be reduced even further if hydrogen or synthetic jet fuel produced from biomass or renewable sources of primary

energy substitutes fossil kerosene and if aircraft are designed for cruising at lower altitude. However, there is large uncertainty connected to current estimates of the climate impact associated with water vapour emitted at high altitude when burning hydrogen, and the environmental acceptability of hydrogen as an aviation fuel is therefore uncertain at present [Marquart et. al. 2001]. Likewise, the introduction of propfans may increase noise levels [Dings et. al. 2000b].

The future fuel intensity of air travel and freight is difficult to forecast. The yearly reductions in fuel intensity will depend on the pace of introducing new aircraft and the phasing out of old aircraft. The pace of introducing new aircraft depends much on air travel growth and the pace of scrapping old aircraft. The pace of scrapping old aircraft can be speeded up in the future by fuel price increases and the possible emergence of environmental charges such as taxes on in-flight emissions or fuel tax. Furthermore, other measures such as voluntary agreements with airlines on yearly fuel efficiency improvements or scrapping schemes could come to play a role. However, none of these measures have yet been implemented at a larger scale.

The future fuel intensity will to some extent depend on airline preferences for speed over fuel efficiency. In the short-haul market turboprops are currently to some extent being substituted by new regional jets that offer higher speed but are also more fuel-intensive than turboprops. If regional airlines and aircraft producers favoured development of new advanced types of turboprops instead of high-speed regional jets the fuel-intensity could be reduced. Boeing's suggestion to introduce a family of sonic cruisers cruising at high altitude near the speed of sound is the latest development in the quest for higher speed. If sonic cruisers or even a new generation of supersonic airliners become widely used they will tend to impede the future reduction in the average fuel intensity of air travel. However, it should be noted that actual fuel consumption data for the still on the drawing board sonic cruiser has not been published at the time of writing this report.

♦ **What role may commercial civil air transport come to play in the future energy system?**

CO_2 emissions from commercial civil air transport are likely to grow considerably in the future. Air travel growth and technological innovation will be the main determinants of the future development in the environmental impact. In a "business as usual" scenario

for the development of the future energy system commercial civil air transport is likely to become a much larger source of GHG emissions than today. But the sector may still not become one of the biggest sources, if energy consumption and the related GHG emissions continues rising also in the other sectors. However, if the rest of the energy system develops in an environmentally sustainable direction the GHG emissions from commercial civil air transport may become a relatively large source. Growth in passenger air travel and airfreight can thereby become a major obstacle to the development of a sustainable energy system, increasing the pressure on the other sectors to reduce emissions.

- **What may be required for achieving sustainable commercial civil air transport?**

There is no common agreement as to what environmental sustainability means. This project assesses possibilities to reduce GHG emissions from commercial civil air transport. In this respect, inspired by scenarios for the future global CO_2 emissions and the resulting CO_2 concentration in the atmosphere developed by the IPCC, a proposal for an environmental sustainability target has been defined in this project. The target aims at reducing global CO_2 emissions from combustion of fossil fuels by 30 percent by the middle of this century (as compared to 2000). Furthermore, inspired by the Brundtland Commission, sustainable development is interpreted to mean that the earth's resources should be allocated more equally between the world's population that is anticipated to grow to around 9 billion inhabitants in the period. Therefore, the sustainability target argued for in this report estimate that current global per capita CO_2 emissions from combustion of fossil fuels of around 4 tonnes should be reduced to around 2 tonnes in 2050. It should be noted that there is no common agreement on this proposed sustainability target, and that the current international debate over the agreement from Kyoto on reducing emissions of greenhouse gases does not indicate that such radical targets can currently be agreed upon by the nations of the World.

The implications of the sustainability target for the whole energy system that is proposed here for commercial civil air transport is not necessarily straightforward. Politicians could decide upon that commercial civil air transport would have to reduce emissions of greenhouse gases in line with the overall goal. It could also be argued that the sector's share of global emissions should be allowed to grow while other sectors would have to reduce their shares, and this seems to be an important political

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discussion for the future. One argument for letting air transport increase it's share of global CO_2 emissions in the future is that it may be technically more difficult and also more expensive to substitute fossil jet fuel by less GHG intensive fuels than it will be to change fuels in for instance domestic households and in the power generating sector.

Two suggestions for sustainability targets for air travel GHG emissions in 2050 of 180 kg and 500 kg of CO_2-equivalent per capita respectively have been proposed in this study. These targets are based on simple assumptions that air travels' future contribution to emissions of greenhouse gases (measured in CO_2-equivalent) should not exceed 9% and 25% respectively of the global per capita CO_2 sustainability target of 2 tonnes. For comparison, commercial civil air transport currently contributes by around 2% of total CO_2 emissions from combustion of fossil fuels, but the share of GHG emissions may be 2-4 times higher because aircraft emissions at high altitude may contribute more to global warming than gases emitted at ground level. It should be noted that the sustainability targets are basically proposals for political discussion. No scientific or political consensus exists in this area.

The current average level of air travel per capita on a global scale is within the high sustainability limit proposed for 2050 in this report, but Europeans and Americans already emit more GHGs than what may be allowable within such a budget. If air travel GHG intensity is reduced by 50 percent by the middle of this century, current global level of air travel per capita may be within the low sustainability target whereas current European air travel volume may be within the limits of the high sustainability target. The high sustainability target allows global air travel volume to grow by around a factor of three within the next fifty years. However, air travel volume is currently growing fast, prognoses from the aeronautical industry envisioning that air travel volume may triple shortly after 2020, and therefore looks set to become a major source of GHGs in the future. Therefore, if the emissions of GHGs are to be reduced according to the sustainability targets proposed here, governments ought to implement measures aimed at reducing air traffic growth and at increasing the incentive of the commercial civil air transport industry to speed up its efforts to reduce the specific emissions of GHGs.

♦ **What drives development of environmentally friendly aircraft, and what could be done to facilitate the introduction of aircraft that emit less GHGs?**

In general, aircraft producers compete to produce the most efficient aircraft, focusing on reducing direct operating costs and emissions and noise while improving performance parameters such as reliability, safety, range, speed, fuel-efficiency, and passenger- and freight capacity. However, there are tradeoffs between these parameters. These tradeoffs make it difficult to put out goals for the development of more environmentally friendly aircraft.

Even though lower cruise speed would lead to higher fuel-efficiency while reducing emissions, this option is not favourable to airlines because of productivity and revenue losses. Likewise, new efficient aircraft technology reduces fuel costs, but are disadvantaged by higher capital costs than mature technology because of the high development costs connected to developing radically new concepts. Currently there is limited incentive for aircraft manufacturers to move ahead to revolutionary designs. Unless fuel price raises dramatically or a substantial tax is added to aircraft engine emissions, there will most likely be more evolution than revolution in aircraft design, because development of new aircraft types is an expensive and risky business. The cost and risk connected to developing new aircraft technologies is a major impeder to development of environmentally friendly aircraft.

Future policies may first of all aim at introducing tax on fuel and emissions to give the airlines and the aircraft producers incentives to introduce more fuel-efficient technologies. Secondly, policies may aim at committing the industry to initiating research and development into long-term future technologies.

♦ **What drives air travel growth?**

The strong growth in air travel is generated by life-style changes. People living in industrialised countries have become accustomed to travel by air. The building up of a large socio-technical system surrounding commercial civil air transport facilitates air travel growth. Airport and aircraft capacity is constantly being enlarged, while the real cost of air travel is reduced. The building up of the socio-technical system is furthered by government subsidies, which again contribute to reduce airfares.

National interests and geopolitics play important roles in the subsidisation of commercial civil air transport's socio-technical system. National governments support local airports, airlines and aerospace industries to maintain and increase the relatively large number of people employed in these industries. Further aspects are the prestige connected to maintaining aeronautical and military leadership as well as the prestige connected to operating national flag carriers. The industry becomes increasingly important for global and local economies.

Market forces contribute to reduce the cost of air travel in that aircraft producers compete to produce the most efficient aircraft at the lowest possible prices while airline competition in an increasingly global and liberalised market contributes to reduce real airfares.

Economic growth policy leads to increasing income in many countries thereby allowing more and more people to travel by air. Today, most air travel is related to leisure, holidays and visiting friends and family. Air travel is an important social status maker and current trends in social values and preferences leads people to travel more often and further away to discover new exotic cultures and resorts.

Globalisation of businesses and the economy in general are major drivers for air travel growth. As businesses, political forums and personal relations become increasingly global the need to communicate over longer distances rises. Business travel is a major driver for air travel growth in the sense that business fares are substantially higher than normal economy fares and discount fares. Business travellers thereby subsidise leisure travellers, by allowing airlines to sell leisure tickets at artificially low fares. This structure is furthered by airline frequent flier programmes and other marketing tools.

- **What effect may a kerosene tax have on the environmental impact of commercial civil air transport?**

The potential environmental effects of a jet fuel tax are difficult to quantify. Some main parameters of crucial importance are future developments in the general economy, airline productivity and airfares, consumer income and consumer preferences for air travel over other modes of consumption. Most fuel tax studies reviewed for this report anticipate quite high growth rates in air travel and freight, mainly basing it on forecasting historical trends. Forecasts are based on the assumptions that continuing

economic growth and increasing income combined with reductions in real airfares will allow such demand increases. Furthermore, studies seem to assume that adequate airport infrastructure will be provided to meet rising demand, being another crucial assumption, considering that it is becoming increasingly difficult for airports to get approvals for enlarging their capacity in many industrialised countries.

The studies reviewed suggest that at current growth rates in air travel and freight a relatively high level of kerosene tax would be needed to stabilise CO_2 emissions from commercial civil air transport. Some studies suggest that a fuel tax of some 80-180 US¢/kg may be adequate, whereas other studies indicate that the tax may have to be even higher. For comparison, EU minimum fuel tax for road diesel fuel is around 30 US¢/kg, but many countries levy much higher tax, up to 87 US¢/kg in United Kingdom. Because aircraft emissions at high altitude contribute more to global warming than emissions at ground level one could argue for applying a higher tax on jet fuel.

A jet fuel tax of some 126 US¢/kg may raise average airline operating costs per revenue passenger kilometre on international flights by some 75%. Fare increases will be proportionally higher in Asia than in North America and Europe and fares will tend to increase considerably more on long haul flights than on medium- and short haul.

As has been suggested in this report a sustainability target for commercial civil air transport may aim at keeping the greenhouse gas emissions related to passenger air travel within a limit of between 124 to 350kg of CO_2-equivalent per capita in 2050. If the average GHG intensity is reduced by some 50% in 2050 global air travel may be allowed to increase by a factor of 3 until 2050 and still remain within the high sustainability target. This would correspond to a yearly growth rate in air travel of some 2,25%, and current level of growth at around 5% per annum would have to be more than halved. Assuming that the demand elasticity estimates used in the fuel tax studies reviewed for this report are correct one would need a fuel tax that raises airfares by some 75%, corresponding a tax level of some 126 US¢/kg. If a lower tax is chosen emissions will most likely surpass the high sustainability target, unless other measures are used to supplement the fuel tax. Note that there is a high level of uncertainty connected to estimating the future impact on air traffic GHG emissions of introducing a fuel tax.

However, in the current political climate, a global kerosene tax seems unlikely to emerge. Rather, ICAO seems to be heading for investigating further the possibility of setting up a scheme for CO_2 emissions trading. This seems to be a long-term solution. Furthermore, such a system is likely to be designed to allow the commercial civil air transport sector to buy emission quotas in other sectors. This will allow air transport to rise further. The environmental NGOs argue that commercial civil air transport ought to reduce its emissions [T&E/ICSA 2001] and that all types of greenhouse gases should be controlled, not only CO_2 [T&E/ICSA 2001] [Lee 2000].

♦ **Which other policies may be used to impede air travel growth?**

The commercial civil air transport sector has until now been exempted from international agreements on GHG reduction. In the future, alternative policies may aim at putting out GHG reduction schemes for the sector. For example, governments may put out regulation on maximum GHG intensity of next-generation aircraft or they could agree upon a definite cap for the amount of emissions that the commercial civil air transport sector can be allowed. Similarly, governments could make agreements with the airlines on reducing specific emissions by purchasing new aircraft and scrapping older models. Adoption of measures, such as voluntary agreements with the industry on energy efficiency, jet fuel tax, emission trading schemes etc., may play an important role in implementing alternative policies. However, if focusing solely on market based measures, such as a jet fuel tax, a rather high tax level would be needed to reduce growth in the environmental impact. It is therefore important to look for other policies to curb the growth in air transport.

Many government policies are today directly aimed at supporting air travel growth. Obvious examples are authorities' approval of expanding airport capacity and policies aimed at subsidising airlines, aircraft production and airports. Such policies are often directly spurred by the wish to maintain and expand the number of work places within the industry. Alternative policies aimed at impeding air travel growth may therefore aim at stopping airport capacity expansion and eliminating direct economic subsidies for the commercial civil air transport sector. Furthermore, the sector is to a large extent exempted from paying tax and VAT. For example, airlines are exempted from paying jet fuel tax. Policies aiming at introducing taxes would impede air travel growth.

Furthermore, many policies support air travel growth indirectly. Obvious examples are policies aimed at maintaining economic growth in society and improving overall productivity. Economic growth in conjunction with productivity improvements leads to rising personal incomes, which again allows people to choose to fly more often. Furthermore, the increasing tendency towards market liberalisation and globalisation of economic, political, and personal relations tends to increase the need of communicating across national borders. Policies aimed at a satiation economy and at limiting globalisation are therefore likely to reduce growth in air travel.

On the shorter term, governments in industrialised countries could try to promote longer lasting but fewer vacation trips. This would to some extent acquire some restructuring of current work patterns. Promoting alternative lifestyles and ways of life might on the longer term reduce air travel growth. If the social status connected to travelling far away diminishes people might choose nearby holiday destinations. Similarly, if people choose a less materialistic approach to life by working less, having more free time available as well as earning less (than what may otherwise have happened), there is clearly potential for change. Governments may also seek to find alternative ways of measuring progress and growth than Gross Domestic Product. This might allow nations to develop in more sustainable directions than when planning mainly to achieve economic growth.

Developing countries may seek in the future to approach the economic and material wealth of industrialised countries, and this may imply economic growth. This, in conjunction with expectations for strong population growth in these regions of the world, may lead to strong growth in air travel. Any policy aimed at limiting population growth may therefore help to reduce air travel growth. Likewise developing countries may choose to implement policies aimed at achieving increasing welfare without focusing on building up a socio-technical system resembling the one that has been built up around commercial civil air transport in industrialised countries.

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Glossary - abbreviations and terms

A300	Airbus medium/long range twinjet wide-bodied airliner took first flight in 1972. The A300B2 seating 250 went into airline service in 1974 and was the world's first wide-body twinjet. A later improved version, the A300-600 went into airline service in 1983
A310	Airbus medium/long range twinjet wide-bodied airliner first delivered in 1982 seating 187-279 passengers
A318	Airbus short/medium-range twinjet narrow-body airliner, shortened version of A320 seating 107-117 passengers. Next-generation aircraft to enter service in 2002
A319	Airbus short/medium-range twinjet narrow-body airliner, shortened version of A320 seating 124-145 passengers. First delivered in 1996
A320	Airbus medium-range twinjet narrow-body airliner seating 150-179 passengers. First delivered in 1988
A321	Airbus medium-range twinjet narrow-body airliner, stretched version of A320 seating 185-200 passengers. First delivered in 1994
A330	Airbus medium/long range twinjet wide-body airliner seating 256-440 passengers. First delivered in 1993
A340	Airbus long-range four-engine wide-body airliner seating 263-440 passengers. First delivered in 1993
A3XX	Next generation double-deck super-jumbo from Airbus later re-named A380. Seating 555-1000 passengers and expected first delivery in 2006
A380	Next generation double-deck super-jumbo from Airbus, formerly known as the A3XX seating 555-1000 passengers and expected first delivery in 2006
AEA	Association of European Airlines. Its members are Adria Airways, Aer Lingus, Air France, Air Malta, Alitalia, Austrian Airlines, Balkan, British Airways, British Midland, Cargolux, Croatia Airlines, CSA, Cyprus Airways, Finnair, Iberia, Icelandair, JAT, KLM, Lufthansa, Luxair, Malev, Olympic Airways, Sabena, SAS, Swissair, TAP Air Portugal and Turkish Airlines.
AECMA	European Association of Aerospace Industries. Its members are the national aerospace associations of all 15 EU member states - Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, The Netherlands, Portugal, Spain, Sweden and the United Kingdom - as well as the largest European aerospace companies.
AIA	Aerospace Industries Association of America
ACI	Airports Council International
AEF	Aviation Environment Federation is an environmental NGO based in the UK which have been co-organising a range of campaigns in Europe aimed at introducing kerosene tax and restricting growth of the environmental impact of aviation

Airbus	The major European producer of large civil aircraft. Produces a varied family of aircraft in the category above 100 seats. Main family consists of A300s, A310s, A320s, A330/A340s and next-generation A380s. Each aircraft family exists in a wide range of derivatives featuring differences in capacity, length, engines, technology and seat-configuration
Aircraft-kilometres	Amount of kilometres travelled by an aircraft
Aircraft movement	An aircraft take-off or landing at an airport
Aircraft utilisation	The average number of block hours an aircraft is in use per time unit, e.g. block hours performed per day
ASK	Available Seat Kilometres - is the number of seats made available for sale in aircraft multiplied by the distance flown by those aircraft
ATAG	Air Transport Action Group
ATK	Available Tonne Kilometres - is the number of tonnes of capacity available for the carriage of revenue load (passengers and cargo) multiplied by the distance flown
ATM	Air traffic management
ATR	European producer of the ATR-42 and ATR-72 turboprops
B707	Boeing's first jet introduced in 1958. A four-engine narrow-body airliner accommodating up to 181 passengers. No longer in production
B717	Boeing short/medium range twinjet narrow-body airliner seating 80-120 passengers. First delivery in 1999
B727	Boeing medium-range tri-engine narrow-body airliner seating 163-189 passengers. First delivered in 1963. No longer in production but still in service
B737	Boeing short/medium-range twinjet narrow-body airliner seating 108-189 passengers. First delivered in 1967. Upgraded several times since then, the newest versions being 737-600s, 737-700s, 737-800s and 737-900s introduced in the late 1990s
B747	Boeing long-range four-engine wide-body half double-deck airliner seating 300-568 passengers. First delivered in 1969. Upgraded several times since then, the newest version being the 747-400 introduced in 1989
B757	Boeing medium-range twin-jet wide-body??? airliner seating 178-289 passengers. First delivered in 1982 in the 757-200 version. In 1999 introduced in the 757-300 version
B767	Boeing medium/long-range twin-jet wide-body airliner seating 224-350 passengers. First delivered in 1981 in the B767-200 version. In 1986 came the B767-300 version and the next-generation B767-400 is expected soon
B777	Boeing long-range twin-jet wide-body airliner seating 305-550 passengers. First delivered in 1994 in the B777-200 version. In 1997 came the B777-300 stretched version
BaE	British Aerospace. The British aircraft manufacturer produce a number of turboprops and regional jets as well as the wings for Airbus' aircraft
Boeing	The major American producer of large civil aircraft. Produces a varied family of aircraft in the category above

	100 seats. Main family consists of B717s, B727s, B737s, B747s, B757s, B767s and B777s. B727s are out of production. The other families exists in a wide range of derivatives featuring differences in capacity, length, engines, technology and seat-configuration
Block speed	Average speed for each flight stage calculated from the block time and stage distance
Block time	Time for each flight stage between the switch on of engines at departure and engine switch off at arrival
Business jets	Smaller jets designed for a relatively low number of passengers
Bypass ratio	Term used to measure the amount of air passing through the aircraft engine core to the amount surpassing the core. High-bypass ratio turbofan engines are generally more fuel-efficient than low-bypass versions
Cabin crew	Refers to stewards and stewardesses
CAEP	Committee on Aviation Environmental Protection (set down by ICAO). Among other things, CAEP has recently reviewed a number of market based measures for reducing the environmental impact of commercial civil air transport. CAEP is composed of experts who are nominated by States, major sectors of the commercial civil air transport industry and an environmental NGO umbrella group. Current members were nominated by Austria, Brazil, Canada, Egypt, France, Germany, Greece, Italy, Japan, the Netherlands, Norway, Poland, Russian Federation, Singapore, South Africa, Spain, Sweden, Switzerland, Tunisia, United Kingdom, United States, Arab Civil Aviation Commission (ACAC), Airports Council International (ACI), the European Commission, the International Air Transport Association (IATA), the International Business Aviation Council (IBAC), the International Coordinating Council of Aerospace Industries Associations (ICCAIA), the International Federation of Air Line Pilots' Associations (IFALPA), the European Federation for Transport and Environment (T&E), the United Nations Framework Convention on Climate Change (UNFCCC) and the World Meteorological Organisation (WMO).
CEC	Commission of the European Communities
Chapter 3 aircraft	Aircraft that meet today's strictest noise certification levels. The first noise certification standard was introduced by ICAO in 1977 and have been tightened since then. All new commercial civil aircraft have to meet the Chapter 3 standard. The permitted values depend on the aircraft's maximum take-off weight and the number of engines. Large aircraft may emit more noise than smaller ones and four-engine aircraft may be noisier than twinjets. In January 2001 CAEP agreed upon a new stricter Chapter 4-noise standard to come into force from 2006.
BWB	Blended Wing Body Aircraft, a proposed radically different future airframe design for a very large civil subsonic airliner with the same capacity as the A3XX double-deck super

	jumbo jet from Airbus. The BWB has the shape of a "flying wing"
CH_4	Methane
Commuter aircraft	Small passenger aircraft used for commuting on short distances.
Concorde	Supersonic passenger aircraft
CO_2	Carbon dioxide
DC-3	Douglas twin-piston-engine airliner introduced in the 1930s
DC-8	Douglas' first passenger jet introduced in the late 1950s
DC-9	Douglas short/medium range twin-jet narrowbody airliner introduced in the 1960s and later upgraded several times. After Douglas' merger with MacDonnell aircraft company the DC-9 was re-named MD-80 and later MD-90 in a stretched version
DC-10	Douglas medium/long range tri-jet wide-body airliner introduced in 1971 and later upgraded several times. After Douglas' merger with MacDonnell aircraft company re-named MD-11 in 1990
Embraer	Brasilian producer of regional turboprops and jets
EBAA	European Business Aviation Association
ECAC	European Civil Aviation Conference
ERA	European Regions Airline Association
Fairchild/Dornier	European producer of a family of regional jets
Flight crew	Refers to the pilot, co-pilot and flight engineer if any
FoE	Friends of the Earth, is an NGO which have been co-organising a range of campaigns in Europe aimed at introducing kerosene tax and restricting growth of the environmental impact of commercial civil air transport
Fokker	Dutch producer of regional turboprops and jets
Freight tonne-kilometre	A metric tonne of freight (or mail) carried one kilometre
Frequent flier programme	A promotional device designed by airlines to encourage customer loyalty whereby customers are given credits for each flight flown with the specific airline who runs the programme. Accumulated credits can for example be used for obtaining free tickets or discounts
GDP	Gross Domestic Product
GHG	Greenhouse gas
HACAN	Heathrow Association for the Control of Aircraft Noise is a local NGO opposing the plans to expend the capacity of Heathrow airport
deHavilland Canada	Canadian producer of regional turboprops and jets
Hub-and-spoke	A hub-and-spoke routing network has a structure resembling the hub and spokes of a bicycle, in which a single airport is the focus of an airline system, as opposed to a linear network in which all airports are directly linked. In a hub-and-spoke network passengers are fed by spoke routes into the hub airport from which they take connecting flights to their next or final destination
IACA	International Air Carrier Association
IPCC	Intergovernmental Panel on Climate Change
IATA	International Air Transport Association is an airline industry organisation and currently represents 275 member airlines.

ICAO	International Civil Aviation Organisation is an intergovernmental organisation operating under the auspices of the UN. Among other things ICAO is engaged in setting environmental standards for aircraft. ICAO currently represents 187 member states.
ICSA	International Coalition for Sustainable Aviation. As of January 2000 the membership of ICSA consists of the Aviation Environment Federation, the Center for Clean Air Policy, the Coalition for Clean Air, the Dutch Society for Nature and Environment (SNM), Friends of the Earth Europe, the German League for Nature and Environment (DNR), Germanwatch, European Federation for Transport and Environment (T&E) and World wildlife Fund (WWF). Greenpeace International is in the process of joining
Jet aircraft	Aircraft equipped with turbojet or turbofan engines
Jet fuel	See kerosene
Kerosene	Jet fuel that is used in jet and turboprop engines is chemically similar to petroleum. When burning one kilogram of kerosene 3,15 kg of CO_2 is emitted as well as 1,24 kg of water vapour. Emissions of NOx depends on the engine type in use. One litre of kerosene weighs approximately 0,8 kg
kg	Kilogram
km	Kilometre
L-1011	Lockheed medium range wide-body tri-jet seating 256-400 passengers. First delivered in 1972
Lockheed	Major American producer of large civil aircraft, which has stopped producing civil aircraft. Some of Lockheed's civil jets are still in use, notably the tri-jet L1011 Tristar
Long-haul	Long-distance flights
MacDonnell Douglas	Major American producer of large civil aircraft which has recently been acquired by Boeing. A range of aircraft from Macdonnell Douglas are still in use for civil passenger transportation, notably DC8s, DC9s, DC10s, MD80s, MD90s and MD11s.
Mach	Speed of sound
MD-80s	MacDonnell Douglas short/medium range twin-jet narrowbody airliner. An updated version of Douglas' DC9. The MD-81 first delivered in 1979. Later upgrades are MD-82, MD-83, MD-87 and MD-88.
MD-90	MacDonnell Douglas Short/medium range twin-jet narrowbody airliner, stretched MD-80 follow-on seating up to 172 passengers. First delivered in 1993
MD-11	MacDonnell Douglas medium/long-range three-engine wide-body airliner, DC-10 follow-on, seating 250-410 passengers. First delivered in 1990
Non-scheduled carrier	Air transport operator that offers air transport service to the public on a non-scheduled basis only
NO_x	Nitrogen oxides
Operating expenses	A type of financial measure, typically given as operating expenses per traffic unit, for instance as operating expenses per ASK, ATK, RPK or RTK.

Operating revenue	A type of financial measure, typically given as operating revenue per traffic unit, for instance as operating revenue per ASK, ATK, RPK or RTK.
Passenger kilometre	Unit measuring the amount of people transported multiplied by the amount of kilometres travelled
Passenger load factor	The passenger load factor is calculated as the ratio between the number of passengers carried to the number of seats made available for sale
Piston aircraft	Aircraft powered by piston engine
Propfan	Advanced type of turboprop engine that could substitute current turbofan engines. Its tractor is more efficient than blades on a turbofan due to it's high bypass ratio. Due to perceived safety problems combined with high noise levels and probably also high maintenance costs the propfan engine is not yet in use. Sometimes also named UDF unducted fan engine
Regional jets	Jet powered aircraft in the size categories below approximately 100 seats
RPK	Revenue Passenger Kilometres - is the number of passengers (paying at least 25% of normal applicable fare) multiplied by the distance flown in kilometres
RTK	Revenue Tonne Kilometres - is the revenue load (passengers and cargo) in tonnes multiplied by the distance flown in kilometres
Saab 340	Regional twin-turboprop airliner from the mid-1980s
Saab 2000	Regional twin-turboprop airliner from the early 1990s
SBSTA	United Nations Framework Convention on Climate Change's Subsidiary Body for Scientific and Technological Advice
Seat configuration	There can be different seat configurations in an aircraft. The number of seats per aircraft is dependent on configuration of seats in classes. In all-economy class configuration there are more seats than in configurations with business class and first class seats that take up more space
Seat kilometre	Unit measuring the amount of seats made available in a vehicle multiplied by the amount of kilometres the vehicle travels
Stratosphere	Layer of air above the troposphere at altitudes of about 12 to 50 kilometres. The troposphere and the stratosphere are separated by the so-called tropopause (transition area)
Subsonic	Below the speed of sound
Super Jumbo	Nickname for very large aircraft in the size category above the B747-400
Super sonic	Above the speed of sound
Tonne kilometres	Unit measuring the amount of goods transported (in tonnes) multiplied by the amount of kilometres the vehicle travels
Tri-jet	Aircraft equipped with three jet engines, examples are L-1011 and DC10
Troposphere	The lowest layer of the Earth's atmosphere. Depending on the season, the upper boundaries of the troposphere reach altitudes of 6-8 kilometres above the poles and 16-18 kilometres in tropical areas
Turbofan	Type of engine currently used on all new large civil subsonic aircraft. Current engines are of the high-pressure high-

	bypass ratio type. Turbofans have been constantly improved since their introduction, mainly by improving pressure- and bypass ratios
Turbojet	Initial type of engine used in the first passenger jets introduced in the 1950ties
Turboprop	First type of gas turbine engine used in civil aircraft. Is currently used in a range of small- to mid-sized civil aircraft
Twinjet	Aircraft equipped with two jet engines, examples are A330 and B777
T&E	European Federation for Transport and Environment is a European NGO which have been co-organising a range of campaigns in Europe aimed at introducing kerosene tax and restricting growth of the environmental impact of aviation
UNFCCC	United Nations Framework Convention on Climate Change
Water vapour	For each kilogram of kerosene burnt aircraft engines emit 1,24 kilograms of water vapour. Under certain climatic conditions, the water vapour can lead to the formation of vapour trails. The knowledge of the possible climatic effect of such vapour trails is currently weak
Weight load factor	Tonne-kilometres performed divided by available tonne-kilometres
Yield	Fare per passenger
Yield management	A technique used by airlines to maximise revenue from any one flight. The capacity of a flight is determined, and the demand by full fare passengers for the flight is forecast, generally by using a historical database. The next step is choosing a probability rate for seating all potential full fare passengers and then reserving the appropriate number of seats to be sold at full fare. A discount fare level is then determined for the returning seats, and conditions are attached to discounted tickets so that passengers who are willing to pay full fare are unlikely to be able to take advantage of the discount fares

Units

1 litre of jet fuel	0,80 kg
1 kg jet fuel	1,25 litre
CO_2 per kilogram jet fuel	3,15 kg
CO_2 per litre petrol	2,34 kg
CO_2 per kilogram petrol	3,20 kg
CO_2 per litre diesel	2,71 kg
CO_2 per kilogram diesel	3,15 kg
1 tonne of carbon	3,6667 tonnes of CO_2

Appendix A

The World's top 25 airlines in 1999

Passengers		RPKs		RFTKs		Fleet size	
	[000]		[000.000]		[000]		
Delta	105534	United	201873	FedEx	10312379	American	697
United	86580	American	177334	Lufthansa Cargo	7072000	FedEx	650
American	81507	Delta	168596	UPS	6019476	United	594
Southwest	57500	Northwest	119336	Korean	5962143	Delta	584
Northwest	56114	British Airways	117463	Singapore	5481708	Northwest	423
US Airways	55812	Continental	93367	Air France	4726604	US Airways	398
Continental	44012	Air France	83736	British Airways	4536000	Continental	370
All Nippon	42743	Japan Airlines	82904	Japan Airlines	4423157	Southwest	318
Lufthansa	38872	Lufthansa	81401	KLM	4149000	British Airways	283
Air France	37028	US Airways	66875	Cathay Pacific	3769616	Lufthansa	240
British Airways	36346	Singapore	64529	United	3580863	American Eagle	240
Japan Airlines	32933	KLM	58903	China Airlines	3381658	Air France	234
TWA	25854	Southwest	58695	Cargolux	3246555	UPS	231
Iberia	24274	Qantas	58134	EVA air	3152180	Iberia	172
Alitalia	24048	All Nippon	56725	Northwest	3016405	Air Canada	157
SAS	22225	TWA	41945	American	2511439	America West	153
Japan Air System	20597	Cathay Pacific	41503	Nippon Cargo	2215933	SAS	152
Korean	20537	Air Canada	39005	Martinair	2060400	Alitalia	152
America West	18704	Thai Int'l	38534	Delta	1984966	Continental Express	149
Qantas	16692	Alitalia	36689	Swissair	1948724	All Nippon	141
Thai Int'l	16593	Korean	36662	LanChile	1737300	TWA	138
Malaysia	15659	Iberia	35379	Thai Int'l	1672801	Japan Airlines	138
Air Canada	15200	Swissair	34670	Air China	1611287	Mesa Airlines	135
China Southern	15112	Malaysia	32238	Alitalia	1611287	Aeroflot Russian	121
Swissair	14501	America West	28497	Emery	1576229	Comair	109

Source: [Air Transport World 2000].

Appendix B

Types of civil passenger jets in use, in production, under development or planned (only those above 80 seats)

80-124 seats	125-199 seats	200-314 seats	315+ seats
Airbus A318	Airbus 320	Airbus A300	Airbus A330-300
Airbus A319	Airbus 321	Airbus A310	Airbus A340-600
AVRO RJ85	Boeing 707	Airbus A330-200	Airbus A380-50
AVRO RJ100	Boeing 720	Airbus A340-200	Airbus A380-100
BAC 1-11	Boeing 727-200	Airbus A340-300	Airbus A380-200
Bae 146-200	Boeing 737-300	Airbus A340-500	Boeing 747-100
Bae 146-300	Boeing 737-400	Boeing 747SP	Boeing 747-200
Boeing 717-200	Boeing 737-700	Boeing 767-200	Boeing 747-300
Boeing 727-100	Boeing 737-800	Boeing 767-300	Boeing 747-400
Boeing 737-100	Boeing 737-900	Boeing 767-400	Boeing 747-X
Boeing 737-200	Boeing 757-200	Boeing 777-200	Boeing 747-400X
Boeing 737-500	DC-8	DC-10	Boeing 777-300
Boeing 737-600	MD-81	Il-96	Il-86
Bombardier BRJ-X	MD-82	Lockheed L-1011	
Caravelle	MD-83	MD-11	
DC-9	MD-88		
MD-87	MD-90		
Embraer ERJ-190	Il-62		
Fairchild 928JET	Tu-154		
Fokker 100	Tu-204 family		
Trident			
Tu-334			
Yak 42			

This Appendix lists the types of aircraft that are currently in use, in production, under development or planned for the near future. For comparison purposes generic types of each aircraft model are shown in four seat bands.

Aircraft currently in use but no longer in production are shown on white background.
Aircraft currently in use and still in production are shown on a light grey background.
Next-generation aircraft that are either planned or under development are shown on a dark grey background.

Note that each aircraft type may exist in a range of configurations featuring different seat-configurations, engines etc but it would be impossible to describe these differences within the space available here. Therefore, the table below is only meant to give a rough idea of the passenger capacity of different types of aircraft.

Source: [DTI 1999].

Appendix C

Turbine-engined aircraft in the world airline fleet by model 1994-1998 (Excluding helicopters)

	1994	1995	1996	1997	1998
1. Grand Total:					
Turbojets	**13994**	**14805**	**15421**	**16021**	**16619**
Turboprops	**7978**	**8452**	**8847**	**9069**	**9008**
Total aircraft in service	**21972**	**23257**	**24268**	**25090**	**25627**
2. Turbojets:					
Aerospatiale SE-210 Caravelle	28	27	20	12	12
Airbus A300	391	414	405	397	383
Airbus A310	217	218	222	224	227
Airbus A319	-	-	18	66	118
Airbus A320	463	510	549	612	685
Airbus A321	17	35	52	72	109
Airbus A330	10	38	49	63	87
Airbus A340	44	60	86	119	138
Antonov 72/74	-	4	8	8	9
Antonov 124	13	11	16	16	18
Antonov 225	-	-	1	1	1
AVRO RJ-70/85/100	30	51	77	100	120
Bae/Aerospatiale Concorde	13	13	13	13	13
Bae 146	196	204	206	208	206
Bae one-eleven	120	112	121	122	105
Bae Trident	9	-	-	-	-
Bae (HS) 125	22	19	20	18	17
Beech 400 Beechjet	2	2	3	3	3
Boeing B707/720	151	123	122	112	98
Boeing B727	1373	1346	1363	1322	1263
Boeing B737	2476	2569	2623	2752	2968
Boeing B747	957	963	996	1040	1042
Boeing B757	629	697	718	770	818
Boeing B767	550	580	628	663	710
Boeing B777	-	13	45	111	174
Canadair CL-601 Challenger	2	2	2	2	2
Canadair Regional Jet	49	83	136	189	258
Cessna Citation I/II/II	36	44	45	41	35
Convair 880/990	1	-	-	-	-
Dassault Falcon 10/20/50	60	66	65	60	61
Dassault Mercure	5	-	-	-	-

	1994	1995	1996	1997	1998
Embraer RJ135/RJ145	-	-	-	34	91
Fokker F-28 fellowship	185	185	175	184	160
Fokker 70	-	23	34	36	42
Fokker 100	253	267	272	274	278
Gulfstream II/III/IV G-1159	16	15	16	16	14
Ilyushin IL-62	84	106	105	105	86
Ilyushin IL-76	154	209	238	227	215
Ilyushin IL-86	37	51	98	80	75
Ilyushin IL-96	5	5	7	7	7
Israel aircraft 1121/1124	13	13	11	11	18
Learjet	39	49	54	53	49
Lockheed L-1011 Tristar	208	190	190	169	156
Lockheed L-1329 Jetstar	4	3	3	1	1
MBB Hansa HFB-320	3	13	16	16	17
McDonnell Douglas DC-8	270	274	263	257	261
McDonnell Douglas DC-9	791	787	785	759	749
McDonnell Douglas DC-10	347	335	351	345	354
McDonnell Douglas MD-11	127	146	159	171	180
McDonnell Douglas MD-80	989	1115	1120	1142	1154
McDonnell Douglas MD-90	-	14	36	62	97
Tupolev TU-134	155	192	188	189	189
Tupolev TU-154	283	379	422	451	438
Tupolev TU-204	5	4	6	6	7
Yakolev Yak-40/42	168	231	267	313	303
Turbojet subtotal	**13994**	**14805**	**15421**	**16021**	**16619**

3. Turboprops:

	1994	1995	1996	1997	1998
Aerospatiale N.262/Mohawk 298	12	13	9	9	11
Aerospatiale/Aeritalia ATR 42	245	259	283	296	299
Aerospatiale/Aeritalia ATR 72	138	158	177	177	202
Airtech CN-235	24	25	24	24	24
Antonov An-8	-	-	-	2	-
Antonov An-12	23	46	68	71	83
Antonov An-22	2	2	5	3	3
Antonov An-24/26/28/30/32	307	400	484	530	499
Bae ATP	53	52	55	50	57
Bae Vanguard	2	1	-	-	-
Bae Viscount	25	24	20	18	12
Bae (HP-137) Jetstream 31	306	296	274	287	233
Bae Jetstream 41	30	66	74	91	92
Bae HS-748	122	126	126	125	124
Beech 18 Turbo	21	21	20	20	18
Beech 90 King Air	30	35	39	46	39
Beech 99	140	143	140	138	139

	1994	1995	1996	1997	1998
Beech 100 King Air	44	46	48	39	39
Beech 200/300 Super King Air	101	121	126	122	111
Beech 1300	5	5	5	9	6
Beech 1900C/D	291	371	389	430	467
Bristol 175 Britannia	3	1	1	-	-
Canadair CL-44	4	2	1	-	-
CASA/Nurtanio C-212 Aviocar	107	114	111	113	105
Cessna 208 Caravan I	380	458	528	608	601
Cessna F406 Caravan II	21	35	28	30	31
Cessna 425/441 Conquest I/II	7	4	5	14	19
Convair 580/600/640	110	111	114	107	107
DHC-2/3 Turbo Beaver/Otter	9	17	22	20	20
DHC-5 Buffalo	1	1	1	1	1
DHC-6 Twin Otter	405	395	394	395	371
DHC-7 Dash 7	73	70	75	69	71
DHC-8 Dash 8	358	365	408	424	444
Dornier DO-228	126	106	112	114	118
Dornier DO-328	15	42	59	61	73
Douglas DC-3T Turbo Express	2	2	1	1	1
Embraer EMB-110 Bandeirante	188	192	211	200	199
Embraer EMB-120 Brasilia	276	254	295	308	316
Embraer EMB-121 Xingu	-	-	-	2	2
Fokker/Fairchild F-27/FH-227 Friendship	348	315	312	318	278
Fokker 50	164	171	176	171	167
GAF Nomad	22	18	13	15	15
Grumman G-21 Turbo Goose	1	1	-	-	-
Grumman G-73 Turbo Mallard	5	5	5	5	5
Grumman G-159 Gulfstream I	41	39	34	30	27
Handley Page Herald	16	15	10	2	1
Harbin YU-12 II	40	41	42	42	48
IAI Arava	2	2	2	3	3
Ilyushin IL-18	33	33	38	34	32
Ilyushin IL-114	-	2	2	2	2
LET-410	25	61	87	115	118
Lockheed L-188 Electra	65	51	53	36	44
Lockheed L-100/L-382 Hercules	14	56	56	45	35
Mitsubishi MU-2B	7	14	15	15	16
Nihon AMC YS-11	85	81	78	63	49
Pilatus Britten-Norman BN-2T Turbo Islander	2	2	5	6	6

	1994	1995	1996	1997	1998
Pilatus PC-6 Turbo Porter	-	25	28	30	24
Pilatus PC-XII	-	-	2	2	14
Piper PA-31T/42 Cheyenne	17	16	18	20	20
Piper T-1040	10	12	13	14	13
PZL (Antonov) An-28	1	6	6	3	3
Rockwell Turbo Commander	9	9	9	11	9
Saab SF-340A/B	347	355	379	396	432
Saab 2000	5	22	34	42	45
Shorts SC-5 Belfast	2	2	2	2	2
Shorts SC-7 Skyliner/Skyvan	31	35	35	32	30
Shorts 330	62	50	52	48	42
Shorts 360	108	106	104	103	93
Swearingen Merlin	49	38	45	53	55
Swearingen Metro	396	423	398	394	379
Transall C-160	6	6	-	-	-
Xian (Antonov) Y-7	65	66	66	66	66
Turboprop subtotal	**7978**	**8452**	**8847**	**9069**	**9008**

Source: [AIA 2000].

Appendix D

Distribution of air traffic on carriers situated in different geographical regions 1999

	Aircraft fleet size		Passengers [000]	share	RPKs [000000]	share	FTKs [000]	share	Avrg RPKs per pass	RTK* [000]	share	Weight shares Freight	Pass.
Africa	155	1.0%	9852	0.6%	15321	0.5%	497520	0.4%	1555	2029620	0.5%	25%	75%
Asia/Pacific	2262	14.2%	337716	21.3%	678118	23.9%	41019060	33.1%	2008	108830860	26.7%	38%	62%
Canada	370	2.3%	28699	1.8%	69015	2.4%	1974165	1.6%	2405	8875665	2.2%	22%	78%
Europe	4197	26.4%	432852	27.4%	829301	29.3%	34692714	28.0%	1916	117622814	28.9%	29%	71%
Latin America/Carribb	705	4.4%	64568	4.1%	90752	3.2%	4084377	3.3%	1406	13159577	3.2%	31%	69%
Middle East	295	1.9%	30225	1.9%	60379	2.1%	3401938	2.7%	1998	9439838	2.3%	36%	64%
US Majors	4974	31.3%	563864	35.6%	997728	35.2%	29938202	24.1%	1769	129711002	31.8%	23%	77%
US Nationals	1182	7.4%	70670	4.5%	68890	2.4%	7566996	6.1%	975	14455996	3.5%	52%	48%
US Cargo	172	1.1%	-	-	-		784131	0.6%	-	784131	0.2%	100%	-
US Regional	1589	10.0%	43368	2.7%	25199	0.9%	106133	0.1%	581	2626033	0.6%	4%	96%
Total World	15901		1581814		2834703		124065236		1792	407535536		30%	70%

*Calculated assuming that one RPK=100 kg

Source: [Air Transport World 2000]

Appendix E

Current and next-generation Airbus family specifications

	A318	A319	A320	A321	A310-300	A300-600	A330-200	A330-300
Typical seat capacity	107	124	150	185	220	266	253	335
First class seats	8	8	12	16	20	26	12	30
Business class seats	-	-	-	-	-	-	36	-
Economy class seats	99	116	138	169	200	240	205	305
Max. Seat capacity all-economy class	129	145	180	220	280	361	405	440
Range with typical passenger capacity [km]	2750-3700	4700-6800	4800-5500	4150-5500	8050-9600	7500-7700	12000	8900-10200
Cargo capacity (number of LD3 cargo containers)		4	7	10	14-15	22-23	26-27	32-33
First delivery	2002	1996	1988	1994	1985	1988	1998	1993
Number of engines	2	2	2	2	2	2	2	2
Engine power rating [kN]	98-107	98-120	111-118	133-146	230-260	249-270	303-325	285-325
Engine choices	PW6000	CFM56-5A/B	CFM56-5A/B	V2500-A5	CF6-80C2	CF6-80C2	CF6-80E1	CF6-80E1
…		V2500-A5	V2500-A5	CFM56-5B/P	PW4000	PW4000	PW4000	PW4000
…							Trent 700	Trent 700
Max. Take-off weight [tonnes]	61.5	68-70	75,5-77	85-93	153-164	174.6	230	217-230
Max. Load [tonnes]	14	17.9	19.1	23,4-25,6	31,4-32,2	32-39,7	36.4	43.5
Max. Fuel capacity [liter]	23860	23860-26760	23860	23700-29500	61070-75470	68150	139100	97170-97530

	A340-200	A340-300	A340-500	A340-600	A380-100	A380-100R	A380-200
Typical seat capacity	239	295	313	380	555	555	656
First class seats	16	12	12	12	22	n.a.	n.a.
Business class seats	42	42	42	54	102	n.a.	n.a.
Economy class seats	181	241	259	314	431	n.a.	n.a.
Max. Seat capacity all-economy class	420	440	440	485	854	700	1000
Range with typical passenger capacity [km]	14800	12000-13500	15750	13900	14200	16200	14200
Cargo capacity (number of LD3 cargo containers)	18-19	32-33	30-31	42-43	30	30	44
First delivery	1993	1993	2002	2002	2005	2005	2005
Number of engines	4	4	4	4	4	4	4
Engine power rating [kN]	151	151	236	249	298	333	333
Engine choices	CFM56-5C4	CFM56-5C4	Trent 553	Trent 556	Trent 700	Trent 700	Trent 700
…					Trent 900	Trent 900	Trent 900
…					GP7000	GP7000	GP7000
Max. Take-off weight [tonnes]	275	260-275	365	365	583	583	583
Max. Load [tonnes]	30.8	41-43,5	43.3	55.8	85	85	95
Max. Fuel capacity [liter]	155040	141500-148700	214800	194880	336250	383750	383750

Source: [Flug Revue 2000].

Appendix F

Aviation and environment related Web pages

Aviation fuel taxes
Global Policy Forum - http://www.globalpolicy.org/socecon/glotax/aviation/
Wuppertal Institute Information on environmental tax reform - http://www.wuppertal-forum.de
Aktie Strohalm - http:\\www.vliegtax.nl/

Government agencies
Eurocontrol - http://www.eurocontrol.be/
European Commission - http://europa.eu.int/comm/index.htm
UK Department of the Environment, Transport and the Regions - http://www.aviation.detr.gov.uk/
European Environmental Agency - http://www.eea.eu.int/
United States General Accounting Office -http://www.house.gov
Federal Aviation Administration (FAA) - http://www.faa.org

International organisations
International Civil Aviation Organisation – http://www.icao.org/
European Civil Aviation Conference - http://www.ecac-ceac.org/
Intergovernmental Panel on Climate Change - http://www.ipcc-nggip.iges.or.jp
OECD Organisation for Economic Co-operation and Development - http://www.oecd.org/
United Nations Framework Convention on Climate Change (UNFCCC) - http://www.unfccc.de
World Travel and Tourism Council (WTTC) - http://www.wttc.org

Statistical bureau's
Eurostat - http://europa.eu.int/comm/eurostat/
Bureau of Transportation Statistics, U.S. Department of Transportation - http://www.bts.gov
International Air Transport association - http://www.iata.org
Aerospace Industries Association of America - http://www.aia-aerospace.org/departments/stats/
US Department of Transportation, Bureau of Transportation Statistics - http://www.bts.gov/
US Department of Transportation, the Office of Airline Information - http://www.bts.gov/oai/

Research
Centre for Energy Conservation and Environmental Technology – http://antenna.nl/ce.
Cranfield College of Aeronautics - http://www.cranfield.ac.uk/coa/
SCAN-UK The UK Sustainable Cities and Aviation Network - http://www.scan-uk.mmu.ac.uk/
SENCO general information on air transport and the environment - http://www.btinternet.com/~senco

Aviation environmental impact
NASA The Atmospheric Effects of Aviation Project (AEAP) -
http://hyperion.gsfc.nasa.gov/AEAP/
POLINAT 2 Pollution from Aircraft Emissions in the North Atlantic Flight Corridor -
http://www.pa.op.dlr.de/polinat/
Contrail picture gallery - http://www.astro.ku.dk/~holger/IDA/notes.html
Contrail research results on the influence of contrails on the atmosphere -
http://www.could1.arc.nasa.gov/espo/success/index.html
Website for personal emissions - http://www.benjhm.free-online.co.uk/flying

Aviation and Environment NGO's
Aviation Environment Federation - http://www.aef.org.uk
Airfields Environment Trust - http://www.gael.net/aet/
European Federation for Transport and Environment, Brussels, http://www.t-e.nu/
Friends of the Earth - http://www.milieudefensie.nl/airtravel/.
HACAN Heathrow Association for the Control of Aircraft Noise -
http://www.hacan.org.uk/
Netherlands Society for Nature and Environment - http://www.snm.nl/
Citizens Against Airport Pollution (CAAP) California - http://www.caap.org
No More Noise coalition California - http://www.wenet.net/~hpb
National Research Defense Council (NRDC) - http://www.nrdc.org
US-Citzens Aviation Watch (US-CAW) - http://www.nonoise.org/groups/us-caw/us-
caw.htm
Interessengemeinschaft zur Bekämpfung des Fluglärms - http://www.fluglaerm.de
Union Français Contre les Nuisances des Avions (UFCNA) -
http://altern.org//ufcnaforum
Miljøforeningen for bevarelse af miljøet omkring Københavns lufthavn -
http://hudson.idt.net/~beck/index-engelsk.htm
Sane aviation for everyone - http://pages.prodigy.net/rockaway/safe.htm

Airline Associations
Association of European Airlines - http://www.aea.be/
European regional airlines association - http://www.eraa.org/
Association of Asia Pacific Airlines – http://www.aapa.org.ph/
American Air Transport Association - http://www.air-transport.org

Aerospace industry
European Association of Aerospace Industries - http://www.aecma.org/
Society of British Aerospace Companies - http://www.sbac.co.uk
Airbus - http://www.airbus.com/
Boeing - http://www.boeing.com/
Rolls Royce - http://194.128.225.11/.
EADS European Aerospace and Defense Systems - http://www.eads-
nv.com/eads/en/index.htm

Airline alliances
Star alliance - http://www.star-alliance.com/

Airlines
Air France - http://www.airfrance.com/
Air India - http://www.airindia.com/
Air China - http://www.airchina.com.cn/
Easy Jet - http://easyjet.com/uk/
Finnair - http://www.finnair.fi/
All Nippon Airways - http://svc.ana.co.jp/
British Airways - http://www.britishairways.com/
Condor - http://www.condor.de
KLM Royal Dutch Airline – http://www.klm.com/
SAS Scandinavian Airline Systems - http://www.scandinavian.net/
Premiair – http://www.premiair.dk/
Air 2000 - http://www.air2000.com/
United Airlines - http://www.ual.com/
GO - http://www.go-fly.com/

Airports
Zurich Airport Authority, Switzerland - http://www.zurich-airport.ch
Airport Council International (ACI) Airport branch organisation - http://www.airports.org

Aviation news agencies
Airwise Press Releases - http://news.airwise.com/
ENDS Daily European Environmental news - http://www.ends.co.uk/envdaily/
STAND BY the Scandinavian travel trade journal - http://www.standby.dk/
Flug Revue - http://www.flug-revue.rotor.com/
Cutter environmental news - http://www.cutter.com/envibusi/reports/index.html
Nordic baltic travel report - http://www.nordictravel.com/articl.htm
Air and Space Europe - http://www.airandspaceeurope.com/
Airconnex air travel news - http://www.airconnex.com/bulletin

Advanced aircraft concepts
Cranfield College of Aeronautics BWB design - http://www.cranfield.ac.uk/coa/wing/
NASA BWB design - http://oea.larc.nasa.gov/PAIS/BWB.html

Appendix G

World international tourism development

Indices of world tourism development are given in the statistical yearbook from the World Tourism Organisation. As shown in Figure G-1 total arrivals of tourists from abroad have grown from around 25 million in 1950 to around 625 million in 1998. These data indicate the number of international tourists that arrive in a country and stay there for at least one night. Tourists travelling within their home countries are thereby not included as well as tourists arriving in a country without staying over night. Tourists travelling to several countries within the same year are counted each time, so these data do not show the actual amount of travelling for each individual person within a year. Likewise, these data do not indicate how long time each tourist is staying. Anyway, the data do give an idea of the rise of international tourism.

Figure G-1: Total arrivals of tourists from abroad in the world 1950-98.
The data for tourist arrivals shown here includes both leisure/holidays and business, but excludes same-day visitors (excursionists), i.e. visitors not spending the night in the country. The data for arrivals only refer to arrivals and not to the actual number of people travelling. One person visiting the same country several times during the year is counted each time as a new arrival. Likewise, the same person visiting several countries during the same trip is counted each time as a new arrival. Source: [World Tourism Organisation 1999].

International tourist arrivals in the world's top ten tourism destinations in 1997 are shown in Figure G-2. Figure G-2 also exemplifies the level of growth since 1980 at each destination. France is the world's biggest destination for international tourism, and has remained its share of world international tourism arrivals at eleven percent since 1980. China, being the sixth biggest destination, increased its share from one percent to four percent in the period.

Figure G-2: Tourist arrivals from abroad in the world's top ten tourism destinations in 1997 compared to 1980.
The data for tourist arrivals shown here includes both leisure/holidays and business, but excludes same-day visitors (excursionists), i.e. visitors not spending the night in the country. Data for arrivals only refer to arrivals and not to the actual number of people travelling. One person visiting the same country several times during the year is counted each time as a new arrival. Likewise, the same person visiting several countries during the same trip is counted each time as a new arrival. Data source: [World tourism Organisation 1999].
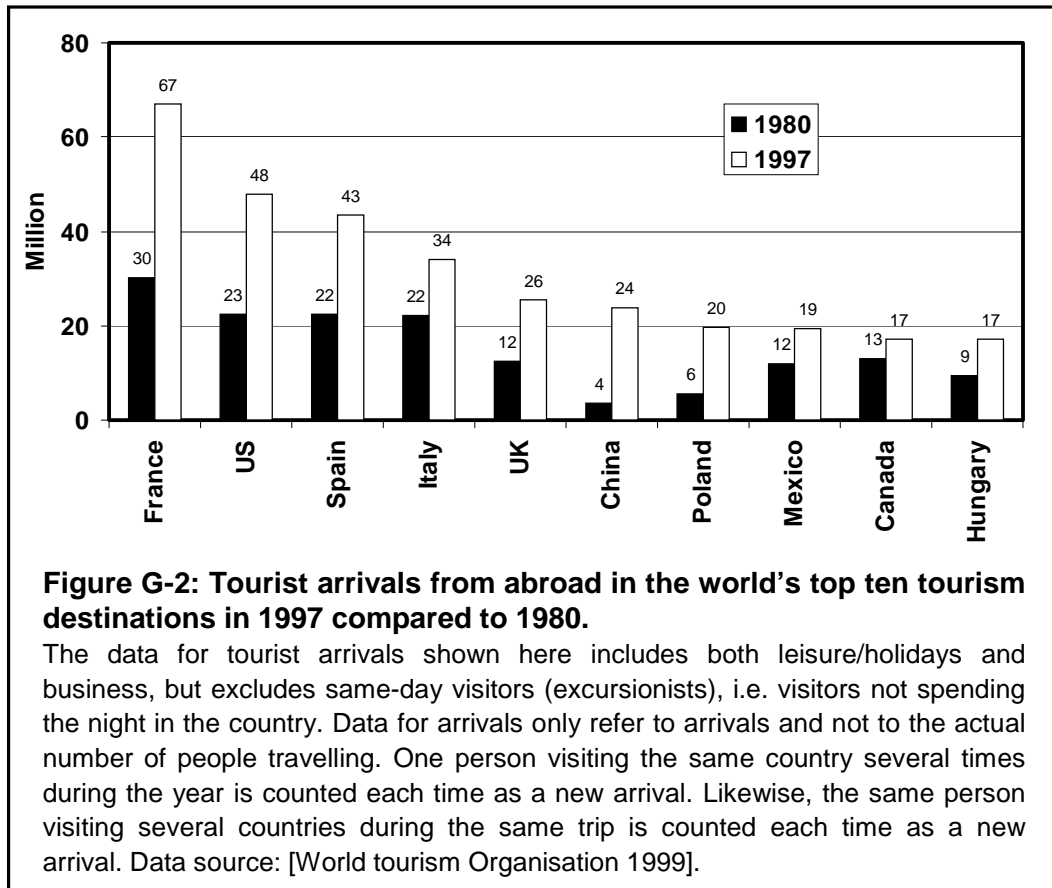
Figure G-3 exemplifies the growth in international tourism arrivals between 1980 and 1997 on world regions. Europe is by far the biggest destination for tourists arriving from abroad receiving 59 percent of world arrivals in 1997. The Americas are second biggest at 19 percent. However, East Asia/Pacific has increased it's share from 8 percent in 1980 to 14 percent in 1997, and is catching up with Americas because of higher yearly growth rates.
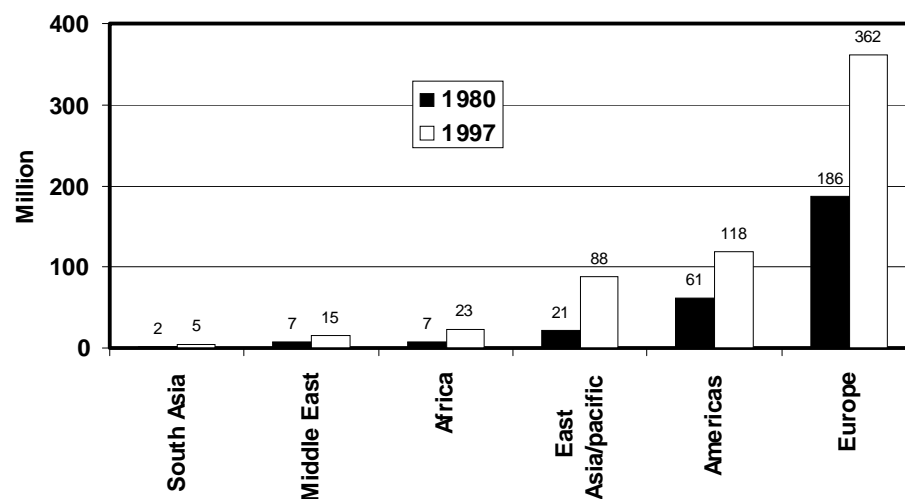
Figure G-3: Arrivals of tourists from abroad by regions 1980 and 1997.
The data for tourist arrivals shown here includes both leisure/holidays and business, but excludes same-day visitors (excursionists), i.e. visitors not spending the night in the country. The data for arrivals only refer to arrivals and not to the actual number of people travelling. One person visiting the same country several times during the year is counted each time as a new arrival. Likewise, the same person visiting several countries during the same trip is counted each time as a new arrival. Data source: [World Tourism Organisation 1999].

Appendix H

Developments in aircraft performance

In this appendix some selected performance parameters, number of seats, range and cruising speed, of selected aircraft used for commercial civil aviation are presented to demonstrate the historical development in aircraft performance. It should be noted that only a few of the many airliners that emerged through the years have been picked out to illustrate the level of development. Often, many competitors with slightly similar performance characteristics could have been chosen.

Year	Event
1919	After the First World War the first commercial airlines began transporting mail and passengers in biplanes in Europe and the US, some of them using leftover bombers rebuilt for passenger transport. These biplanes accommodated between 2-14 seats and cruised at speeds of up to 140 km/h [Heppenheimer 1995].
1928	The three-engine Ford Trimotor made possible twenty-seven hours US coast-to-coast service, including fourteen refuelling stops. Engines were rated at 420 horsepower. The aircraft accommodated 14 seats and cruised at a speed of around 200 km/h [Heppenheimer 1995] [Donald 1999, p. 462].
1934	The twin-engine DC-2 cut US coast-to-coast flight time to eighteen hours including only three refuelling stops [Heppenheimer 1995]. Powered by 875 horsepower engines. Max range 1609 kilometres, Accommodating 14 seats and cruising at around 300 km/h [Donald 1999, p. 405]
1935	First Trans-Pacific four-engine long-range flying boat passenger service from US to the Philippines in 7 days in a Martin M-130 [Heppenheimer 1995] [Donald 1999, p. 8].
1937	The DC-3 cut US coast-to-coast flight time to sixteen hours. The DC 3 was a twin- engine airliner with a maximum range of around 3400 kilometres. Accommodating 21-24 seats and cruising at 315 km/h [Jane's 1940]. This year was also the end of the airship-era when the Hindenburg airship burned following a Trans-Atlantic flight to the US [Donald 1999, p. 7].
1939	Pan-Am introduced flying boat Trans-Atlantic flight with the Boeing 314 Clipper Flying boat with four 1500 horsepower Wright Cyclone engines, cruising speed of around 260 km/h, max. Altitude 4,8 kilometres and range of 4960 kilometres with 40 passengers [Jane's 1940].

Year	Event
1945	The four-engine Lockheed Constellation offered US coast-to-coast scheduled service with one stopover in ten to eleven hours [Heppenheimer 1995]. The Constellation was equipped with 2200 hp engines and accommodated 64 passengers. Cruising speed of around 450 km/h [Donald 1999, p. 572].
1950	In the early 1950s aircraft such as the Boeing Stratocruiser and the Lockheed Constellation made possible non-stop flight between the US and Europe.
	The Boeing Stratocruiser, a four-engine airliner with four 3500 horsepower Pratt & Whitney Double-Wasp engines, featured a two-deck fuselage accommodating between 55 and 100 daytime passengers or 27 sleeping passengers. Crusing speed of around 550 km/h at 7.6 kilometres altitude and a range of 7300 kilometres [Jane's 1951].
	The four-engine Vickers Viscount turboprop becomes the first gas turbine-powered passenger airliner in the world [Donald 1999, p. 786]. The initial version accommodated 32 persons, but was later improved to seat 75 passengers [Donald 1999, p. 9]. Between 1935 and 1965 this aircraft was the only one serious competitor to the American aircraft in the commercial aircraft market. Engine output 1400 shp, range 1510 kilometres with max payload. Cruising speed around 500 km/h.
1952	The de Havilland Comet was the first commercial aircraft powered by turbojet engines with its first flight in 1949 and introduction into service in 1952. It introduced the use of four de Havilland Ghost turbojets of 5000lb thrust each. It had a service ceiling of 12.2 kilometres altitude and a range of 3450 kilometres. The aircraft seated 36-48 passengers. In 1949 the Comet flew 2420 kilometres from England to Libya at an average speed of 708 km/h [Jane's 1951]. Unfortunately two aircraft crashed, and the production was seized [Heppenheimer 1995].
	In the same period four-engine medium-range gas turbine powered turboprop aircraft such as the Bristol Britannia and the Lockheed Electra were introduced. Accommodating up to 90 passengers and cruising at around 550 km/h.
1958	The de Havilland Comet IV was an upgraded version of the Comet, produced in different versions for medium- and long range (5200 kilometres). The aircraft seated 60-81 passengers and could cruise at around 800 km/h. The Comet IV never became popular because of its small size compared to the Boeing B-707 and the McDonnell Douglas DC-8, which came out in 1958 and 1959 respectively [Jane's 1961].
	Boeing's B707-120 with four Pratt & Whitney JT3C-6 turbojet engines each rated at 13500lb accommodated up to 181 passengers and cruised at up to 880 km/h. The initial version was intended primarily for continental use, but capable of operating at full load on many routes over oceans. Range 5177 kilometres. Later versions stretched range to 7800 kilometres [Jane's 1970].

Year	Event
1959	McDonnell Douglas DC-8-10 with four Pratt & Whitney 13500lb JT3C-6 turbojet engines introduced [Jane's 1970]. Seating up to 179 passengers and cruising at around 870 km/h.
1961	Introduction of the 18000lb JT 3D-3 turbofan engine increased the range of the Boeing 707 and the DC-8 to 6800 km, allowing non-stop flights from New York to all the major European cities and from Seattle to Tokyo
1963	Introduction of the three-engine Boeing 727 for the medium-range market. Range up to 4000 kilometres at max. Payload. Seating 163-189 passengers [Donald 1999, p. 787].
1965	Introduction of twin-engine DC-9 designed for the short-haul market [Donald 1999, p. 787].
1968	USSR achieves the maiden flight of the World's first supersonic airliner, the Tupolev Tu-144, typically accommodating 140 passengers. A max. Cruising speed of 2500 km/h and maximum range of 6500 kilometres with maximum payload [Donald 1999, p. 791].
1969	Boeing delivers their first 747-100 to Pan American Airlines in late 1969. Boeing thereby introduced the World's first wide-body jumbo airliner. The biggest aircraft for passenger transport. Initial versions seated up to 490 passengers, but a more typical load was 374, with 66 first-class and 308 tourist-class seats. The range of the 747-100 is around 9000 kilometres. The aircraft is powered by four Pratt & Whitney JT9D-3 turbofan engines each rated at 43500lb [Jane's 1971]. Cruising speed of around 950 km/h.
1971-74	McDonnell Douglas and Lockheed introduced their three-engine wide-bodies DC-10-10 and L-1011-100 in 1971 and 1972 respectively. Airbus introduced the A-300 wide-body twinjet in 1974.
1976	First Concorde flight between the US and Europe. The Concorde introduced cruising speed of up to Mach 2.2. Range of 6470 kilometres. Accommodating around 100 passengers [Jane's 1970].
1979	First flight of the MD-80, a modernised version of the DC-9 [Donald 1999, p. 787].
1982	The first flight of the twin-turbofan Boeing 757, the successor to the Boeing 727 three-turbofan type [Donald 1999, p. 788]. First flight of Airbus' A310 twin-turbofan medium-range airliner [Donald 1999, p. 788].
1983	First flight of the SAAB 340 twin-turboprop commuter airliner and the de Havilland Canada DHC-8 Dash 8 twin turboprop short-range aircraft and the Brasilian EMBRAER EMB-120 twin-turboprop airliner [Donald 1999, p. 788].
1984	First flight of the 48-seat ATR 42-300 twin-turboprop regional airliner [Donald 1999, p. 788].

Year	Event
1985	Boeing 767 the first twin-turbofan airliner to cross the Atlantic [Donald 1999, p. 788].
1987	First flight of the Airbus A320 [Donald 1999, p. 788].
1988	First flight of the 64/74-seat ATR 72-200 regional twin-turboprop airliner, an enlarged ATR 42 [Donald 1999, p. 788].
1991	First flight of the 50-seat Canadair Rgional jet [Flight International 2001b].
1992	First flight of the SAAB 2000, a larger and faster version of the SAAB 340 [Donald 1999, p. 788]. Bae introduces the RJ-family as follow-ups to the Bae 146 [Flight International 2001b].
1993	First flight of the MD-90, a stretched version of the MD-80 with an updated engine [Donald 1999, p. 788]. With the A-330-300 and the A340-200/300 Airbus introduced a single aircraft built in two versions. The A-330 is a twinjet carrying 335 passengers. It fills the need for wide-body twins larger than the B767 and A-300. The A-340 is a four-engine long-range aircraft that can carry two thirds of the B747s capacity. It aims at "long thin routes", that cover world-spanning distances, but attract to few passengers to fill up the B747. The two aircraft share the same wing, and are the first to do so [Heppenheimer 1995].
1994	Boeing introduced the B777-200 long-range high-capacity twin turbofan airliner in 1994. Was followed by the stretched 777-300 version in 1997. Range of 7500 to 9000 kilometres with 375 passengers. New ultra-long range versions B777-300X and B777-200X planned for introduction by end-2002 and mid-2003 respectively. The B777-200X is expected to be able to carry 298 passengers over 16260 kilometres non-stop. With this range it will make possible non-stop connections between almost any two destination airports in the world [Jane's 1998].
1995-98	ATR introduces the improved ATR42-500 and ATR72-500 featuring six-blade propellers offering a higher cruising speed than the earlier ATR42-300 [Flight International 2001b]. First flight of the 107-seat B717-200.
2002	Airbus will introduce the 107-seat A318 regional aircraft [Flight International 2001b].
2006	The Airbus 380-100 will be introduced in 2006 seating 555 in three-class version. Later to be followed by the stretched A380-200 seating up to 1000 passengers in one-class seat-configuration [Flight International 2001c].
200?	Boeings Sonic cruiser may be introduced, offering higher speed and flying at higher altitude than current subsonics.

Sources: [Jane's 1940, 1951, 1961, 1970, 1971, 1979, 1998], [Heppenheimer 1995] and [Donald 1999] [Flight International 2001b and 2001c].