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AVIATION AND SUSTAINABLE DEVELOPMENT

BACKGROUND PAPER NO. 9

Prepared by the

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AVIATION AND SUSTAINABLE DEVELOPMENT

(Presented by the International Civil Aviation Organization)

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1. INTRODUCTION

1.1 This information paper has been prepared by the International Civil Aviation Organization (ICAO) at the request of the United Nations Department of Economic and Social Affairs as part of the documentation being prepared for the ninth session of the Commission on Sustainable Development. Two inputs were originally requested, both in the context of sustainable development, one on air transport, the other on the use of economic instruments for the mitigation of the negative environmental impact of aviation. It was subsequently agreed that these two inputs would be merged into one information paper.

1.2 The paper provides background information on aviation and a brief overview of environmental problems associated with aviation (Section 2). It then focuses on the two principal problems that governments have mandated ICAO to address on a worldwide basis, namely aircraft noise and the impact of aircraft engine emissions (Sections 3 and 4 respectively). Finally, Section 5 explores economic instruments, to address aircraft noise and to address the impact of aircraft engine emissions.

2. BACKGROUND INFORMATION ON AVIATION[1]

2.1 Historical Perspective

2.1.1 Air transport has experienced rapid expansion since the second world war as the global economy has grown and the technology of air transport has developed to its present state. The result has been a steady decline in airline operating costs and fares per unit of traffic (measured in passenger-kms) in real terms, which has stimulated traffic growth. Consequently, scheduled domestic and international air traffic has increased from some 9 million passengers in 1945 to over a billion and a half in 1999. On average, passenger traffic has grown at about 10 per cent annually, although the growth rates varied significantly from very high, exceeding 20 per cent a year in the first post-war decade, to quite moderate in recent decades as the air transport market has become more mature (see **Figure 1** at end of this paper).

2.1.2 As an illustration of this growth, the output of air transport (measured in terms of tonne-kilometres performed) has increased by a factor of 30 since 1960. Gross Domestic Product (GDP), which is the broadest available measure of world output, increased by a factor of 3.8 over the same period.

2.1.3 Although growth in world air traffic has been much greater than world economic growth, there is a high correlation between the two. Statistical analyses have shown that growth in GDP now explains about two-thirds of air travel growth, reflecting increasing commercial and business activity and increasing personal income and propensity to travel. Demand for air freight service is also primarily a function of economic growth and international trade. Air travel growth in excess of GDP growth is usually explained by other economic and structural factors:

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[1] The data in this Section are largely based on civil aviation statistics collected by ICAO and on civil aviation forecasts developed by ICAO. For more details, see ANSConf-WP/13, a paper presented to the Conference on the Economics of Airports and Air Navigation Services (Montreal, 19–28 June 2000) by the ICAO Secretariat.

– improvement in service offerings as routes, frequencies and infrastructure are added, stimulation from reductions in airline fares as costs decline, and increasing trade and the globalization of business;

– population and income distribution; and

– travel behaviour, including travel time budgets and travel costs.

2.1.4 The airline industry has a long history of improving productivity. As a result, the growth in the output of the industry has been greater than the growth in the various inputs used by the industry; the average annual growth in productivity since 1987 has been about 3.5 per cent. The progressive absorption of new technology aircraft into airline fleets has been a major contributor; in particular, new aircraft are more fuel- and labour-efficient. Improved aircraft utilization has also made an important contribution. **Figure 2** depicts the contributors to declining trend in real yields and unit costs over the 1961–1997 period.

2.2 Traffic Forecasts

2.2.1 In terms of scheduled passenger kilometres performed, the most recent ICAO 10-year forecasts show domestic traffic growing at an average annual rate of 3.5 per cent and international traffic at 5.2 per cent for the period 1999–2010. Overall (domestic plus international) growth is projected at 4.5 per cent per annum, with total traffic by airline region varying from 7.2 per cent per annum for airlines of the Asia/Pacific region to 2.8 per cent per annum for airlines of the North American region.

2.2.2 In the longer term, passenger traffic worldwide, expressed in passenger-kilometres performed, is projected to grow for the period 1997–2020 at an average annual rate of 4.5 per cent, with freight traffic growth expected to be somewhat higher (it should be borne in mind that approximately 70 per cent of freight traffic is carried on bellies of passenger aircraft). The growth rates vary from a high of 6.2 per cent per annum for the transpacific compared with a low of 2.9 per cent for the more mature intra-North American market as illustrated in **Table 1**. The North Atlantic route group which has the highest share in passenger traffic is projected to grow at 3.8 per cent per annum.

2.2.3 These traffic forecasts have been developed with the implicit assumption that sufficient system infrastructure and capacity will be available to handle the demand. This growth will therefore be influenced by the extent to which the industry faces up to major challenges, such as airport and airspace congestion, environmental protection and increasing capital investment requirements. The shape and the size of the air transport system will be also affected by government decisions, notably those determining the nature and extent of economic regulation of airlines.

2.2.4 In some parts of the world, particularly in Europe and North America, the airports and airspaces are operating under constraints that limit their ability to provide efficient service. These constraints are likely to become more acute in the future as air transport continues to expand. Major new airports in most developed countries appear to be unlikely. The ICAO-promoted global Communications, Navigation, Satellite/Air Traffic Management (CNS/ATM) system that is in the process of being implemented promises enhanced system capacity, even higher margins of safety, and environmental benefits. However, airport and airspace capacity will remain finite resources that have to serve the anticipated growth in traffic.

2.2.5 Other system constraints are related to environmental issues. Aircraft noise has become a major issue affecting airport expansion in some countries and there are also concerns regarding the impact of aircraft engine emissions at both the local and global levels. These issues are being studied by ICAO. Meanwhile, some States are calling for greater use of economic instruments as a means of limiting the growth of international air transport.

2.2.6 Finally, air transport is particularly vulnerable to fuel prices. The industry has benefited over the past from relatively low and stable prices of aircraft fuel, but even today fuel represents some 13 per cent of airline operating costs worldwide. Prevailing industry expectations are for no increase in real terms, but a surge in prices (which occurred in 1973–4, 1979, 1990 and, to a lesser extent, in 1999–2000) has a dual impact, increasing air transport costs and reducing demand.

2.3 Environmental Problems Associated with Aviation – A Brief Overview

2.3.1 Civil aviation, like most other economic activities, gives rise to environmental problems of various kinds. In 1999, the ICAO Secretariat compiled an inventory of environmental problems that may be associated with civil aviation, to assist the ICAO Council in identifying future priorities in the environmental field[2]. It was assumed that "the environment" means all those natural and man-made surroundings which may be adversely affected by the presence of civil aviation, but which are not directly involved in the aviation itself. The inventory therefore excluded problems concerning the conditions for passengers and crew, or problems concerning the working conditions of airline or airport employees. It also excluded aircraft-manufacturing processes, because such processes fall outside ICAO's ambit.

2.3.2 Environmental problems associated with aviation include:

1) Aircraft noise

2) The impact of aircraft engine emissions, at ground level and globally

3) Other local problems at airports, including problems arising from construction and expansion of airports and associated infrastructure, water and soil pollution, and management of wastes.

2.3.3 This paper does not attempt to cover all these environmental problems. It focuses on the two principal problems that governments have mandated ICAO to address on a worldwide basis, namely aircraft noise (see Section 3) and the impact of aircraft engine emissions (see Section 4).

2.3.4 ICAO's work on these two problems, noise and emissions, is largely undertaken by the Organization's Committee on Aviation Environmental Protection (CAEP), which reports to and makes recommendations to the Council of ICAO. CAEP consists of experts from States and observers from international organizations, including representatives of industry and environmental interests. CAEP and its predecessor committees have been working on noise matters for some 30 years and on emissions matters for some 20 years.

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[2] Recommendations regarding ICAO's environmental activities. C-WP/9375, 17 October 1991.

3. AIRCRAFT NOISE

3.1 Description of the problem

3.1.1 How people perceive the noisiness of a sound is dependent on such factors as its intensity, its frequency characteristics, and the length of time that they are exposed to it. Whereas road traffic and industrial noise is usually fluctuating but continuous, aircraft noise consists of a series of discrete events corresponding to aircraft movements (take-offs, landings). Consequently, aircraft noise can be described in terms of single events, or in terms of cumulative noise exposure. Many different noise exposure indices have been developed, taking into such factors as the number of aircraft, their individual noise levels, and time (day or night)[3].

3.1.2 Exposure to aircraft noise is difficult to quantify on a worldwide basis. However, estimates have recently become available based on a new analytical tool that is being used within ICAO, the Model for Assessing the Global Exposure to the Noise of Transport Aircraft (MAGENTA)[4]. Approximately 30 million people are estimated to be exposed to levels of aircraft noise at which many States formally recognize the existence of noise nuisance, including approximately 3 million people who are exposed to higher levels at which many States make noise insulation provisions[5].

3.1.3 A summary of the effects of aircraft noise in the United States[6] identifies annoyance as the most prevalent effect. Within a community, some individuals will be much more and others much less upset or annoyed with the sound in question, making the measurement of "community response" a rather complicated matter. In addition, speech and sleep interference are identified as major concerns of neighbours close to airports, while it is noted that hearing damage is not a common result of aircraft noise exposure.

3.1.4 Aircraft noise is one of the main environmental problems constraining the future growth of air transport. In this connection, Airports Council International, the international body representing airports worldwide, recently stated "The extreme difficulty encountered in the construction of new airports, the expansion of existing airports and the scheduling of aircraft operations, especially at night, is primarily the result of community opposition to aircraft noise at many airports"[7].

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[3] For additional information, see "Recommended Method for Computing Noise Contours around Airports", ICAO Circular 205-AN/1/25.

[4] Developed by Wyle Laboratories, under contract to the United States Federal Aviation Administration.

[5] Noise levels of DNL55 and DNL65 respectively. The DNL (Day-Night Sound Level) scale is equivalent to A-weighted Leq, but with a 10dB night penalty applied between 2200 hours and 0700 hours.

[6] Aviation Noise Effects. Federal Aviation Administration, Report No. FAA-EE-85-2, March 1985.

[7] Policy Handbook, Third Edition — 2000, Airports Council International.

3.2 **Mitigation measures**

3.2.1 In very simple terms, mitigation of noise problems usually involves taking action at the source of the noise, or somewhere along the transmission path between the source and those affected, or at the point where they are affected. In the case of aircraft noise, where the source is moving fast in three dimensions, this translates into:

a) making aircraft quieter or introducing restrictions on the use of noisier aircraft;

b) operational measures, that is adapting an aircraft's operational procedures at an airport so as to minimize community exposure to noise; and

c) appropriate use of land-use planning near airports.

3.2.2 There is also some experience with the use of noise charges to address aircraft noise problems. This is described briefly in Section 5.1 on economic instruments.

3.3 **Reducing noise at source**

3.3.1 Much of the effort that has gone into tackling aircraft noise over the past 30 years has been aimed at reducing noise at source. The aircraft built today are required to meet the environmental standards set by ICAO. In 1971, ICAO adopted the document which constitutes Annex 16 to the Convention on International Civil Aviation[8]. Volume I of Annex 16, entitled *Aircraft Noise*, sets Standards for the noise certification of large subsonic jet and propeller-driven aircraft, small propeller-driven aircraft and helicopters. It also includes descriptions and methods of measurement of aircraft noise.

3.3.2 For jet-powered aircraft, there are two levels of stringency in the Standards. Chapter 2 of the Annex contains the Standards which are essentially applicable to jet aircraft designed before October 1977, and Chapter 3 contains more stringent Standards applicable to those designed after that date. There are also some jet aircraft, which are now no longer in production, that are not subject to noise certification requirements by the Annex and are commonly referred to as non-noise certificated (NNC). The CAEP keeps the noise certification Standards under review and is currently working on a possible new standard more stringent than the present one in Chapter 3, with a view to making recommendations for consideration by the Council of ICAO in 2001.

3.3.3 Although noise levels have declined at many airports as the proportion of total movements which are performed by new quieter aircraft has increased, aircraft noise has continued to be a major problem, particularly in developed countries. Many States have therefore found it necessary to impose operating restrictions on noisier aircraft. Initially, in the 1980s, the focus was on NNC aircraft (for example, Boeing 707 and McDonnell Douglas DC-8). Later, attention turned to those aircraft which meet the Standards in Chapter 2,

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[8] The Standards in Annexes to the Convention on Civil Aviation are considered binding. However, if any Contracting State finds it impossible to comply with them, the State is require to inform ICAO of any differences that exist. The differences notified are then published by ICAO in Supplements to Annexes.

but which exceed the noise levels of the more stringent Standards in Chapter 3 (for example, Boeing 727 and early models of the Boeing 737 and McDonnell Douglas DC-9).

3.3.4 However, operating restrictions can have significant economic implications for the airlines concerned, particularly those from developing countries. Unless they are able to transfer these noisier aircraft to other routes, they have either to replace them with newer aircraft or to retrofit them with quieter engines or noise-muffling equipment known as "hush-kits". In both cases — NNC aircraft and Chapter 2 aircraft — ICAO played a leading role in developing a worldwide approach to the introduction of operating restrictions.

3.3.5 In the case of Chapter 2 aircraft, an extraordinary session of the ICAO Assembly in October 1990 adopted unanimously a resolution[9] on a worldwide policy framework on operating restrictions that represented a careful balance between the interests of developing and developed States and took into account the concerns of the airline industry, airports and environmental interests.

3.3.6 The resolution allows States to start phasing out operations of Chapter 2 aircraft from 1 April 1995 and to have all of them withdrawn from service by 31 March 2002. However, prior to the latter date, Chapter 2 aircraft are guaranteed 25 years of service after the issue of their first certificate of airworthiness. Thus a Chapter 2 aircraft which has completed less than 25 years of service on 1 April 1995 would not be immediately affected by this requirement. Similarly, wide-body Chapter 2 aircraft and those fitted with quieter (high by-pass ratio) engines would not be immediately affected after 1 April 1995.

3.3.7 The Assembly also urged ICAO to promote, and States to develop, an integrated approach to the problem of noise, including land-use planning procedures around international airports, so as to minimize the adverse effect of aircraft noise on any residential, industrial or other land-use.

3.3.8 Many developed countries have since implemented restrictions on operations of Chapter 2 aircraft at their airports, along the lines of the policy framework agreed in 1990 and this has been successful in reducing noise levels near many airports. For example, in the United States, the Federal Aviation Administration (FAA) calculated that the number of people exposed to levels of aircraft noise that create a significant annoyance would fall from 2.7 million to 1.3 million in the year 2000 by normal attrition of Chapter 2 aircraft, but would fall to 400 000 in the same year under its phase-out plan[10].

3.3.9 In recent years, governments have been turning their attention to the situation that will exist, once operations of Chapter 2 aircraft at their airports have largely been replaced by Chapter 3 aircraft. There are concerns that the rapid growth of air transport could increase noise levels once again. A consensus has yet to emerge in ICAO on how to address these concerns.

3.3.10 In Europe, governments have focussed on preventing an increase in operations of aircraft which have been recertificated to Chapter 3 standards through re-engining or hush-kitting. While this pertains to European airports only, it nevertheless could impact on carriers based elsewhere, and it has raised questions

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[9]Adopted as Assembly Resolution A28-3. Subsequently incorporated into Assembly Resolution A32-8: Consolidated statement of continuing ICAO policies and practices related to environmental protection, as its Appendix D.

[10] Phase-out of Stage 2 Airplanes Operating in the 48 Contiguous United States and the District of Columbia. Notice of proposed rulemaking by the United States Federal Aviation Administration. Federal Register, Vol. 56, No. 40. February 28, 1991. The figures quoted are based on a DNL of 65 dB.

within ICAO about consistency with the compromise solution of 1990 as well as the possible impact on ICAO's worldwide noise standards. In April 1999, the EU Council adopted a regulation[11] on this subject which became applicable on 4 May 2000. This regulation recently became the subject of a complaint filed by the United States with ICAO under the Chicago Convention's provisions for settling disputes (Article 84) and the relevant procedures for dealing with such issues are now under way.

3.3.11 In June 1999, in the light of these developments, the ICAO Council decided to expand the mandate of the CAEP in the noise field. In addition to work already under way concerning a new noise standard more stringent than Chapter 3, CAEP is now exploring the issue of possible operating restrictions on Chapter 3 aircraft from a worldwide perspective, and has been requested to develop technical options, for consideration by the Council in 2001.

3.3.12 CAEP will be making use of the MAGENTA model referred to in paragraph 3.1.3 above. The model will estimate the benefits of policy measures to reduce noise, in terms of changes in the number of people who would be exposed to a given level of noise. While information about the estimated benefits was sometimes available for a particular airport, until now there has been no reliable means for extrapolating this information to cover many airports. Using MAGENTA, it should be possible to estimate the benefits of different options on both a regional and worldwide basis.

3.4 **Operational measures**

3.4.1 While the primary focus has been to reduce noise at source through certification or through restrictions on noisier aircraft, there is some scope for alleviating impact on neighbouring communities through noise abatement operating measures. There are several methods of achieving noise abatement. The appropriateness of any of these measures depends on the physical lay-out of the airport and its surroundings, but in all cases the procedures must give priority to safety considerations.

3.4.2 ICAO has developed standard operating procedures for take-off and initial climb which are designed to minimize noise on the ground. At many airports, aircraft use these procedures or others specific to the local situation. New take-off noise abatement procedures are currently under consideration by CAEP, following a review by safety experts.

3.4.3 Airlines are often assigned the preferential use of runways and minimum altitudes for take-off and landing when overflying populated areas. Sometimes airport authorities make directional use of certain runways, or use them primarily for take-offs or landings. Rotation of runway use and restrictions on the use of reverse thrust on landing are also in effect at some airports to reduce sideline and other ground noise.

[11]Council Regulation (EC) No 925/1999 of 29 April 1999 on the registration and operation within the Community of certain types of civil subsonic jet aeroplanes which have been modified and recertificated as meeting the standards of Volume I, Part II, Chapter 3 of Annex 16 to the *Convention on International Civil Aviation*, third edition (July 1993).

3.5 Land-use planning

3.5.1 Land-use planning is an effective means to ensure that the activities nearby airports are compatible with aviation. Its main goal is to minimize the population affected by aircraft noise by introducing land-use zoning around airports. Compatible land-use planning and control is also a vital instrument in ensuring that the gains achieved by the reduced noise of the latest generation of aircraft are not offset by further residential development around airports.

3.5.2 ICAO has developed guidance on land-use planning.[12] This includes guidance on using various tools for the minimization of the impact of aircraft noise in the vicinity of airports and describes the practices adopted for land-use planning and control in several States.

4. AIRCRAFT ENGINE EMISSIONS

4.1 Description of the problem

4.1.1 When aircraft engines burn fuel, they produce emissions that are similar to other emissions resulting from fossil fuel combustion. However, aircraft emissions are unusual in that a significant proportion is emitted at altitude. These emissions give rise to important environmental concerns regarding their global impact and their effect on local air quality.

4.1.2 At a global level, the most comprehensive assessment to date is a *Special Report on Aviation and the Global Atmosphere*[13], which was produced in 1999 at ICAO's request by the Intergovernmental Panel on Climate Change (IPCC), in collaboration with the Scientific Assessment Panel to the Montreal Protocol. This report assesses the effects of the past, present and potential future fleets of subsonic and supersonic aircraft on climate and atmospheric ozone. The objective of the report is to provide accurate, unbiased, policy-relevant information to serve the aviation industry, environmental experts and policymakers. In describing the current state of knowledge, it also identifies areas where our understanding is inadequate and where further work is urgently required. Consistent with IPCC practice, the report does not make policy recommendations or suggest policy preferences. This is the first IPCC report for a specific industrial subsector and a unique aspect of the report is the integral involvement of technical experts from the aviation industry, including airlines and airframe and engine manufacturers, alongside atmospheric scientists.

4.1.3 With regard to climate change, the IPCC Report estimates that aircraft contribute about 3.5 per cent of the total radiative forcing[14] by all human activities and that this proportion is likely to increase. The emissions from aircraft of relevance for climate change include carbon dioxide (CO_2), water vapour,

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[12]Airport Planning Manual (Part 2 — Land-Use and Environmental Control. Document 9084. A revised edition of this manual is currently in preparation.

[13]This report has a *Summary for Policymakers* which is available in six UN languages (Arabic, Chinese, English, French, Russian and Spanish) and is accessible at IPCC's Website (www.ipcc.ch). The report itself (over 300 pages) is published in English only and can be purchased from Cambridge University Press (www.cup.cam.ac.uk).

[14]Radiative forcing is a measure of the importance of a potential climate change mechanism.

nitrogen oxides (NO_x), sulphur oxides and soot. For more information on some of the key findings of the IPCC Report insofar as they relate to describing aviation's contribution to climate change, see the Box on page 9.

4.1.4 The IPCC Report also assesses what is known about aviation and depletion of the ozone layer. This does not appear to be an issue insofar as emissions from the present subsonic fleet are concerned, but could possible become one if there were to be a significant fleet of supersonic civil aircraft.

4.1.5 At ground level, in the immediate vicinity of airports, and regionally, concerns focus on the potential health and environmental effects of emissions such as NO_x, volatile organic compounds and particulates.

4.1.6 Future concerns about aviation's role in both climate change and local air quality are largely due to the projected continued growth. While past technological improvements have reduced the growth rate of emissions and this progress is expected to continue into the future, total emissions will continue to increase. For example, the IPCC Report projects aviation growth of 5 per cent per year between 1990 and 2015 with fuel consumption and CO_2 emissions growing at 3 per cent annually over the same period.

Key findings of the IPCC Report
concerning aviation's contribution to climate change

Aircraft Emissions. Aircraft emit gases and particles directly into the upper troposphere and lower stratosphere where they have an impact on atmospheric composition. These gases and particles alter the concentration of greenhouse gases, including carbon dioxide, ozone, water vapour and methane, trigger the formation of condensation trails (otherwise known as contrails), and may increase cirrus cloudiness — all of which contribute to climate change.

Radiative Forcing. The climate impacts of the gases and particles emitted and formed as a result of aviation can be compared to each other and to climate effects from other sectors by using the concept of radiative forcing. This is a measure of the importance of a potential climate change mechanism and expresses the perturbation or change to the energy balance of the Earth-atmosphere system in watts per square metre (Wm^{-2}). Positive values of radiative forcing imply a net warming, while negative values imply cooling. The major contributors from aircraft emissions to the radiative forcing are carbon dioxide, ozone, methane (negative effect) and contrails, with minor contributions from water vapour, sulfate aerosols (negative effect) and soot. The contribution from cirrus clouds is projected to be positive and could be quite significant, but our current lack of scientific understanding precludes a quantitative assessment of its contribution. While the contributions from carbon dioxide, ozone, methane (opposite sign) and contrails are comparable in magnitude, the uncertainties associated with ozone, methane and contrails are much larger than those associated with carbon dioxide.

Current impact of aircraft emissions on climate. The best estimate of the radiative forcing by aircraft is 0.05 Wm^{-2} (0.01 to 0.1 Wm^{-2}) for the year 1992, or about 3.5 per cent of the total radiative forcing by all human activities. These estimates of forcing combine the effects of changes in all greenhouse gas concentrations, aerosols and line-shaped contrails, but do not include possible changes in cirrus.

Projected impact of subsonic aircraft emissions on climate. For the reference scenario used in the IPCC Report, the projected radiative forcing from subsonic aircraft emissions in 2050 is 0.19 Wm^{-2} or 5 per cent of the radiative forcing in the mid-range IS92a scenario (one of a range of scenarios, IS92a-f that IPCC has developed for future emissions from all anthropogenic sources, based on assumptions concerning population and economic growth, land use, technological changes, energy availability, and fuel mix during the period 1990 to 2100). For the full range of scenarios considered in the report, the radiative forcing is projected to grow to 0.13 to 0.56 Wm^{-2} in 2050, which is 2.6 to 11 times the value in 1992, and compares to the mid-range IS92a scenario of 3.8 Wm^{-2} in 2050.

Projected impact of supersonic aircraft emissions on climate. One possibility for the future is the development of a fleet of second-generation supersonic, high speed civil transport aircraft (HSCT)[15]. If a fleet of supersonic aircraft were developed to cruise at an altitude of about 19 kilometres, they would emit carbon dioxide, water vapour, oxides of nitrogen and sulfur, and soot directly into the lower stratosphere. Assuming a fleet of supersonic aircraft started operation in 2015, growing to a maximum of 1 000 aircraft by 2040 and displacing a portion of the subsonic fleet in the reference scenario, by 2050 the combined subsonic and supersonic fleet is projected to add a further 0.08 Wm^{-2} to the 0.19 Wm^{-2} radiative forcing projected for the reference scenario. Most of this additional forcing is due to the increased concentration of stratospheric water vapour.

Source: Article by Robert Watson, Chairman of the IPCC. ICAO Journal, September 1999.

4.2 **Mitigation measures**

4.2.1 In addition to assessing what is known about aviation's contribution to global atmospheric problems, the IPCC Report also explored options to reduce aircraft emissions. It identified a range of options, including changes in aircraft and engine technology, fuel, operational practices, and regulatory and economic measures. However, the IPCC Report noted that a number of factors will govern the rate at which technology advances and policy options related to technology can reduce aviation emissions: safety of operation, operational and environmental performance, cost, and the typical life expectancy of an aircraft of 25 to 35 years.

4.2.2 Whereas mitigating aircraft noise primarily involves ICAO and the aviation community, addressing the impact of aircraft engine emissions is somewhat more complex in that aviation is one of many contributors to emission-related problems. Consequently, responsibility for mitigation is shared among many human activities, each with different scope for taking action and differences in likely costs. There are also

[15] As the IPCC Report notes in the Summary for Policymakers, there is considerable uncertainty whether any such fleet will be developed.

institutional considerations. A number of other UN bodies with mandates in the emissions field have expressed an interest in aircraft engine emissions, including the policy-making bodies of the UN Framework Convention on Climate Change (UNFCCC), the Montreal Protocol on Substances that Deplete the Ozone Layer and, under the auspices of the UN Economic Commission for Europe, the Convention on Long-range Transboundary Air Pollution. In each of these cases, an understanding has been reached based on cooperation and avoidance of unnecessary duplication.

4.2.3 Of primary importance is the UN Framework Convention on Climate Change. Although the Convention does not specifically refer to emissions from aviation, its coverage includes emissions from all sources. One of the commitments in the Convention is that parties compile national inventories of their emissions sources. For domestic flights, emissions are considered to be part of the national inventory of the country within which the flights occur. For international flights, the problem is how to allocate the emissions (referred to as "emissions from international aviation bunker fuels" in UNFCCC terminology, although "international" is not always specified) to national inventories. A similar problem exists for shipping. To date, there has been no agreement among parties to the Convention on how to resolve this problem.

4.2.4 The Kyoto Protocol to the Convention, which was adopted in December 1997 but has not yet entered into force, requires countries listed in Annex I to the Convention (industrialized countries) to reduce their collective emissions of greenhouse gases by approximately 5 per cent by the 2008–12 period compared with 1990 levels, with the reduction varying from country to country. These targets focus on six greenhouse gases, the one most relevant to aviation being CO_2. Since the targets apply to national totals of greenhouse gases, each Annex I country can determine how the various emission-producing sectors in its economy should be called upon to assist in achieving the country's national target. Because international aviation emissions are not included in national inventories, they are currently excluded from the targets. Instead, Article 2, paragraph 2 of the Kyoto Protocol states that the responsibility for limiting or reducing emissions from aviation bunker fuels shall fall to the Annex I parties, working through ICAO.

4.2.5 The adoption of the Kyoto Protocol has given increased momentum to the work of ICAO's Committee on Aviation Environmental Protection (CAEP) in the emissions field. The 32nd Session of the ICAO Assembly, in September/October 1998, requested the Council of ICAO, through CAEP, to "study policy options to limit or reduce the greenhouse gas emissions from civil aviation, taking into account the IPCC special report and the requirements of the Kyoto Protocol", and to report to the next ordinary session of the Assembly in late 2001.[16]

4.2.6 In addressing concerns associated with aircraft engine emissions, the work in progress in CAEP is guided by three main principles:

– Measures to address emissions should take into account environmental need, technical feasibility and economic reasonableness.

– Measures to address emissions should also take into account any potential implications for safety, which must not be compromised, and for aircraft noise. Measures aimed at one type of emission (for example, CO_2) or one emission-related problem (for example,

[16]Assembly Resolution A32-8, Appendix F.

climate change) should take into account any potential implications for other types of emission or for other emission-related problems.

– Measures to address emissions should be developed on a harmonised worldwide basis, wherever possible.

4.2.7 This work on emissions falls into three categories, namely technology and standards, operational measures, and market-based options, each of which is considered separately below.

4.3 **Improved technology and new standards**

4.3.1 CAEP has been considering to what extent technology can help, through improved engine or airframe design, to achieve reductions in emissions.

4.3.2 The present ICAO standards for emissions certification of aircraft engines, which are contained in Volume II of Annex 16 to the Convention on International Civil Aviation, were originally designed to respond to concerns regarding air quality in the vicinity of airports. As a consequence, they establish limits for emissions of NO_x, carbon monoxide (CO), unburned hydrocarbons (HC) and smoke, for a reference landing and take-off (LTO) cycle below 915 metres of altitude (3 000 ft). These limits are expressed in terms of mass of emissions per unit of engine thrust.

4.3.3 While these standards are based on an aircraft's LTO cycle, they also help to limit emissions at altitude. Of particular relevance is the standard for NO_x, a precursor for ozone. At ground level, ozone takes part in the smog chemistry, while at altitude it is a greenhouse gas. The standard for NO_x was first adopted in 1981, then made more stringent in 1993, when ICAO reduced the permitted levels by 20 per cent for newly certificated engines, with a production cut-off on 31 December 1999. In 1998, CAEP recommended a further tightening of about 16 per cent on average for engines newly certificated from 31 December 2003, a measure adopted by the ICAO Council in February 1999.

4.3.4 CAEP is now carrying out assessments of technological advances so that ICAO standards can be modified to specifically address emissions of greenhouse gases. In particular, it is studying alternate emissions methodologies that will encompass all phases of flight (climb and cruise emissions as well as the LTO cycle). In addition to considering the types of emissions already covered by ICAO standards, the new methodologies will take into account fuel efficiency and productivity of the whole aircraft, which would have a direct bearing on CO_2 emissions. CAEP will also follow developments in the characterization and measurement of other emissions, such as particulates that could be relevant to contrail production and additional cirrus cloud formation. This is a very complex task, requiring close cooperation with industry and scientific experts, and recommendations for new methodologies are not expected to be competed until 2001. If required, new provisions based on these emissions methodologies will subsequently be developed for inclusion in Annex 16.

4.4 **Operational measures**

4.4.1 ICAO is considering to what extent operational measures might help to reduce the amount of emissions of greenhouse gases produced. Work is currently focussed on two key deliverables by January 2001.

4.4.2 The first is a quantification of the environmental benefits possible with the implementation of ICAO's satellite-based CNS/ATM (communications, navigation, surveillance/air traffic management) systems. This is a coordinated effort between the Federal Aviation Administration (United States) and the European Organization for Safety of Air Navigation – EUROCONTROL (29 European States). The study methodology and an initial global assessment of the environmental benefits of CNS/ATM have been completed. This initial study quantifies the emissions reductions to be achieved both in Europe and the United States based on planned enhancements to the respective air traffic environments, and provides baseline assessments of the various ICAO regions on which to base future improvements. Next steps will be to work with ICAO's regional planning groups to help them incorporate environmental considerations into their CNS/ATM implementation plans, and to provide an assessment of those benefits.

4.4.3 The second is draft guidance material for States and the wider aviation community on operational opportunities to reduce aircraft engine emissions. The goal of the document is to offer practical information to reduce aircraft engine emissions through changes in operational procedures and practices. The document incorporates a wide variety of inputs from airlines, airports, and air traffic service providers to provide an end-to-end look at practices now in use to reduce emissions. It has sections on technology, maintenance, non-revenue flying, weight reduction, load factor, flight planning, airports, take-off, climb, cruise, descent and landing, infrastructure, etc. The next step will be to finalize the document and to make it publicly available as an ICAO Circular.

4.5 **Market-based options**

4.5.1 CAEP is also considering the use of market-based options as a potentially attractive means of limiting greenhouse gas emissions at the lowest possible cost, with a main emphasis on carbon dioxide. This work is described in greater detail in Section 5 on economic instruments.

5. **ECONOMIC INSTRUMENTS**

5.1 **Economic instruments to address aircraft noise**

5.1.1 ICAO has been addressing the application of economic instruments to reduce or eliminate the adverse environmental consequences of civil aviation for many years. Initially attention was focussed on aircraft noise, which led to the development in 1981 of a specific ICAO policy on noise-related charges[17], reproduced in **Appendix 1**, which is contained in the *Statements by the Council to Contracting States on Charges for Airports and Air Navigation Services* (Doc 9082/5).

5.1.2 Noise-related charges have been effective in encouraging aircraft operators to accelerate the introduction of quieter aircraft. The ICAO policy on noise-related charges has found wide acceptance, and requests for change have not been received from States nor aircraft operators directly or through the CAEP process. Practical advice on determining the cost basis for noise-related charges and their collection is provided

[17]As defined by ICAO "charges are levies to defray the costs of providing facilities and services for civil aviation whereas taxes are levies to raise general national and local government revenues that are applied for non-aviation purposes".

in the ICAO *Airport Economics Manual* (Doc 9562), and information on noise-related charges actually levied is provided in the ICAO *Manual of Airport and Air Navigation Facility Tariffs* (Doc 7100).

5.2 Economic instruments to address the impact of aircraft engine emissions

5.2.1 ICAO first addressed the introduction of emission-related charges at the 1991 Conference on Airport and Route Facility Management. The Conference recommended that a study be undertaken of whether charges could be an effective means of reducing adverse environmental consequences of aircraft engine emissions. It also recommended that in the meantime if charges were to be considered, some basic principles should be taken into account (no fiscal aims, no distortion of competition with other modes of transport, efficient use of aircraft capacity not prevented, and cost relatedness), an approach subsequently endorsed by the 31st Session of the ICAO Assembly in 1995. The Council of ICAO subsequently approved this recommendation and assigned the study to CAEP.

5.2.2 Subsequent to the 31st Session of the Assembly it became apparent that there was a need for a formal indication of ICAO's position with regard to emission-related levies. Underlying this development was the growing interest in the possible application of environmental charges or taxes to civil aviation expressed in other international fora, primarily ones within the United Nations system (for example, the Commission on Sustainable Development and the UN Framework Convention on Climate Change) and also the European Union. The Council noted that delaying a policy statement by ICAO on emission charges until CAEP had completed its work in that area could compromise ICAO's role in protecting the interests of civil aviation since other UN policy-making bodies might take action with regard to emission-related levies, possibly detrimental to civil aviation in the absence of an ICAO policy. At least an interim statement from ICAO was therefore required. The Council also noted in this respect that relevant policy guidance already existed in the Council Statements in Doc 9082/5 and ICAO's *Policies on Taxation in the Field of International Air Transport* (Doc 8632). However, neither emission-related charges nor emission-related taxes were specifically identified in these policy statements and it was desirable to have ICAO's position on this complex subject recorded in a single concise text. On the basis of these and other factors the Council adopted in December 1996 the *Council Resolution on Environmental Charges and Taxes*, reproduced in **Appendix 2**. Although the title of the Resolution refers to environmental charges and taxes, the Resolution in fact focusses only on emission-related charges and taxes. In the resolution the Council "Strongly recommends that any environmental levies on air transport which States may introduce should be in the form of charges rather than taxes...".

5.2.3 In April 1998, CAEP presented a major progress report on emission-related levies, based on a study carried out within the Committee. While initially having intended to focus on emission-related charges, CAEP, in the report considered a number of options that were either charges or taxes as defined by ICAO. Noting that the generic term "levies" covered both charges and taxes, CAEP used this term throughout the report. The report addressed, *inter alia*, specification of the emission levies such as the substance to which a levy would apply (for example CO_2 and NO_x), and the collection and application of the levy. Basically four options were considered, that is a fuel levy, a ticket levy, a route levy and an airport levy; as well as the effectiveness of each in reducing emissions depending on whether a global or local pollution problem is involved. As to levy application the report considered a revenue neutral application, a general taxation application, levy application based on a prevention cost approach, and application involving paying damages suffered by third parties. The report also addressed implementation aspects of environmental levies both as they relate to levy collection as well as to levy application, and the role of ICAO with regard to such levies. Preliminary analysis had shown that with regard to the global problem the route or fuel levy would be most

effective, while an airport levy would be most effective in reducing local emission problems. However, with regard to a fuel levy – in effect tax – option, the report noted that ninety-seven per cent of bilateral air services agreements contained provisions exempting fuel used in international operations from taxes, consistent with well-established and long-standing policies of ICAO. CAEP emphasized the preliminary nature of its report and that much further work needed to be undertaken, including harmonizing the many different views that existed in this area.

5.2.4 In the light of the report prepared by CAEP, the 32nd Session of the ICAO Assembly in September/October 1998 requested the Council of ICAO to further pursue the issue of emission-related levies with a view to reaching conclusions prior to the next Assembly session in late 2001, while requesting States follow the existing Council guidance in the interim and not take unilateral action inconsistent with that guidance.[18]

5.2.5 CAEP has subsequently taken up this matter again. It is currently identifying and evaluating the potential role of market-based options, including emission-related levies, emissions trading and voluntary programmes, as a means of limiting greenhouse gas emissions. As the IPCC Special Report has indicated, there are several different emissions from aircraft engines that play a role in climate change. However, this tends to complicate the design and evaluation of market-based options. It has therefore been decided to focus on CO_2 emissions only at this stage, while leaving open the possibility of accommodating other emissions later, if appropriate. Since CO_2 production is proportional to fuel consumption, focussing on CO_2 means focussing on fuel consumption.

5.2.6 The use of market-based options raises a number of important economic, environmental, legal and administrative issues that must be fully evaluated. In order that different types of market-based options can be evaluated on a consistent basis, an initial set of common assumptions has been developed:

– Initially, two targets for emission reductions will be examined. Starting with a business-as-usual scenario, one target would reflect the average emission reduction required in the Kyoto Protocol for the first commitment period (5% below the chosen base year), while a second target would reflect a reduction of half the projected aviation growth rate in that period.

– Two alternatives for geographic scope will be examined, one assuming implementation on a world-wide basis, the other assuming industrialized countries only.

5.2.7 On this basis, an initial set of specifications for the various market-based options have been developed.

5.2.8 As regards **emission-related levies**, the initial options being evaluated include:

– A fuel tax, with revenue going to national treasuries.

– A revenue-neutral charge based on aircraft efficiency, with higher charges on less fuel-efficient aircraft offset by lower charges on more fuel-efficient ones.

[18]Assembly Resolution A32-8, Appendix H.

– An en-route emissions charge, with revenues recycled to the aviation sector (for example, to defray the costs of the harmful effects of emissions and to support air traffic modernisation, early retirement of aircraft, and research and development activities).

5.2.9 For **emissions trading**, options include an open system, in which emissions from all aviation sources (domestic and international) are treated identically to other emissions, and trading may take place between the aviation sector and other sectors.

5.2.10 CAEP is also considering the possibilities of voluntary programmes, as well as hybrid options drawing on elements from each of the three approaches under consideration (levies, trading and voluntary programmes).

5.2.11 Following specification of the initial set of market-based options, analysis has begun on the associated economic impacts and environmental benefits. Meanwhile, work continues on refining these options and assessing administrative and legal issues. The assessment and option refinement process will continue over the next several months, leading to the preparation of an assessment report in time for the next full CAEP meeting in early 2001.

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Table 1

ICAO Traffic Forecasts by Route Group to The Year 2020

	Passenger-kms (billions)		Average Annual Growth(%)
	1997	**2020**	**1997–2020**
International Routes			
North Atlantic	316.1	753	3.8
South Atlantic	35.6	119	5.4
Mid Atlantic	41.2	140	5.5
Transpacific	178.0	712	6.2
Europe<=>Asia/Pacific	208.4	758	5.8
Europe<=>Africa	76.6	217	4.6
Europe<=>Middle East	38.3	98	4.2
North America<=>South America	39.5	114	4.7
North America<=>Central America/ Caribbean	39.3	125	5.1
Intra Africa	7.1	18	4.1
Intra Asia/Pacific	208.9	701	5.4
Intra Europe	150.5	370	4.0
Intra Latin America	15.1	48	5.1
Intra Middle East	4.7	12	4.2
Intra North America	24.0	46	2.9
Other International Routes	94.8	334	5.6
Total International	**1478**	**4564**	**5**
Domestic Routes			
Africa	9.4	22	3.7
Asia/Pacific	201.1	651	5.2
Europe	111.6	280	4.1
Latin America	42.5	105	4.0
Middle East	11.8	30	4.1
North America	716.5	1428	3
Total Domestic	**1092.9**	**2516**	**3.7**
Global (International + Domestic)	**2570.9**	**7080**	**4.5**

Figure 1

54 Years of Traffic Development

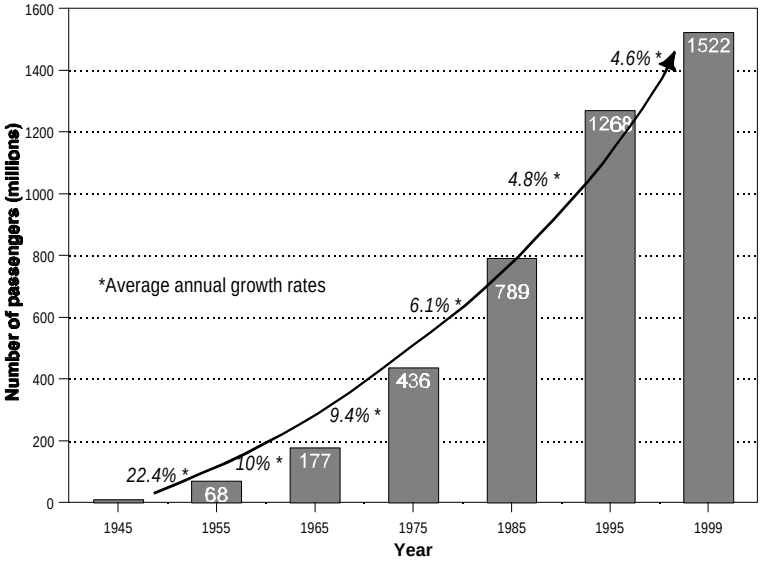
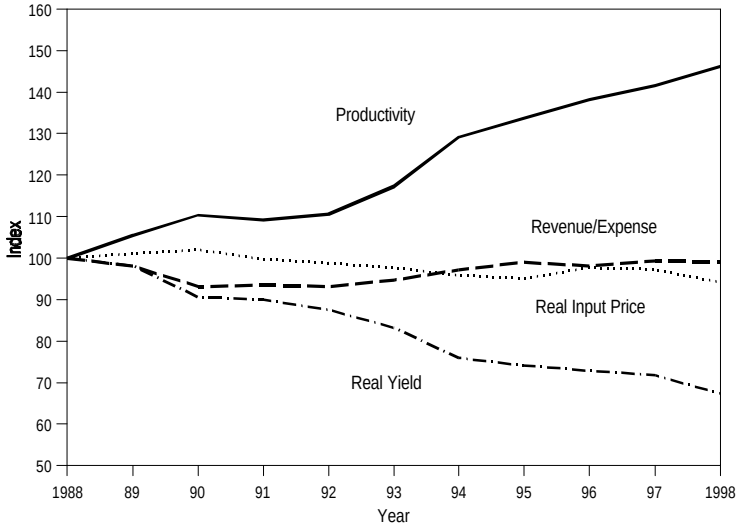


Figure 2

Trends in Performance of the Airline Industry
Scheduled Operations



Appendix 1

EXCERPT FROM THE *STATEMENTS BY THE COUNCIL TO CONTRACTING STATES ON CHARGES FOR AIRPORTS AND AIR NAVIGATION SERVICES* (DOC 9082/5)

"**Noise-related charges**

21. The Council recognizes that although reductions are being achieved in aircraft noise at source, many airports will need to continue the application of noise alleviation or prevention measures. The Council considers that the costs incurred in implementing such measures may, at the discretion of States, be attributed to airports and recovered from the users and that States have the flexibility to decide on the method of cost recovery and charging to be used in the light of local circumstances. In the event that noise-related charges are to be levied the Council recommends that consultations should take place on any items of expenditure to be recovered from users and that the following principles be applied:

i) Noise-related charges should be levied only at airports experiencing noise problems and should be designed to recover no more than the costs applied to their alleviation or prevention.

ii) Any noise-related charges should be associated with the landing fee, possibly by means of surcharges or rebates, and should take into account the noise certification provisions of Annex 16 in respect of aircraft noise levels.

iii) Noise-related charges should be non-discriminatory between users and not be established at such levels as to be prohibitively high for the operation of certain aircraft."

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Appendix 2

COUNCIL RESOLUTION
ON ENVIRONMENTAL CHARGES AND TAXES

Adopted by the Council on 9 December 1996 at the 16th Meeting of its 149th Session

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

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

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

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

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

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

Having in mind:

a) that ICAO has established emission standards for new aircraft engines and the work programme of the Council's Committee on Aviation Environmental Protection (CAEP) is aimed at addressing emission-related problems and identifying appropriate solutions, taking into account technical feasibility, economic reasonableness and environmental effectiveness;

b) that work on emission-related charges is in progress within CAEP, the results so far indicating that the environmental impact of aircraft emissions needs to be understood and quantified before determining the best method for reducing their impact and that both regulatory measures and charges can provide effective instruments in reducing emission levels, but that it is not possible to make any general conclusion at this time as to which of these is preferable;

c) that Article 15 of the *Convention on International Civil Aviation* contains provisions regarding airport and similar charges, including the principle of non-discrimination, and that

ICAO has developed policy guidance for States regarding charges (*Statements by the Council to Contracting States on Charges for Airports and Air Navigation Services*, Doc 9082/4); and

d) that ICAO has developed separate policy guidance to States on taxation (*ICAO's Policies on Taxation in the Field of International Air Transport*, Doc 8632), which recommends *inter alia* the reciprocal exemption from all taxes levied on fuel taken on board by aircraft in connection with international air services, a policy implemented in practice through bilateral air services agreements, and also calls on States to the fullest practicable extent to reduce or eliminate taxes related to the sale or use of international air transport;

The Council

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

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

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

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

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

b) funding scientific research into their environmental impact; or

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

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

a) there should be no fiscal aims behind the charges;

b) the charges should be related to costs; and

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

—END—