ICAO Environmental Report 2007

Produced by the Environmental Unit of the International Civil Aviation Organization (ICAO)
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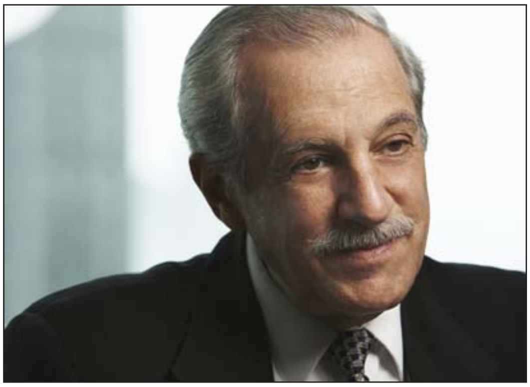
Foreword



President of the Council of the International Civil Aviation Organization (ICAO), Mr. Roberto Kobeh González

Leadership in environmental protection requires consensus among a wide variety of stakeholders, sometimes with widely diverging interests, on highly complex social, economic and technological issues.

As the global forum for international civil aviation, ICAO has succeeded for more than forty years in bringing the world together around increasingly stringent regulations for noise at airports and aircraft engine emissions, yet more must be done. The growth of air transport in many parts of the world is outpacing our capability to limit the impacts of air travel on local air quality and climate change.

Fortunately, there has emerged in recent years a willingness to confront the problems. Environmental concerns now permeate the planning and strategies of global aviation stakeholders. There is a growing recognition that solutions must and will come from the aviation sector.

We need to find the most effective way of reaching and maintaining an appropriate balance between the growth of the air transport industry and environmental protection. As we proceed, it is imperative that we base our discussions and decisions on the most authoritative and credible technical and scientific information available. We need to better understand aviation's contribution to climate change as we strive for effective and long-term solutions.

This is the *raison d'être* of the first-ever ICAO Environmental Report. It serves as a comprehensive update on technical and policy aspects of aircraft noise and engine emissions. Readers will find within these pages a detailed review of progress achieved under the leadership of ICAO, the official global forum for addressing aviation environmental matters.

As important as accurate and authoritative information is cooperation among all stakeholders and parties concerned. Moving forward, we must ensure that whatever action is taken is done so in a harmonized manner, taking into account diverging views on addressing environmental matters. Our common focus must remain an appropriate balance between aviation and the environment.

It is my hope that this Environmental Report becomes a catalyst for generating a wide consensus, in a spirit of global cooperation, on the way to a sustainable air transport system.

Mr. Roberto Kobeh González

Report Overview

Mrs. Jane Hupe
Chief of ICAO Environmental Unit

As the world evolved to a truly global society over the years, the need for mobility increased. At the same time, technological improvements and market forces made air travel more accessible and more affordable. About 2.2 billion passengers fly on the scheduled services of the world's airlines per year, one third of them on international flights. Initiatives to promote the sustainability of aviation activities in synchronization with the growth of the industry over the past four decades have been quite successful, with noise from aircraft reduced by 75% and CO_2 emissions intensity by 70%. New advances in technology and operational measures, however, will not be sufficient to offset the projected growth of the sector and new strategies to achieve sustainability must be developed and implemented.

In this global pursuit, transparent and accurate information on aviation's performance relative to the environment is critical and must be available to decision makers and the public. A case in point is the latest IPCC report which provides scientific evidence that human activities are contributing to climate change. It reveals that aviation's CO_2 contribution (international and domestic operations) remains at about 2% of total global amounts. This percentage is by far less important than the contributions from road transport or power generation, amongst other sources. Nevertheless, ICAO is firmly committed to ensuring that international civil aviation contributes its share to efforts on climate change.

As with all of ICAO policies, those that deal with the environment are developed in keeping with the fundamental principle that aviation is a global industry and, as such, requires global solutions. In fact, this may be more so with environmental matters (please see inset box).

The goal of this report is to consolidate in one single publication comprehensive and reliable information on aviation and the environment. In accessible language, readers will find up to date information on the work of ICAO and other relevant bodies. Intended primarily for ICAO Contracting States, the aviation community and interested members of the public, the Report focuses on the results of the seventh meeting of ICAO's Committee on Aviation Environmental Protection (CAEP/7), held in February 2007 and on the ICAO Aviation Emissions Colloquium (May 2007). It also pays particular attention to studies and reports from the IPCC and developments emanating from other relevant UN fora such as the UNFCCC in reference to aviation.

The Report consists of six parts which, together, cover the full range of issues, developments and trends: **Aviation Outlook; Aircraft Noise; Local Emissions; Global Emissions; Modelling and Databases; and International Cooperation**. For ease of reading and consulting, each part begins with an overview to bring readers up to speed on the subject discussed, followed by articles from experts. Most of the material covered in this Report reflects the work of ICAO and its groups of experts, although some articles are dedicated to main developments outside ICAO of relevance to the discussions on aviation and the environment. The Report also contains advertorials which provide the opportunity for stakeholders to promote their own perspective and activities.

We sincerely hope that this Report will stimulate productive and enlightened discussions on aviation and the environment, while at the same time demystifying commonly-held beliefs and misconceptions. Arriving at optimal solutions begins with clearly defining the challenges and these can only be done using the most recent and sound information available. This is especially true for climate change, one of the most pressing societal issues of this early part of the 21st century and a priority for both the UN and ICAO. Without a global approach, unilateral actions may well lead to fragmented and ineffective measures.

As we prepare for the post-2012 period, we must consider a long-term global response in line with the latest scientific findings. We must set development goals in a sustainable way; realizing the full potential of technological, operational and market-based measures. Above all, we must do it together, under the leadership of ICAO and in cooperation with all stakeholders.

Acknowledgements

This Report is a good example of global cooperation towards a common cause. ICAO wishes to thank the authors from various countries and disciplines who have honoured by shared their expertise, imagination and enthusiasm. We are truly grateful, for we feel that their collective insight will stimulate dialogue and contribute to defining sustainable solutions.

We look forward to comments and suggestions on how we can improve the Environment Report which, in years to come, will be published to coincide with the triennial Assemblies of ICAO.

Mrs. Jane Hupe

ABOUT ICAO AND THE ENVIRONMENT

ICAO is a specialized agency of the United Nations created in 1944, with the signing of the Convention on International Civil Aviation, to promote the safe and orderly development of global air transport. ICAO has been in the forefront of aviation environmental issues since the late 1960's. The Organization's work on the environment focuses primarily on those problems that benefit most from a common and coordinated approach on a worldwide basis, namely aircraft noise and engine emissions. Standards and Recommended Practices (SARPs) for the certification of aircraft noise and aircraft engine emissions are covered by Annex 16 of the Convention.

ICAO has a membership of 190 Contracting States and works closely with other UN bodies and international organizations with an interest in aviation. ICAO has established three environmental goals:

- to limit or reduce the number of people affected by significant aircraft noise;
- to limit or reduce the adverse impact of aviation emissions on local air quality; and
- to limit or reduce the impact of aviation greenhouse gas emissions on the global climate.

ICAO's Committee on Aviation Environmental Protection (CAEP) is a technical committee of the ICAO Council and undertakes most of the Organization's work in this area. It is the international forum of expertise for the study and development of proposals to minimize the impact of aviation on the environment. Every proposal in CAEP is analysed according to four criteria: technical feasibility; environmental benefit; economic reasonableness and in terms of the interrelationship between measures.

The ICAO Council reviews and adopts the CAEP recommendations. It then reports to the ICAO Assembly, the highest body of the Organization, where the main policies on aviation environmental protection are defined and translated into Assembly Resolutions. The Organization also produces studies, reports, manuals and circulars on the subject of aviation and environment. More information on ICAO's activities in this area can be found at:

www.icao.int/environment

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Aviation Outlook

Aviation Outlook Overview

By ICAO Secretariat

This part of the report presents ICAO's outlook on global demand for air transport services, as well as the global air traffic and aircraft fleet forecasts as prepared by ICAO/CAEP's Forecasting and Economic analysis Support Group (FESG).

Air Traffic Outlook

The development and growth of air transport depends on various factors including economic growth, fuel price changes, airline productivity gains, and airports and airspace capacity. This article briefly describes the past trends observed in these factors, and summarizes ICAO's long-term air traffic forecast up to the year 2025.

Global Air Traffic and Aircraft Fleet Forecasts

Air traffic and aircraft fleet forecasts produced by the FESG are used by CAEP in their assessments of the costs and the environmental benefits of the potential options available to mitigate the impact of civil aviation on the environment.

This article describes the methodology used by the FESG to develop such forecasts, summarizes the most recent set of forecasts available, and assesses its accuracy by comparing its results to the actual data. It shows that over the period 2000-2005, the gap between actual traffic and fleet and the forecast is insignificant.

Key Points

The main conclusions that can be drawn from this part of the report are the following:

- Over 3 940 billion passenger-kilometres were logged by the world's scheduled airlines in 2006 (domestic and international).
- Nearly 150 billion tonne-kilometres of freight were transported by scheduled airline services in 2006 (domestic and international).
- International traffic represents almost 60% of the total scheduled passenger traffic and about 83% of freight air traffic.
- Total air passenger traffic worldwide is forecast to increase at an average annual rate of 4.6 per cent for the period 2005–2025.
- International scheduled passenger traffic is expected to increase at 5.3 per cent per annum from 2005 to 2025.
- The FESG's Global Traffic and Aircraft Fleet Forecasts continue to be the cornerstone of CAEP's analytical work.
- The FESG's Global Traffic and Fleet Forecast is scheduled to be revised in 2008 in support of the ICAO CAEP/8 work programme.

Air Traffic Outlook

By ICAO Secretariat

The development and growth of air transport depends on various factors including economic growth, fuel price changes, airline productivity gains and airports and airspace capacity. This article briefly describes the past trends observed in these factors and summarizes ICAO's long-term air traffic forecast up to the year 2025.

Trends In Major Factors Affecting Air Transport

World Economic Development

Analytical studies indicate that there is a high correlation between the growth patterns of air traffic and general economic trends in that, the demand for air transport is primarily driven by economic development. Changes in personal income affect the level of consumer purchasing power and the propensity to undertake leisure travel. Commercial activity and trade have a direct impact on the demand for business travel and for air freight. Figure 1 provides evidence of the relationship between the strength of the economy and traffic demand by illustrating the fluctuations in the rate of growth of each for the period 1960 to the present. The impact of economic slowdowns and recessions on air traffic trends is clearly visible during the following periods: 1974–75, 1980–82, 1990–91, 1998 and 2001 (the latter coupled with the unprecedented events of 11 September, 2001).

As shown in Figure 1, the world economy is subject to economic cycles; nevertheless it has steadily grown over the long term. During the period 1985–2005, the aggregate world economy measured in terms of Gross Domestic Product (GDP) increased at an average annual rate of 3.6 per cent in real terms. Over the long-term horizon to 2025, the world economy is projected to grow at an average annual rate of 3.5 per cent in real terms, marginally lower than the actual rate for the past 20 years. However, there are significant differences in the average annual rate forecast for individual regions, as shown in Table 1 below. In particular, it should be noted that the Asia/Pacific region, excluding its mature markets, is anticipated to register the highest growth of 5.7 per cent per annum mainly driven by the economies of China and India whose share in the world economy is expected to double by 2025 due to an expanding middle class and the growth in export oriented industries and services.

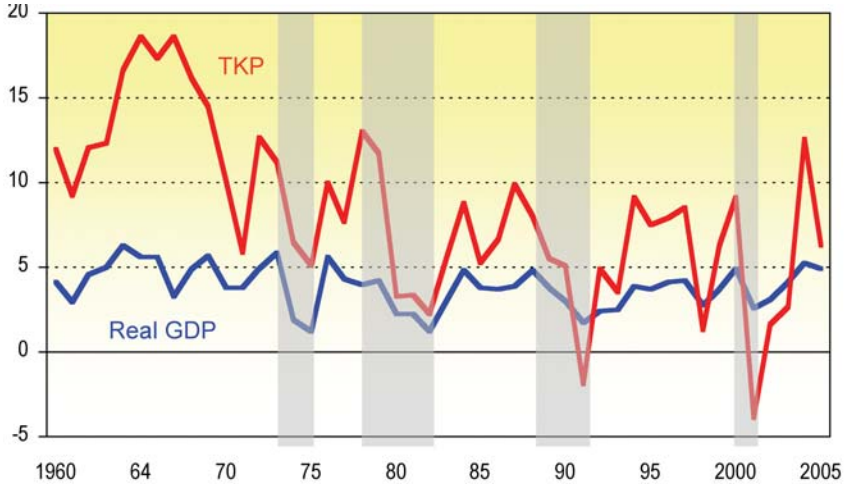

Figure 1 - Economic and airline traffic trends — World (1960–2005).
(Real GDP and total scheduled TKPs [1]).
Source: IMF, ICAO Reporting Form A

Table 1 – Economic Growth (GDP) By Region
(real average annual growth rates, per cent)

Region	Average annual growth(%) 1985-2005 Actual	2005-2025 Forecast
Africa	3.0	5.0
Asia/Pacific	5.9	4.0
Europe	2.2	2.5
Middle East	3.7	4.2
North America	3.1	3.0
Latin America and Caribbean	2.9	4.0
World	**3.6**	**3.5**

Sources: ICAO estimates based on data from the IMF, World Bank and other sources.

Fuel Price Changes

Airline operating costs are heavily influenced by jet fuel prices. As illustrated in Figure 2, the share of aircraft fuel and oil costs of total operating costs varies in direct relation to fuel prices. In the long term, fuel prices are expected to remain within the range of 40 to 60 dollars per barrel (in 2006 U.S. Dollars) and its pressure on costs is expected to remain at its current level.

[1] TKP : Tonne Kilometres Performed

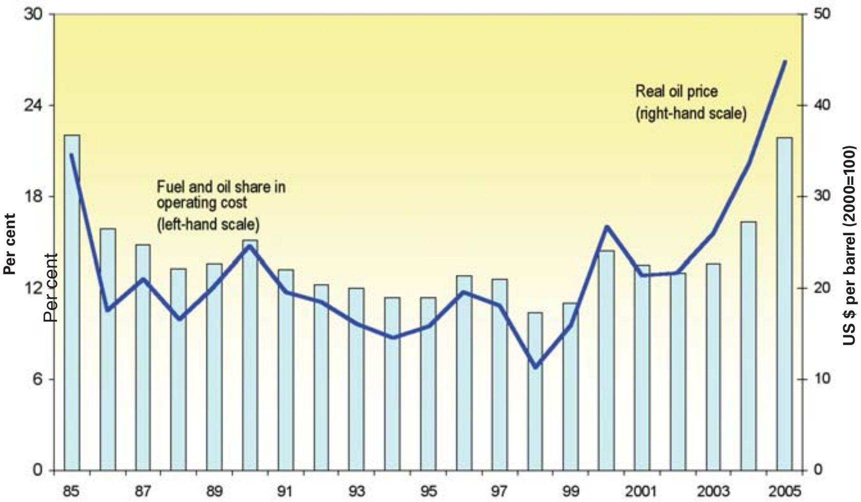

Figure 2 - Fuel and oil share of total in operating expenses for scheduled airlines - World (1985–2005).
Note: Excluding domestic operations of airlines registered in the Russia Federation prior to 1996.
Source: ICAO Reporting Forms A and EF, US Department of Energy.

Aircraft Utilization, Capacity and Load Factors

In addition to aircraft fuel costs, the other factors that have an important impact on unit costs are the productivity parameters: aircraft utilization, capacity, and load factors. As shown in Table 2, all of these parameters have increased over the past four decades, leading to substantial reductions in unit costs.

Airline Unit Revenues and Costs

Historically, airline fares have reflected the trends in operating costs and the changing competitive conditions. Airline revenue yields have declined in real terms almost every year since the advent of jet aircraft. The reductions in fares and freight rates, expressed in real terms, which occurred between 1975 and 2005, are reflected in real declines in passenger revenue per passenger kilometre as well as freight revenue per freight tonne kilometre. The reductions in passenger and freight rates contributed substantially to traffic growth because air fares represented a steadily improving bargain in comparison with many other services. Figure 3 illustrates the annual change in average passenger yield over the 1975–2005 period as well as the annual change in freight yield. Average world passenger yield measured in real terms decreased at a rate of 2.6 per cent per annum, while freight and mail yield decreased at a rate of 3.5 per cent per annum over that period. These declines in yield were the result of technological advances, better operational utilization, longer average trip lengths, greater competition, and certain economies of scale.

Over the same period (1975–2005), the operating costs per available tonne kilometre (ATK) of world scheduled airlines measured in real terms, declined on average by 2.0 per cent per annum.

Airspace and Airport Congestion

With the expected traffic growth taking place in all regions of the world, traffic congestion will put increasing pressure on the capacity of those airports where this is already an issue. The land intensive characteristics of airports and their envi-

Table 2 – Productivity Parameters - World (1965–2005).
(ICAO Contracting States)

Productivity Parameter	1965	1975	1985	1995	2005
	Average Annual Levels				
Aircraft load factor (weight load factor in per cent)	52	50	58	60	63
Aircraft utilization (hours per aircraft per year)	1 678	2 064	2 179	2 790	3 556
Average aircraft capacity (seats)	86	144	182	183	172

Note: Excluding operations of airlines registered in the CIS.
Source: ICAO

ronmental impact are serious barriers to the provision of extra runway capacity and, to a lesser extent, terminal capacity. Barriers to building new airport infrastructure may be regulatory, political or environmental in nature; in addition to the financial issues such as funding availability and barriers to foreign investment.

However to mitigate this problem, technological developments and investment in aircraft, airports and air navigation equipment will create more capacity in the air transport system to help meet future demand. A number of new airports, as well as airport expansion projects, are due for completion over the next few years. In addition, implementation of the global air traffic management operational concept under the leadership of ICAO is expected to lead to significant improvements in the management of air traffic in all phases of flight.

Scheduled Air Traffic

Over the decades, the growth experienced by the total demand for air transport has been shared to a varying extent by each of its major components — passenger, freight and mail traffic. The average growth rate for each of these components has declined since the mid-1970s as shown in Table 3. The gradual decline in mail traffic has been particularly seep, partly because of increasing competition from telecommunications and the Internet.

Over the period 1985–2005, total scheduled traffic, measured in terms of tonne-kilometres performed, grew at an average annual rate of 5.5 per cent (i.e. 1985-1995 – 5.8%, 1995-2005 – 5.2%). It is estimated that in 2006, the world's airlines carried over 2.1 billion passengers and some 40 million tonnes of freight on scheduled services. During the same year, airlines performed on scheduled services 3940 billion passenger kilometres (equivalent to 365 billion tonne kilometres), some 150 billion freight tonne kilometres (FTKs) and 4.6 billion mail tonne kilometres.

International and Domestic Traffic

International traffic has tended to grow more rapidly than domestic traffic, particularly in the case of freight. Figure 4 shows the expansion in the international and domestic components of scheduled passenger and freight traffic over the period 1985 to 2005. Over this 20-year period both passenger and freight traffic almost quadrupled on international routes.

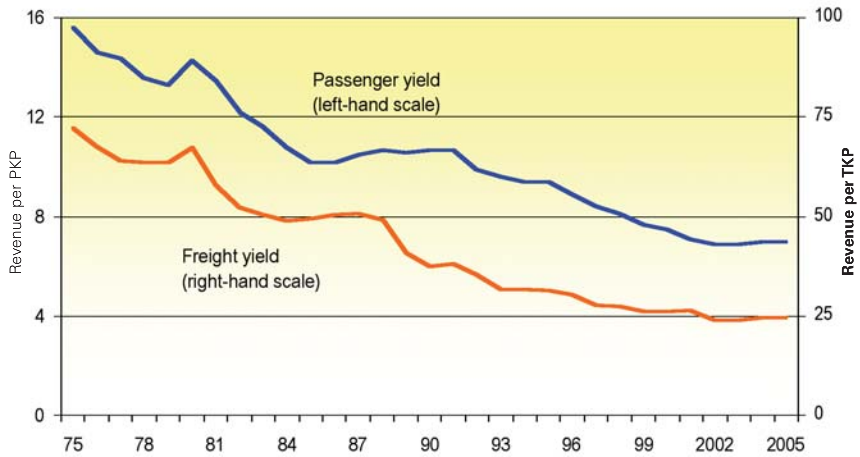

Figure 3 - Passenger and freight yields of scheduled airlines - World (1975–2005). (U.S. cents in real terms)
Note: Excluding domestic operations of airlines registered in the USSR prior to 1992 and the Russian Federation from 1992 to 1996.
Source: ICAO Reporting Form EF.

Table 3 – Trends in Total Scheduled Air Traffic — World (1975–2005). (ICAO Contracting States)

Scheduled services	Average annual growth (per cent) 1975–1985	1985–1995	1995–2005
Passenger-kilometres	7.0	5.1	5.2
Freight tonne-kilometres	7.5	7.6	5.5
Mail tonne-kilometres	4.3	2.5	-1.9
Total tonne-kilometres	7.1	5.8	5.2

Source: ICAO Reporting Form A.

Regional Distribution Of Scheduled International Traffic

Figure 5 compares the share of international passenger and freight traffic by region of airline registration in 1985 and 2005. The scheduled international traffic regional ranking in terms of passenger-kilometres performed remained almost unchanged. However, there will be a notable redistribution of freight tonne-kilometres.

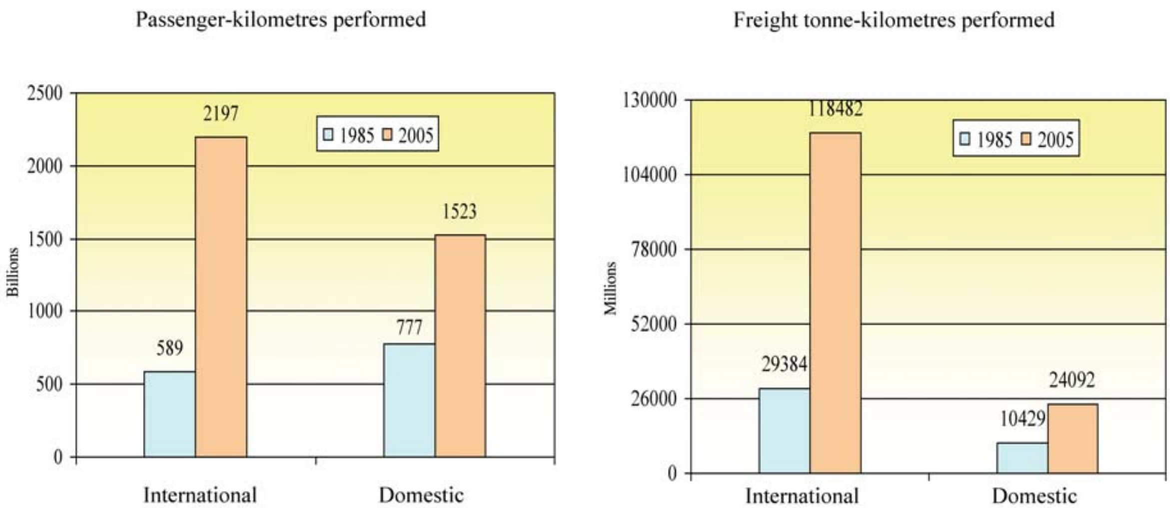

Figure 4 – Trends in scheduled international and domestic traffic - World (1985 and 2005).
Source: ICAO Reporting Form A.

Trends In Aircraft Departures and Distance Flown

The growing demand for passenger and freight air services since 1960 led to an expanded fleet capacity. Growth patterns of passenger numbers, aircraft departures and aircraft kilometres are portrayed in Figure 6[2].

The large gap between the growth rates for passengers carried and aircraft departures that existed in the 1960s and 1970s is primarily a reflection of the increases in average aircraft size over this period. In the 1980s, as this trend in aircraft size levelled off, the growth rate for aircraft departures increased towards the passenger growth rate.

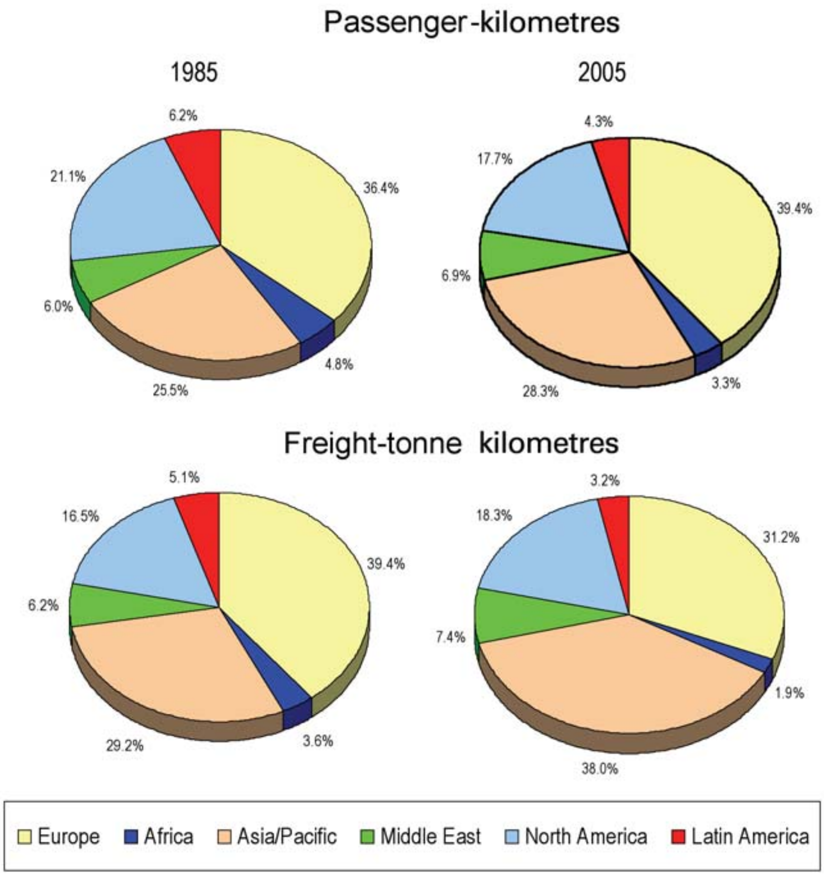

Figure 5 - International passenger and freight traffic - Shares by region (1985 and 2005).
Source: ICAO

[2] A statistical smoothing technique has been used to eliminate large, short term fluctuations in order to better illustrate the trends in the relationships between the variables.

The growth in aircraft kilometres has been consistently higher than the growth in aircraft departures, with a particularly large gap in the 1960s and early 1970s, since the average aircraft stage length (i.e. average length of non-stop flights) has been increasing. The rate of increase in average stage length was greatest when jet aircraft were replacing piston engine aircraft.

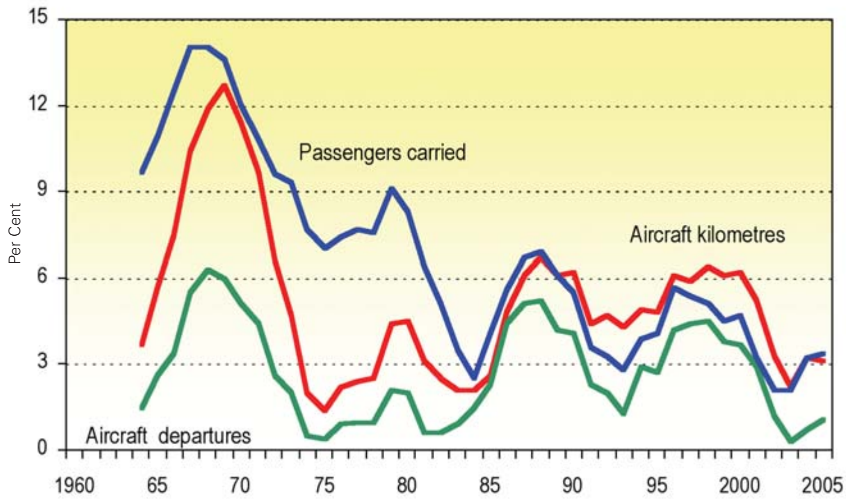

Figure 6 - Growth in passengers and aircraft movements — World (1960–2005).
(Total scheduled operations)
Note: 5-year moving average of annual growth rate.
Excluding operations of airlines registered in the Commonwealth of Independent States (CIS).
Source: ICAO Reporting Form A.

Air Traffic Outlook

Future growth of air transport will continue to depend primarily on world economic and trade growth and airline cost developments. This growth will also be influenced, however, by the extent to which major challenges such as airport and airspace congestion, environmental protection, and increasing capital investment needs are successfully addressed. The shape and size of the air transport system will also be affected by governmental decisions, notably those determining the type and extent of economic regulation of airlines.

For the forecast period 2005–2025, world economic growth (GDP) is expected to increase at an average annual rate of 3.5 per cent in real terms. Airline yields are expected to remain unchanged in real terms for the forecast horizon.

World scheduled traffic measured in terms of passenger-kilometres performed (PKPs) is forecast to increase at a "most likely" average annual rate of 4.6 per cent for the period 2005–2025. As shown in Table 4, international traffic is expected to increase at 5.3 per cent per annum, while domestic traffic is expected to increase at an average annual rate of 3.4 per cent.

On a regional basis, between 2005 and 2025, the airlines of the Middle East and the Asia/Pacific regions are expected to experience the highest growth in passenger traffic at 5.8 per cent per annum, followed by the airlines of the African and

Table 4 – ICAO air traffic forecasts - World (1985–2025).
(ICAO Contracting States)

Scheduled services	Actual 1985	Actual 2005	Forecast 2025	Average annual growth rate (per cent) 1985–2005	2005–2025
TOTAL					
Passenger-kilometres (billions)	1 366	3 720	9 180	5.1	4.6
Freight tonne-kilometres (millions)	39 813	142 579	510 000	6.6	6.6
Passengers carried (millions)	896	2 022	4 500	4.2	4.1
Freight tonnes carried (thousands)	13 742	37 660	110 000	5.2	5.5
Aircraft-kilometres (millions)[1]	n.a.	30 845	69 040	n.a.	4.1
Aircraft departures (thousands)[1]	n.a.	24 904	50 450	n.a.	3.6
INTERNATIONAL					
Passenger-kilometres (billions)	589	2 197	6 225	6.8	5.3
Freight tonne-kilometres (millions)	29 384	118 482	452 120	7.2	6.9
Passengers carried (millions)	194	704	1 950	6.7	5.2
Freight tonnes carried (thousands)	5 884	22 630	80 000	7.0	6.5

[1]. Data on operations of airlines registered in the former USSR not available for 1985.
Source: ICAO

the Latin American/Caribbean regions with a 5.1 and 4.8 per cent annual growth rates, respectively. Traffic of the airlines of the European and North American regions is expected to grow more slowly than the world average at the rates, at 4.3 and 3.6 per cent per annum, respectively (Table 5).

World scheduled freight traffic measured in terms of tonne kilometres performed is forecast to increase at an average annual rate of 6.6 per cent for the period 2005–2025 (Table 4). International freight traffic is expected to increase at an average annual growth rate of 6.9 per cent compared with a domestic freight traffic growth of 4.5 per cent per annum. Table 5 also shows variations in regional growth between international and domestic traffic.

Aircraft movements in terms of aircraft departures and aircraft kilometres flown for the period 2005–2025 are expected to increase at average annual rates of 3.6 and 4.1 per cent, respectively.

References

1. ICAO Circular 313 – Outlook for air transport to the year 2025.

Table 5 – ICAO air traffic forecasts — Regions of airline registration (1985–2025).
(ICAO Contracting States)

Scheduled services by region of airline registration	Actual 1985	Actual 2005	Forecast 2025	Average annual growth rate (per cent)	
				1985–2005	2005–2025
TOTAL					
Passenger-kilometres (billions)					
Africa	36.7	84.8	230	4.3	5.1
Asia/Pacific	222.3	967.4	2 980	7.6	5.8
Europe	428.2	1 004.9	2 350	4.4	4.3
Middle East	42.7	168.9	520	7.1	5.8
North America	567.4	1 334.5	2 690	4.4	3.6
Latin America and Caribbean	68.3	159.2	410	4.3	4.8
Freight tonne-kilometres (millions)					
Africa	1 163	2 349	6 000	3.6	4.8
Asia/Pacific	9 605	50 105	235 000	8.6	8.0
Europe	14 422	37 875	97 000	4.9	4.8
Middle East	1 880	8 880	40 000	8.1	7.8
North America	10 638	38 803	120 000	6.7	5.8
Latin America and Caribbean	2 105	4 567	12 000	3.9	4.9
INTERNATIONAL					
Passenger-kilometres (billions)					
Africa	28.5	72.2	205	4.8	5.4
Asia/Pacific	150.3	622.5	2 100	7.4	6.3
Europe	214.4	865.9	2 160	7.2	4.7
Middle East	35.1	152.5	480	7.6	5.9
North America	124.5	389.2	1 020	5.9	4.9
Latin America and Caribbean	36.5	95.1	260	4.9	5.2
Freight tonne-kilometres (millions)					
Africa	1 070	2 256	5 870	3.8	4.9
Asia/Pacific	8 589	45 070	215 000	8.6	8.1
Europe	11 589	36 981	95 900	6.0	4.9
Middle East	1 808	8 764	39 750	8.2	7.9
North America	4 841	21 634	85 000	7.8	7.1
Latin America and Caribbean	1 487	3 777	10 600	4.8	5.3

Source: ICAO

Development and Use of Global Air Traffic and Aircraft Fleet Forecasts

By Roger Roy,
Sylvie Mallet and
Chaouki Mustapha

Forecasting is an important tool that is used for long-term decision-making. The ICAO Committee on Aviation Environmental Protection (CAEP) uses forecasts to assess costs, cost-effectiveness, and cost-benefits of various proposed environmental stringency standards, as well as for tracking the projected results that depend on the decision-scenarios chosen for the future.

Producing a forecast of global air transport activity is a challenging task. The approach used by the CAEP's Forecast and Economic analysis Support Group (FESG) to develop such forecasts and how they are used in the CAEP work program is described in this article.

The article gives an overview of the process used to produce a new forecast, summarizes the most recent forecast update produced by FESG[1], and assesses the forecast by comparing them with some actual data.

Methodology To Produce A Forecast

The point in time at which a new forecast is produced in the CAEP cycle influences the choice of the base year around which the forecast (e.g. aviation traffic) will be developed. That timing also dictates the time at which the forecast becomes available for use in the CAEP work programme.

The choice of the base year is driven by factors such as the availability of traffic, fleet and service data, and the robustness and "representativeness" of the base year[2]. The forecast produced for CAEP work becomes less precise when unpredictable event(s) take place during the forecast period that have immediate and significant impacts on demand for air travel.

The FESG global air forecast generates a traffic forecast (demand side) and a fleet forecast (supply side) for the entire world.

Traffic Forecast

The CAEP FESG traffic forecast is a consensus forecast that is developed from forecasts produced by both ICAO and the industry[3]. The forecasts produced by the various industry stakeholders using econometric air transport demand models serve as the basis for discussions and debate among the forecasting experts within FESG. The resulting FESG forecast emerges from discussions as a consensus among expert members on future trends in air traffic growth rates.

The consensus FESG global air traffic forecast is derived from certain inputs and a number of steps, the main ones being:

- Define base year to be used for developing the forecast;
- Define how to divide the world air transport market into regions and/or route groups;
- Identify source of historical and base year traffic data (by regions/route groups);
- Define time horizon over which the forecast is to be developed;
- Collect forecasts of passenger traffic growth rates from various sources[4] ;
- Agree on a consensus traffic growth rate forecast for each defined route group covering the forecast time horizon (including intermediate years);
- Determine the resulting global traffic forecast;
- Develop a methodology to extend the forecast time horizon (if a forecast is needed over a time horizon longer than one of the forecasts from which the consensus forecast was derived).

Roger Roy

Roger Roy is Director General of Economic Analysis at Transport Canada. He holds a degree in economics from the University of Ottawa. He has worked for over 30 years in the field of transportation at Canada's transportation regulatory agency and department of transport, where he has been involved in a range of diversified analytical work related to air transportation. He served for over 17 years on the board of the Canadian Transportation Research Forum in various positions, including President. During CAEP 6 and 7, Mr. Roy served as co-rapporteur of the Forecast and Economic Analysis Support Group.

1 Traffic and fleet forecasts developed for CAEP/6.
2 That is a year with no outstanding and non-representative events that may distort its use as a base year.
3 ICAO and aircraft and engine manufacturers' forecast of the global demand for air services – forecasts of passenger and freight traffic growth rates for the world and major route groups.
4 That is, from aircraft and engine manufacturers.

Sylvie Mallet

Sylvie Mallet is Senior Economist in the Economic Analysis Directorate at Transport Canada, where she has worked since 1997. She has been a member of ICAO's CAEP Forecasting and Economic Analysis Support Group (FESG) since 2004. Ms. Mallet graduated from the University of Montreal in Economics and is also the holder of diplomas in accounting for business management from HEC Montreal and in civil law from University of Ottawa.

The last consensus-based forecast produced by FESG was developed for a 20-year time horizon using the following 22 route groups[5]:

International

1. North Atlantic
2. South Atlantic
3. Mid Atlantic
4. Transpacific
5. Europe ↔ Asia/Pacific
6. Europe ↔ Africa
7. Europe ↔ Middle East
8. North America ↔ South America
9. North America ↔ Central America and Caribbean
10. Intra Africa
11. Intra Asia/Pacific
12. Intra Europe
13. Intra Latin America
14. Intra Middle East
15. Intra North America
16. Other International Routes

Domestic

17. Africa
18. Asia/Pacific
19. Europe
20. Latin America
21. Middle East
22. North America

Fleet Mix Forecast

The passenger aircraft fleet mix forecast also requires a number of inputs and assumptions, either defined through a consensus process within FESG, or obtained from existing data sources. These inputs comprise:

- Base-year operational data for each defined route group;

- Traffic demand forecasts for each defined route group over the horizon of the forecast;

- Generic aircraft seat categories used to categorize the global aircraft fleet; the seating capacity and break point of each seating category, as defined by consensus.

For the last FESG forecast, the chosen seating categories were: 20-49 (i.e. aircraft having from 20 to 49 seats), 50-99, 100-150, 151-210, 211-300, 301-400, 401-500, 501-600, 601+ (for aircraft having more than 600 seats).

A fleet-mix forecast model is used, with frequency/capacity considerations, to assign a number of aircraft to each seat category needed to serve the forecast traffic demand.

- Aircraft average load factors are determined for each route group from existing historical load factors, recent trends, and consensus-driven assumptions for the forecast horizon. Similarly, assumptions on aircraft utilization (i.e. the number of hours flown per day per aircraft) are defined for the forecast horizon through a consensus process based on existing data and trends.

For the last FESG forecast, the average aircraft utilization was assumed to increase by 5% over the 20-year forecast horizon.

- Assumptions about average aircraft size and productivity improvements over the forecast horizon are developed based on existing data and recent trends. For the fleet mix forecast, the growth in the available seat-kilometres requirements translates into increases in aircraft productivity coming from such factors as higher aircraft utilization, more non-stop air services, or improvements in load factors. The growth in available seat-kilometres is allocated through a combination of additional frequencies and increases in average seat size per aircraft (larger aircraft), taking into account the minimum and maximum level of service desirable on each route group.

[5] The definitions of the route groups are the ones used by ICAO.

- As a new forecast is being produced, consideration is given to aircraft with some remaining useful life but no longer in use. Through consensus, an assumption is developed to deal with parked (stored) aircraft determining the percentage to return into service by type of aircraft. Known firm orders of new aircraft at the end of the base year are also considered in the development of the fleet mix forecast, as these aircraft will be placed in service within the forecast period. Passenger aircraft retirement/survival curves projecting future retirements are developed using the most current information on the age of aircraft in use and an analysis of actual historical aircraft retirements. Forecasts are then produced based on: the existing in-service fleet, stored aircraft, and the firm order backlog over the forecast period.

The freighter aircraft fleet mix forecast is developed with a process similar to the one used for the passenger aircraft fleet mix forecast, with cargo traffic measured in terms of revenue tonne-kilometres (RTK), adjustments for parked (stored) aircraft, firm order backlog, and retired passenger aircraft converted into freighter aircraft.

Sensitivity Analysis of the Forecast

A sensitivity analysis is conducted of the forecast at the time it is produced by varying passenger traffic growth rates of each of the major route groups.

Comparison of the Forecast with Actual Data

The CAEP/6 forecast under-estimated the average annual growth for the period 2000-2005, but the impact on the 2000-2020 forecast is expected to be insignificant. The comparison of the forecast by route group to the actual traffic provided in Table 1, shows that the forecast exceeded the actual traffic for the years 2002 and 2003 while it under-estimated the steep recovery registered in the years 2004 and 2005. Actual average growth rates for the period 2005-2020 are expected to be somewhat lower than those of the CAEP/6 forecast.

Chaouki Mustapha

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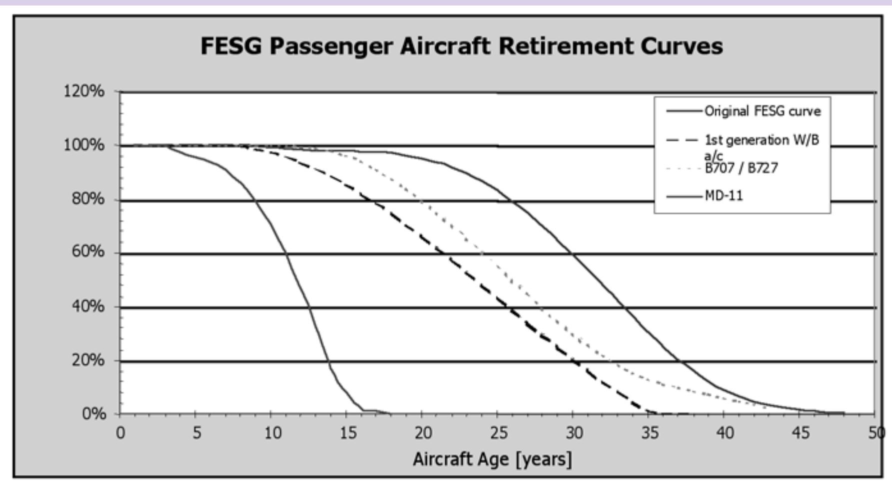
For the last FESG forecast, four different survival curves were developed to project the retirement of the in-service passenger aircraft fleet: one for each of the following technologies:

- Newer generation aircraft (as well as the older two member flight crew aircraft)
- First generation wide body aircraft
- Boeing 707 and 727 aircraft [B707/B727]
- McDonnell Douglas MD-11 aircraft



The chart covers all passenger aircraft manufactured to the year 2001. The horizontal axis represents the average aircraft age while the vertical axis represents proportion of aircraft remaining in passenger service at each average age.

Table 1
Comparison of FESG CAEP/6 Forecast with Actual Traffic, by Route Group (2002 to 2005)

Passenger-Kilometres [billions]

Route Groups	FESG CAEP/6 Forecast				Actual Year-end Traffic			
	2002	**2003**	**2004**	**2005**	**2002**	**2003**	**2004**	**2005**
International								
North Atlantic	399.4	403.4	407.4	411.5	354.9	359.5	389.4	412.8
South Atlantic	51.8	53.3	54.9	56.6	44.5	48.3	57.0	60.0
Mid Atlantic	50.7	52.2	53.8	55.4	47.3	51.8	55.1	58.2
Transpacific	215.9	220.0	224.2	228.4	181.9	170.3	197.0	211.0
Europe <-> Asia/Pacific	254.6	261.2	268.0	275.0	241.7	228.4	269.7	295.3
Europe <-> Africa	107.7	112.0	116.5	121.2	110.7	107.3	115.1	121.8
Europe <-> Middle East	52.3	54.4	56.6	58.8	47.1	51.8	63.2	69.2
North America <-> South America	44.2	45.1	46.0	46.9	36.8	36.0	43.3	48.3
North America <-> Central America/Carib.	49.5	50.3	51.0	51.8	45.3	48.0	55.7	56.4
Intra Africa	8.9	9.2	9.6	9.9	9.8	10.2	11.5	13.4
Intra Asia/Pacific	266.1	279.5	293.4	308.1	254.8	225.7	275.0	295.9
Intra Europe	199.8	203.8	207.9	212.1	203.2	214.6	235.6	253.2
Intra Latin America	17.8	18.4	18.9	19.5	16.0	16.0	18.5	20.1
Intra Middle East	7.4	7.6	7.9	8.1	8.7	9.8	11.1	12.2
Intra North America	27.4	27.9	28.5	29.0	24.8	24.3	26.2	27.4
Other International Routes	117.0	120.5	124.1	127.9	98.5	132.1	191.6	242.9
Total International	1,870.7	1,918.9	1,968.7	2,020.2	1,725.9	1,734.2	2,015.2	2,198.0
Variance: Forecast minus Actual					144.8	184.8	-46.4	-177.8
Variance (%)					8.4%	10.7%	-2.3%	-8.1%
Domestic								
Africa	10.1	10.4	10.8	11.2	8.7	10.0	10.9	12.6
Asia/Pacific	236.5	248.3	260.7	273.8	250.5	264.0	315.8	344.9
Europe	132.0	135.3	138.6	142.1	125.3	129.4	135.2	139.0
Latin America	56.4	57.0	57.5	58.1	56.1	55.2	60.5	64.1
Middle East	12.8	13.2	13.6	14.0	13.2	16.5	14.9	16.4
North America	832.3	837.3	842.3	847.4	777.6	788.5	892.9	945.3
Total Domestic	1,280.1	1,301.5	1,323.6	1,346.5	1,231.4	1,263.6	1,430.2	1,522.3
Variance: Forecast minus Actual					48.6	37.9	-106.6	-175.8
Variance (%)					4.0%	3.0%	-7.5%	-11.5%
Global (International + Domestic)	3,150.7	3,220.4	3,292.4	3,366.7	2,957.3	2,997.8	3,445.4	3,720.3
Variance: Forecast minus Actual					193.4	222.6	-153.0	-353.6
Variance (%)					6.5%	7.4%	-4.4%	-9.5%

A comparison of the actual year-end active commercial aviation fleet to the fleet mix forecast for the years 2002 to 2005 is presented in Table 2. The passenger fleet forecast was higher than the actual fleet by 11%, 9%, 4% and 1% for 2002, 2003, 2004 and 2005 respectively. The cargo aircraft projections were higher than actual fleet by 10%, 10%, 8% and 8% respectively, for the same four years. Clearly the difficulty of predicting air transportation after the events of September 11th, 2001 made the production of the last forecast quite a challenging task. However, the industry has since been on the recovery path and the next forecast, assuming no major event occurs, should be more stable.

Use of the Forecast

The forecast is used to conduct economic analyses that assess costs and benefits resulting from more stringent standard environmental options – emissions or noise – against a "no policy action" base case. The forecast is also used, in conjunction with other models and databases, to determine costs incurred and benefits arising from var-

Table 2
Comparison of FESG CAEP/6 Forecast with Actual Year-End Fleet Traffic, (2002 to 2005)

	FESG CAEP/6 Forecast				Actual Year-End Active Fleet (Source: BACK / Lundkvist) Boeing Standard Seating			
		Interpolated Values						
Generic Seat Category	2002	2003	2004	2005	2002	2003	2004	2005
Passenger Fleet (including combis)								
20-49	1,131	1,143	1,154	1,166	226	246	229	237
50 - 99	2,385	2,415	2,444	2,474	1,923	2,150	2,414	2,599
100 - 150	5,605	5,645	5,685	5,725	5,901	6,100	6,380	6,688
151 - 210	2,805	2,851	2,897	2,943	2,166	2,301	2,424	2,478
211 - 300	1,667	1,710	1,752	1,794	1,765	1,624	1,714	1,844
301 - 400	772	784	796	808	556	591	613	595
401 - 500	177	193	210	226	555	544	551	554
501 - 600	15	17	18	20	8	6	2	1
601 - 650	0	0	0	0	0	0	0	0
Subtotal -	14,558	14,758	14,956	15,157	13,100	13,562	14,327	14,996
Variance: Forecast minus Actual					1,458	1,196	629	161
Variance (%)					11%	9%	4%	1%
Freighter Fleet	*Derived from CAEP/5 Freighter Forecast*							
50 - 99	46	46	47	47	45	45	44	34
100 - 150	712	718	723	731	253	245	236	200
151 - 210	416	416	415	414	465	511	518	458
211 - 300	117	128	139	150	528	509	560	688
301 - 400	187	200	214	226	154	156	156	159
401 - 500	213	219	225	231	86	97	109	121
501 - 600	0	0	0	0	4	4	4	4
601 - 650								
Subtotal -	1,691	1,727	1,763	1,799	1,535	1,567	1,627	1,664
Variance: Forecast minus Actual					156	160	136	135
Variance (%)					10%	10%	8%	8%
Grand Total	**16,249**	**16,485**	**16,719**	**16,956**	**14,635**	**15,129**	**15,954**	**16,660**
Variance: Forecast minus Actual					1,614	1,356	765	296
Variance (%)					11%	9%	5%	2%

ious stringency scenarios at different times over the forecast period. Generic new-delivery aircraft in the fleet forecast are replaced by airframe/engine combinations from an in-production airframe/engine combinations database containing emissions/noise data developed by the appropriate technical working group within CAEP.

Costs and benefits based on various stringency options are estimated over time, some occurring far into the future, and therefore yielding different values than those occurring at earlier stages. A discounting methodology is used to ensure comparability of costs and benefits for each option considered. Benefits are not monetized and are stated in terms of actual reductions in emissions/noise from the different stringency options. Costs are measured in constant terms. Those considered are: non-recurring manufacturer costs of engine changes necessary to meet a given stringency option, operator acquisition costs, and costs associated with fleet operations of aircraft equipped with the newly compliant engines. To prevent double-counting of costs, operator acquisition costs include only recurring material costs and other costs required to change engines to meet an option. Recurring manufacturing and operator costs occur over the forecast period and yearly increases are a function of the number of improved technology aircraft entering the fleet.

Technological changes needed to make a non-compliant current-production engine to comply with a given stringency option are categorized by technology levels. The technology levels define the nature of the new technology required, i.e. the effect on the combustor and engine design, from which costs are derived.

Conclusion

The methodology used to develop the global air traffic and fleet mix forecasts summarized in this document is to be used for the forthcoming CAEP/8 forecast.

The forecast is done for a twenty-year time horizon and is extended by an additional ten-year period using mathematical extrapolation. For future work, FESG intends to consider methodologies that will forecast 50-year scenarios that could serve in the assessment of longer-term technological goals.

The forecast will remain a cornerstone for the assessment of future environmental stringency options to alleviate the environmental impacts of air transport activities.

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Aircraft Noise

Aircraft Noise Overview

By ICAO Secretariat

Aircraft noise is the most significant cause of adverse community reaction related to the operation and expansion of airports both in developed and developing countries. This is expected to remain the case in most regions of the world for the foreseeable future. Reducing or limiting the effect of aircraft noise on people and the communities they live in is therefore one of ICAO's main priorities and one of the Organization's key environmental goals.

Aircraft Noise – Defining the Problem

The noise emanating from aircraft operations in and around an airport depends upon a number of factors including: the types of aircraft using the airport, the overall number of daily take-offs and landings, general operating conditions, the time of day that the aircraft operations occur, the runways that are used, weather conditions, topography, and airport-specific flight procedures. The noise effect caused by aircraft operations is somewhat subjective and can depend on a number of factors related to the individual listener's cultural, socio-economic, psychological and physical situation, and may vary from no effect to severe annoyance.

Aircraft coming off the production line today are about 75% quieter than they were 40 years ago and the aircraft manufacturers are working to reduce this even more (see article *Aircraft Community Noise Reduction – Technology Status and Prospects*). These developments are reflected in ICAO Certification Standards and ICAO's continuing promotion of the implementation of noise reduction technologies.

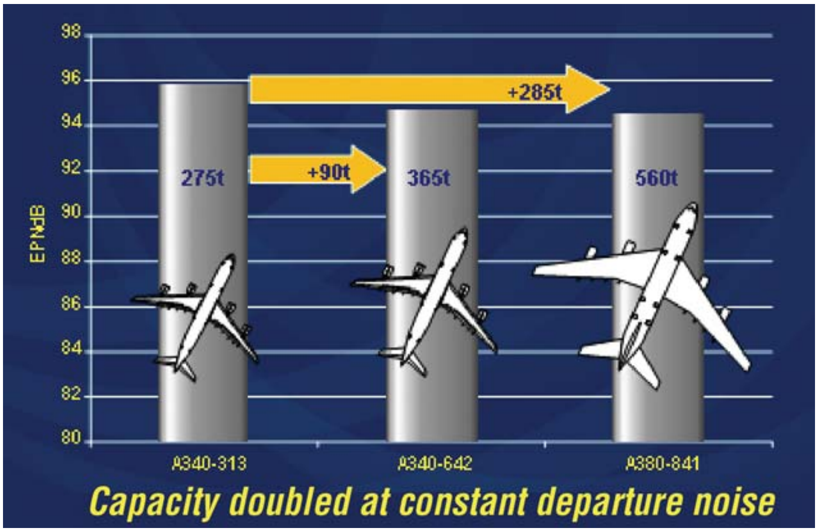

Figure 1 – Capacity growth without noise increase.
Source: Airbus

Figure 1 provides an illustration of how technology has helped to increase aircraft noise efficiency. This figure compares two types of A-340-series jets to the new A-380 jumbo transport. It shows the significant increases in carrying-capacity of the new A-380, while achieving reductions in aircraft noise. Boeing's new Dreamliner aircraft (B787) is also expected to deliver significant improvements in noise, about 15 to 20 decibels (dB) below the Chapter 4 limits, and therefore at least 10dB better than the older aircraft (e.g. B767, A330) it replaces.

The number of people exposed to aircraft noise is the metric normally used to estimate aircraft noise impact. ICAO's Committee on Aviation Environmental Protection (CAEP) has developed a computer model for assessing global exposure to the noise of transport aircraft, known as MAGENTA (see Part 5 – Modelling and Databases). Recent estimates from the MAGENTA model have shown an improvement in the global noise situation with a reduction in the size of the population within the 65 dB DNL[1] contours of about 30 percent in 2006, relative to the 2000 level. Noise insulation programmes and other noise management and reduction initiatives are often developed around airports to reduce the noise experienced by the exposed population.

ICAO Work on Aircraft Noise Reduction

ICAO has been addressing the issue of aircraft noise since the 1960s. The first Standards and Recommended Practices (SARPs) for aircraft noise certification were published in 1971. They are contained in Annex 16 to the Convention on International Civil Aviation (Volume I - *Environmental Protection — Aircraft Noise*). These Standards have been updated since then to reflect improvements in technology (see article on *Reduction of Aircraft Noise At Source*).

[1] DNL (Day Night Level) is a descriptor of noise level based on energy equivalent noise level (Leq) over a whole day with a penalty of 10 dB(A) for night time noise.

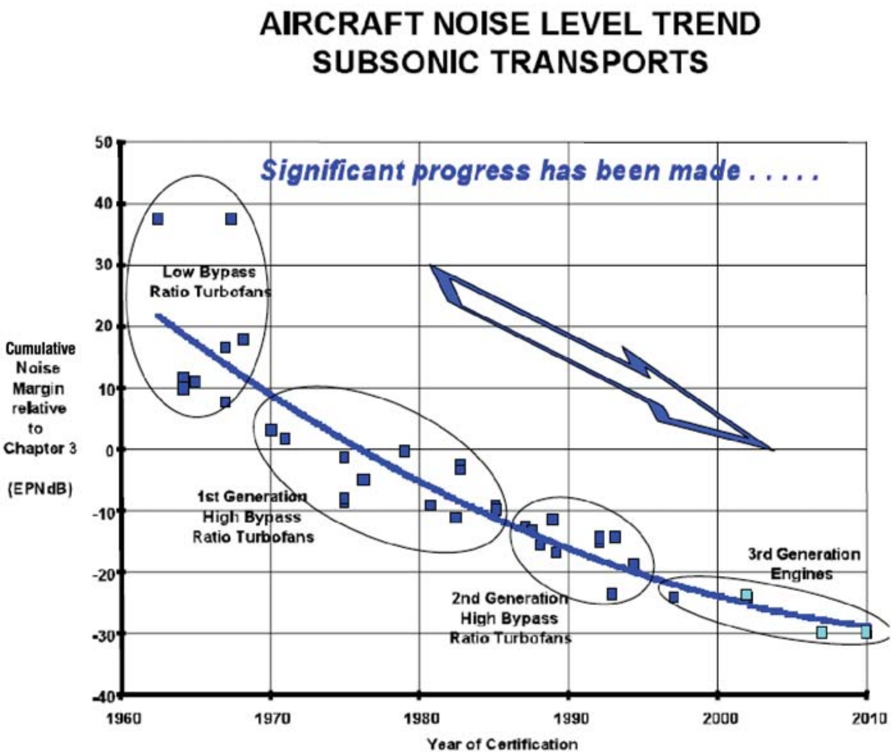

Figure 2 – Noise levels of commercial aircraft models over time.
Source: International Industry Working Group - Fifth Edition R1, 2007.
Note: EPNdB – Effective Perceived Noise (EPN) decibels is a unit developed specifically for use in the measurement of aircraft noise.

At the 33rd Session of the ICAO Assembly, in September 2001, a new policy to address aircraft noise, referred to as the "balanced approach" to noise management, was adopted. This has provided ICAO Contracting States with an internationally-agreed approach for addressing aircraft noise problems in a comprehensive, and economically-responsive way. It is ultimately the responsibility of individual States to implement the various elements of the balanced approach by developing appropriate solutions to the noise problems at airports. This needs to be done with due regard to ICAO provisions and policies, while recognizing that States have relevant legal obligations, existing agreements, current laws and established policies on noise management which may influence the way they implement the Balanced Approach.

The Balanced Approach guidance is contained in the - *Guidance on the Balanced Approach to Aircraft Noise Management (Doc 9829)*. An amended version will be published in 2007 including socio-acoustic factors and airport case studies.

ICAO/CAEP's - Balanced Approach to Aircraft Noise Management
ICAO's Balanced Approach consists of identifying the noise problem at an airport and then analyzing the various measures available to reduce the noise using four principal elements, namely:

1. reduction of noise at source;
2. land-use planning and management;
3. noise abatement operational procedures; and
4. operating restrictions.

The goal is to address the local noise problems on an individual airport basis and to identify the noise-related measures that achieve maximum environmental benefit most cost-effectively using objective and measurable criteria.

The Four Elements of the Balanced Approach – An Overview

A brief overview of each element of the balanced approach is provided below. They are described in more detail in a number of articles contained later in this part of the report.

1. Reduction of Aircraft Noise at Source

Newly manufactured aircraft must comply with the Noise Standards set out in ICAO Annex 16 - Volume I. Aircraft acoustic certification involves measuring the noise level of an aircraft in Effective Perceived Noise Level (EPN) dB at three points: two at take-off (flyover and sideline), and the third during the approach (see inset box on certification points and Figure 3).

Noise Certification Reference Points - Defined

In noise certification, aircraft noise levels are measured at three certification points:

1- **Fly-over**: 6.5 km from the brake release point, under the take-off flight path;

2- **Sideline**: the highest noise measurement recorded at any point 450 m from the runway axis during take-off;

3- **Approach**: 2 km from the runway threshold, under the approach flight path.

Cumulative levels are defined as the arithmetic sum of the certification levels at each of the three points.

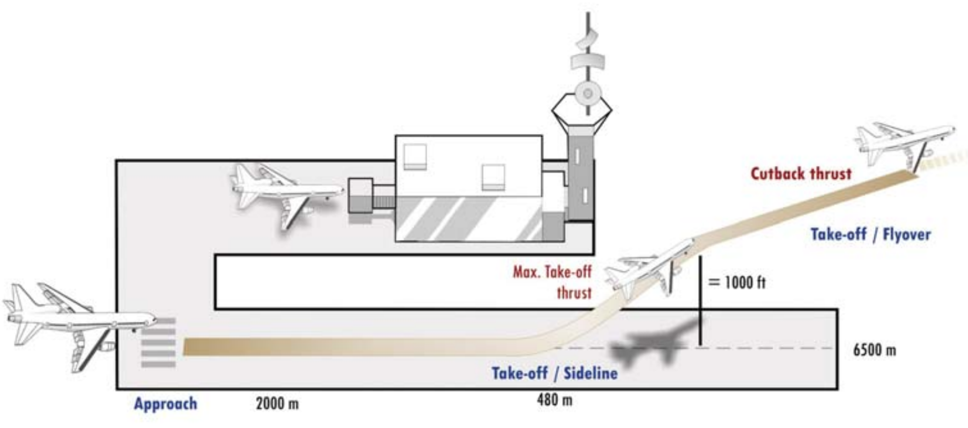

Figure 3 – Aircraft noise certification reference points.

Certification of jet aircraft is addressed in Annex 16, Chapters 2, 3 and 4. Chapter 4 is the most recent one and is applicable to aircraft types certificated after January 2006. The Annex also contains provisions for the certification of propeller driven aeroplanes and helicopters.

Environmental Standards are developed to be technologically feasible, environmentally friendly, and economically reasonable. Trade-offs between noise and emissions are also taken into consideration.

2. Land-Use Planning and Management

An efficient way of reducing the effect of noise on people living close to airports is by planning and managing land-use near airports. Both the number of people and their activities are important factors to be considered. In general, schools, hospitals, religious institutions and libraries are land uses considered incompatible with aeronautical activities and therefore should be avoided in the vicinity of airports.

As aircraft become quieter, a significant reduction of the area affected by noise is observed.

ICAO guidance on this subject is contained in the *Airport Planning Manual* (APM), Part 2 - *Land Use and Environmental Control (Doc 9184)* and the *Guidance on the Balanced Approach to Aircraft Noise Management (Doc 9829)*. The APM provides guidance on the use of various tools for the minimization, control or prevention of the impact of aircraft noise in the vicinity of airports and describes the practices adopted for land-use planning and management by some States. In addition, with a view to promoting a uniform method of assessing noise around airports, ICAO recommends the use of the methodology contained in *Recommended Method for Computing Noise Contours around Airports*[2] (see article on *Land-use Planning and Management Issues*).

Land-use planning and management measures include: noise zoning, mitigation measures such as noise insulation programmes and relocation, and financial instruments such as tax incentives and noise-related airport charges. ICAO's policy with respect to noise charges was first developed in 1981 and is contained in *ICAO's Policies on Charges for Airports and Air Navigation Services (Doc 9082/7)*. Practical advice on determining the cost basis for noise-related charges and their collection is provided in the ICAO *Airport Economics Manual (Doc 9562)*, and information on noise-related charges actually

[2] This ICAO document replaces ICAO circular 205 and will be published in 2008.

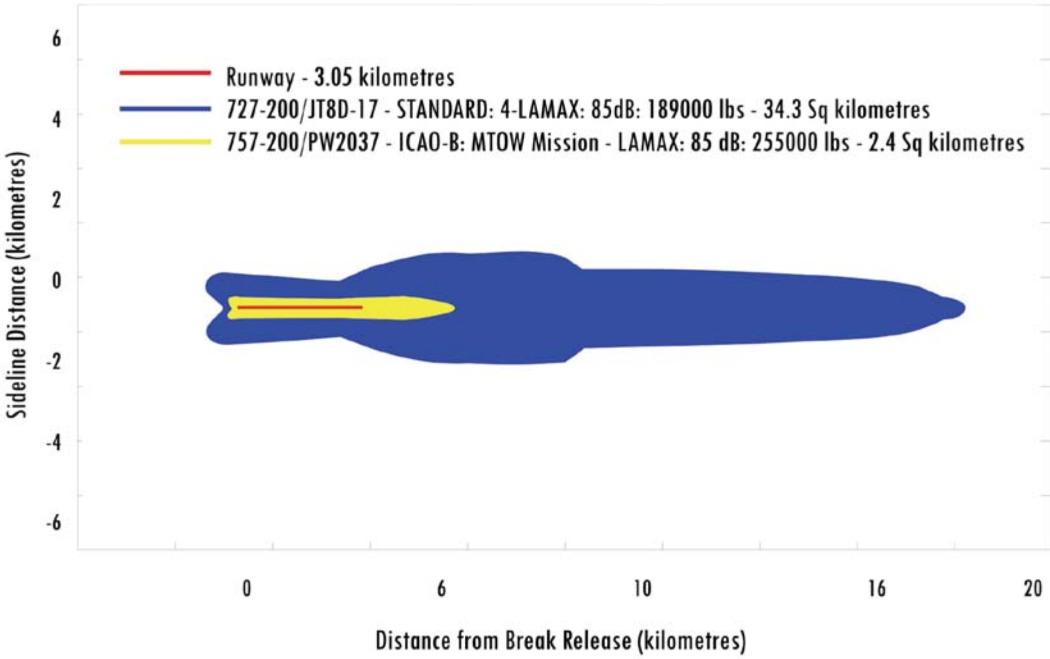

Figure 4 – Comparison of noise footprints of a Boeing 757-200 (Chapter 3) and of a Boeing 727-200 (Chapter 2).

levied is provided in the ICAO *Manual of Airport and Air Navigation Facility Tariffs (Doc 7100)*. In general, the basis for user charges is defined as the full cost of providing the required airport services and facilities. In the context of noise-related charges, this can include the costs of: noise monitoring, noise insulation for housing, and purchasing houses and land in areas adversely affected by noise.

3. Noise Abatement Operational Procedures

It is possible to achieve noise reductions in a relatively short time period through changes in aircraft operational procedures. In fact, noise abatement procedures are used to redistribute the noise produced during the flight to alleviate the impact of noise on the most sensitive areas. There are several operational measures that can be adopted, such as changing runways and routes, special noise abatement manoeuvres during take-off and approach, thereby reducing the number of people exposed to noise in specific areas around airports. Noise abatement procedures are contained in *Procedures for Air Navigation Services — Aircraft Operations*, Volume I - *Flight Procedures (Doc 8168)*, Part I, Section 7.

4. Aircraft Operating Restrictions

Under the balanced approach, an operating restriction is defined as "any noise-related action that limits or reduces an aircraft's access to an airport". Operating restrictions can improve the noise climate by limiting or prohibiting movements of certain aircraft or limiting access of all aircraft during certain hours of the day at an airport. ICAO does not encourage applying aircraft operating restrictions measures as a first resort; the other elements of the balanced approach should be considered first.

Future Work on Aircraft Noise

As projected growth in air traffic has the potential to aggravate the problem of aircraft noise around airports, ICAO will continue to work vigorously towards the development of Standards and Recommented Practices (SARPs) and other guidance material to support the balanced approach policy. To support the current work on evaluating the need for updating its aircraft noise certification standards and to ensure that the latest technology is always reflected, ICAO is currently developing medium-term (10 years) and long-term (20 years) technology goals for aircraft noise.

More work is also envisaged on noise standards for future supersonic aircraft and rotorcraft.

In addition, ICAO plans to carry on its continuous assessment of the evolution of aircraft noise impacts by using models and indicators to reflect the number of people affected by noise in both the present and the future. These ongoing assessments will facilitate future development of cost-benefit approaches designed to alleviate the detrimental environmental health and welfare impacts of aircraft noise. ICAO/CAEP is currently studying this subject and a workshop is planned for October 2007 with experts in these areas.

ICAO's Balanced Approach to Aircraft Noise Management

Noise at Source

Reduction of Aircraft Noise at Source

By ICAO Secretariat

Reduction of aircraft noise at source is one of four principal elements of ICAO's balanced approach to noise management and it remains a cornerstone of the Organizations's efforts to reduce the adverse effects of aircraft noise on the public. This article will describe how this approach to noise reduction has developed historically at ICAO, and what holds for the future.

Sources of Aircraft Noise

The expression "Reduction of noise at source", as used in ICAO's balanced approach simply means reducing the noise emitted by the actual aeroplane. The noise heard at points on the ground caused by aircraft flying into and out of an airport depends on a number of factors. Principal among these are: the type of aircraft and engine type, the power, flap and airspeed management procedures being used, distances from the listening points to the various flight paths, as well as the local topography and weather, both of which affect the sound propagation.

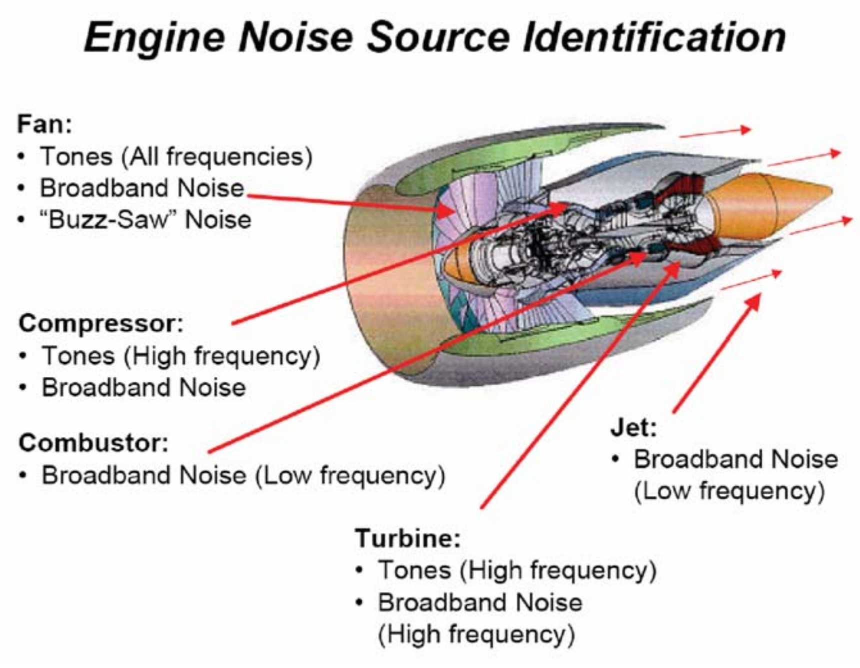

Figure 1 – Engine noise source identification by engine component and sub-component. *Source: ICCAIA*

Noise from a single aircraft is primarily produced by the engine as air is sucked into the engine and exits from the exhaust at high velocity. Noise is also created by the airframe as it moves through the air. As higher bypass ratio engines have become more common, and aircraft have become larger, airframe-related noise has increased, but engine noise still accounts for most of the aircraft external noise. The total engine noise is the sum of fan noise, compressor noise, combustor noise, turbine noise and jet noise. Figure 1 shows a breakdown of typical engine noise sources.

Airframe noise is the sum of aerodynamic noise generated by all parts of the aircraft except the engine. Major sources of airframe noise are high lift devices and the undercarriage (landing gear).

The noise emitted by a departing or approaching aircraft changes in space and time mainly depending on thrust settings, climbing/descending angle, and speed. All of these depend in turn on the Maximum Take-Off Mass (MTOM) of an aircraft. MTOM and the number of engines are the determining parameters for the certification of jet-propelled aircraft noise emissions. The number of engines is the determining parameter for turboprops. Figure 2 illustrates the airframe and engine contribution to overall aircraft noise during takeoff and landing.

Engine noise reduction has so far been achieved by reducing jet, compressor, turbine and fan noise as well as associated combustor and mechanical noise by careful component design, increased bypass ratio, and the addition of sound proofing to the engine and nacelle (i.e. engine housing/cover). Progress on reducing airframe noise has largely been achieved through the improvement of components that generate aerodynamic noise such as landing gears and high lift devices.

Early Standards

Within ICAO, noise at source has been controlled from the outset by the setting of noise limits for aircraft in the form of ICAO Standards, namely Annex 16 to the Chicago Convention. This continues to be the case today, although noise provisions now appear in Volume I of that Annex, with Volume II devoted to engine emissions. The ICAO noise certification scheme considers the overall noise produced by the operation of an aircraft, the engine plus the airframe.

It should be noted that the first generation of jet-powered aeroplanes was not covered by Annex 16 and these are consequently referred to as non-noise certificated (NNC) airplanes (e.g. Boeing 707 and Douglas DC-8).

The first meeting of the ICAO Committee on Aircraft Noise (CAN), in 1971, developed a set of noise limit Standards which, in essence, ensured that any new aircraft entering service would have to use the best noise reduction technology available at that time. The first Standards, which became applicable in August 1973, set noise limits as a direct function of MTOM. This was recognition of the fact that heavier aircraft, which were capable of carrying greater passenger loads, and thereby potentially reducing the number of aircraft movements, would be inherently noisier than lighter ones.

Those Standards appear in Chapter 2 of Annex 16, Volume I. The Boeing 727 and the Douglas DC-9 are examples of aircraft covered by Chapter 2. Those limits were set for three measurement points; at the side of the runway on take-off, under the flight path on climb after take-off, and under the flight path on the approach to landing. The Standards were of limited applicability since they only applied to new production models of aircraft types certified after 1 January 1969. However, all of the principles applied in developing that first set of Standards have been retained for the setting of subsequent noise limitation standards.

Chapter 3 Standards

The earliest noise limits applied only to jet aircraft and were based on the noise characteristics of the either straight or low bypass ratio jet engines in operation at that time. However, much higher bypass ratio jet engines were being introduced into service to achieve better fuel economy. Not only did this new technology render much better fuel economy, it also resulted in much less engine noise. This new development made it possible to increase the stringency of the Annex 16 Noise Standards to ensure that all future aircraft would use the quietest technology. This was done by

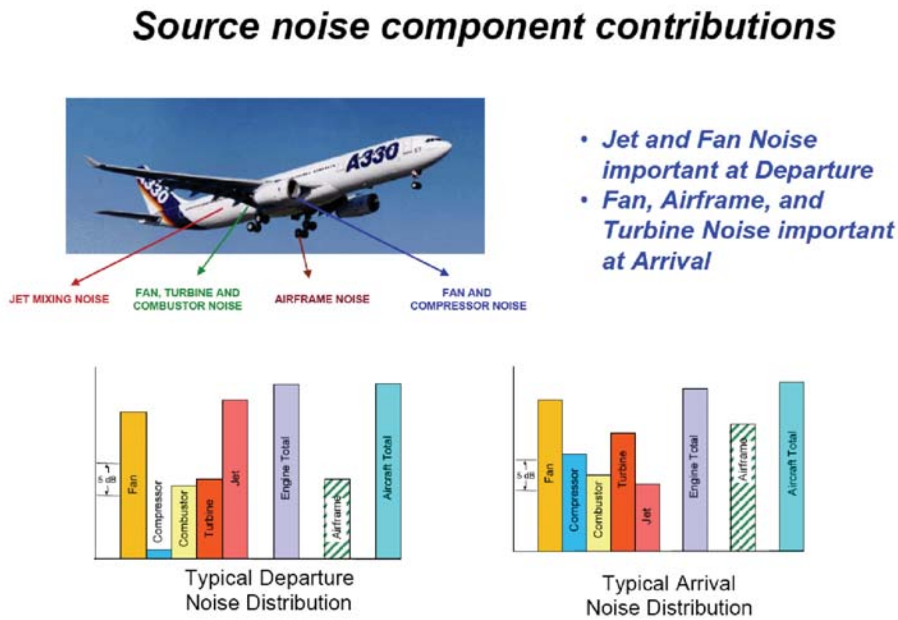

Figure 2 – Typical component contributions to total aircraft noise for a modern turbofan-powered aircraft.
Source: ICCAIA

CAN and the new Standards were published in Chapter 3 of Annex 16, Volume I. They became applicable in October 1977 and applied to all jet aircraft types certified after that date. The Boeing 737-300/400, Boeing 767 and Airbus 319 are examples of aircraft covered by this chapter.

The ICAO Noise dB Database

Noise levels measured in accordance with the requirements of ICAO Annex 16, Volume I for the purposes of noise certification of the great majority of the world's current large jet aircraft have been collected into an ICAO database. This database, called ICAO Noisedb, is accessible on the Internet and is intended for the use of State aviation authorities and others involved in research involving aircraft noise, and for the information of the public in general. The aircraft covered are mainly those certificated according to Chapters 3 and 4 of Annex 16, Volume I or United States FAR Part 36, Stages 3 and 4. The information has been supplied by State certification authorities. The database has been prepared and is maintained by the DGAC of France in cooperation with ICAO/CAEP.

Over the years, those requirements were expanded to include aircraft types with other than jet engines, and also to include helicopters. Noise limits became applicable in 1975 for light propeller-driven aircraft and in 1977 for heavy propeller-driven aircraft. In 1981, noise limits for helicopters were introduced. All of these provisions have, with time, been refined and expanded.

Chapter 4 Standards

In parallel with this, aircraft manufacturers were continuously researching and developing technologies to reduce aircraft noise and striving for a better understanding of the sources of aircraft noise. Accordingly, the inclusion of noise absorbing material in engines and engine nacelles, as well as overall nacelle design, and mechanical refinements on engines, together with airframe adjustments, have all contributed incrementally to further reducing the noise of jet powered aircraft. Although none of these improvements individually has matched the step forward that came from the increase in bypass ratio, together they have been significant.

At its fifth meeting, ICAO's Committee on Aviation Environmental Protection (CAEP - the successor to CAN), agreed that a further change to the jet aircraft noise limits could be introduced. It concluded that although no increase in stringency of the noise limit at any one measuring point was possible, it was reasonable to introduce a limit on the sum of the noise indices at all three measuring points. It therefore decided that this sum of the measured noise levels would have to be lower (by 10 dB) than the sum of the limits imposed by Chapter 3 of Annex 16.

A further requirement was that the sum of the measured levels at any two measuring points would have to be below the sum of the corresponding Chapter 3 limits by at least 2 dB. These requirements subsequently became applicable in March 2002. This change in approach to the method of applying noise limits, while ensuring an overall reduction in noise, still allowed manufacturers some freedom to take advantage of large improvements at some measuring points to offset smaller reductions, or no reductions, at others.

Additional changes to Annex 16, Volume I, are proposed for applicability in November 2008. That proposal includes: provisions related to atmospheric conditions in noise certification testing and measurement conditions (e.g. clarification of definitions relating to wind speeds), the measurement of aircraft noise perceived on the ground, the evaluation method for noise certification of helicopters, and an update to the guidelines for obtaining helicopter noise data for land-use planning purposes.

An illustration of the reduction in noise limits over time is shown in Figure 3.

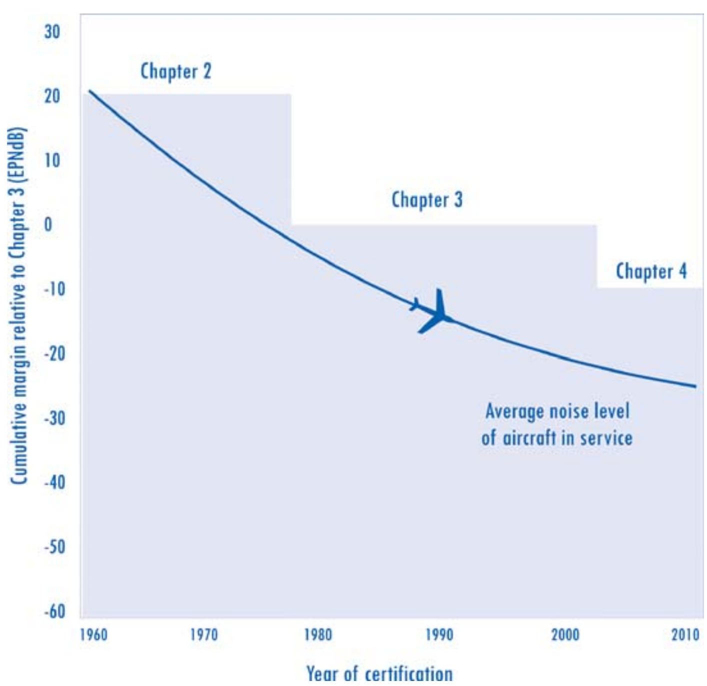

Figure 3 – Progress made in noise reduction at source since implementation of aircraft noise standards.

Conclusions

The reduction of noise at source has always been one of the cornerstones of ICAO's noise mitigation efforts and will no doubt continue to be. While research and development in noise reduction technology continues, it appears likely that the future will be similar to the past, with steady incremental progress in a number of areas; but no dramatic improvement in any one area. We may therefore expect small advances which will only accumulate into significant changes over a longer period of time.

Of all of the elements of ICAO's balanced approach to noise management, the reduction of noise at source remains the most significant, and ICAO, through CAEP, will continue to closely monitor the latest developments in technology which might lead to quieter aircraft and will translate this new technology into even more effective noise standards.

Reference

This article is mainly based on information developed by CAEP as contained in the CAEP/7 Report (Doc 9886).

Aircraft Community Noise Reduction – Technology Status and Prospects

By ICCAIA
International Coordinating
Council of Aerospace
Industries Associations

For the past half century, aircraft and engine manufacturers, together with research establishments and universities, governments, and international organizations have worked aggressively to reduce aircraft noise levels. With a focus on the contributions of aircraft technology to noise reduction; this article provides an overview of the progress in aircraft noise reduction made to-date, the technological advances that have driven that progress, and the outlook for the future.

Historical Progress

Since the introduction of jet aircraft in the late 1950s and early 1960s about a 20 decibel reduction in perceived takeoff noise level has been achieved (Figure 1). Compared with early turbojets and first-generation turbofans, current-generation turbofans show a significant reduction in total engine noise. In addition, major advances in airframe and propulsion system designs (engine and nacelle), combined with improvements in aircraft performance have further contributed to reducing aircraft noise. Over the same period, major advances have also been made that reduced the noise of propeller-driven regional aircraft (Figure 2). Against the backdrop of this significant progress toward reduced aircraft noise and in view of the anticipated growth of the world aircraft fleet, manufacturers are committed to continuing their efforts to further mitigate the impact of aircraft noise in and around the airport communities.

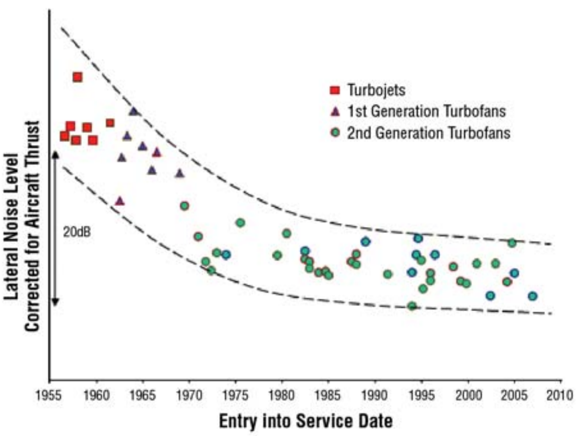

Figure 1 – Historical Progress in Jet-Powered Aircraft Noise Reduction.

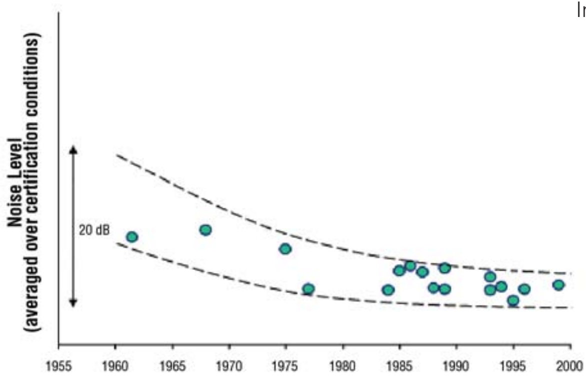

Figure 2 – Historical Progress in Propeller-Driven Regional Aircraft Noise Reduction

The High-Bypass-Ratio[1] Engine Revolution

The turbojets and first generation turbofans of the 1960s were dominated by high jet exhaust noise (a loud roar or rumble). The high-bypass-ratio turbofans of the 1990s, however, significantly reduced jet velocities for the same thrust and consequently generated much less jet noise. Although jet exhaust noise is still a significant contributor to total aircraft noise at full power, fan noise (characterized by a high-pitched whine or whistle) is now a more significant contributor to total noise, especially at reduced power and landing approach conditions (Figure 3).

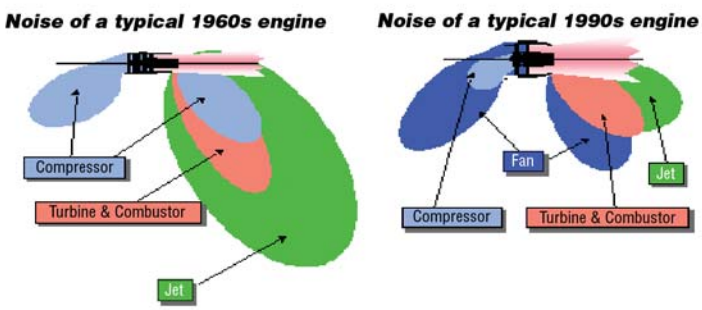

Figure 3 – Engine Noise Source Contributions High Bypass Benefits and Changes in Source Ranking.

[1] The Bypass-Ratio (BPR) is the relationship between the amount of air passing through the core of a turbofan engine, compared with the amount of air drawn in by the fan but bypassing the core.

Figure 4 – Noise Reduction By Sweeping Highly-loaded Propellers

High-Performance Turboprops

The 1990s saw the emergence of high-performance turboprop aircraft, which combined various technologies to improve performance while at the same time reducing community noise levels. The technologies that helped reduce noise include the design of slowly-rotating highly-loaded multi-bladed propellers with optimized blade forms including swept tips (Figure 4). Aircraft have been able to take advantage of newer more powerful engines with advanced control systems, while maintaining the low community noise levels this class of aircraft has traditionally produced.

Relative Roles of Airframe and Engine

Both the engine and airframe designs are important in determining the noise levels around airports. The engine has been the major source of aircraft noise although its relative contribution to total aircraft noise continues to be reduced. The nacelle acoustic performance is important in reducing many of the engine noise sources. On modern aircraft, the noise produced by the airframe moving through the air is almost as important as the engine noise during the landing approach phase. Furthermore, the aircraft low-speed performance has an important influence on take-off noise. This is because the required thrust and altitude reached greatly affect the noise levels on the ground. Finally, noise abatement procedures play an important role in minimizing community noise.

National and International Programs on Aircraft Noise Technology

The aircraft industry has achieved significant noise reduction through advances in technology. The industry has an ongoing, long-term commitment for further significant improvements in noise reduction. One important factor in determining success is sustained Research and Technology funding from industry and governments. Noise technology programs are typically organized and directed by national or multinational organizations. Examples of programs are the U.S. NASA Advanced Subsonic Technology (AST) Noise Reduction program, the NASA Quiet aircraft Technology (QAT) program, the European Union X-Noise and Silence(R) programs, the Russian National program, the Canadian Aviation Environmental Initiative (CAEWG), and the Japanese HYPR/ESPR, ASET and ECO/Small Aircraft programs. (Figure 5).

Teams comprising of government, industry, and academic engineers and scientists conduct the technology programs, with the funding provided by Government agencies and industry.

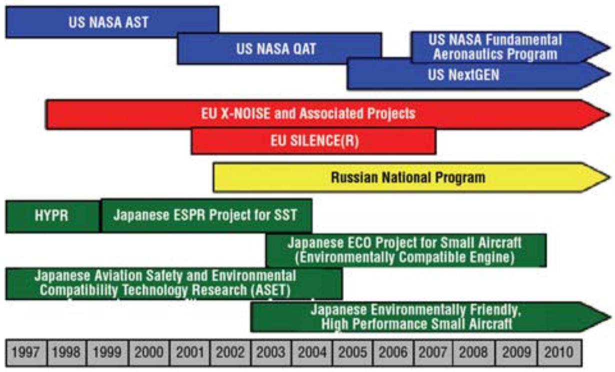

Figure 5 – Main Research programmes Worldwide.

Overview of Recent Research Developments

The advent of the high-bypass-ratio aircraft engine has provided a substantial, revolutionary reduction in engine noise. In recent years, technology advancements have allowed even higher bypass ratios to be considered; today's bypass ratio of around 5:1 will someday go as high as 8:1 to 10:1, and beyond. These very-high-bypass-ratio engines provide a noise advantage as well as reduced specific fuel consumption. The price to pay for very-high-bypass-ratio engines is increased size, weight, and drag, which result in more mission fuel burn. Higher bypass ratio engines require much higher pressure-ratio and temperature gas generator cores, which may have a negative effect on emissions, especially nitrogen oxides (NOx). Nevertheless, substantial exhaust noise benefit has been demonstrated for aircraft engines with very high bypass ratios; the B777 powered by the GE90 and the A340 powered by the Trent 500 being examples.

The efficiency of exhaust nozzle "lip treatment", in the form of serrations or "chevrons" has been verified and incorporated on some jet aircraft including the newest regional jets. This concept provides reduction in jet exhaust mixing noise with minimal fuel burn increase. More complex shapes, as well as adaptation of the concept to the fan exhaust nozzle, are also being studied (Figure 6A).

Design features of the fan system for minimum noise have to address the key issues of fan aerodynamic and mechanical performance, stability and stall margin, and the manufacturing complexity and cost. Just as swept propellers developed for regional aircraft have reduced noise, the sweeping of fan rotor blades (Figure 7) also reduces noise and is particularly effective when the fan blades operate at supersonic speeds. Advanced stationary-guide-vanes with reduced response to the wakes from the fan blades have also been designed and tested. This concept holds promise for both near-term and longer-term engine designs.

Figure 6 – Jet Exhaust Noise Reduction by Nozzle Tip Treatment.

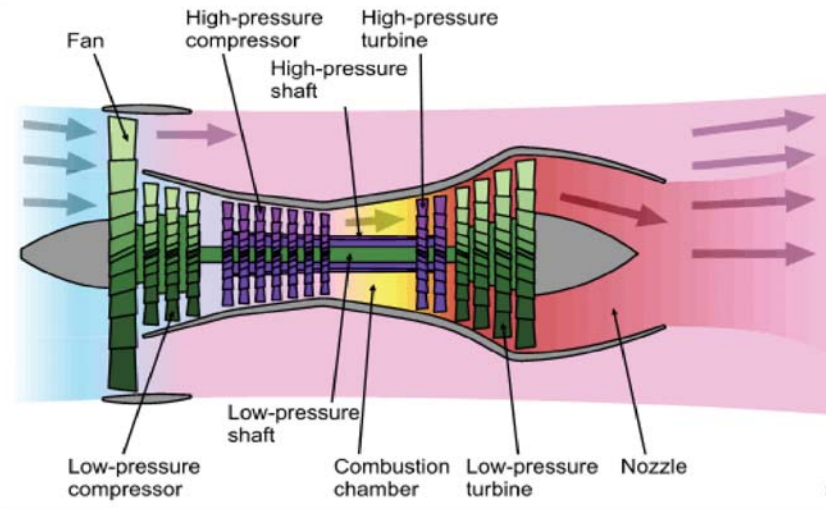

Figure 6A – The high-bypass engine has a large fan that routes much air around the turbine.

Enhanced attenuation of turbo-machinery noise within the nacelle can be achieved both by optimizing acoustic-lining design technology and by optimizing the nacelle aerodynamic design. Acoustic liner area maximization and continuity are key manufacturing and design technology trends being developed to increase effective acoustic liner areas in the inlet, fan case, and bypass ducts. The technology includes extending the inlet liner to the inlet lip highlight and minimizing acoustic liner splices, gaps, and patches (Figure 8). Advanced anti-icing systems are required for liner area maximization to the lip highlight. Other key implementation issues include structural integrity, weight, and maintenance in terms of replacement or repair of damaged panels.

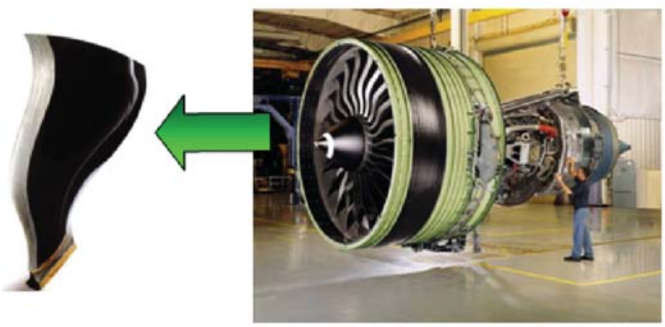

Figure 7 – Noise Reduction By Sweeping Fan Rotors.

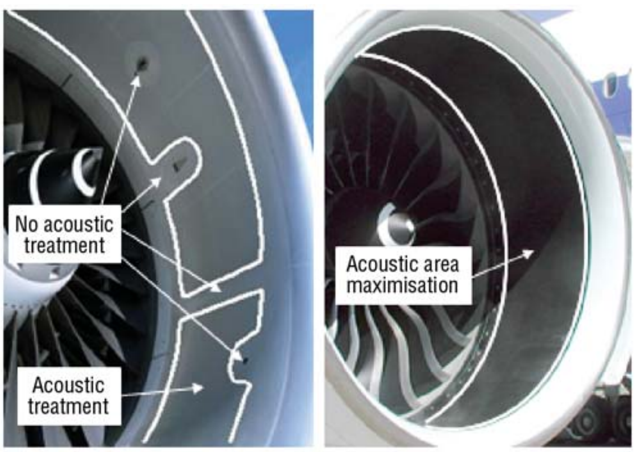

Figure 8 – Maximizing Inlet Acoustic Liner Area.

Figure 9 – Negatively Scarfed Inlec.

The concept of a negative-scarf inlet with a lower lip extending forward of the upper lip in order to reduce forward fan noise has recently been validated by flight test (Figure 9). The major challenges for the negative-scarf inlet are aerodynamic performance and operability, weight penalty, potential cabin noise increase due to higher buzz-saw noise, and difficulty in retrofitting to existing aircraft.

Figure 10 – Landing-Gear Fairing

In parallel, airframe noise research is addressing noise sources associated with high-lift systems (where dominant noise sources have been identified in the slat cove and flap edge vortices as well as simple holes and excrescences) and the undercarriage. Add-on treatments to high-lift systems and landing gear fairing (Figure 10) could provide short-term noise reduction for conventional designs; future aircraft may incorporate novel low noise designs for the wing in high-lift configuration and the undercarriage.

Noise Reduction Goals and Technology Readiness

Noise technology research programs are addressing all the significant sources of aircraft noise; in particular, jet noise, fan noise, and airframe noise - the most important contributors to the aircraft noise signature. Progress in reducing any one of these primary noise sources, however, does not produce the same reduction in the total aircraft noise. An aircraft powered by a typical modern high-bypass-ratio engine will have jet and fan noise dominating at high power, and fan and airframe noise dominating at low power.

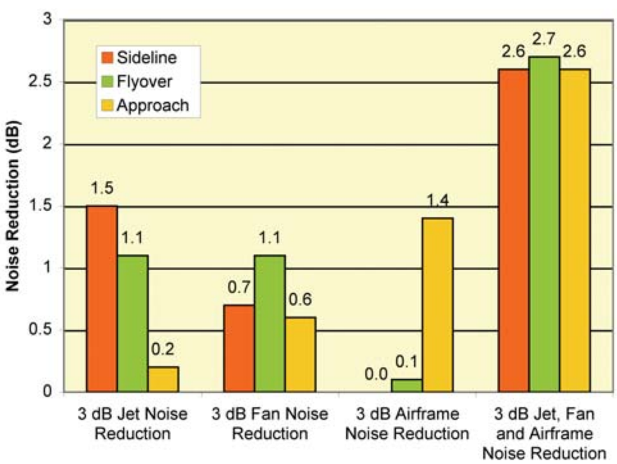

Figure 11 – Typical Relationship Between Component and Overall Aircraft Noise Reductions

Consequently, the impact of component noise reductions on the aircraft system noise levels varies with power setting. This is illustrated in Figure 11, where examples of 3 decibel (dB) reductions in jet noise, fan noise, and airframe noise have been evaluated for total aircraft noise impact, both individually and combined. Jet noise reduction has the greatest effect at sideline, fan noise reduction has an effect at all three certification conditions, but is most effective at flyover, and airframe noise reduction has a significant impact only at approach. Addressing only one of these component noise sources typically produces only modest reductions in total aircraft noise, but when 3 dB reductions are achieved in all three components, the reduction in total aircraft noise is almost 3 dB. Noise from the engine core is now the barrier to further reductions, and prevents the achievement of a full 3 dB reduction in the total aircraft noise.

The European and US noise research programs have ambitious noise goals. These research goals, however, cannot be translated directly into long-term regulatory goals since much work is required to develop and demonstrate the ideas for application in very demanding aircraft and engine environments (reliability, durability, safety, etc.). Much work is also required to assess the impact of these emerging low-noise technologies on other aircraft design requirements. The Technology Readiness Level metric (TRL) indicates the extent to which any given technology has been developed, and its benefit in the aircraft environment demonstrated. As the technology matures from conception to being available 'on the shelf' for the next application, the TRL increases from one to seven. The TRL then increases to eight and nine as the technology is built into a real aircraft design and is proven in service.

Aircraft Design Requirements

Noise reduction is one of the major drivers for current and future aircraft designs. There are several conflicting requirements in designing an aircraft and an engine. Any noise solutions must remain compatible with other requirements, viz., emissions, fuel burn, aircraft performance, cost of aircraft, and operating costs. To best match the different requirements, the aircraft and engine manufacturers work closely together to provide the optimum airframe/engine combination. A simple example can illustrate the interdependence between different environmental requirements: adding large extensions to the cowling around an engine to install additional sound absorption liner material to reduce aircraft noise also potentially leads to more fuel being used in operation, so an optimum trade-off has to be found.

Associated with the implementation of any new low-noise technology is inevitably a benefit gap - a reduction in the noise benefit achieved compared with benefits identified early in the technology development process. In other words, expected noise benefits can erode significantly as the technology is developed for realistic applications and incorporated into the product, with attendant trade-offs between noise and other requirements. There is also a product transition time - a delay between technology being available 'on-the-shelf', its integration into a specific aircraft development and the general spreading of such technology throughout the worldwide fleet. The benefit gap and product transition time need to be considered when relating research goals to future aircraft noise levels.

Balanced Approach

Noise reduction technologies are developed through extensive programs whose scope and timeframes cannot be related to the timeframe associated with the design optimization of a particular airplane. The aviation industry relies on a rational, stable, internationally harmonized regulatory framework adapted to its long development cycles and long product life. During the later stages of an aircraft design, local noise rules applied at specific airports may in some cases be taken into account as additional constraints in the aircraft design optimization process. This can be done only when the development of an airplane permits such in terms of timing, performance and fuel burn capability. The development of noise reduction technologies, however, is driven by a broad and balanced long-term vision of the worldwide future environmental requirements.

ICAO's Committee for Aviation Environmental Protection (CAEP) provides a unique international framework for developing rules and guidelines on aviation environmental issues. CAEP is an unequalled platform for exchanging and consolidating data, developing and sharing visions, analyses and proposals at different levels, from technological feasibility to policy imperatives. Thus, ICAO/CAEP provides a forum that helps in particular to optimize the different design requirements and the balancing of the needs of all the stakeholders. CAEP is central to ensuring the balance between environmental benefit, technological feasibility, and economic reasonableness.

In developing and implementing technologies to reduce airport noise at source, the manufacturing industry plays a major role in addressing one of the four elements of the Balanced Approach to managing noise in the vicinity of airports. The manufacturing industry is also heavily involved in the development of noise abatement operational procedures, another element of the Balanced Approach. CAEP is working hard with all stakeholders in this complex area toward the objective of making substantial noise reduction through aircraft operational procedures a reality. The development of advanced aircraft systems will further enable optimized procedures, but progress in this area will be dependent upon the development of advanced ground infrastructure and ATM systems. The third element of the Balanced Approach, land use planning and management, is needed to protect the benefits gained from the first two elements. Operating restrictions provide the final element, when all other elements have been exhausted.

In order to maximize the benefits from the large investment in developing the technology to reduce noise at source, it is essential that all stakeholders work together on the multiple interdependent factors involved (technology, operational procedures, traffic and fleet developments, Air Traffic Management, airport infrastructure etc.) using a global systems approach. This implies a high level of cooperation and a permanent productive dialogue among all the different parties.

The Future

In the future, technology will continue to play a significant role in reducing the noise around airports. Significant progress has been made in reducing aircraft noise over the past half century. Aircraft, engine, and nacelle manufacturers continue to invest in extensive research programs targeted at delivering additional technologically feasible and economically reasonable improvements with timely and effective environmental benefits. Further significant noise reductions, however, will require substantial progress in reducing the many different complex noise sources that contribute to the aircraft noise signature, and will therefore necessitate sustained investment.

Comprehensive international noise research programs have been launched, involving industry, research establishments and universities. Many promising and exciting concepts for reducing noise are being evaluated and developed, but substantial efforts will be required to prove and implement these ideas for practical aircraft application. In parallel with the development of such technologies to reduce noise, it is crucial that technology is not considered in isolation, but in the broader context of the ICAO/CAEP Balanced Approach to reducing the noise around airports. All possible cost-effective means to improve the noise situation must be explored, including noise abatement procedures that can themselves benefit from technology advances. Finally those noise benefits achieved must be protected through proper land-use management around airports.

A Comparative Study of Certificated and Operational Aircraft Noise Levels

By ICAO Secretariat

Background

The prime purpose of noise certification of aircraft is to ensure that the latest available noise reduction technology is incorporated into the aircraft design. This has to be demonstrated through certification procedures which are intended to be directly related to day-to-day aircraft operations, in order to ensure that the noise reduction offered by a technology is actually reflected in noise reductions around airports. The ICAO aircraft noise certification scheme was developed almost 40 years ago and defines a specific procedure for comparing the noise produced by different aircraft types with noise certification levels at three specific reference points.

With increasing air traffic and growing sensitivity of the populations around airports to aircraft noise, airport authorities have put in-place programmes for monitoring the actual noise levels generated by aircraft operations. These observations have made it possible to make comparisons of noise levels required by the certification process with actual monitored levels. Some of these comparisons have raised questions about the continuing validity of the existing ICAO noise certification scheme in reflecting the operational noise of modern aircraft.

Noise Level Comparison Study

ICAO's CAEP consequently decided that a study should be conducted to determine the relevance of the current certification scheme. The study was divided into three parts: design process, problem identification, and comparison of certificated noise levels with noise levels monitored around airports during day-to-day operations. The main conclusions of this study are summarized in this article.

Consideration of Noise Requirements in the Design Process of Jet Aircraft

There are numerous criteria that must be addressed when designing a new aircraft and environmental performance is only one of them. For noise, the design of an aircraft is driven by targets expressed in terms of the noise levels required to obtain aircraft certification. If needed, a validation of the design is performed by assessing the anticipated acoustic performance of the aircraft in operational conditions.

This part of the study concluded that, because the noise design of an aircraft is driven by targets expressed in terms of noise levels required for certification, incorporating them into the design of noise abatement features should not necessarily be encouraged. However, work already underway concerning selectable and variable technology should rectify this situation, allowing more consideration of these aspects in the future.

Is Noise Reduction Offered by Technology Reflected in Quieter Areas Around Airports?

(Or in other words; is currently deployed noise reduction technology in aircraft doing what it was supposed to do in relatively close proximity to airports?)

The method chosen to address this question was to assess the distribution of noise-impacted population in terms of noise contribution made by aircraft departures and arrivals at various altitudes and distances along flight tracks, and then associating the problem (number of people exposed) with aircraft operational factors (departure/arrival, distance, and aircraft altitude), which could then be related to one of the noise certification demonstration procedures (i.e. flyover, lateral, or approach).

Twenty-four airports were selected to provide a geographically and operationally diverse sample of airports representing worldwide exposure (as shown in Table 1). The study used the MAGENTA[1] noise model [see part on Models and databases].

The study concluded that the majority of the population that was "highly annoyed" by departing aircraft would seem to be living some 7 to 12 km from start of take-off roll. At this distance, departing aircraft would probably be in the lateral or flyover phases of flight, suggesting that the certification procedures are relevant and that noise reduction achieved by technology is indeed reflected in reductions of noise close to the airports at the locations studied.

It was further concluded that for arriving aircraft there are two locations at which significant numbers of people are highly annoyed: between 0 and 3 km and between 9 and 12 km from the runway threshold. The certification point at 2 km is representative of the first location (0 to 3 km) and a preliminary assessment suggests that it may also be representative, in terms of configuration at least, of the second. However the study con-

[1] MAGENTA stands for - Model for Assessing the Global Exposure to the Noise of Transport Aircraft.

Table 1 – Airports Included In the Analysis.

Airports	Country
Perth	Australia
Sydney	Australia
Sao Paulo	Brazil
Guangzhou	China
Paris Roissy	France
Cologne / Bonn	Germany
Tehran	Iran
Fukuoka	Japan
Nagoya	Japan
Osaka	Japan
Tokyo Narita	Japan
Mexico City	Mexico
Manila	Philippines
Madrid	Spain
Bangkok	Thailand
Schiphol	The Netherlands
Istanbul	Turkey
London Heathrow	UK
Chicago O'Hare	USA
Los Angeles	USA
Miami	USA
NY La Guardia	USA
San Diego	USA
Seattle Tacoma	USA
Source: CAEP/7 WP 34	

cluded that noise problems at such "far out" locations, where they are shown to exist, would probably be best solved by operational means rather than changing the aircraft technology certification scheme.

It was therefore concluded that the results of the study do not reveal a compelling need to change the current certification scheme.

Comparison of Certificated Noise Levels with Noise Levels Monitored Around Airports

This part of the study was carried out using the noise levels recorded by airport noise monitoring stations at airports located in North America, Europe and Australia. The monitoring points were relative to the start of the take-off roll or landing touchdown points, as representing the noise certification reference points. Whenever possible, each of the monitored events recorded at each of the microphone locations around the airports was associated with radar tracking information. Accepted statistical techniques were used for assessing the correlation between noise certification data and operational data.

The various statistical analyses applied yielded similar results. In nearly all cases the analyses revealed significant correlation between the two types of noise levels; certification points and actual noise observations.

Conclusion

Although evidence from the overall study shows that the current noise certification scheme does not necessarily simulate typical aircraft operational noise around airports, due to many factors, there exists a reasonably high degree of correlation between noise certification levels and measured operational levels. Therefore, the current noise certification scheme is still considered to be very pertinent.

References

This article is mainly based on information developed by CAEP as contained in the CAEP/7 Report (Doc 9886).

Report of the Committee on Aviation Environmental Protection, Seventh Meeting Montréal, 5 – 16 February 2007 (Doc 9886, CAEP/7)

ICAO CAEP/7 - Working Group 1 (WG1) – Technical noise, et al "Report of WG1-task concerning the future of the noise certification scheme – WP 34" Presented to the Committee on Aviation Environmental Protection (February 2007)

Land-Use Planning

Land-Use Planning and Management Issues

By Ms. Elizabeth Andrade

Elizabeth Andrade is head of the Land Use Compatibility Group of the Civil Aviation National Agency – Brazil. She coordinates programs related to the compatibility between airports and surrounding urban activities including: Brazilian airports Master Plans, development of legislation and land-use regulations for noise impacted areas, and Noise Compatibility Plans. As part of ICAO's Committee on Aviation Environmental Protection (CAEP) Working Group 2 (WG2) – Operations since 2000, she was a co-focal point for WG2 Land Use Planning and Noise Management Task Group (TG1). With TG1 she participated in the development of the *Guidance on the Balanced Approach to Aircraft Noise Management* (ICAO Doc 9829) and the review/ update of the *Airport Planning Manual.*

Airports are major centres of attraction in urban areas. Their impacts are many and usually include economic, environmental (noise and emissions), and land use issues; all of which may affect the future development of the airport.

One of the major problems affecting the people living and working around airports is noise due to aircraft operations. Accordingly, residential developments near noise-sensitive airports have generated all sorts of complaints and community actions aiming to reduce noise due to aircraft operations. Of course, this may impose airport capacity constraints and significantly increase the costs of providing commercial services.

Over the years, technological improvements to aircraft have managed to considerably reduce noise at the source, which has required heavy investments from the air transport industry. However, since noise reduction at source alone is no longer sufficient there is a need to explore additional solutions for noise problem management.

Conscious of the need to incorporate new policies and guidance material related to noise problems due to aircraft operations, ICAO introduced the concept of the "balanced approach" to noise management in Assembly Resolution 33-7 (A33-7) "*Consolidated Statement of continuing ICAO policies and practices related to environmental protection*". This was superseded by Assembly Resolution 35-5 (A35-5), in 2004.

This article deals with "land-use planning and management," which represents one of the elements of the balanced approach.

Land Use Planning and Management - Explained

Many airports in the world have been encroached by incompatible uses, thus forcing them to adopt costly operational restrictions to deal with the adverse effects of aircraft noise. Also, the number of people affected by aircraft noise depends on, among other things, the way in which the use of land surrounding an airport is planned and managed. Noise-sensitive activities such as those related to residences, schools and hospitals must be controlled, so as to prevent constraints on future airport development.

Consequently, considering the fact that airports are usually located within the limits of large urban areas, in order to minimize the adverse impacts of its operations, it is necessary to organize the airport and surrounding areas through the development and adoption of a set of plans that govern urban planning and management with respect to the airport. It is important to keep in mind that each airport is different in its operational characteristics, its social, economic and political situation,as well as in the type of land use in its surrounding area. All of these factors must be taken into account when planning land use in the vicinity of airports. Therefore, when adopting planning instruments, airport administrations should include a land use control system to assure that the measures comply not only with the necessities of the airport as a whole, but also with the aspirations of the communities involved.

With these issues in mind, ICAO dedicated an appendix (Appendix F) of its Assembly Resolution A35-5 to land use planning and management. In this appendix, States are urged to:

- avoid inappropriate land-use or encroachment, whenever possible in areas where reduction in noise levels have been achieved;
- ensure that the potential reductions in noise levels to be gained from the introduction of quieter aircraft, particularly those complying with the new Chapter 4 standard, are also not avoidably compromised by inappropriate land-use or encroachment;

- minimize aircraft noise problems where the opportunity still exists through preventive measures, most of which are related to land use planning.

Moreover, the appendix requests the Council to "ensure that the guidance on land use in Doc 9184 is current and responsive to the requirements of States". ICAO Doc 9184 is the *Airport Planning Manual – Part 2 – Land Use and Environmental Control*.

Airport Planning Manual

ICAO's Airport Planning Manual (APM) was designed to provide guidance material on land use planning and management in the vicinity of airports and on environmental controls regarding airport development and operations. It covers three key issues: land-use, land-use planning, and land-use management.

Land-Use

Activities around an airport that can adversely affect the safe and efficient operation of aircraft need to be considered when planning land uses in the vicinity of airports. In addition, land use around airports may impact the operational safety of the airport as well as the safety of the surrounding communities. Since aircraft noise has undoubtedly been the major airport environmental problem impacting the development of land use around airports, the compatibility of land use and aircraft noise is an important concern relating to the development of land around airports. In order to provide guidance on proper airport and land-use compatibility planning, the APM presents a variety of possible land-uses with a broad estimation of their relative sensitivity to aircraft noise exposure, indicating their compatibility or incompatibility to aircraft noise and also to airport operations.

In this context, land uses such as natural, agricultural and recreational are the most compatible with noise, since they are outdoors and normally don't involve constant human use. Commercial and industrial land uses are also considered compatible with aircraft noise, because those activities are normally carried out during daylight hours and are not affected by the problem of noise at night or during sleeping hours as happens in residential areas are. On the other hand, the development of residential and institutional land uses, which include single and multi-family dwellings and community support facilities such as schools, hospital and churches should not be encouraged on airport surrounding areas, since they are mostly noise sensitive and, therefore, extremely incompatible with noise.

Land Use Planning

The problem of noise in the vicinity of airports can only be solved by pursuing all possible means for its alleviation, and the benefits which can be derived from proper land-use planning can contribute significantly to the solution. Even though, in many instances the benefits from land-use planning may only be realized in the long-term, any solution to the problem will likely be a long range one. Efforts to correct situations detrimental to proper land use around airports should not be ignored because of the time required for such measures to become effective. This is particularly relevant to applications of land-use planning to existing airports where it is recognized that the ability to make immediate land-use changes is often limited. In these cases, it is important to prevent additional encroachment of incompatible land uses as aircraft source noise decreases and noise contours retreat closer to the airport boundary. Of course, substantial benefits can be gained from the correct application of land-use planning techniques to the development of new airports where initial constraints are minimal.

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The intensity of the impact of aircraft noise on the community located in airport surrounding areas is dependent upon several factors related to the operation of aircraft, including: noise duration, number of operations, operating procedures, mix of aircraft, runway utilization, flight path, and time of day. These factors, as well as forecasts of traffic growth, contribute to the development of noise contours that assess the levels of aircraft noise to which the community is currently exposed, or will be in the future, and define areas where the utilization of land should be compatible with noise.

On the other hand, the sensitivity of the community to this kind of aircraft noise is dependent on, among other things, factors such as: type of land use, building use, type of building construction, distance from airport, ambient noise in the absence of aircraft noise, and sociological factors.

Accordingly, in order to make airport operations and community life mutually compatible, it is important to restrict developments within the noise contours, taking into account the levels of aircraft noise and also the characteristics of the land use. It is recognized that land-use planning and management is the responsibility of local authorities, therefore the airport authority should work together with those groups in order to assure the development and implementation of appropriate land-use planning and control measures in affected areas surrounding the airport.

Figure 1 – Example of Noise Contours - Salgado Filho International Airport – Porto Alegre, Brazil.

Figure 1 depicts typical noise contours for an airport. Note the overlap of urban areas within the contours, indicating that a large population is affected by noise. In this case, control measures such as the ones discussed below can be adopted to ensure that future developments are compatible with aircraft noise.

Land-Use Management

There are many alternatives that can be implemented to regulate developments affected by the airport, including the modification or restriction of land uses to achieve greater compatibility between the airport and its environs. The Airport Planning Manual divides these control measures into three categories, as follows: Planning Instruments, Mitigating Instruments, and Financial Instruments.

1. Planning Instruments

(The instruments listed below are only some examples.)

Comprehensive Planning

Comprehensive Planning takes into account existing development and ensures that future development is compatible with various community goals. In most countries, land-use planning and control authority rests with local governmental bodies, which may be obliged or advised to take into account aviation noise measures. This instrument is important to guide local land-use decisions and development controls.

Noise Zoning

Noise zoning for land use serves a two-fold purpose: the protection of the airport and the protection of the residents. It enables a national or local government to define the uses for each parcel of land, depending on the level of noise exposure. It usually consists of zoning regulations, which specify land development and use restrictions, based on certain specified noise exposure levels.

Easement Acquisition

An easement confers the right to use a landowner's property for a limited purpose. To be effective, easements should restrict the use of land to that which is compatible with aircraft noise levels. They should also ensure the right of flights over the property, the right to create noise, and the right to prohibit future height obstructions into airspace.

2. Mitigating Instruments

(The instruments listed below are only some examples.)

Building Codes

Building codes are essentially a legal means of requiring the incorporation of adequate sound insulation in new construction. Minimum structural construction techniques and material standards often determine whether changes in current standards or the adoption of new standards can increase the interior noise-reduction levels of residential or commercial structures in noise-impacted areas.

Noise Insulation Programmes

Noise insulation can lower interior noise levels for structures that cannot reasonably be removed from noise-exposed areas (e.g., residential buildings). Noise insulation is particularly effective for commercial buildings, including offices and hotels. Nevertheless, for effective noise insulation it is necessary to have a closed-window condition, which may not be desirable to home owners in all seasons and which imposes additional ongoing costs to home owners.

Land Acquisition and Relocation

This strategy involves the acquisition of land through purchase by the airport operator (or planning authority in case of new developments) and the relocation from the acquired land of residences and businesses that are not compatible with airport-generated noise levels.

3. Financial Instruments

(The instruments listed below are only some examples.)

Capital Improvements Planning

Building development can be stimulated or discouraged by the presence or absence of a support infrastructure network, which typically includes roads and utilities. Capital improvements can be planned in order to locate infrastructure in areas where industrial and commercial growth would be compatible.

Tax Incentives

Tax incentives can be provided to occupants of existing incompatible use facilities in order to encourage structural improvements to reduce interior noise levels. Governmental bodies may also institute this measure as a means of redeveloping specific areas, and to encourage relocation or expansion of industry as a means to diversify the local economy.

Noise-related Airport Charges

Airports with noise problems may levy such charges in order to recover the costs incurred for the alleviation or prevention of noise.

Revision of the Airport Planning Manuel

ICAO's Airport Planning Manual is currently in its third edition, dated 2002. A new edition containing updated information on current practices of several States regarding land-use planning and management of land in airport surrounding areas, with particular emphasis on environmental considerations, is expected by the end of 2007.

Aircraft Noise - A Broad-Area Issue

By Dave Southgate

David Southgate is Head of the Aviation Environment Policy Section in the Australian Government Department of Transport and Regional Services. His group focuses on improving communications and building trust between airports and their communities on aircraft noise issues. In 2000 David's department published a well-received discussion paper entitled *Expanding Ways to Describe and Assess Aircraft Noise*. As a result of the positive feedback, the group developed a software package called *Transparent Noise Information Package* (TNIP) which reveals information on aircraft noise, previously not been accessible to the non expert. David Southgate has worked as an environmental noise specialist in the Australian Government for over 25 years and has a science/engineering background, with degrees from the Universities of Liverpool, London and Tasmania.

Until recently aircraft noise assessment and management has been focused on the 'close in' areas around airports which are exposed to the highest levels of aircraft noise. However, community pressures to impose operational constraints or oppose airport growth are increasingly coming from residents living in areas outside of conventional 'close in' noise contours. These aggrieved residents of the more 'distant' areas generally live under busy flight paths. This fundamental change in public reaction to aircraft noise raises the question of whether members of the public are becoming more sensitive to aircraft noise or whether this geographically broadened response is due to changes in the nature of noise exposure patterns around airports.

Changing Public Expectations

While it is difficult to be definitive about the evolution of community sensitivity to aircraft noise it is very evident that in recent years the nature of aircraft noise patterns around airports has changed significantly. That is, individual aircraft are much quieter, but numbers of aircraft movements have increased substantially. As a result, while the total noise dose received at a particular point on the ground near an airport may not have changed, or even may well have reduced, the composition of that noise dose is very different. The resident living at that particular point today is likely to receive their noise dose from a higher number of relatively quiet overflights; rather than from a relatively small number of very loud noise events, as was formerly the case.

Thus, the issue of concern for many people living in the areas outside the conventional sound contours is not so much the level of noise generated by individual aircraft, but rather the cumulative impact of a large number of overflights. They perceive that the times when there are no overflights, the periods of 'respite', are rapidly disappearing and that noise events are becoming more frequent in the sensitive time periods such as evenings and weekends. This change in the nature of the noise pattern would appear to be a significant factor in the widening geographic range of adverse community reaction to aircraft noise.

New Approaches Needed

Over the past four decades a large number of strategies have evolved to deal with noise in the 'close in' areas around airports. While some of these have the potential to bring benefits across broad areas, some of the key 'close in' tools would not appear to be directly applicable to managing noise in the outer areas. The residents living in the outer areas are too distant from the airport to be eligible for acoustic insulation or other common remediation programs (e.g. property buyouts, aviation easements, etc) and are generally in areas where it would be impractical to impose aircraft noise-related land-use planning controls. Similarly, they are living in houses where noise disclosure information could not reasonably be placed on house titles, sales documentation, etc.

Given the above, there would now appear to be benefit in developing strategies for assessing and managing aircraft noise at much greater distances from airports than has conventionally been the case. This is not to say that the 'close in' areas should no longer receive attention – we have well developed strategies in-place for managing noise in these areas – rather, we now need to consider developing additional strategies to extend the geographic areas which are actively taken into account when managing aircraft noise.

Noise Expectations – a Key Driver

Experience in recent years indicates that non auditory factors, particularly noise expectations, are very important in determining the level of public annoyance from aircraft noise. Residents of the outer areas commonly have an expectation that, due to the distance from the airport, their homes will be exposed to little or possibly no aircraft noise. Therefore, if a person unknowingly moves into a house under a busy flight path in an outer area they may find the unexpected noise highly annoying.

Furthermore, this dissatisfaction is very likely to be compounded if they have made a housing decision after examining 'official' information (eg. published noise contours) that has led them to believe they will experience no noise. Similarly residents can be exposed to 'surprise noise' when flight paths are moved over their home without consultation. For example, this may occur if they have been effectively ignored in an environmental impact assessment (EIA) process because they are in an area which is considered to have 'insignificant' levels of aircraft noise exposure.

While this issue has primarily arisen at the airport level, in recent times, noise associated with major air routes at significant distances from airports has also become an issue in some countries. In a similar vein to the above, the two following examples demonstrate that even in circumstances where the total aircraft noise dose for the community may be low, public annoyance or concern can be very high if there is a community expectation that certain areas should be 'quiet'.

In late 2005 in the UK the High Court, when considering a 'distant noise' issue, ruled that '*airspace managers must take account of any environmental impact on…the Dedham Vale areas of outstanding natural beauty in terms of aircraft noise and visual intrusions*.' These areas are overflown at heights in excess of 10,000ft by aircraft on approach to Stansted and other London airports [2]. In the United States the proposal to redesign the airspace across a wide area in the New York/New Jersey/Philadelphia region [3] is generating considerable debate with regard to noise impacts.

In light of such examples, it is believed that considerable benefits could be gained by extending aircraft noise assessment and management to an areawide basis.

Assessing Aircraft Noise on an Area-Wide Basis

Conventional aircraft noise assessment is usually based on some form of noise contouring. These contouring techniques typically involve the computation of the number of people living within the contours in order to compare competing options in an Environmental Impact Assessment (EIA) process, or to track changes in noise exposure over time.

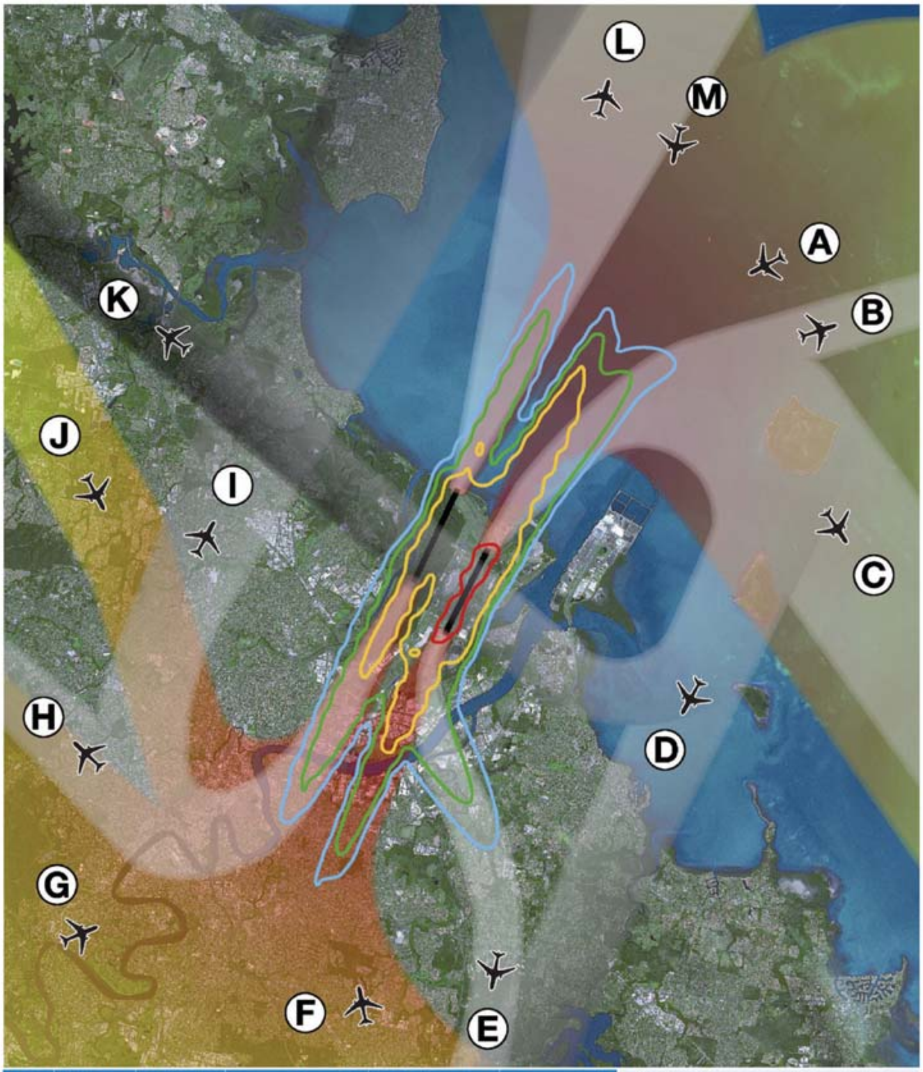
In Australia, pressures to move away from the conventional noise contouring techniques arose as the result of a major EIA process for a new runway at Sydney Airport in the early 1990s. The new runway was approved on the basis of information provided in the project's Environmental Impact Statement (EIS), but when the runway opened there were concerted community claims that the noise analysis in the EIS, based on conventional noise contouring, was misleading [4]. A key factor in this dissatisfaction was that communities living outside the noise contours believed they had been effectively excluded from the EIA process.

This experience clearly demonstrated that if there is to be community confidence in an EIA process, there needs to be a good match between the noise expectations generated during the EIA process and the actual outcomes once a project comes on stream. In order to address the concerns raised by the Sydney EIS, new noise analysis approaches have now been adopted in Australia in an effort to ensure that distant communities are not excluded from EIA processes. These new techniques are focused on the examination of flight paths across the terminal area; on time stamped activity levels on those flight paths; and on noise information based on comprehensive area wide noise grids.

By way of illustration, a major EIA process examining a proposed new parallel runway at Brisbane Airport commenced in late 2006 [5]. The projected noise exposure patterns for the new runway have primarily been portrayed using flight path movement and N70 charts[1] for selected times of day and seasons of the year. An example chart extracted from the project's draft EIS is shown in Figure 1; the area covered by the image is approx 30 km by 40 km.

[1] This chart reports the actual average number of noise events per day recorded around the airport

2015 With the NPR – Summer Weekend Evening Saturday and Sunday 6.00pm – 10.00pm



Flight path	Flight path type	Average number of jet flights on flight path	Expected minimum and maximum numbers of jet flights on path	Percentage of Brisbane Airport's total jet flights on path	Percentage of days with no jet flights on path
A	Arrival	20	0 - 46	18%	42%
B	Departure	2	0 - 4	2%	27%
C	Departure	<1	0 - 1	<1%	48%
D	Departure	15	0 - 30	14%	23%
E	Departure	15	0 - 31	13%	40%
F	Arrival	20	0 - 42	18%	40%
G	Arrival	3	0 - 21	3%	40%
H	Departure	5	0 - 10	4%	42%
I	Departure	7	0 - 15	6%	42%
J	Arrival	5	0 - 13	4%	51%
K	Departure	4	0 - 8	4%	24%
L	Departure	7	0 - 14	6%	41%
M	Arrival	8	0 - 19	7%	40%

Altitude Key

Arrivals
Mean Altitude
4,500 ft
0 ft

Departures
Mean Altitude
12,000 ft
0 ft

Contour Key

The number of overflights of 70dB(A) and above during the indicated time period

- 5 to 9 overflights
- 10 to 19 overflights
- 20 to 49 overflights
- 50 or more overflights

Individual values are rounded. Totals may not add to 100% due to rounding.

Figure 1 – Diagram extracted from the Draft EIS for a proposed new parallel runway at Brisbane Airport, Queensland.

Similar approaches are being adopted in the United States. A segment of an area-wide representation of aircraft noise around St Petersburg Clearwater International Airport in Florida, using the DNL[2] metric, is shown in Figure 2. This figure was extracted from a noise study that was carried out to support ongoing work of the Airport's Noise Abatement Task Force [6].

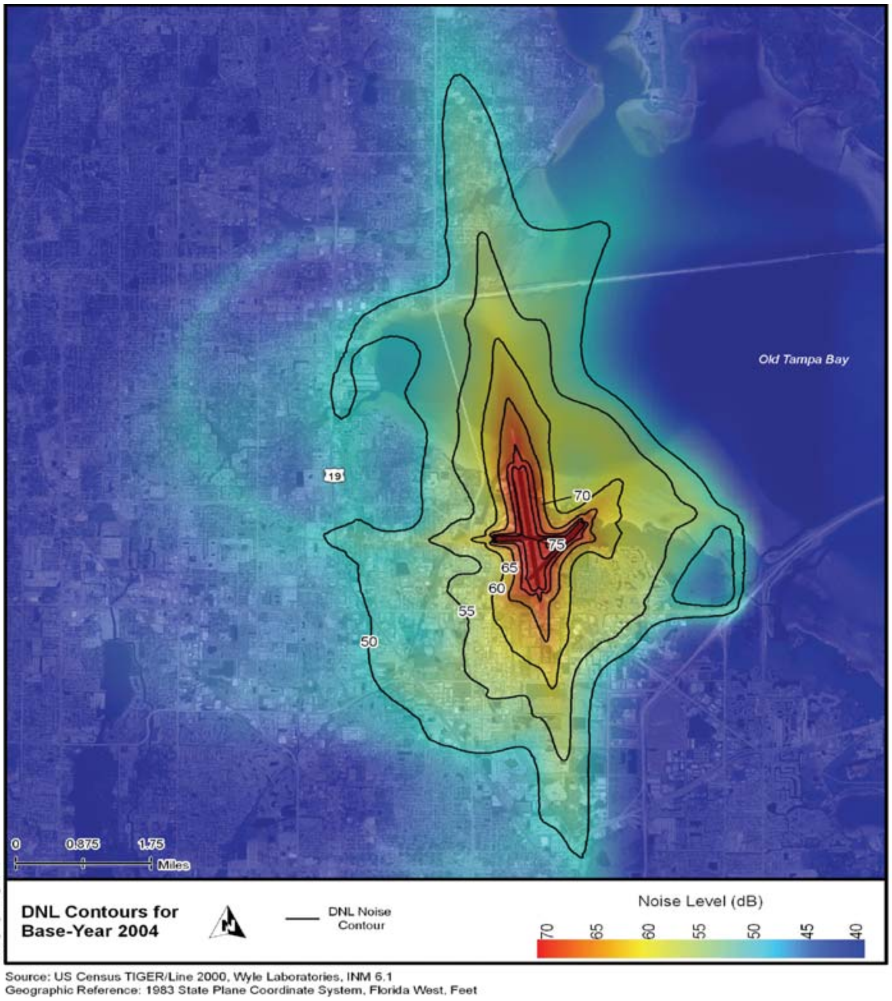


Figure 2 – Area wide noise information for an area to the south of St Petersburg Clearwater International Airport,Florida.

Managing Aircraft Noise In the Outer Areas

Are 'Close In' Noise Management Strategies Effective in the Outer Areas?

ICAO's Balanced Approach to managing aircraft noise [1] defines the four broad strategic strands which have evolved over time in order to deal with problems faced in 'high noise' areas. The question arises as to whether these 'close in' noise management techniques have applicability to broad areas around airports.

Land-use planning has limited area wide application since, irrespective of the noise exposure levels, in general it is not practical to impose aircraft noise based restrictions on land use at long distances from airports. However, at some airports opportunities do exist for basing land-use planning on flight path corridors rather than on conventional noise contours. In these instances where concentrated flight paths over unoccupied land can be fully integrated with planning it may be feasible to impose planning constraints at considerable distances from airports.

Reduction of noise at source may be beneficial. However, for many residents living in outer areas, aircraft noise disturbance primarily arises from high numbers of aircraft movements, and a lack of respite, rather than the loudness of individual flights.

Noise abatement operational procedures have potential beneficial application. For example, these may be used to optimise the location of flight paths relative to the location of housing in the 'distant' areas and the use of noise preferred runways at an airport can impact on which flight paths are used at a significant distance from an airport. The noise benefits of some specific operational procedures (eg. Continuous Descent Approachess) may have greatest positive effect in the outer areas.

Implementation of *operating restrictions* (eg. curfews and movement caps) will generally provide relief for distant residents. However, application of the 'distant' noise management strategies spelled out in the next section would probably be preferred if assessed using the cost/benefit analysis principles specified in Chapter 9 of the Balanced Approach Guidance document.

Specific Strategies for Managing Distant Noise

A number of strategies, which are distinctly different to the conventional 'close in' noise management approaches, can be applied to manage noise on an area-wide basis.

[2] The Day-night average sound level (DNL) represents the noise as it occurs over a 24-hour period, with a 10 dB penalty for noise events occurring at night to account for greater sensitivity to night-time noise and the fact that noise events at night are perceived to be more intrusive because night-time ambient noise is less than daytime ambient noise.

Managing flight paths is a key tool in the outer areas. Close to an airport, the opportunities for varying flight paths are limited since aircraft have to be marshalled into relatively concentrated flight path zones in order to safely land on, and take off from, the runways. However, with increasing distance from the airport there are greater opportunities to be selective about the location of flight paths and to adopt strategies which influence the number, and times, the flight paths are used. Opportunities exist to disperse aircraft noise across the outer areas through the spreading of tracks and the rotation of runways and flight paths.

Area wide noise disclosure is also a key aircraft noise management tool. In this context, 'noise disclosure' does not signify the conventional placing of notifications on house titles or sales documentation. Rather, it means providing all members of a community access to comprehensible, and up-to-date, area-wide aircraft noise information. As indicated earlier, the residents of areas located a long way from an airport commonly have an expectation that they will not be subjected to aircraft noise and have a heightened adverse reaction if they discover they are unexpectedly living under a busy flight path. With recent advances in flight path tracking and home computing it is relatively simple to provide the community with ready access to effective area wide aircraft noise information in order to manage 'surprise noise'. The information is likely to revolve around showing the location of flight paths and the numbers and times of movements on those flight paths. Information on aircraft noise levels can now be readily provided using single event based noise metrics. In Australia the Federal Transport and Environment agencies have jointly published Guidance Material on selecting and providing aircraft noise information [7].

Ultimately, if there is to be broad community support for an airport there needs to be an avenue for all members of the community, both the 'close in' and those from the outer areas to have confidence that all options for managing aircraft noise have been examined and that an equitable outcome has been adopted. Experience has shown that in order for these relationships to be established there needs to be a fully transparent exchange of information between the parties. To this end, information needs to be presented using aircraft noise descriptors that can be easily understood and that show noise exposure patterns across the broad area around an airport.

Emerging Issue in the Outer Areas – Noise/Emissions Trade-Offs

At present, many countries are putting great emphasis on the introduction of new air traffic management (ATM) procedures in order to increase operational efficiencies and to reduce gaseous emissions from aircraft. Invariably these new procedures involve some changes to existing flight paths. The opportunities for introducing more operationally efficient flight paths will generally increase with increasing distance from an airport and hence introduction of these new procedures will most likely involve relocation of flight paths over areas that are situated outside the conventional noise contours.

Commonly, flight paths in the vicinity of airports are negotiated with local communities and incorporated into Noise Abatement Procedures (NAPs) in order to minimise an airport's noise impacts (eg. flight paths are designed to avoid overflying particular communities). In many cases the NAPs are implemented fully recognising that they will require aircraft to travel greater distances, and hence burn more fuel and increase emissions. Historically, noise has been given a higher priority than emissions in optimising flight path design.

With the advent of new navigational capabilities, there is now a large potential for reducing emissions through redesigning flight paths and the question arises to what extent, if any, the balance between noise and emissions should change in response to the growing pressures to reduce aviation emissions. Some procedures such as continuous descent approaches (CDAs) have the potential to deliver both fuel burn and noise benefits. Other changes which provide emissions benefits will inevitably have noise downsides. In practice, a range of approaches could be adopted in an effort to achieve a balance between noise and emissions. For example, operations could be optimised on noise during noise sensitive periods such as the evenings and weekends and then be optimised for emissions at other times. An alternative may be to introduce some form of emissions offsetting to take account of additional emissions incurred by managing noise.

This noise/emissions 'interdependency' question is a key issue for CAEP and its work program now contains a project to examine how the environmental benefits of proposed ATM efficiencies should be assessed. While the committee has yet to tackle this issue, it would appear that conventional average day noise assessment techniques will not assist in analysing noise/emissions trade off questions in the outer areas. These impacts are likely to need some form of 'micro' assessment, using time-stamping and single event analysis approaches of the type referred to earlier, in order to enable the community and the aviation industry to have a fully transparent discussion on the merits of any particular proposed course of action.

The Future

If current trends continue, the noise exposure patterns around airports are likely to progressively evolve as aircraft become quieter and airports become busier. It is important that we continuously review our approaches to assessing and managing aircraft noise in order to respond to these ongoing changes. The imperatives to reduce aviation engine emissions is now posing additional challenges for the way we assess and manage aircraft noise. Fortunately technological advances are providing us with numerous tools to take these issues forward.

The aviation industry is only likely to be sustainable in the long-term if it is able to build relationships with communities that lead to aviation environmental impacts being managed in a way that is perceived by the public to be fair and equitable. Treating aircraft noise as an area-wide, rather than a 'close in', issue is an important step towards building trust between airports and their communities.

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A New Approach to the Calculation of Noise Contours Around Airports

By ICAO Secretariat

It is often necessary for State authorities, research organizations, and others to determine the noise impact of airport operations on the surrounding population. In recent years, it has become clear that the traditional methodology for computing and mapping these contours was outdated and needed to be revised to take into account new aircraft technology, as well as new computing capabilities. This article summarizes that updating process and the features of the new approach.

Background

A convenient and often-used method of determining noise impact is to prepare a map of the airport and surrounding areas, on which is superimposed a set of noise contours (as illustrated in Figure 1). These contours are lines joining points of constant values of some chosen noise measuring parameter (e.g. decibels, as also shown in Figure 1). Typically this parameter will be the total of all the individual noise contributions by aircraft arriving at, and departing from, all of the airport's runways over a specific pre-determined time period, typically days or months.

A method for calculating these contours was first included in ICAO Circular 205: *Recommended Method for Computing Noise Contours around Airports*. However, that Circular was published in 1988 and, although it described the "best practices" in use internationally at the time, it is somewhat outdated now and of limited value. Apart from having been overtaken by improvements in technology, it suffers from two major limitations. Firstly, it focuses mainly on the parameters that have to be incorporated into a computer programme and contains little advice on the practical application of the methodology. Secondly, it provides none of the data which is essential to the application of a real modelling system, particularly noise – power – distance data for specific aircraft. Thus, its practical value has diminished, and for noise modelling specialists this approach has become obsolete, and for general users it has become too narrow and theoretical.

Because of these limitations, CAEP agreed to develop an updated version of the methodology, taking advantage of all existing material. A new

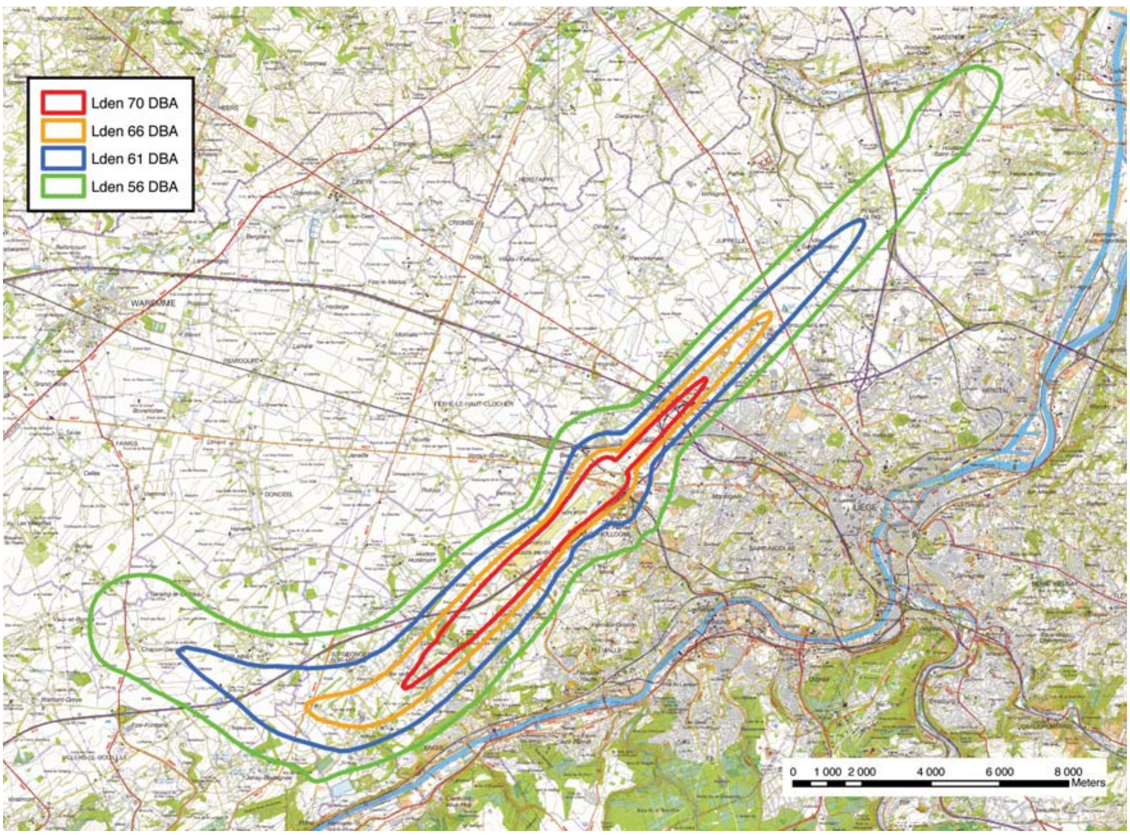


Figure 1 – Noise Contours Map to 2013 at Liege Airport – Belgium – Société Wallonne des Aéroports (SOWAER).

methodology was consequently developed and approved by ICAO in February 2007, for publication in 2008.

Features of the New Methodology

The new method is designed principally for people who construct and maintain aircraft noise contour models. The methodology is described in sufficient detail that it will be possible to construct a computer model. Although the actual computer code is not included, the formulas necessary to create such code are fully described.

The new method provides guidance on the practical implementation of noise contour modelling, especially regarding the representation of aircraft types and their operating configurations and procedures. It also incorporates the latest advances in flight segmentation modelling. Furthermore, it is supported by an international industry-fed aircraft noise and performance database (ANP). It can be applied to any airport situation, and allows typical operational conditions to be taken into account.

A major advancement using this new approach is the improved method of modelling noise contours at the side of the flight path (i.e. lateral noise). The previous model calculated lateral noise heard at ground level as a function of lateral distance and elevation angle only. This old methodology is based on data gathered largely from aircraft with fuselage mounted engines (e.g., B727; DC9). While that methodology remains valid for aircraft with fuselage-mounted engines, it is now recognized that the lateral attenuation from wing-mounted engines is different. Therefore, the new methodology allows for this more common type of aircraft with wing-mounted engines.

The new document describes in detail how to calculate, at a chosen observation point, the noise from each segment of a single aircraft's arrival or departure from the airport. It takes into account such parameters as: normal aircraft operating and air traffic control procedures, typical Maximum Take-Off Mass (MTOM) for that aircraft on that flight, and the typical meteorological conditions. This process is repeated for all expected aircraft movements to or from all of the runways of the airport over a chosen time period. The noise levels gathered at the observation point are then averaged or accumulated to arrive at a noise index for that specific observation point. This process is then repeated for a grid of observation points covering the whole area of interest around the airport and the index values at all these points can then be interpolated to draw the required contours.

It should be noted that this methodology is intended to apply only to long-term average noise exposure. It is not intended to be used to predict the absolute level of noise from a single aircraft movement. It should also be noted that the methodology does not take into account noise generating activities at an airport other than normal aircraft arrivals and departures. Such events as taxiing, engine testing, and the use of auxiliary power units are therefore not covered. Although not insignificant sources of noise within the airport boundaries, these sources are unlikely to affect noise contours in surrounding areas.

The ANP Database

As mentioned earlier, a major advantage of the new methodology comes from its use of the online, industry-backed aircraft noise and performance database. This database is maintained by EUROCONTROL[1] in Europe. In most cases, data is provided by manufacturers in the prescribed manner required for modelling purposes, but the quality of new submissions is systematically inspected for consistency and reasonableness. The database has been endorsed for international use by ICAO and is publicly available[2].

Conclusion

The new methodology for computing noise contours around airports should provide States with a powerful and flexible tool that combines the most up-to-date estimating techniques with the most accurate aircraft data available.

Reference

This article is mainly based on information developed by CAEP as contained in the CAEP/7 Report (Doc 9886).

[1] European Organization for the safety of air navigation.
[2] www.aircraftnoisemodel.org

Noise Abatement Operational Procedures

Aircraft Operational Measures for Noise Reduction

By James Brooks[1]

James Brooks is Senior Research Scientist at Georgia Institute of Technology where he conducts research on the mitigation of environmental impacts of aviation through improved flight operation procedures. As Chair of the Committee for Aircraft Noise and Engine Emission Modelling, he has contributed to several projects including Continuous Descent Arrival procedures at Los Angeles and Atlanta airports. Before joining Georgia Tech in 2006, Mr. Brooks spent 37 years with Delta Air Lines, the last 19 of which were in Flight Operations Engineering. He served as industry representative on numerous industry panels and committees including ICAO/CAEP working groups. Mr. Brooks has a Bachelor Degree in Mechanical Engineering from Auburn University.

This article discusses the use of aircraft operational measures as a noise reduction method, one of the elements of ICAO's Balanced Approach. It presents a discussion of aircraft procedures for both departures and arrivals/approaches, and their potential effect on noise levels. (Emissions such as CO_2 and NO_X are covered in Part 3). Absolute numbers with regard to noise benefits are not given here since a specific analysis of the aircraft/engine combination would be required.

Departure Procedures

Prior to 2001, the PANS OPS guidance contained only two recommended procedures; ICAO A and ICAO B. This guidelines imposed the selection of either of the two prescribed departure profiles without regard to differences in aircraft performance or noise attenuation technology. This constraint within PANS OPS[2] effectively blocked ICAO's initiatives to achieve departure noise benefits through operational procedures.

In 2001, the PANS OPS guidance was revised to replace the prescriptive ICAO A and B with minimum criteria for the design and development of noise abatement departure procedures (NADPs). These criteria were approved by the ICAO Council and in a condensed form are:

- Engine thrust reductions cannot be made below 800' above the runway;

- The thrust reduction cannot be below the thrust level required by the certificated aircraft flight manual or approved manufacturers' operations manual.

The current ICAO guidance on Noise Abatement Departure Procedures (NADP) is contained in Procedures for Air Navigation Services — *Aircraft Operations (PANS OPS) Volume I - Flight Procedures (Doc 8168), Part I, Section 7.*

Included in the revised PANS OPS section were recommendations that air carriers coordinate development of aircraft-specific NADPs in cooperation with the respective manufacturers, and it further recommended that air carriers develop one procedure for noise sensitive areas near the airport (NADP 1) and one for areas more distant (NADP 2). The differences in NADP 1 and NADP 2 are discussed below.

The departure profile specified in a procedure affects the distribution of the noise along the ground path associated with that flight. Each departure can be divided into a number of distinct elements designed to configure the aircraft for the constant-speed climb-to-cruise altitude:

- Takeoff Power Setting;
- Takeoff roll;
- Rotation;
- Initial climb;
- Engine power reduction;
- Flap retraction (acceleration segment);
- Acceleration to 250 knots (if necessary);
- Constant-speed-climb to initial cruise altitude.

Two of the items in the above list: engine power reduction and flap retraction; are the variable elements that have a pronounced affect on the noise profile of a flight. Figure 1 depicts the resulting profile differences between a procedure that incorporates the acceleration segment at 800 ft (NADP 2) above the runway, and one that delays that segment until 3000 ft (NADP 1). In both cases, the initial thrust reduction is at 800 ft. Since the thrust is the same after 800 ft, the difference in the respective altitude profiles produces noise benefits along the ground path of the flight. Also shown in Figure 1 is a "cross-over" point where the benefits of the delayed acceleration segment are overtaken by the early acceleration segment procedure. Analyses to date, have shown that this "cross-over" normally occurs approximately 50,000 ft. from brake release at the takeoff end of the runway.

[1] Mr. Erwin Lassooij and Mr. Vincent Galotti from ICAO Secretariat contributed to this article.
[2] PANS OPS stands for Procedures for Air Navigation Services, Aircraft Operations.

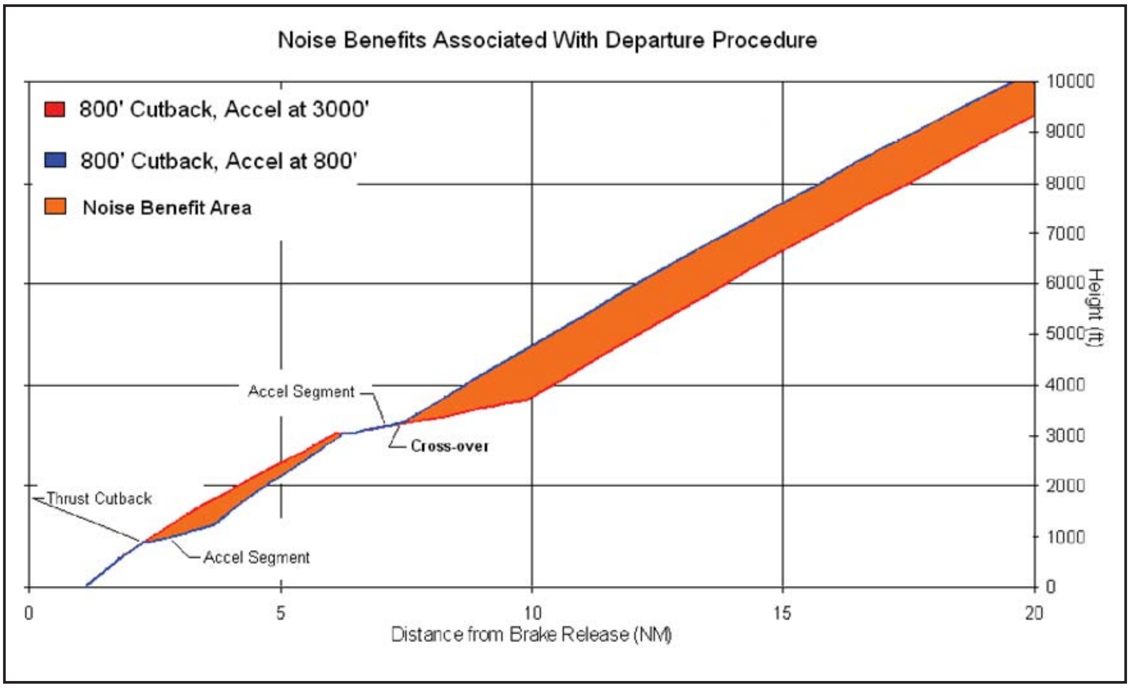


Figure 1 – Comparison of noise benefits using two different departure procedures.

Air carrier departure procedures vary, and can be aircraft specific. While the profile comparison given in Figure 1 is representative of the trend in altitude and distance, the target altitudes for thrust reduction are normally 800', 1000' or 1500' above the runway, depending on the specific type of aircraft. A few aircraft-specific procedures may specify the thrust reduction at an intermediate point, or even at the end of the acceleration segment. Acceleration segments are either concurrent with the initial thrust reduction, or the target altitudes and procedures that delay the segment to a higher altitude do not exceed 3000'.

The distribution of noise along the departure ground track of a flight is influenced by the departure profile, and guidance contained in PANS OPS now recommends that air carriers develop two aircraft specific departure procedures for operational use.

A new ICAO circular on noise abatement departure procedures (NADP) noise and emissions effects was developed in 2007 to replace circular 205 - *Recommended Method for Computing Noise Contours around Airports* - providing information to airports and operators on noise and emissions effects of departure procedures designed according to the provisions in PANS-OPS. The new circular will be published in 2008.

Arrival/Approach Procedures

Operationally, the Continuous Descent Arrival/Approach (CDA) procedures can produce significant reductions in noise and emissions. This concept is not new and is straightforward; whereby the arrival and/or approach of an aircraft is made with the engine thrust at or near the flight idle power setting and the level flight segments typically used in traffic management are eliminated, or at least significantly reduced.

However, the separation between individual aircraft making up part of a "flow" of multiple aircraft approaching the terminal area is negatively impacted by the "compression" that takes place as the leading aircraft executes a number of deceleration manoeuvres necessary to slow to landing speed, while the trailing aircraft is at a higher speed. Air Traffic Management (ATM) currently manages this separation using distance which is more easily accomplished by issuing speed changes to aircraft flowing along a level flight segment. Management of separation with multiple aircraft continuously descending is more complex and the algorithms and required automation does not currently exist to support these ATM requirements.

While CDA procedures currently exist at some airports in various forms, the fully optimized CDA for the environmental protection purposes would involve an unrestricted descent from cruise altitude to the final approach fix, at or near flight idle thrust without level flight segments. Unfortunately, the complexity of the airspace and lack of both airborne and ground based tools to control this, limits ATM personnel from managing this type of operation on a large-scale. Currently, at high-density traffic airports, controllers typically resort to extensive vectoring and speed control to synchronize traffic with minimum spacing to keep arrival rates at their optimum level. It is generally accepted that CDAs for high-density traffic will only be possible with the next generation of airborne avionics equipment and ground-based ATM management automation tools, coupled with an airspace redesign.

The results of some specific unrestricted CDA demonstrations resulted in a 5 to 6 dB reduction in peak noise levels along some portions of the flight path, resulting in noise contour area reductions of approximately 30%. As with departure noise reductions, the exact amount of noise reduction is airport and aircraft/engine specific. As the continuous descent flight path under CDAs replaces level flight segments, there will be some segments that will be lower in altitude, but since level flight segments require higher engine power settings, the resulting noise along the ground path could be offset.

Currently there are a number of research and development efforts underway that are geared toward identifying the issues, as well as the airborne and ground equipment necessary for effective CDA operations in high-density traffic. Other R & D efforts are looking at the near-term development and implementation of CDAs for low to medium traffic operations using existing equipment. A review of the results of both of these efforts has clearly identified common issues that need to be resolved and is directing the next phase of development work. To assist these development programs, ICAO is actively involved in the field of standardization of CDAs, developing guidelines for ATM and flight operations to prevent a proliferation of non-standard CDAs. The development of these standardized CDAs takes into account environmental aspects (noise and emissions), as well as fuel efficiency issues, while ensuring safe and efficient operations of the ATM operations.

CDA is only one of many aspects of a complex ATM system that is required to guarantee safe and efficient operation of air traffic (i.e., capacity, accessibility), while at the same time taking into account environmental concerns. Other important ATM operational improvements include performance-based navigation and optimized route structures.

Conclusion

These measures are also rendering environmental benefits such as: shortened routes with less emissions, more robust distribution of aircraft along the nominal flight path, and providing air navigation system providers with a better tool for avoiding noise sensitive areas. Nevertheless, the environmental problem cannot be viewed in isolation and has to be considered in the context of the efficient operation of a complex ATM system. To achieve this, ICAO is working with the various regions on several initiatives based upon their individual performance objectives.

Aircraft Operating Restrictions

Aircraft Operating Restrictions to Reduce Noise Pollution

By ICAO Secretariat

Under ICAO's balanced approach to aircraft noise management, an operating restriction is defined as "any noise-related action that limits or reduces an aircraft's access to an airport". Accordingly, depending on the noise problem at an airport, operating restrictions may be implemented as part of the set of measures to reduce noise at that location. ICAO encourages States not to apply operating restrictions as a first resort, but after considering the benefits to be gained from the other three elements of the balanced approach.

Types of Operating Restrictions

Operating restrictions can be global, aircraft-specific, partial and/or progressive, as described below:

Global – restrictions applied to all traffic at an airport based on total fleet noise performance.

Aircraft-specific - restrictions applied to a specific aircraft or a group of aircraft based on individual noise performance.

Partial – restrictions applied for an identified time period during the day, on specific days of the week, or only for certain runways at the airport.

Progressive – restrictions which provide for a gradual decrease in the maximum level of traffic or noise energy used to define a limit over a period of time. This period is typically defined as a number of years before reaching a final level.

Operating restrictions can be implemented in different ways:

- Number of movements per period of the day and/or year for the airport or per runway direction; for example, a maximum annual number of movements at the airport; and/or
- Quotas expressed as a combination of movements and aircraft acoustic characteristics or a fixed contour. Consequences of quotas may be a restriction on available slots or the closure of certain runway directions during a certain period.

Examples of Operating Restrictions

Source: Guidance on the Balanced Approach to Aircraft Noise Management (Doc 9829).

Following are specific examples of aircraft operating restrictions to reduce noise emissions. Any of them may fall into one or more of the four categories of the above-described operating restrictions, depending on how they are applied.

Cap rules - These global measures define the maximum number of operations not to be exceeded at an airport often for a given time period of the year. They can be partial, i.e. applicable to all operations of all aircraft during an identified period of the day on specific runways or on all runways of an airport. Sometimes the operations are weighted per period of the day or according to the noise (certified characteristics) of the aircraft (e.g. certified level, certified margin, cumulative margin).

Noise quotas - A noise quota (sometimes expressed as a "noise budget") is generally used to cap the total noise level from aircraft operations within a given area over or around the airport to some established total value over a given period of time (e.g. six months, one year, etc.). This may be expressed as an established noise energy over a period of time or the allocation of a maximum number of operations weighted by noise certification levels of the aircraft over a period of time. Noise quotas may be based on a historic noise level at the airport or on a future noise goal for the airport. They may be implemented to maintain a certain total noise level or to decrease the total noise level over a period of time. In the former case, as operators begin to use quieter aircraft, more slots could conceivably be available. Under the latter system, the use of quieter aircraft becomes necessary just to maintain a given number of slots.

Non-addition rules - Non-addition rules are measures of aircraft-specific restrictions aimed at prohibiting the new operation of specific aircraft or the operation of new (additional) aircraft based on noise performance using noise certification levels. These restrictions may apply to all runways of an airport or to specified runway directions.

Nature of flights - The nature of flights may be used as the criteria for partial operating restrictions in order to limit access to an airport. This kind of restriction often applies to non-scheduled flights and/or non-maintenance based flights, check flights and training flights. These flights may be forbidden, or not permitted during a specified period of the day; for instance during night hours and/or on specific days of the week.

Night-time restrictions - Due to the particular importance of the night for sleep, restrictions during night-time are of special concern. The operating restrictions described in this chapter may be applicable during the day and/or night, but due to the demand of people for undisturbed sleep, the measures introduced at the airport may be enhanced at night.

Curfews - Airport curfews are global or aircraft-specific partial operating restrictions that prohibit take-off and/or landing during an identified time period. Curfews might be tightened from the evening to the night and softened from the night to the morning as well. Curfews might be applied to specific runways.

History

ICAO started to address operating restrictions in the 1980's. In the late '80s some Contracting States, especially the developed ones, considered banning the operation of certain noisy aircraft at noise-sensitive airports. This measure was discussed inconclusively at the 27th Session of the ICAO Assembly ICAO in 1989. In 1990, following in-depth economic analyses and broad-ranging consultations an Extraordinary Session of the Assembly (A28) reached a consensus on a global framework for the eventual phase-out of aircraft compliant with Volume 1, Chapter 2 of Annex 16 but unable to comply with Chapter 3 Standards[1].

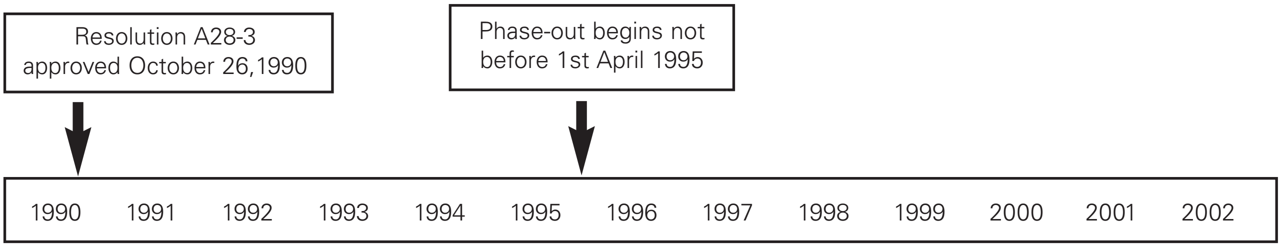
In the case of the older, noisier Chapter 2 aircraft, the ICAO Assembly in 1990 urged States not to restrict aircraft operations without first considering other possibilities described in the balanced approach. It then provided a basis on which States wishing to restrict operations of Chapter 2 aircraft could do so. States could start phasing out operations of Chapter 2 aircraft beginning 1 April 1995, and have all of them withdrawn from service by 31 March 2002. However, prior to the latter date, Chapter 2 aircraft were guaranteed 25 years of service after the issue of their first certificate of airworthiness. Thus, Chapter 2 aircraft which had completed less than 25 years of service on 1 April 1995 were not immediately affected by this requirement. Similarly, wide-body Chapter 2 aircraft and those fitted with quieter (high by-pass ratio) engines were not immediately affected after 1 April 1995. Most of the Chapter 2 phase-out results were felt in 2002, and by 2007 97% of Chapter 2 aircraft had been phased-out worldwide.

Later in the 90's some States took steps to phase-out operations of aircraft which had engines fitted with hushkits in order to comply the Chapter 3 Standards; in most cases only marginally. Other States were concerned that this was inconsistent with the Assembly agreement and would have a major impact on operations of aircraft and the operating economics of some carriers as well as the significant "hushkitting" industry. This concern subsequently lead to invocation of the rarely used Article 84 of the Chicago Convention on the "Settlement of Disputes". The dispute was eventually resolved amicably, but only after extensive analysis and many lengthy consultations under the aegis of the President of the ICAO Council.

In 2001, the question of phase-out was again raised by some States, prompting ICAO/CAEP to carry out a comprehensive review of the potential phase-out of Chapter 3 aircraft along with consideration of a new noise certification Standard, the Chapter 4 Standard. In its review, CAEP performed a detailed analysis of noise scenarios including the certification stringency and phase-out options using sophisticated modelling tools. The analysis of the options showed that an additional phase-out would only have a very limited environmental benefit and that the cost would be extreme. The conclusions of that study led ICAO to decide in 2001 to not introduce any operating restrictions at any airports on Chapter 3 aircraft

[1] See article "Noise Reduction of Aircraft Noise At Source" for more information on Chapter 2 and 3 aircraft.

Summary - ICAO Chapter 2 Phase-Out



ICAO Recommendations to Member States:
- Do not require a Chapter 2 phase-out to start before 1st April, 1995.
- Do not require a total Chapter 2 phase-out before April, 2002.
- Do not require a phase-out of Chapter 2 airplanes less than 25 years old.
- Exempt Chapter 2 airplanes with HBPR (hushkits) until at least 4/1/2002.
- Exempt Chapter 2 wide-bodied airplanes until at least 4/1/2002.

before fully assessing available measures to address the noise problem at the airport concerned, in accordance with the balanced approach.

Operating restrictions of this kind can have significant economic implications for the airlines concerned, both those based in the States taking action and those based in other States that operate to and from the affected airports. On each occasion, the ICAO Assembly succeeded in reaching an agreement – in the form of an Assembly resolution – 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.

The ICAO policy on phase-outs is contained in Doc 9848 - Assembly Resolutions in Force as of 8 October 2004 - Appendix D – Phase out of subsonic jet aircraft which exceed the noise levels in Volume I of Annex 16. Table 1 presents examples of measures taken by States for the implementation of ICAO Chapter 2.

Table 1 – Examples of countries or regions that have implemented Chapter 2 noise phase-out rules.

Countries or Regions	Status
United States	– Stage 2 fleet phase-out completed 31 December 1999. – No waivers granted.
Canada	– 100% Chapter 3 compliance by 1 April 2002.
Europe (European Union)	– Required phase-out of all Chapter 2 aircraft completed 1 April 2002. – Rule stated that: At 25 years of age, narrow-body Chapter 2 aircraft will be ineligible for operation in the European airspace without Chapter 3 modifications. **Exceptions**: – No more than 10% of an operator's total fleet can be phased-out in any given year. – Wide-body aircraft are exempted from the interim age-based phase-out schedule, but must be phased-out by the final compliance date of 1 April 2002.

Table 1 (cont'd)

Japan, Australia, New Zealand	– Required phase-out of all Chapter 2 aircraft by 1 April 2002. – At 25 years of age, Chapter 2 narrow-body aircraft will be prohibited from operating in Japan, unless modified to Chapter 3. – Phase-out of Chapter 2 aircraft began after 1 April 1995. **Exceptions**: – No more than 10% of an operator's total fleet can be phased-out in any given year. – Wide-body aircraft exempted from the interim age-based phase-out schedule, but had to be phased-out by the final compliance date of 1 April 2002.
Singapore	– Chapter 2 aircraft be phased out in 1 April 2002.
Philippines	– Starting 1 January 2003, airlines started removing Chapter 2 aircraft as follows: • 25% by 31 December 2003. • 50% by 31 December 2004. • 75% by 31 December 2005. • 100% Chapter 3 compliance in 31 December 2006.
Brazil	– After 31 December 1998, it was prohibited to register additional Chapter 2 aircraft in Brazil. – After 31 December 2004, airlines must progressively remove from operation a minimum of 20% of Chapter 2 aircraft from their fleet per year. – After 31 December 2010, all Chapter 2 aircraft are prohibited from operating in all Brazilian airports.
Colombia	– As of 1 January 1997, a non-addition of Stage 2 aircraft is in effect in Colombia. – As of 1 January 2000, all Stage 2 operations at Eldorado International Airport are banned; • The Bogota airport noise rule might have been amended to be aligned with the final Colombian phase out date. – By 1 January 2003, all Stage 2 aircraft had to be phased out or brought up to Stage 3 Standards.
Argentina	– Considering implementing rule modelled after Brazil rule
Mexico	– Non-Addition of Chapter 2 Aircraft to Mexico Implemented Effective 1 January 2000. – Passage of the Stage 2 noise phase-out proposal completed in November 2000. – Rule states that starting 1 January 2000, Airlines started removing Chapter 2 aircraft as follows: • 30% in 31 December 2001. • 60% in 31 December 2002. • 80% in 31 December 2003. • 100% in 31 December 2004.
Chile	– Non-addition of Chapter 2 aircraft currently implemented. – By 31 December 2008, all operations to Chilean airports must be Chapter 3.
Ecuador	– Airlines had to be 100% Chapter 3 by the 31 December 2003.
Peru	– Non-Addition Rule for Chapter 2 aircraft - 27 September 2000. – Domestic Operators - Must be Chapter 3 by December 2002. – International Operators - Must be Chapter 3 by August 2001.

South Africa	– After 1 January 2001 it was prohibited to register additional Chapter 2 aircraft in South Africa. – Foreign airlines were not allowed to operate additional Chapter 2 aircraft to South Africa as of 1 January 2001. Phase-out of Chapter 2 aircraft had the following schedule starting on 1 January 2003: • 50% of the Chapter 2 fleet had to be phased-out OR 80% of the total fleet must consist of Chapter 3 aircraft by 31 December 2006. • 75% of the Chapter 2 fleet must be phased-out OR 90% of the total fleet must consist of Chapter 3 aircraft by 31 December 2008. • 100% Chapter 3 compliance by 31 December 2009.

Source: Boeing

ICAO's Policy on Operating Restrictions

The decisions of the 35th Session of the ICAO Assembly regarding operating restrictions are contained in Assembly Resolution A35-5, Appendix E - Local noise-related operating restrictions at airports.

ICAO discourages the application of operating restrictions as the first option to mitigate noise around a specific airport. As stated above, the other elements of the balanced approach should be considered first. Nevertheless, if operating restrictions are to be considered, these should:

a) be based on the noise performance of the aircraft, as determined by the certification procedure conducted, consistent with Annex 16, Volume I;

b) be tailored to the noise problem of the airport concerned in accordance with the balanced approach;

c) be limited to those of a partial nature wherever possible, rather than the complete withdrawal of operations at an airport;

d) take into account possible consequences for air transport services for which there are no suitable alternatives (for example, long-haul services);

e) consider the special circumstances of operators from developing countries, in order to avoid undue hardship for such operators; by granting exemptions;

f) introduce such restrictions gradually over time, where possible, in order to take into account the economic impact on operators of the affected aircraft; and

g) give operators a reasonable period of advance notice.

In addition, ICAO encourages States to continue to cooperate bilaterally, regionally and interregionally with a view to alleviating the noise burden on communities around airports without imposing severe economic hardship on aircraft operators, and taking into account the problems of operators of developing countries.

Figure 1 illustrates the growth of noise restrictions at worldwide airports. As shown, the number of airports applying noise restrictions has increased significantly during the last 30 years. Noise Abatement Procedures (NAPs) and curfews are the measures that have observed the highest growth.

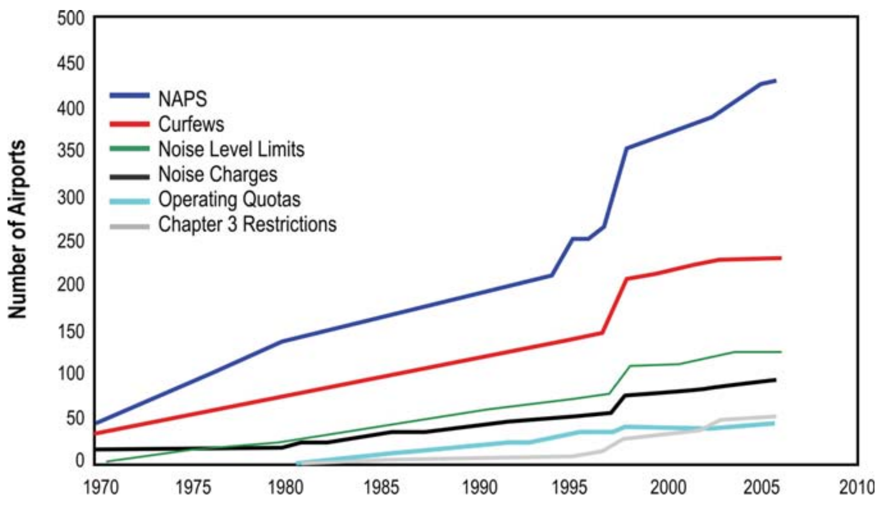


Figure 1 – Growth in Airport noise restrictions at airports, worldwide.
Source: Boeing, 09/06/2006

Curfews Study

There is growing pressure in some parts of the world to impose curfews at busy airports, as they are often seen as simple and ready-to-use instruments for reducing noise around an airport. A curfew is defined in the Balanced Approach guidance document as "a global or aircraft-specific partial operating restriction that prohibits take-off and/or landing during an identified time period." A global curfew is one which bans all flights during a specific time period. A partial curfew prohibits the operation of specific aircraft types, prevents the use of specific runways or only affects landings or take-offs. Curfews normally apply at night, e.g. from 2300 hr to 0700 hr.

Curfews could affect many types of operations carried out at night such as: scheduled short and long-haul passenger flights, passenger charter flights, scheduled and charter freight flights, and express and mail flights. A curfew established at a specific airport does not only affect that airport and its environs, it may also affect the departure and arrival times at other airports as well as the noise situation in a different region or country. For example, a curfew at a European airport with flights to far away destinations (e.g. India) could reduce the number of people exposed to noise during the night locally but could significantly increase the number of people exposed to noise at the corresponding Indian airport of destination.

Some States, expressed concerns during the 35th Session of the ICAO Assembly about the global impact of night curfews. Airports without curfews, because of the restrictions by other airports, will have to accommodate a large volume of international operations at less convenient hours, as well as the potentially adverse effects for market access, the use of traffic rights and air transport growth. It was recognized by the Assembly that this was a delicate matter and that it should be further studied by ICAO, particularly with a view to determine the scope and scale of the problem.

In response to the Assembly's request, a study was carried out by ICAO CAEP in 2007 to examine the types, the reasons for, and the global scope and scale of curfews. In this context, scale is understood to be the number of airports that apply curfews, while scope is the type of restriction (i.e. partial or total). In order to draw conclusions and to have sound data on worldwide curfews, a database of worldwide regulations on noise was used. The Boeing database contains information on 610 of the world's major international and regional airports, approximately half of which are in North America. This database was updated with support from ICAO/CAEP and was used as the basis for the study.

It was observed that out of the 610 airports studied, about 227 of them had curfews. Approximately one-half of the airports with curfews were in Europe and one-third were in North America, with the remainder spread over the rest of the world. The 30 busiest airports (arrival passenger numbers above 30 million) of the database were located as follows: 18 in North America (4 had curfews); 6 in Europe (all had curfews); and 6 in Asia (2 had curfews).

The issue of curfews and their environmental impact will be studied further by ICAO. A case study for a major airport will be carried out and results are expected by 2010.

Conclusions

Aircraft operating restrictions have the potential to provide fast and significant reductions of noise around airports but they can also impose impacts and constraints that may influence other aspects of an airport's operation (e.g. extra financial burden in operators, imposing fleet or route changes on other airports).

Consistent with its goal of achieving maximum compatibility between the safe, economically effective and orderly development of civil aviation, and taking into consideration the quality of the environment, ICAO advises its Contracting States not to introduce any operating restrictions at airports before undertaking a cost-effectiveness assessment of available measures to address the noise problem in accordance with the balanced approach.

References

Guidance on the Balanced Approach to Aircraft Noise Management (Doc 9829).

Assembly Resolutions in Force (as of 8 October 2004) (Doc 9848).

IATA – Balanced approach to noise management around airports.

Boeing database on Airport Noise regulations for Commercial Airplanes.
http://www.boeing.com/commercial/noise/index.html

Other Developments

Review of Supersonic Technology and Standards

By Kenneth Orth

Kenneth Orth is an Associate Technical Fellow (Retired), Boeing Commercial Airplane Company. Mr. Orth is a senior aircraft noise specialist with more than thirty years in the aircraft manufacturing industry. With Boeing he was responsible for noise design of future airplane models and assisting airlines in selecting models with noise profiles compatible with their community noise requirements. Mr. Orth was international manufacturers' Observer to the ICAO Committee on Aviation Environmental Protection (CAEP) where he participated in working groups developing policies and standards dealing with aviation noise and emissions and he was leader of the manufacturers at the CAEP/4 and CAEP/5 meetings. He worked closely with the FAA in the US and with ICAO on Noise Technology Working Group (WG1) of CAEP and served as focal point for the Supersonic Task Group of WG1 after CAEP6 in 2004.

Until recently there has been no reason to be concerned about the adequacy of ICAO environmental standards for supersonic airplanes. In the past, supersonic airplanes were believed to be so environmentally unfriendly that flight over populated areas was considered unacceptable, making them not commercially viable. In fact, the only commercial supersonic model, the Concorde, was removed from service in 2003. It has been assumed by most people that any supersonic flight would create objectionable sonic boom noise, like that of the Concorde, making future supersonic models unlikely, and updates to their environmental standards a non-issue. However, there have been advances in technology in recent years that are bringing the need for environmental standards related to supersonic aircraft back into focus.

Background

In the late 1960s and early 1970s, George and Seebass (1) and others put forward workable ideas on how one could design aircraft to have minimal sonic booms. Those ideas were expanded by Mack and Darden (2) in the 1980s. As sonic boom is intimately linked to the detailed geometrical shape of an aircraft and the lift distribution on the wings, the basic idea was to carefully control the cross-sectional area and lift of the aircraft. However, it wasn't until the last 15 or 20 years that there has been sufficient computing power, advances in computational fluid dynamics, and optimization, that these shaping concepts could be significantly advanced.

As a result of those advancements, computational and design tools are now being developed that designers believe will allow them to create aircraft designs that will reduce or eliminate objectionable sonic boom noise. With those rapidly developing tools for designing sonic boom reduction technologies, corporations and consortiums are currently seriously looking into commercial supersonic airplane programs.

Figure 1 – Conceptual design of a Supersonic commercial aircraft. By Gulfstream Aerospace Inc.

There are several different groups in the United States and Europe that are right now developing smaller size supersonic airplanes for use as business jets. More visible among those groups are: Aerion Corporation, Gulfstream Aerospace, Dassault Aviation, and Supersonic Aerospace International. The Government of Japan is exploring development of even larger supersonic airplanes. An example concept of one of these supersonic airplanes is shown in figure 1.

With these continuing advancements in sonic boom reduction technologies, many experts now believe that designers may be able to design airplanes that would have sufficiently low sonic boom signatures, (or without sonic booms that reach the ground), that they may be acceptable for flight over populated areas. That raises the question as to what might be an acceptable sonic boom level to permit over-flight of populated areas.

Both Japan and the United States have looked into developing such acceptability criteria for sonic boom and have done limited work in the area. Some work towards developing acceptability criteria in both countries has been done using sonic boom simulators. Background for previous studies was described in more detail by Sparrow and Coulouvrat (3) in their February, 2007 paper presented to the 7th meeting of the ICAO Committee on Aviation Environmental Protection (CAEP/7). Much more of such work is believed to be required, primarily involving large-scale testing, involving flight demonstrations of low-boom test vehicles.

Regulatory Issues

ICAO instructed the Council in Assembly Resolution 33-7 and reaffirmed in Appendix G of Resolution 35-5 "… to review the Annexes and other relevant documents, so as to ensure that they take due account of the problems which the operation of supersonic aircraft may create for the public and, in particular, as regards sonic boom, to take action to achieve international agreement on measurement of the sonic boom, the definition in quantitative or qualitative terms of the expression 'unacceptable situations for the public' and the establishment of the corresponding limits."

A full discussion of the background for the current noise and emissions Standards and Recommended Practices (SARPs) for supersonic airplanes is available in the CAEP/7 documentation (4). Neither the emissions nor the noise SARPs for supersonic airplanes have been revised in the last 30 years. The reason they have not been updated in that time period is that new supersonic models were thought to be unlikely.

For noise, there is a note that states:

"Standards and Recommended Practices for these aeroplanes are not yet developed but the noise levels of Chapter 3 of this Part applicable to subsonic jet aeroplanes may be used as guidelines for aeroplanes for which the application for a certificate of airworthiness for the prototype was accepted or another equivalent prescribed procedure was carried out by the certificating authority on or after 1 January 1975."

As stated above, these are guidelines. New types of subsonic airplanes must meet the recently adopted Chapter 4 Noise Standards which are at least a cumulative of 10 EPNdB more stringent than the current Chapter 3 Standards used as guidelines for supersonic airplanes.

For engine emissions, there is a parallel situation. Since it was believed that there was little likelihood of another supersonic airplane, after the Concorde, little effort was put into developing

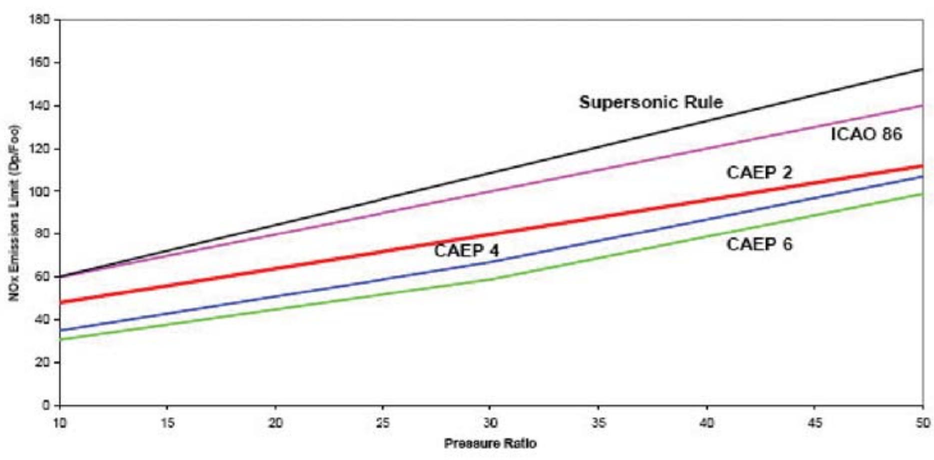


Figure 2 – Comparison of NOx Regulations for Subsonic and Supersonic Aircraft.

new emission standards for such aircraft. Consequently, the emissions standards are also more than 30 years old. A sample of the NOx standards for supersonic airplanes, compared with the standards for subsonic airplanes, including the most recent CAEP 6 standard, is shown in Figure 2.

Work Program for Noise and Emissions Standards

There is little doubt that the noise and emissions standards for supersonic airplanes should be reconsidered by ICAO. Therefore, in February 2007 at CAEP/7, work was recommended to include reconsideration of the noise and emissions standards for future supersonic models (5).

Work programmes related to noise are:

1. Monitor, and report on, status of SST projects and expectations for their operation (nature, frequency, etc.);
2. Investigate the adoption of current subsonic noise rules for supersonic standards and make recommendations as appropriate;
3. Monitor, and report on, research to characterize, quantify and measure (including metric) sonic boom signatures, and their acceptability;
4. Assess the extent of knowledge on sonic boom and decide if it is appropriate to consider drafting standards for sonic boom.

Work programme items for emissions:

1. Promote new global impact assessments associated with a fleet of supersonic aircraft and report progress;
2. Review and revise, as appropriate, the existing methodology for supersonic aircraft engine emissions certification.

Conclusions

Supersonic airplane technology research and development is progressing rapidly. However, the timing of individual commercial development programmes is unknown, or at least not yet publicly available. Nevertheless, there have been indications that some supersonic models could start flying as soon as the next 3 to 4 years, although there is still much uncertainty about that. Reasons for this uncertainty include; financing concerns, competitive positioning and secrecy, uncertainty over sonic boom acceptability criteria, and unknowns about the pace of the actual technology development. If the technology advances relatively rapidly, subsequent programmes may be able to produce a substantially superior airplane.

ICAO is required to make sure that airplanes are designed to have minimum impact on the environment, consistent with economic reasonableness and with technical practicality. With their recently adopted work programme, CAEP is moving to make sure that ICAO Standards and Recommended Practices for noise and emissions are updated as soon as possible to include supersonic airplanes.

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Rotorcraft Noise Technology Developments

By Alain Depitre

Alain Depitre joined the Directorate General of Civil Aviation (DCAC) of France as an Acoustical Engineer in 1970. He became a licensed aircraft pilot in 1979, and he continues to fly for pleasure. While Chief of DGAC's Environment Unit, he built a laboratory for aircraft noise certification and airport noise studies which became recognized internationally. He also built a laboratory for measurement and analysis of pollutants, and worked on analysis of cockpit voice recorders. Over 30 years, Alain has worked with a variety of different ICAO Working Groups (CAN and CAEP) and has been France's advisor to CAEP for 25 years.

This article briefly describes the advances made in helicopter noise reduction over the last twenty years and highlights recent developments. It also indicates the areas where further development of ICAO provisions is taking place, such as the use of selectable/variable technology and the provision of helicopter data for land use planning.

History

ICAO Standards for helicopter noise certification became applicable in 1985, about ten years later than those for fixed-wing aeroplanes. The first standards are contained in Annex 16, Volume I, Chapter 8 and were developed during the Sixth Meeting of the Committee on Aircraft Noise in 1981. In November 1993 a new standard was adopted for light helicopters (helicopters not exceeding 3 175 kg) and became Chapter 11 of the Annex 16.

The necessity of decreasing the noise pollution from helicopters is especially problematic since the noise accrued from the operation of helicopters is not confined to airports (helicopters fly into the hearts of cities). Conscious of this need, manufacturers have improved the noise performance of helicopters and substantial progress has been achieved. Some of today's most modern helicopters can achieve noise levels well below the Chapter 8 and Chapter 11 noise limits, and it is common now to find helicopters certificated with a cumulative margin about twenty decibels (EPNdB[1]) below the limits for Chapter 8 helicopters and nine to ten decibels (SEL[2]) for Chapter 11 helicopters. This is good progress compared with the first certificated helicopters which had noise levels close to Chapter 8 limits.

This progress has been made through modifications to several principal noise sources, such as:

- the main rotor: reducing broadband noise, impulsive noise , thickness noise , loading noise, blade vortex interaction;
- the tail rotor: reducing broadband noise and tones (charge of traction, interaction with structure, wake, stators);
- the engine(s): reducing broadband noise and tones (compressor, turbines, combustor, and nozzle).

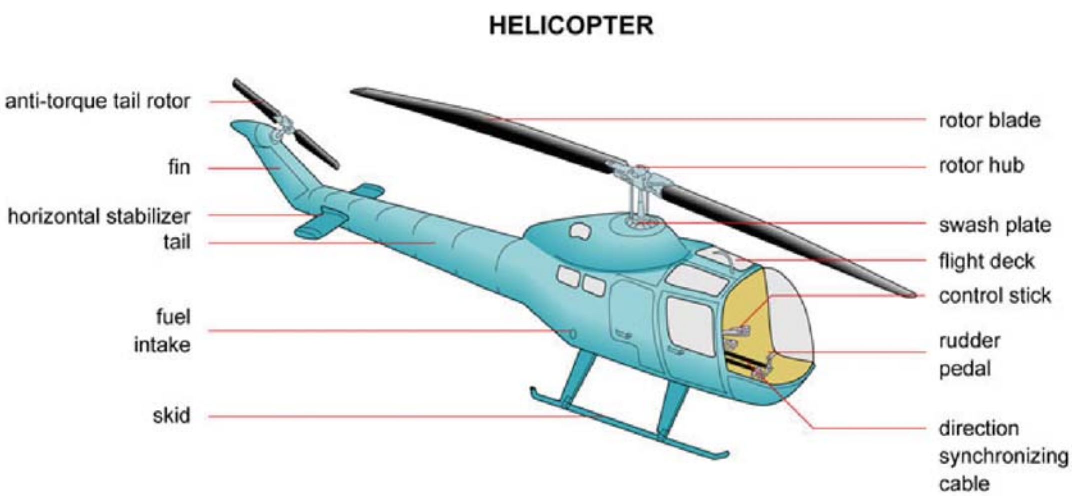

Figure 1 – Helicopter main components.

1 EPN Effective perceived noise level; dB – decibel.
2 SEL- Sound Exposure Level.

Figure 2 – Helicopter main rotor hub where the rotor's drive shaft and blades connect.
Source: Marshall Brain

In practice, this progress has been obtained by the use of reduced rotor speeds, more silent rotor blades and new tail rotor/anti-torque concepts (e.g., the Fenstron[3] and the NOTAR[4]), and by ìactive controlî for engines/rotor speed. Active flap control and other similar systems have also been examined for reducing blade vortex interaction.

Some helicopter manufacturers are involved in ambitious noise reduction (noise abatement) programmes which, it is hoped, will eventually lead to *noiseless* helicopter flight.

Since the introduction of noise limits for helicopters into Annex 16, Volume I (in Chapters 8 and 11), CAEP's work has been mainly directed toward refining and improving the certification methodology.

Accomplishments at CAEP/7

At the CAEP/7 meeting held in February, 2007, progress was made in a number of areas with respect to helicopter noise issues. These included areas of technical detail such as the definition of "no acoustical change" and the certification of helicopters capable of carrying external loads or incorporating Category A procedures. The more significant decisions concerned selectable/variable noise reduction technology and land use planning, as described below.

Selectable/Variable Noise Reduction Technologies

In the last decade, an effort to reduce the exterior noise generated by rotorcraft, in particular rotor noise has been carried out by research centres and manufacturers with the support of ICAO Member States. The status of several selectable/variable noise reduction technologies applicable to rotorcraft has been discussed. These

[3] A Fenestron (or Fantail) is a totally enclosed tail rotor of a helicopter and is essentially a ducted fan. The term Fenestron is a trademark of Eurocopter.
[4] NOTAR - is an acronym for NO TAil Rotor, is a relatively new helicopter anti-torque system developed by McDonnell Douglas Helicopter Systems which eliminates the use of the tail rotor on a helicopter, yielding quieter and safer operation.

technologies include variable rotor speed, active rotor control, automated flight guidance, engine noise reduction, and tilt-rotor nacelle angle control. Furthermore, new engine technology permits more flexibility in changing the rotor rpm so that, if required, it can be changed during takeoff, landing or cruise flight to give a lower rotor tip speed compared to the normal operating speed. The reduction of tip speed is known to be one of the most effective means of noise reduction.

Active rotor control technologies can also be used to reduce noise. These systems are mainly useful in the approach where blade vortex interaction (BVI) can be the main source of helicopter noise. Such systems could make it possible to control the blade position during the rotor revolution to increase the distance between a blade and the incoming vortex generated by the previous rotor blades, so that BVI is avoided. Some of these technologies are ready to be tested on full scale rotors or directly on helicopters.

Rotorcraft flows are dominated by unsteadiness. One critical aspect of this is the formation of spiral trailing-vortex systems from the tip of each main-rotor blade and the subsequent interaction of these trailing vortices with the other main-rotor blades or with the tail-rotor system. These are collectively referred to as BVI - blade vortex interactions. The interactions can occur from low speeds up to transonic speeds and are responsible both for near-field unsteady aerodynamic loading of the blades and also for near- and far-field acoustic radiation and sound levels.

Source: Imperial College London

Noise abatement procedures have been successfully applied to rotorcraft without any additional cost or technical modification. In recent years the development of Global Positioning Systems has improved the ability to use such techniques because they permit the use of steeper approach procedures which can allow a rotorcraft to avoid the generation of noise such as BVI during landing.

It is considered that the use of such technologies needs to be recognized in the noise certification procedures and in the development of land-use planning data, to ensure that the development of such technologies is stimulated and the noise reduction benefits quantified in a manner which is internationally agreed.

Land-Use Planning

One component of ICAO’s ìbalanced approachî to noise reduction is land-use planning (LUP) and management. Since there were no specific tools for developing rotorcraft noise contours for land use planning purposes, Guidelines were developed and approved as Attachment H to Annex 16, Volume I. The objective of Attachment H is the provision of noise data, in metrics suitable for land use planning purposes, at the noise certification flight conditions and/or alternative flight conditions representing normal operating procedures or other recommended flight procedures.

It will be necessary in the future to continue to develop the new guidelines in light of ongoing studies and field tests. These activities offer the opportunity to increase our understanding of the requirements for LUP related to rotorcraft noise reduction. As the understanding of noise abatement and LUP requirements increases and LUP models evolve, more noise measurement points may be advisable. Additional flight procedures may be developed and consistent data processing and corrections may need to be considered to provide the necessary accuracy for LUP applications. It is expected that further results from research programmes will be available in time for the CAEP/8 meeting (2010), at which time further development of guidance material can be proposed.

Conclusion

Considerable progress has been made over the years in reducing helicopter noise and work continues with developments in a number of areas. Application of the Balanced Approach to helicopter noise has led to continuing improvements similar to those already achieved for aeroplanes. In the area of selectable/variable systems it is interesting to note that the issue was first raised in relation to helicopters and is now being investigated for all aircraft.

The helicopter noise certification world is similar to that for aeroplane noise certification in its spirit and purposes. However, it differs due to the unique features of helicopters which also make it more open to operational possibilities. These specificities need to be addressed separately.

Local Emissions

Local Emissions Overview

By ICAO Secretariat

One of the environmental goals set by ICAO is to limit or reduce the effects of emissions from aviation on local air quality (LAQ). LAQ environmental concerns tend to pertain to effects created by aircraft emissions during the landing and take-off (LTO) cycle. Typically these emissions occur up to 3 000 feet (or 915 metres) above ground level.

Background

Since the advent of commercial civil aviation, aircraft noise has been (and continues to be) at the centre of local environmental concerns due largely to the fact that aircraft noise is easily perceived. However, other potential environmental effects of aviation have been gaining global attention since the late 1970s, for example the increased public concern regarding potential consequences of aircraft engine emissions (and associated activities) on local air quality and global climate change (see Part 4 of this report).

Potential adverse effects of air pollutants on LAQ primarily pertain to human health and welfare (which include, among other things, potential problems in the form of respiratory and cardiovascular disease).[1] Common air pollutants from aircraft emissions are oxides of nitrogen (NO_x – includes nitrogen oxide and nitrogen dioxide), carbon monoxide (CO), sulphur oxides (SO_X), unburned hydrocarbons (HC) and smoke. Particles (such as particulate matter $PM_{2.5}$ and PM_{10}) present the most serious adverse health impacts from aviation emissions.[2]

The generation of these pollutants also arises from other airport related activities which involve the combustion of fossil fuels, e.g. ground support equipment, auxiliary power units and ground transport at and near airports.

While CO_2, emitted from aircraft engines and other sources at airports imposes no adverse effects on LAQ, it is considered an environmental concern related to climate change. Thus, articles related to CO_2 will be presented in the climate change section of this report (see Part 4).

This part of the report contains a number of articles related to the mitigation of the effects of aircraft emissions on local air quality. These articles fall into three general areas: Technology and Standards, Operational Measures and Market-Based Measures, and also cover the Development of an Airport Air Quality Guidance Manual. Those subjects are summarized in the paragraphs below.

Technology and Standards

The current ICAO Standards for emissions certification of aircraft engines (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. To achieve certification, it must be demostrative that the characteristic emissions of the engine type for HC, CO, NO_x and smoke are below the limits defined by ICAO. The certification process is performed on a test bed (as shown in Figure 1), where the engine is run at four different thrust settings, to simulate the various phases of the LTO cycle, as follows:

- **take-off** (100% available thrust) for 0.7 min;
- **climb** (85% available thrust) for 2.2 min;
- **approach** (30% available thrust) for 4.0 min; and
- **taxi** (7% available thrust) for 26 min.

The setting of standards is linked closely to technological innovations; which stem from research and development and market forces. Technological innovations in aviation continue to pave the way towards effective and efficient measures in support of ICAO's environmental goals of limiting or reducing the impact of aircraft emissions on local air quality.

[1] As part of its future work programme ICAO's CAEP/8 will examine and model the potential health effects of aviation. This work will examine both aircraft emissions and aircraft noise concerns. The first phase will take place at the Scientific Workshop on Aviation Health Effects, scheduled for October 29 – 30, 2007, ICAO Headquarters, Montreal, Canada, QC.
[2] CAEP/7 IP/25 entitled, "Aviation Environmental Portfolio Management Tool (APMT) Progress."

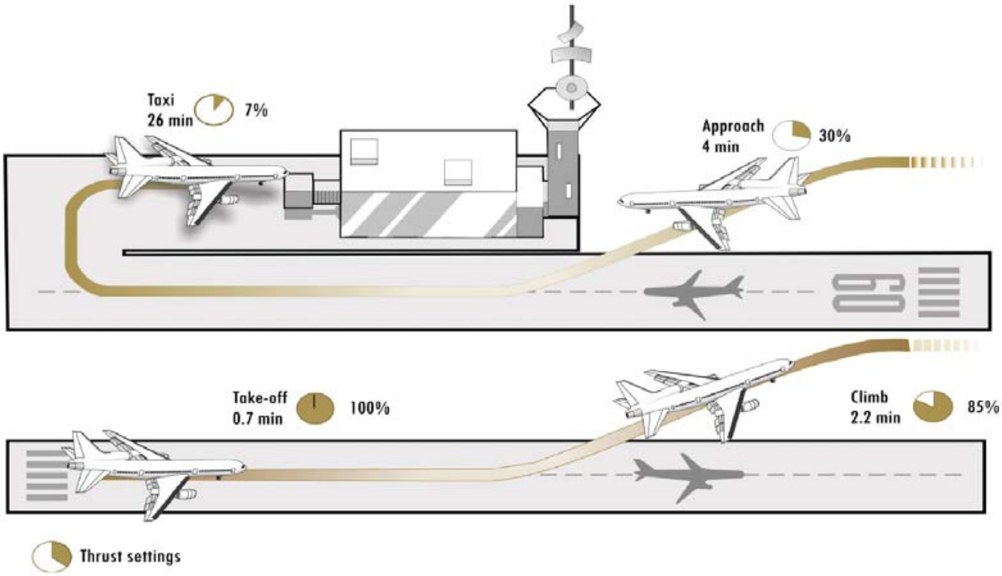

Figure 1 - Illustration of ICAO Emissions Certification Procedure LTO Cycle.
Source: ICAO.

For a snapshot of the progress made by ICAO regarding technology and Standards (in collaboration with its stakeholders from industry and academia), one need not look any further than advances in aviation over the past 20 to 40 years. Since becoming effective in 1986[3], ICAO has increased the stringency of international NO_x emission Standards by about 40% for newly certificated aircraft engines[4]. This action has significantly reduced the impact of NO_x emissions from aircraft engines on local air quality, including some mitigation effects on climate change since NO_x is a precursor to ozone. Additionally, today's modern large transport jet aircraft are 70% more fuel efficient than they were 40 years ago. Figure 2 shows how technological innovations in aircraft engines have resulted in reductions of key air pollutants. ICAO's leadership in the emissions Standards setting process has been instrumental to these achievements.

Figure 2 illustrates the relative reductions in emission levels from landings and take-offs (LTO) before and after implementation of ICAO's CAEP Standards. For example, in the first comparison from left to right for the Pratt & Whitney (P & W) JT8D-200 engines, emissions levels for NO_x, UHC, and CO are at their highest. However, after compliance with ICAO's Standards, overall emissions from the P&W JT8D-200 E-Kit, dropped sig-

[3] This increase in the NO_x stringency standard of about 40 percent is based on a pressure ratio of 30, and it includes the CAEP/6 NO_x stringency increase of 12 percent, which takes place in 2008. ICAO/CAEP continues to evaluate the merits of increasing its stringency standards for NO_x emissions in its future work programme.
[4] The standard for NO_x was adopted by ICAO in 1981 and became effective in 1986.

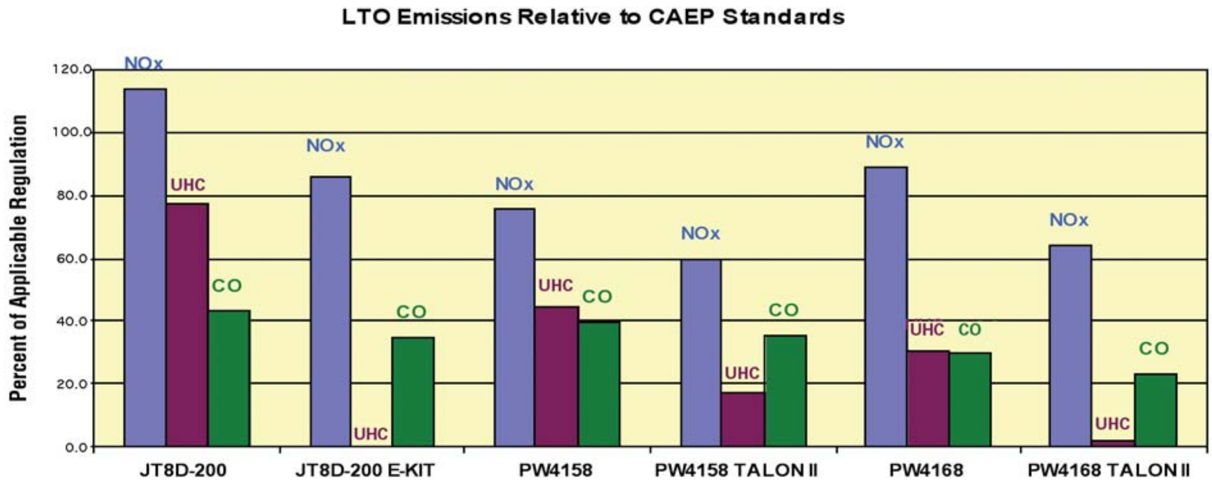

Figure 2 – Reductions in Pollutants from Aviation by Engine Type. Before and After CAEP.
Source: Pratt & Whitney.

nificantly. In fact, unburned hydrocarbons have been virtually eliminated. Although this example focuses on P&W aircraft engines, similar examples could be cited for aircraft engines from other manufacturers.

To complement the standard-setting process, CAEP/7 developed, with the assistance of a panel of independent experts, medium and long term NO_x technology goals (respectively 10 and 20 years time). The medium-term NO_x goal is a reduction from current standards of 45% by 2016. The long term NO_x goal is an improvement of engine emissions performance of 60% by 2026.

More about CAEP's technical work regarding emissions is discussed in four following articles in this Part of the report.

Operational Measures

Within the context of local air quality, operational measures represent procedures aimed at increasing operational efficiency (which includes fuel-burn reduction) of commercial jet aircraft through more direct routings. These operational measures take many forms including continuous descent approach or arrival (CDA.) The benefits take the form of reducing the levels of aircraft engine emissions on LAQ, global climate, and aircraft noise.[5]

An example of CDA's potential mitigation benefits on LAQ is shown in the Figure 3, where the average NO_x produced by the B757-200 (includes both engine types Pratt and Whitney and Rolls Royce) performing the CDA and the conventional approach (referred to as baseline) is reduced by 37%, (from 1510g to 951g). The corresponding reduction for the B767-300 is 39.9%, (from 2882g to 1732g). These significant reductions in NO_x were not surprising as they are very much in line with those reported by other studies.

Market-Based Measures

Before 1998, all of ICAO/CAEP focus regarding controlling emissions was technology-based. Since then, however, the mitigation mechanisms for limiting or reducing the effects of aircraft emissions on LAQ have been extended to include the use of market-based measures (MBMs). MBMs typically include aircraft emissions levies (or charges) and emissions trading schemes (mandatory or voluntary). They offer a potentially cost-

[5] The discussion of CDA, however, in this part of the report focuses only on the mitigation of aircraft emissions on LAQ through fuel-burn reduction operating manoeuvres.

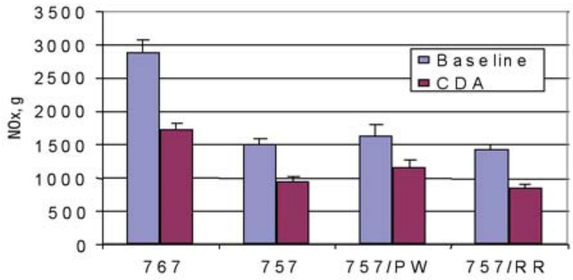

Figure 3 – NOx Emitted by Aircraft With and Without CDA Operations
Source: J-P Clarke and Liling Ren, Georgia Institute of Technology, Atlanta, Georgia (USA).

effective approach to achieving CAEP's environmental goals. Two articles on these MBMs are presented later in this part of the report.

Airport Air Quality and Aircraft Emissions Charges Guidance

One of ICAO's objectives is to develop harmonized best practices related to civil aviation. In keeping with this objective, ICAO/CAEP recently developed guidance to Contracting States on how to implement harmonized best practices with respect to local air quality and emission charges at airports. With respect to emissions charges, this part of the report include articles providing an overview of ICAO's newly developed guidance on aircraft emissions charges related to LAQ (Guidance on Aircraft Emissions Charges Related to Local Air Quality, Document 9884) and an overview of ICAO existing policy guidance on charges and taxes.

Another key aspect of this part of the report pertain to the newly developed guidance of the airport air quality manual. This guidance manual would provide assistant to States in assessing and quatifying airpoirt sources of emissions (Airport Air Quality Guidance Manual, Document 9889).

The first part will help users create a regulatory framework, inventories of airports, and airport sources of emissions (already developed by CAEP/7 in 2007),

The second part which includes dispersion modelling, airport measurements, mitigation options, etc., is expected to be developed for CAEP/8 in 2010.

Challenges

The subject of emission sources is a complex topic. This complexity is compounded by the fact that sources of airport emissions other than those associated with aircraft include ground support equipment (e.g. passenger buses, mobile lounges, fuel trucks, aircraft tractors, etc.), landside vehicles (cars, taxis, trains, etc.) and stationary power generation plants. This makes it difficult to determine the specific contribution of aircraft to the local air quality situation.

Accordingly, there are many challenges confronting ICAO with respect to mitigating the effects of aircraft emissions on local air quality. Some of these challenges include: the continuous evaluation of the merits of imposing more stringent standards for NO_x, reviewing medium and long-term NO_x technology goals, and exploring the need to develop certification standards for particulate matter due to its potential by adverse impact on human health.

Technology and Standards

Review of Aircraft Emissions in the Vicinity of Airports

By ICAO Secretariat

When the first edition of ICAO's Annex 16, Volume II – *Aircraft Engine Emissions* was adopted in 1981, it focused on the control of aircraft engine emissions which were perceived as potentially affecting the air quality in the vicinity of airports. The subject of global atmospheric pollution was not originally considered for aircraft engine certification. Based on the knowledge then available, the gaseous emissions determined to be in need of control were oxides of nitrogen (NO_x), carbon monoxide (CO) and unburned hydrocarbons (UHC). Also designated for control was smoke, mostly for aesthetic reasons at that time.

Review of Emissions

Many changes to the provisions of Annex 16 have been introduced since the initial issue of *Annex 16, Volume II*; for example permissible levels of the emissions, particularly NO_x have been made more stringent. Further, this article examines more closely what developments have taken place in the intervening years and review the latest information on those emissions [1]. Figure 1 illustrates how aviation emissions are emitted from commercial aircraft engines (turbofans).

Oxides of Nitrogen

The designation "oxides of nitrogen" (NO_x) includes both nitric oxide (NO) and nitrogen dioxide (NO_2). Both compounds have historically been of concern for their relationship with ozone, but more recently there has also been concern about exposure to NO_2 in its own right. There may therefore be an emerging need to distinguish between the emissions of the separate types of oxides of nitrogen. Overall, much more NO_x is produced at high engine power than at idle, but the relative amounts of NO and NO_2 produced also vary with engine power. In general terms, at idle power, the majority of the NO_x produced is in the form of NO_2, while at high power settings, more NO than NO_2 is produced. Moreover, outside of the engine, in the exhaust plume, NO typically is oxidized in the atmosphere, often through reaction with ozone, to form NO_2. The situation has become even more complicated, however, since it has been discovered that the relationship between NO_x and ozone can be site specific. This means that regulating engine NO_x output does not necessarily have the same, or even a direct, effect on the ozone concentration at all locations.

It has always been understood that there are trade-off issues concerning engine emissions. It is known that NO_x is formed in the hottest parts of the combustion chamber and the production of NO_x can be reduced by keeping temperatures as low as possible and by keeping residence time at higher temperatures as low as possible also. However, for maximum thermodynamic efficiency, and consequently for lowest fuel consumption, high temperatures are very desirable. From the very beginning of emissions control efforts therefore, a balance has always been struck between reducing NO_x and reducing fuel consumption. Originally, the pressure to minimize fuel consumption was economic, but today there is the added need to minimize fuel consumption in order to minimize emissions of the greenhouse gas carbon dioxide. It is also apparent now that there are trade-offs between NO_x and particulate and hydrocarbon emissions.

Carbon Monoxide

Carbon monoxide is formed as a result of incomplete combustion within the engine. It is unique in the list of emissions in that there have been no changes to its significance and it continues to be of relatively low importance compared with the other emissions.

The engine produces:

- Unburned excess gases (oxygen and nitrogen);
- Normal combustion products: water vapour and carbon dioxide (CO_2), which are Green House gases;
- Residuals from non-ideal combustion: carbon monoxide (CO), unburned hydrocarbons (HC), smoke and nitrogen oxides (NO_x): these represent small percentages, but they have significant potential effects, especially for NO_x;
- Particulates.

Unburned Hydrocarbons

Unburned hydrocarbons (HC) include a fairly long list of compounds, also arising from incomplete combustion within the engine. Some of these are now known to be highly toxic or carcinogenic with varying concentrations and exposure time, thereby summoning the need to distinguish between the different species. It is also apparent that for the identified species, as with species that comprise NO_x, chemical interactions continue to occur in the exhaust plume. The implication in both cases is that measurement of emissions taken immediately downstream of the engine, as is now the practice for engine certification purposes, may not be adequate for the purposes of evaluating all environmental impacts.

Hydrocarbons (HC) and NO_x are both known to be involved in producing ozone, but some studies have revealed that this also is a site-dependent effect. For example, in the vicinity of Los Angeles airport, analysis indicates that decreasing hydrocarbons decreases ozone in much of the eastern part of the LA basin, but decreasing NO_x has little effect on ozone in the downtown area. In Pasadena meanwhile, decreasing airport NO_x emissions initially increases ozone. This is another example of, why it is very difficult to draw any general conclusions concerning engine design measures which might be taken to trade off one type of emission against another.

As mentioned above, several different hydrocarbon compounds are emitted by an engine. Before any decision can be made concerning whether specific compounds need to be regulated, it is necessary to know what compounds are produced, how they react outside the engine with other emissions and/or ambient air chemicals, and what the ultimate environmental impacts are. After that, it will then be necessary to determine if such compounds can be included in a certification scheme.

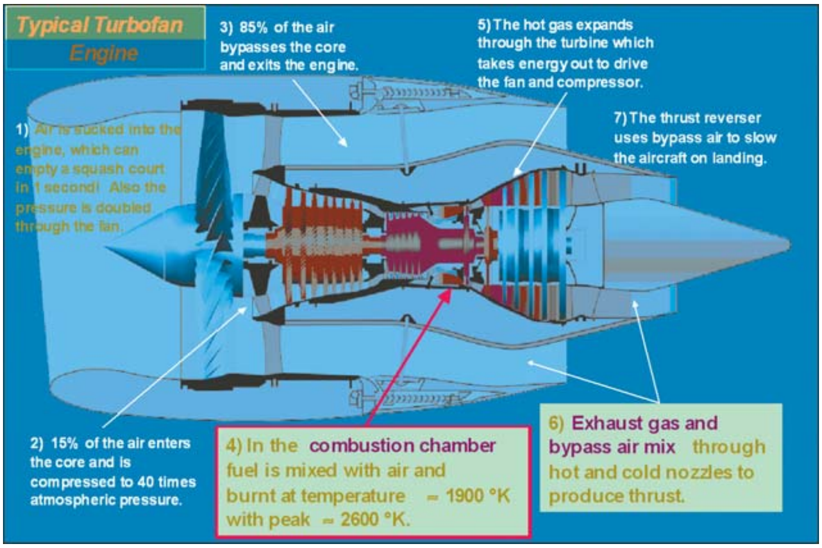

Figure 1 - How Aviation Emissions are produced.
Source: Rolls Royce.

It is generally recognized that hydrocarbons produced by modern engines are minimal but as mentioned above, several different hydrocarbon compounds are emitted by an engine. It is necessary to know what compounds are produced, how they react with other emissions and/or ambient air chemicals and what the ultimate environmental impacts are. After these measurements and analysis have been completed it will be necessary to determine how such compounds should be handled in emissions inventories.

Smoke

As mentioned above, smoke was originally controlled because of its appearance and the perception that it was undesirable. It was considered to be mainly a matter of visibility; and by that measure modern engines are essentially smoke-free. However, it is now known that the particulate matter that makes up smoke is still largely present in engine emissions, but reduced particle size makes it less visible than before. Particulate matter continues to be emitted by modern engines, but the particles are generally smaller in size and often fewer in number as well. In order to quantify the particulate emissions and to capture the trends as engine technology advances, measurements are now focusing on the total mass of particulate matter, along with a consideration of the particle size and number.

Again, it is of interest to consider what is taking place in the engine exhaust plume. The particles leaving the engine are predominantly black carbon, but other primary particles, often too small to measure, may also be present; in addition to the precursor gaseous components which will later add to the particle mass. Apart from the NO_x and CO, these gaseous components and smaller particles are volatile hydrocarbons and sulphur compounds. These volatile compounds can then condense into volatile particles downstream from the engine exhaust to form new particles of environmental concern. These same volatile species also condense on the existing soot particles, coating their surface. As with the NO_x components, the quantities of these particles and volatile compounds vary with engine power setting in both absolute and relative terms. The proportion of volatile components is greatest at idle, while black carbon predominates at high power settings.

The need to pay more attention to the size, number and composition of particles for health-related reasons is complicated by the difficulties encountered in trying to take the necessary measurements in the high temperature/high gas velocity environment at the engine exhaust plane. Furthermore, there is the complication that the volatile particles form downstream of the engine exhaust, and thus are not present where certification measurements are taken. Considerable research work is in progress to try to resolve these issues.

Sulphur

Sulphur and its compounds have always been acknowledged as environmentally undesirable, but, since their presence in the exhaust was solely a function of their presence in the fuel, and was not affected by the design and operation of the engine, they were not regulated by *Annex 16, Volume II*, but were controlled through fuel specifications. It has been discovered, however, that if fuel sulphur content increases, not only does the concentration of sulphates in the exhaust increase, adding to volatile particle contributions as would be expected, but the amount of condensed hydrocarbons in those particles also rises in concert with the increase in the sulphate in the volatile particles. These results raise the possibility that engine technology may be involved in determining volatile particle contributions, in addition to the direct effect that fuel sulphur content has on the availability of sulphur to add to particle mass.

Environmental Impact Analyses

Apart from the measurement of emissions for certification purposes, there is also a need to conduct environmental impact analyses at and around airports. Currently, certification measurements are often the only available sources of data for this purpose. Environmental impacts are influenced not only by aircraft operations, but also by other emission sources on and around the airport. Such other emission sources include ground service, passenger vehicles and airport fixed equipment. The outside air conditions, without the contribution from the airport, may also be relevant.

Conclusions

The emissions and measurement methods incorporated in the original and still applicable certification scheme in *Annex 16, Volume II* have stood the test of time quite well and remain relevant to its purpose. However, changes may well be necessary in the not too distant future to encompass recent findings and developments. It seems likely that more attention will need to be paid to chemical and physical changes taking place outside the engine in the exhaust plume. It also appears that both NO_x and unburned hydrocarbons may need to be broken down into their component parts to better understand the potential health and environmental impacts. Greater attention will also have to be given to the size, mass and composition of the particles previously regulated as smoke.

Reference

1. This article is based largely on the work developed for the ICAO/CAEP, by its Local Air Quality Science Focal Points and information contained in the presentation entitled, "Local Air Quality (LAQ)" by Dr. Richard C. Miake-Lye (Director, Aerodyne, Inc. and CAEP Focal Point for LAQ), ICAO Colloquium on Aviation Emissions (14 - 16 May 2007).

Defining Technical Feasibility for Setting Standards

By ICAO Secretariat

In the process of setting engine emissions Standards for inclusion in Annex 16, Volume II – *Aircraft Engine Emissions*, ICAO's Committee on Aviation Environmental Protection (CAEP) established, several years ago, a set of principles for its own guidance. This was to ensure that there would be continuity and that future Standards would be developed using the same criteria that had been used previously. These three guiding principles are that any Standard should be: technically feasible, economically reasonable, and environmentally beneficial. In the light of further experience, these have been expanded to ensure that interrelationships and trade-offs with other environmental considerations are taken into account; for example, to ensure that increased stringency of engine emissions Standards does not have adverse effects on aircraft noise [1].

Technical Feasibility

ICAO's technology Standards for aircraft engine emissions are based on the three principles noted above. The first of these principles concerns technical feasibility; it is clearly of no value, at least in the short-term, to establish mandatory emission levels which engine manufacturers cannot achieve. Even in the longer term, for the purposes of establishing long-term emissions goals, the industry, or supporting research establishments, must have some technological concept, which, although undeveloped and unproven, might at some future time be able to achieve the goals.

CAEP found that to apply this principle in a consistent manner, it needed a more precise understanding of what was meant by technical feasibility. It therefore, developed a working assumption to the effect that "…technical feasibility refers to any technology demonstrated to be safe and airworthy, and available for application over a sufficient range of newly certificated aircraft". For the purposes of short-term standard setting, this definition was adequate; however, CAEP needed to look further ahead to the possibility of setting emissions goals at which the industry and research establishments should aim in the middle- and long-term future.

Technical Readiness Level

CAEP, therefore, undertook a study to determine whether a system of describing technical feasibility or readiness could be developed which encompassed both near-term standard-setting and mid/long term goals. The study determined that there was already in existence a Technical Readiness Level (TRL) scale that had been originally developed by the National Aeronautical and Space Administration in the United States (NASA) and which was well-suited to CAEP's needs. This scale, as adapted for CAEP's use, is illustrated in Figure 1. It contains nine levels, starting from development of the basic principles of a technology to the production system's being flight-proven in operational conditions.

At its Seventh Meeting in February, 2007, the Committee agreed to the use of this scale in its future work for the purposes of standard-setting and for setting medium and long-term goals. It also agreed that before setting standards for emission levels, the technology involved would need to have reached Level 8 on the NASA TRL scale (as shown in Figure 1); that is, the system must be completed and flight-qualified through test and demonstration. It was further agreed that medium-term goals could be set for emission levels for which the technology demonstrated at Levels 6 and 7, and long-term emission level goals could be set for technology at Levels 2 to 5 of the scale (as shown in Figure 1).

Since the stringency increases recommended by CAEP typically become applicable to engines that will be individually certificated three or four years later, it can be seen that Levels 8 and 9 will include technologies that are already proven and about to enter service or which are already in service; this being the technology level that CAEP has historically used to determine "technical feasibility" in the setting of Standards.

The TRL Scale shown in Figure 1 was originally developed by NASA as a general tool to characterize the level of development of new technologies across a wide range of applications including space vehicles, aircraft systems, aircraft engines

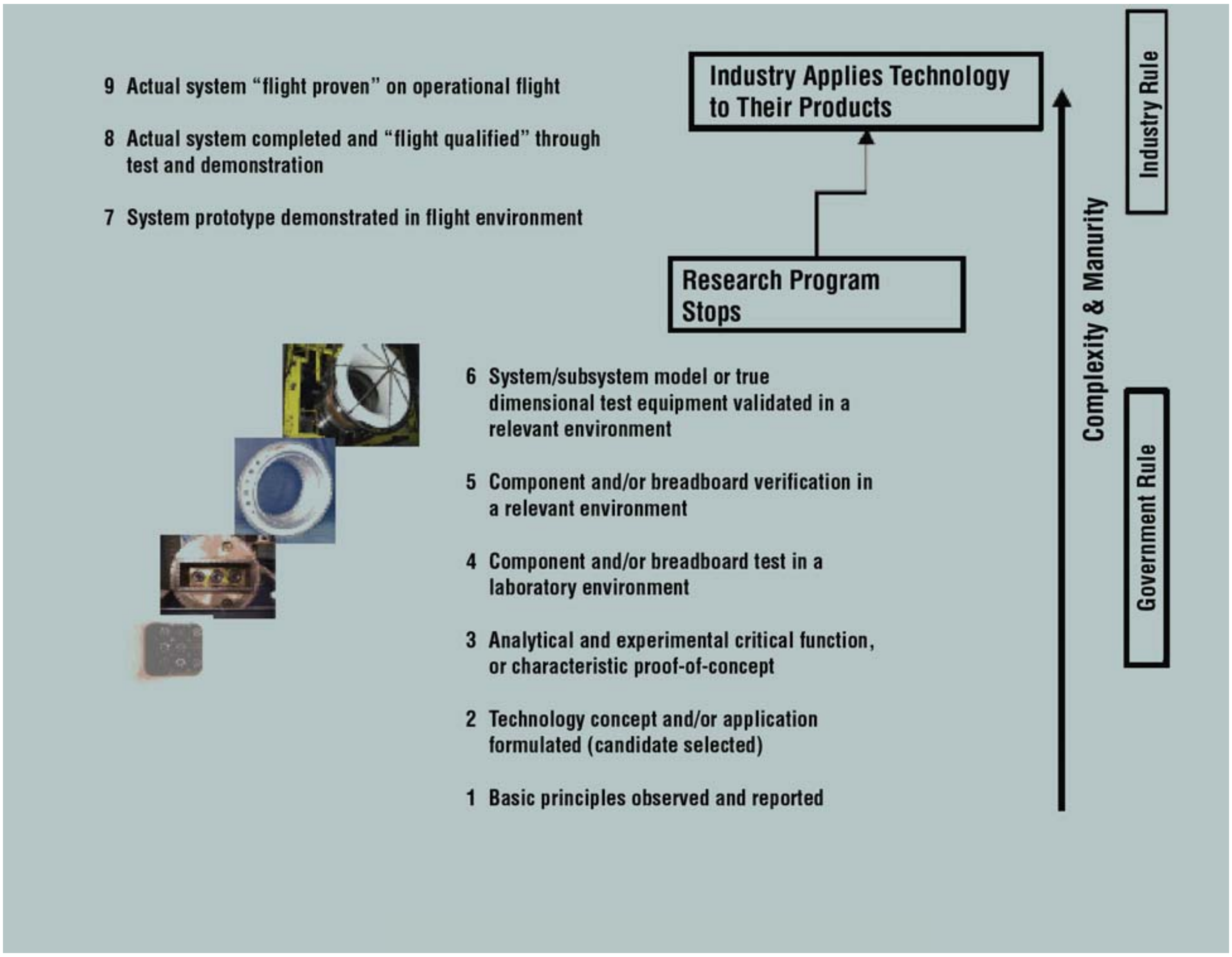

Figure 1 – Technology readiness levels.

and engine components. It has been slightly modified with the input of the European Commission. The terms used are general in nature, to fit a wide range of technologies.

This technology readiness level scale system has been widely accepted among research organizations and industry groups involved in the ICAO/CAEP process. Figure 1 describes the analyses and tests necessary to meet a given TRL level for a low emission combustor technology.

Conclusion

With the adoption of this Technical Readiness Scale, CAEP has now armed itself with a tool that will assist it in the future to apply a consistent means of assessing whether a technology is sufficiently mature to be used as a basis for setting current Standards as well as technological goals for the more distant future

Reference

1. This above article is based on information contained in ICAO/CAEP/7 Working Paper/9 and the technical emissions section of the CAEP/7 Report (Doc 9886). Useful information was also acquired from the presentation entitled, "Engine Exhaust Emissions Standards and Transition Goals to Standards" by Curtis Holsclaw from the 2007 ICAO Colloquium on Aviation Emissions held in Montreal.

Setting Technology Goals

By ICAO Secretariat

Technology goals in the context of aircraft engine emissions may be defined as statements of the capabilities of manufacturers to reduce emissions, as determined by an industry-wide assessment by independent experts (IEs). It should be stressed that goals are not guarantees of future performance; progress in meeting the goals must be assessed over several years before they can be used as a basis for the setting of emissions standards. Goals are nevertheless valuable to determine what the long-term trends in emissions reduction technology might be. They can also be used to provide inputs to long-term emissions impact scenarios. While in the ICAO/CAEP process long-term technological trends have been reviewed before, the preparation of mid- and long-term emissions goals was carried out in a systematic way for the first time for the recent CAEP/7 meeting, held in February, 2007 [1].

The Goal Setting Process

The process of goal setting was carried out by a panel of six independent experts, nominated at CAEP's request by interested States. The independence of the experts was a crucial element of the process. There was active participation by the major aircraft and engine manufacturers, six representatives of which joined the six IEs on the panel heading the technology review. The review assessed non-sensitive data presented by individual manufacturers and deliberations were carried out in an open forum. This procedure was designed to ensure that the assessment would not be seen as a self-assessment by manufacturers. This first attempt at goal setting was restricted to NO_x emissions and it was agreed that the goals would be set in terms of the regulatory parameters currently used in Annex 16, Volume II. Goals were determined for both medium- and long-terms, set at 10 and 20 years, respectively.

In addition to manufacturers, the review panel was addressed by atmospheric scientists, academics, policy makers, and airline industry representatives. The manufacturing industry presentations were detailed; they covered the basic facts of combustor technology and what technological developments were possible, and what were not. The technology of recently certificated engines was studied, as well as the currently evolving technologies and longer term technology prospects. It should be stressed that a great deal of judgement had to be exercised by the independent experts in coming to their conclusions and their results were reached by consensus following an "iterative and advocative" process.

Results

The results of the study are illustrated in Figure 1 titled "*LTTG Technology Goals: Mid- and Long-term*." It shows the NO_x control parameter as a function of pressure ratio for both the past and present Annex 16, Volume II Standards (the four top lines). A pale green band represents the range of performance of engines currently certificated, with brown dots and linking lines representing specific engine families. The darker green band represents evolving technology, and the purple band represents what is predicted for new technologies. Based on these data and predictions, the IE panel, by consensus, set medium-term goals at 45% below the latest Annex 16, Volume II, Standards, and long-term goals 60% below the current regulatory level; although it was accepted that these were challenging targets. These goals were subsequently endorsed by the ICAO/CAEP Meeting.

Future Activity

It was agreed that progress towards meeting these goals would need to be continuously monitored by CAEP. Moreover, it was agreed that the process should now be applied to noise, fuel consumption and operational measures. It is believed that the goals will provide an added impetus to the development of low-NO_x technology and lead ultimately to the possibility of more stringent emissions standards. They could also be used in developing longer term emission impact scenarios so that the future effect of aviation on the environment, and possible responses, if needed, can be better estimated. Such information will help CAEP/ICAO analyse how the industry might evolve in the long-term.

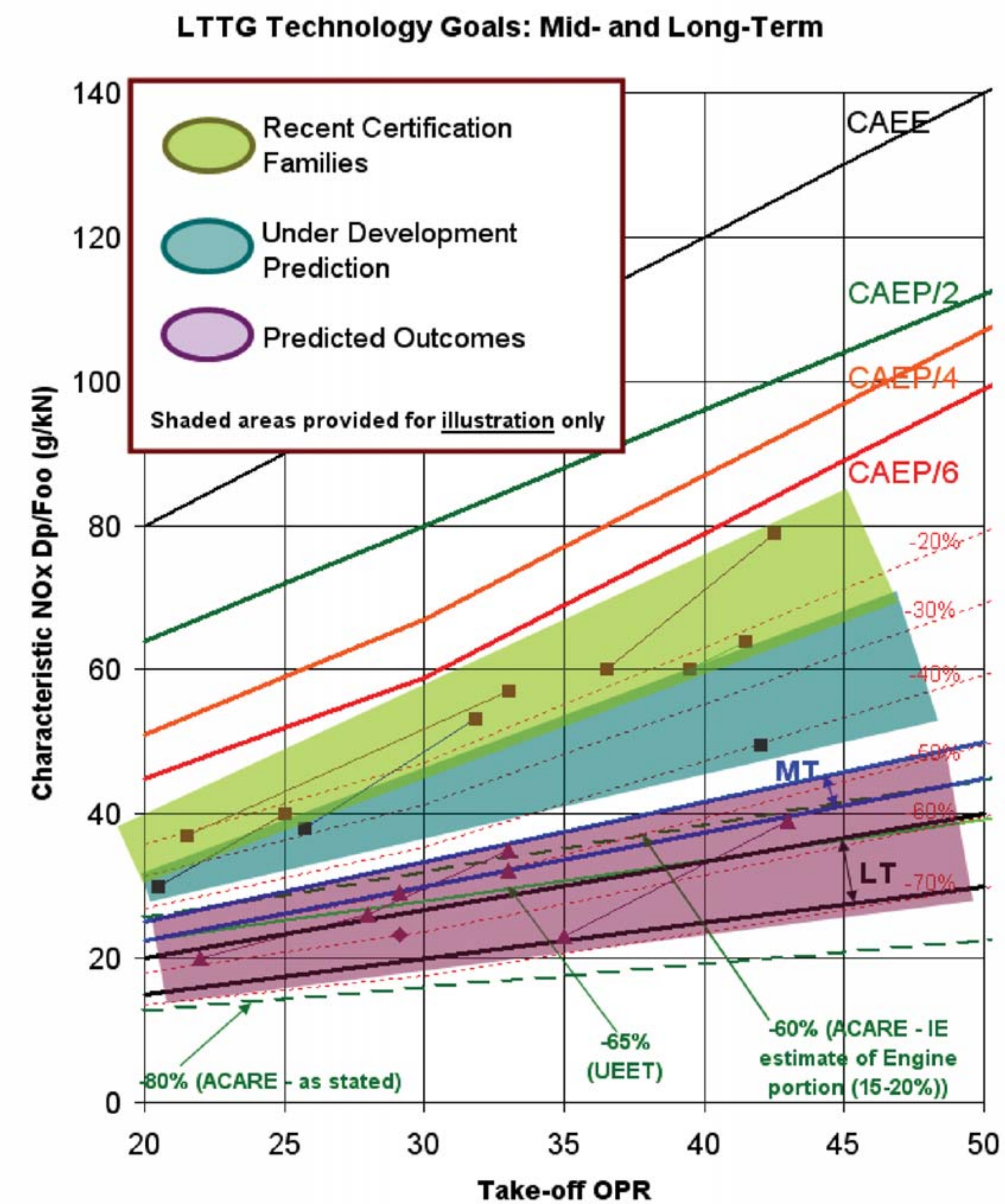

Figure 1 – ACARE :Advisory Council for Aeronautics Research in Europe
UEET : Ultra Efficient Engine Technology program
Source: Peter Newton's presentation entitled, "Long-term Technology Goals for CAEP", ICAO Colloquium on Aviation Emissions, 14 – 16 May 2007.

Conclusions

This first attempt at goal setting was successful and should be repeated for other factors affecting emissions. A further major conclusion that can be drawn from the exercise is the value that was gained by using independent experts. This conferred a great degree of credibility to the process, although it also involved resource and cost implications which will need more consideration in the future. It was also concluded that it is essential to carry out such assessments in a fully open and transparent manner.

Reference

1. This section and the remainder of the article is based on information developed by CAEP as contained in the CAEP/7 Report (Doc 9886) on Peter Newton's presentation entitled, "Long-term Technology Goals for CAEP", ICAO Colloquium on Aviation Emissions, 14 – 16 May 2007.

Engine Technology Developments for Reduced NO_x

By ICAO Secretariat

The latest ICAO Oxides of Nitrogen (NO_x) Emission Standards became applicable in November 2005 and apply to engines manufactured after 31 December 2007. This article reviews the mechanisms which affect the production of NO_x inside an engine and examines the technical prospects for developing engines with lower NO_x emissions, which would allow the setting of more stringent emission standards. It also stresses the fact that engine design is a compromise between many different and sometimes conflicting requirements. This sometimes necessitates making choices about which emission is more significant from an environmental viewpoint, so that a design may be finalized. In this sense, engine designers need the advice of atmospheric scientists concerning which emission or emissions they should seek to minimize, at the possible expense of others.

The Mechanisms of NO_x Production

The energy required to produce the power to drive the fan of a turbojet engine (and to provide the residual thrust) comes from the chemical energy released when fuel and air are mixed and burned in the combustor. The interior of the combustor is a very hostile environment with high speed gas flows and a flame temperature well above the melting point of metals. Maximum engine efficiency in terms of minimum fuel consumption (and hence minimum carbon dioxide production) depends on having a high pressure ratio which in turn leads to a high temperature at the inlet to the combustor even before the fuel is burned. In turn, burning fuel most efficiently at the optimum fuel/air ratio, which minimizes fuel consumption with the minimum production of carbon monoxide (CO) and unburned hydrocarbons (UHC), also results in the highest flame temperatures.

These high temperatures, which are desirable from the viewpoint of minimizing fuel consumption and also minimizing carbon dioxide, CO and HC production, unfortunately create the conditions in which oxides of nitrogen (NO_x) are formed. The problem for the engine designer therefore is to maintain the fuel efficiency of the engine while at the same time preventing the formation of NO_x. The designer faces further challenges relating to the safety and economic operation of the aircraft. Despite the very high temperatures the combustor must be capable of operating safely for long, trouble-free periods. The engine must operate smoothly and reliably at settings ranging from idle to maximum take-off power, and it must be possible to restart the engine over a wide range of speeds and altitudes.

Designing Engines for Reduced NO_x

Since NO_x is produced at the higher combustor temperatures, the challenge for designers is to reduce the combustor temperature while maintaining the overall fuel efficiency of the engine. NO_x production can also be reduced by minimizing the time that the products of combustion spend at the highest temperatures – the so-called "residence time". Reducing the temperature can be achieved by running the combustor at air fuel ratios away from the optimum – either with more air than is actually required for combustion, e.g. "lean", or with less air than is required, e.g. "rich". Residence time is reduced by curtailing combustor volume. All combustors in service today that meet the latest ICAO emissions requirements use a system known as "rich quench lean" (RQL). In this system, initial combustion occurs in the rich zone which provides good running stability; more air is then added quickly to move combustion into the lean zone; it is essential to add air quickly to avoid time in the optimum but high temperature zone; and this is a major technical challenge. An illustration of where current production engines stand in relation to the ICAO Standards is shown in Figure 1, entitled, "Recent Certification Emissions Relative to Standards". It can be seen that although all engines meet the Standards at present, the margins they have from the limits are generally quite small. This means that on the basis of the technology currently in service there is little or no scope for increasing the stringency of the Standards.

Gas emissions depend on the engine power; some are produced mostly at high engine speed, like NO_x, others at low engine speed, others proportionally, like CO_2. This depends on specific physico-chemical generation processes.

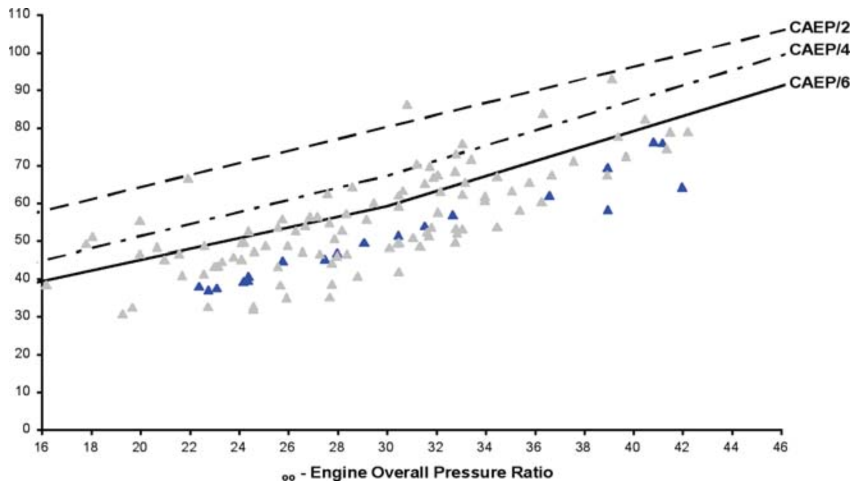

Figure 1 - Recent Certification Emissions Relative to Standards.

Manufacturers and research organizations are, however, investing a great deal of money and resources into the development of advanced combustors which show promise for achieving lower NO_x emission rates. All manufacturers are working on further developing RQL combustors and also on designing lean burn combustors as a way of reducing combustor temperatures. It is known that lean burning reduces temperatures, but an engine designed for lean burn at high power tends not to run in a stable way at idle and is difficult to relight under some conditions. Possible ways of overcoming these problems include pilot burning systems for use in idling conditions, otherwise known as fuel staging. Such systems, however, suffer from increased weight, cost and complexity as well as other technical drawbacks such as pre-ignition of the fuel and fuel coking. Nevertheless, at least one manufacturer has considerable development experience with a lean burn aero-engine and there is considerable experience with lean burn gas turbine engines for industrial use. The latter, however, use natural gas as their fuel and are not subject to exacting airworthiness requirements.

These advanced RQL and lean burn combustors are all at the TRL 5-6 stage (see earlier article in this Chapter on *Technical Feasibility For Setting Standards*), and therefore are not yet suitable as a basis for setting emission standards.

Emissions Design Tradeoffs

As indicated earlier, there are tradeoffs among the different emissions to be considered in engine design. The trend toward higher engine pressure ratios reduces carbon dioxide, CO and HC but increases NO_x. Rich burning reduces NO_x but increases soot formation. Lean burning reduces NO_x and soot but increases CO and HC and makes for a less stable engine at low power settings. Reduced combustor volumes compromise the engine's relight capability. It is not possible to reduce all emissions equally at the same time, and manufacturers therefore need guidance from the atmospheric sciences community concerning the emissions on which they should focus their efforts.

Summary

The present situation is that there are engines which meet the latest NO_x Emissions Standards, but with little margin to spare. Active efforts are underway to develop engines with lower NO_x emissions, using RQL and lean burn concepts but they are as yet not developed to the point where greater stringency of the standards can be considered. In the meantime industry needs clearer guidance on the direction it should be heading in where the tradeoffs among pollutants are concerned.

Reference

This article is based on the presentation entitled, "Engine Technology Development to Address Local Air Quality Concerns," by John Moran (Rolls-Royce Associate Fellow Combustion), ICAO Colloquium on Aviation Emissions (14 - 16 May 2007).

Operational Measures

Mitigating Local Emissions Through Operational Procedures: Continuous Descent Approach Flight Test Results

By John-Paul Clarke
and Liling Ren

John-Paul Clarke is an Associate Professor in the School of Aerospace Engineering and Director of the Air Transportation Laboratory (ATL) at the Georgia Institute of Technology. His research and teaching address issues of optimization and robustness in aircraft and airline operations, air traffic management and the environmental impact of aviation. He received his S.B. (1991), S.M. (1992) and Sc.D. (1997) from the Massachusetts Institute of Technology, and was a faculty member there prior to moving to Georgia Tech. He has also been a researcher at the NASA Jet Propulsion Laboratory and a visiting scholar at the Boeing Company.

Although aircraft noise issues are the primary environmental challenge for airports, local air quality is an increasing concern, despite the fact that emissions from aviation operations comprise a relatively small portion of total gaseous emissions from all sources. Because of the strong growth in aviation demand, emissions of some pollutants from aviation sources are increasing against a background of emission reductions from many other sources at airports [Waitz et al 2004]. As the global economy and demand for air transportation continue to grow, the impacts of aircraft engine exhaust emissions (along with the impacts of aircraft noise and runoff water from airports), may become a fundamental constraint on air transportation growth. On a global scale, the climate impacts of aviation are considered the most significant adverse impact of aviation.

The effects of aviation on the environment result from a complex system of interdependent technologies, operations, policies and market conditions. Thus there is no single solution to the problem. Aside from technological and policy options, operational procedures provide a short to medium-term means to mitigate the environmental impacts from aviation.

This article describes and reports on the results of an Area Navigation (RNAV) based Continuous Descent Arrival (CDA) flight test conducted at Louisville International Airport (KSDF) in 2004 [Clarke et al 2006]. This was a joint effort of the Massachusetts Institute of Technology (MIT), the Boeing Company, FAA, NASA, KSDF, and UPS.

Test Background

The focus of this analysis was the local emissions produced in the atmospheric mixed layer during the approach/landing phase of the flight. The atmospheric mixed layer results from convective air motions. Typically, this is the region within 3,000 ft of the airport elevation. This region is important because the aircraft engine exhaust emissions that are produced within this region may play a role in local air quality. Hence the assumption in all Landing and Take-Off (LTO) cycle calculations for the corresponding ICAO emissions standard is that the mixing layer extends from the ground to 3,000 ft above ground level. Thus, it is very appropriate that the difference in the emissions produced by aircraft performing the CDA and aircraft performing the conventional approach is determined for this region.

KSDF is the major hub for UPS overnight package delivery operations. Due to the nature of its business, most UPS flight operations at KSDF occur during the night. Each weekday, about 100 jet transport aircraft (mostly UPS package freighters)

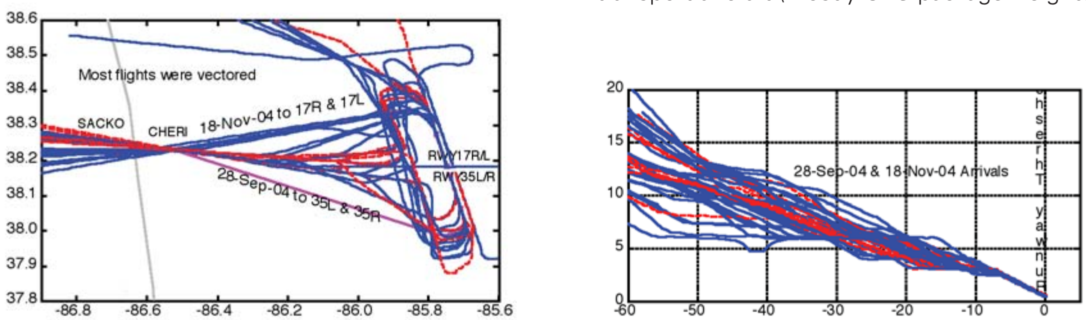

Figure 1 - KSDF conventional ground track and vertical profile.

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land at KSDF in the four-hour period between 10:00 PM and 03:00 AM, when residents are most sensitive to noise disturbance. Thus, KSDF was a perfect candidate site for conducting CDA studies. As shown by the example radar tracks in Figure 1, in conventional operations, aircraft are often laterally vectored for spacing prior to establishing on the final approach. Successive altitude and speed commands are given to arrival aircraft, resulting in dive and drive step-down vertical profile.

Flight Test Parameters

The CDA flight test started on September 14, 2004 and lasted for two weeks. It involved 12 to 14 UPS B757-200 and B767-300 revenue flights each night. The objectives of this flight test included: demonstration of the effectiveness of the separation analysis methodology for managing CDA flights; demonstration of the consistency of the procedure; measurement of the reductions in noise, fuel burn, emissions, and flight time; and collecting the data necessary to support the approval to implement the procedure on a regular basis.

The arrival chart for the CDA flown in the KSDF 2004 flight test is shown in Figure 2. The procedure requires the Lateral Navigation (LNAV) and Vertical Navigation (VNAV) functions of the onboard Flight Management System (FMS). The nominal lateral flight path of the procedure was a routing via waypoints CENTRALIA, ZARDA, PENTO, SACKO, to CHERI and then to either runway 17R or 35L, depending on the prevailing winds on a given day.

The vertical profile was a continuous descent starting at the cruise altitude, and was defined by altitude and speed constraints given at waypoints TRN17, CHR27, and CHRCL for the CDA to runway 17R, or waypoints TRN35, CRD27, and CRDNL for the CDA to runway 35L. The characteristics of the vertical profile are shown in Figure 3. Two shallower segments are facilitated by the FMS to allow proper deceleration. Ideally, the engine throttle would remain at idle until the aircraft is established on the final approach.

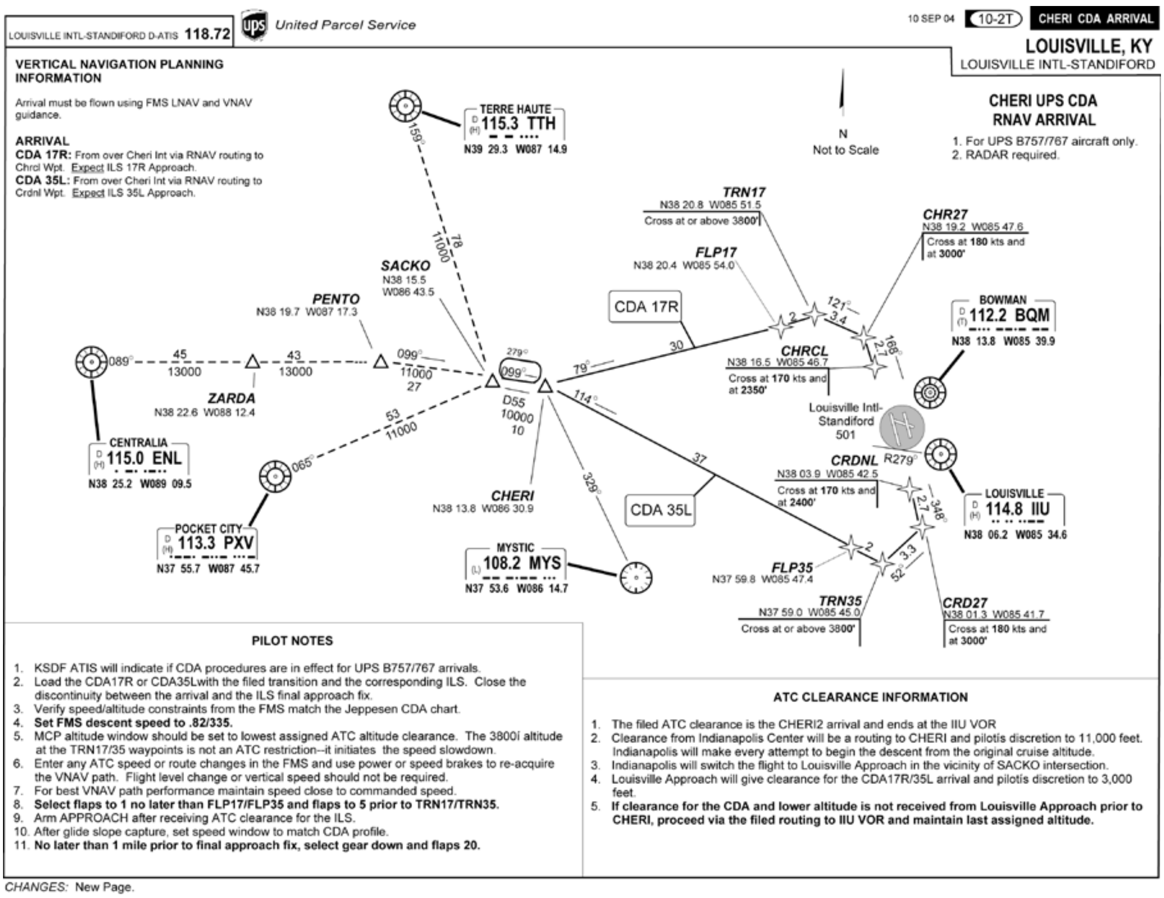

Figure 2 – Chart of the KSDF 2004 RNAV CDA.

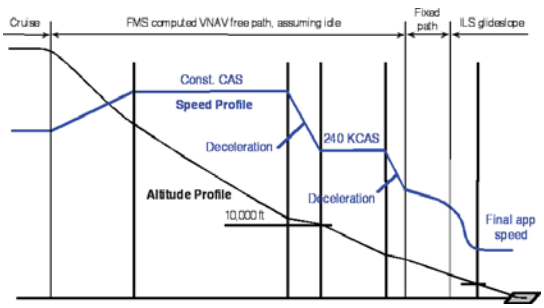

Figure 3 – Vertical profile of KSDF RNAV CDA

To estimate the emissions produced within 3,000 ft above the airport elevation, flight recorder (FDR) data collected during the flight test and after the flight test were used. The parameters used for this analysis include time, pressure altitude, calibrated airspeed, static air temperature and fuel flow rate. The fuel flows for both engines were averaged together for each data point. As there was no relative humidity recorded by FDR, 60% relative humidity was assumed. The total emissions expelled within 3,000 ft above the airport elevation were then calculated using the Boeing Fuel Flow Method 2 [Baughcum et al 1996].

Emission Test Results

The NO_x produced by the B757-200 and B767-300 aircraft performing the CDA and the conventional approach (referred to as baseline) are shown in Figure 4 versus time and fuel burned respectively. It is noted that the B757-200 emission results are shown separately for Pratt and Whitney (PW) and Rolls Royce (RR) engine types in the UPS fleet. During the CDA testing, aircraft spent less time and burned less fuel resulting in lower NO_x than baseline.

As shown in Figure 5, in summary, the average NO_x produced by the B757-200 (including both engine types) is reduced by 37.0%, from 1510g to 951g. The corresponding reduction for the B767-300 is 39.9%, from 2882g to 1732g. These significant reductions in NO_x were not surprising as they are very much in line with those reported by Lee [Lee 2005] based on data collected during a CDA flight test conducted in 2002 [Clarke et al 2004].

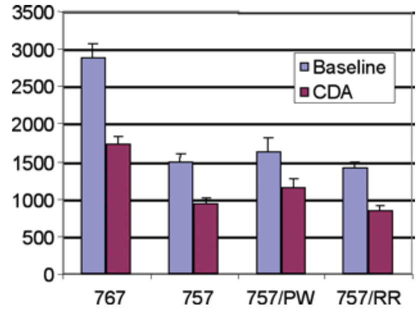

Figure 5 – Average NO_x produced by the B757-200 and B767-300 aircraft.

The CO produced by the B757-200 and B767-300 aircraft performing the CDA and the conventional approach is shown in Figure 6 versus time and fuel burned.

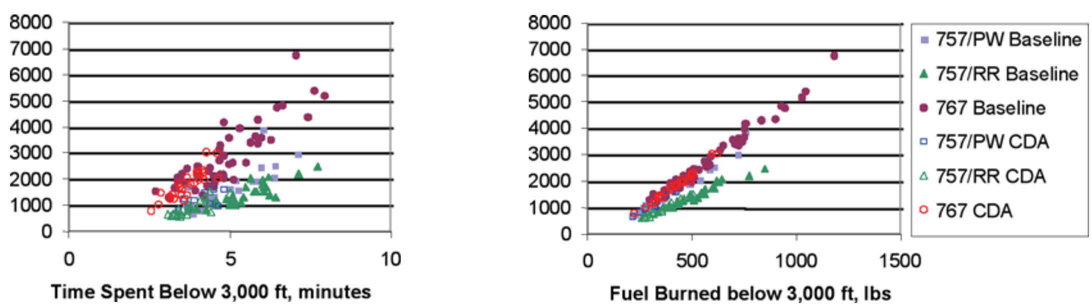

Figure 4 – NO_x produced below 3,000 ft vs. time and fuel burned.

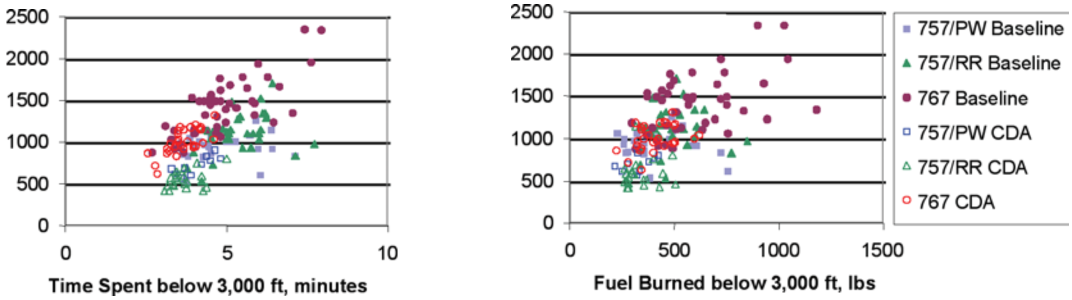

Figure 6 – CO produced below 3,000 ft vs. time and fuel burned.

As shown in Figure 7, in summary, the average CO produced by the B757-200 (including both engine types) is reduced by 39.9%, from 1030g to 620g. The corresponding reduction for the B767-300 is 28.5%, from 1408g to 1007g. These significant reductions in CO were somewhat surprising given the very slight increase in CO reported by Lee for the CDA relative to the conventional approach [Lee 2005]. However, the comparison by Lee was conducted for two aircraft following the same routing. As was seen in Figure 1, conventional aircraft are typically vectored to fly significantly longer distances at low altitude, thus spending greater time below the mixing height of 3,000 ft. Further analysis confirmed that the more time that the aircraft spends below the mixing height overcomes the slight decrease in the CO emission rate that occurs at the higher throttle settings that are typical of the conventional approach.

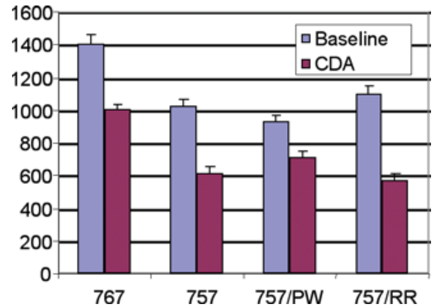

Figure 7 – Average CO produced by the B757-200 and B767-300 aircraft.

The HC produced by the B757-200 and B767-300 aircraft performing the CDA and the conventional approach is shown in Figure 8, versus time and fuel burned respectively.

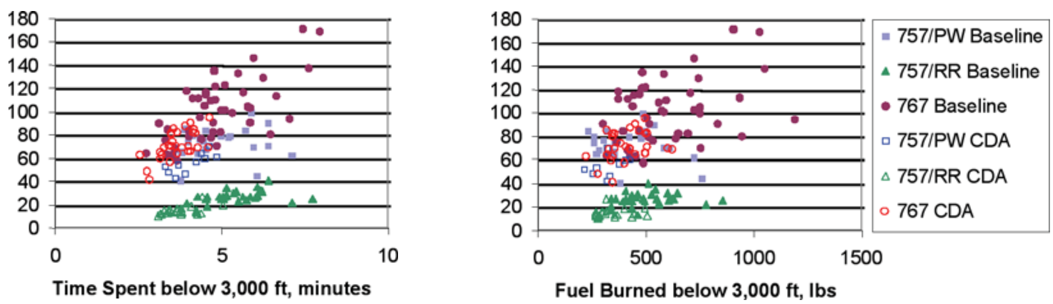

Figure 8 – HC produced below 3,000 ft vs. time and fuel burned.

As shown in Figure 9, in summary, the average HC produced by the B757-200 is reduced by 29.0%, from 45g to 27g. The corresponding reduction for the B767-300 is 39.2%, from 101g to 72g. As was the case for CO, the more time that the aircraft spends below the mixing height overcomes the slight decrease in the HC emission rate that occurs at the higher throttle settings that are typical of the conventional approach.

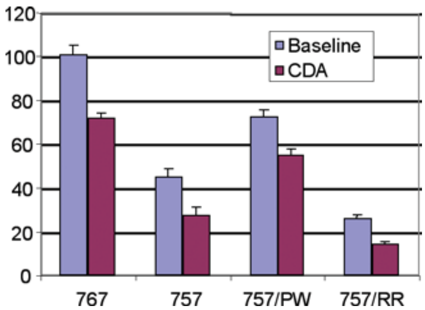

Figure 9 – Average HC produced by the B757-200 and B767-300 aircraft.

Conclusion

In summary, by improving both lateral flight path and vertical profile, the KSDF CDA flight test demonstrated for the UPS B757-200 and B767-300 aircraft that:

- The average NO_x produced below 3,000 ft above airport elevation is reduced by 37.0% and 39.9%, respectively;
- The average CO produced below 3,000 ft above airport elevation is reduced by 39.9% and 28.5%, respectively;
- The average HC produced below 3,000 ft above airport elevation is reduced by 29.0% and 39.2%, respectively.

These numbers are site and procedure specific. Nonetheless, they indicate that the impact to local air quality from arrival aircraft can be significantly reduced by implementing CDA.

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Market Based Measures

Local Aircraft Emission Charges in Europe

By Emanuel Fleuti

Emanuel Fleuti he has been Head of Environmental Services Department at Unique (formerly Zurich Airport Authority) since 1990. He graduated from the University of Berne where he majored in physical geography and computer science. Mr Fleurti specializes in environmental management and local air quality and is responsible for all environmental subjects at Zurich Airport, excluding aircraft noise. That Airport has gained a worldwide reputation in airport air quality assessments and mitigation planning, and currently holds ISO certificates for Environmental and Quality Management. Mr Fleuti has participated in numerous international programs studying the impact of aviation on environment. He is active in CAEP and is currently Chairman of ACI's World Environment Standing Committee.

Europe is a highly industrialized and densely populated world region where infrastructure for air transport demand is provided by over 400 major airports. The strict air quality regulations that exist there have created situations where airports are obliged to investigate mitigation options that include the introduction of local aircraft emission charges through a structured process.

An aircraft emission charge is an actual financial charge levied against a polluter based on the degree to which they are considered to be polluting the air in a particular local area.

While national air quality standards had already been introduced in Europe in the 1950s, the European Air Quality Directives (e.g. 1999/EC/30 and 2000/EC/69) moved air quality into the spotlight in 1999, or in the case of Switzerland, in 1986. Table 1 illustrates some air quality standards in Europe. Current values for nitrogen dioxide (NO_2), ozone (O_3) and particle matter (PM10) are often exceeded. In fact, many regions in Europe will face non-compliances by 2010 when the standards will have to be fully met. The regulations not only set standards, but also define the required procedures in case of non-compliance.

Table 1 – Air Quality Standards in Europe (EU: European Union; CH: Switzerland).

Pollutant			EU	CH
Nitrogen dioxide	NO_2	(µg/m^3 /a)	40	30
Particle Matter	PM10	(µg/m^3 /a)	40	20
Sulfur dioxide	SO_2	(µg/m^3 /a)	20	30
Ozone	O_3	(µg/m^3 /8-hr)	120	-

Air Quality Situation in Switzerland

The focus in this article is on the Swiss experience since that country was the first to design and implement aircraft emission charges at its major airports. National air quality assessments in 1988 in Switzerland show that it considerably exceeded NO_2 annual concentration in the larger airport region (Figure 1). Shortly thereafter, Zurich airport presented an environmental assessment in conjunction with its Master Plan 2000. It indicated an increase of NO_x (oxides of nitrogen) emissions by 50% within 10 years. Thus, the local (i.e. cantonal) authorities were required to draft mitigation plans that also included the airport. As air traffic growth increased, the Environmental Impact Assessment for the airport's expansion program in 1997 predicted a doubling of NO_x emissions until 2010 and identified aircraft engines as the main contributor.

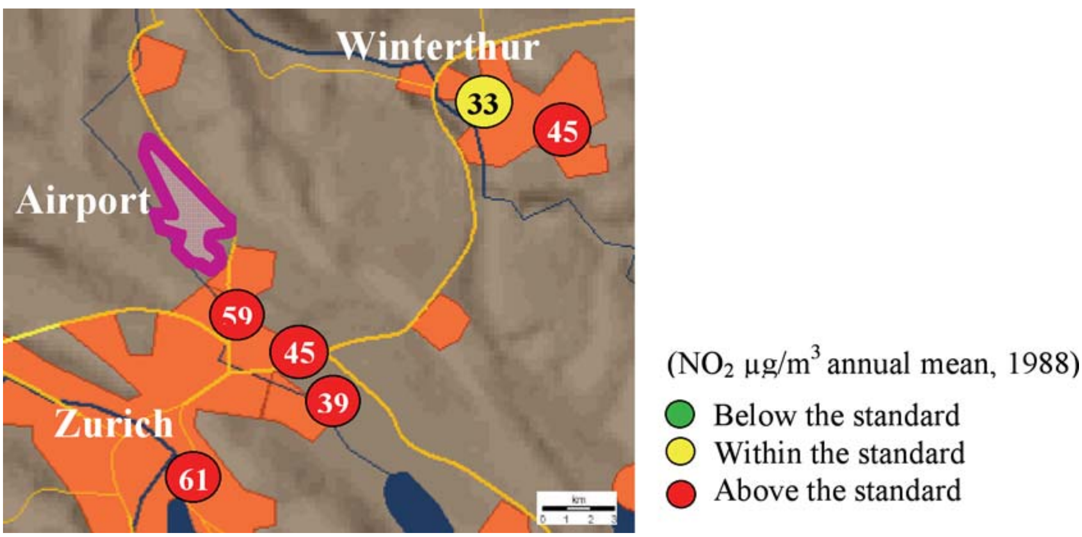


Figure 1 – Annual NO2 mean values in relation to the Swiss Clean Air Standards.

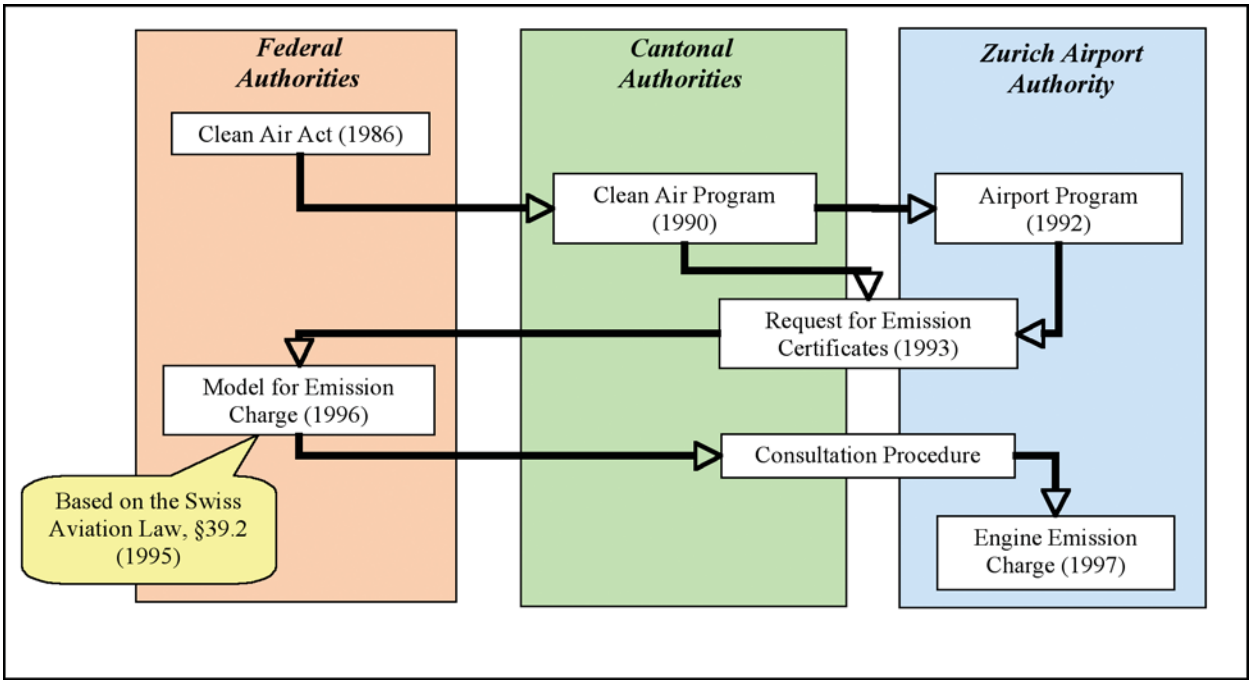


Figure 2 – Introduction process of local aircraft emission charge (Zurich Airport).

First Local Emission Charges in Zurich

In line with the clean air act, Zurich airport and the local authorities identified all emission sources and drafted a mitigation plan addressing those sources. As engine emission standards are not within the purview of the airport or local authorities, a request was placed with the federal authorities for introduction of engine emission certificates (i.e. emission trading).

Instead, emission charges were implemented following the process shown in Figure 2. Zurich airport introduced emission charges based on a national model in September 1997. That was soon followed by the Swedish airports and then Geneva airport (1998). Responding to a legal challenge, the Swiss Federal Court confirmed the legal compliance of the charges in 1999. The federal authorities, responding to the airport's Environmental Impact Assessment in 1997, made the introduction of charges mandatory for the airport, and furthermore imposed a NO_x ceiling for aircraft, handling and infrastructure emissions and requested an additional mitigation plan.

Added-Value Results Achieved

Based on the Swiss experience, the results of emission charges are threefold.

Operational and financial results:

An improvement in technology was observed through a shift of movements into better technology classes over several years. However, this also depends on the home carrier's fleet planning and implementation and thus offers limited comparability to other airports. The charging scheme has been designed to be revenue neutral and the rates designed accordingly. Over time, the aircraft fleet mix will change and so the rates would have to be adjusted to fully maintain the zero balance. Zurich airport has chosen to keep the charging rates for consistency reasons, even if these revenues are slightly decreasing.

Environmental benefits:

There were limited direct effects observed from airline operators changing their operations. However, there has been a considerable benefit through the avoidance effect by the home carrier. By voluntarily choosing low emission engines for the new fleet, charges were avoided and emissions significantly reduced (approx. 10% of the total airport emissions at that time). In addition, spin-off effects were observed in other areas that also implemented emission reduction programs for their emission sources (e.g. fixed ground power for aircraft to reduce APU usage).

Added-value results:
A very important local effect was the widespread public and political acceptance. By including the main emission source in the mitigation planning, acceptance for the CHF 2 billion airport expansion program was gained and a "license to grow" was obtained through the construction permit. A very notable effect was the immediate response of the aviation industry which started to reflect the Swiss charging scheme in developing and commercializing new aircraft engines.

While economic evaluation assessments usually focus on operational, financial and environmental impacts, the added-value results are more difficult to assess. For example, "What are the operational and financial impacts of NOT being able to realize a CHF 2 billion airport expansion program to enable and accommodate future growth?" As such, current analysis can only partially address the results of such charging schemes.

European Harmonization Envisaged

Responding to requests from the aviation industry and European Commission activities, and considering the new EC air quality directives, a harmonization of the different charges schemes (Switzerland and Sweden) was envisaged through the European Civil Aviation Conference (ECAC) in 2003.. An industry wide task group developed a new, polluter-pays principle based model, known as ERLIG that became ECAC Recommendation 27-4 in June 2003.

That emission charges model considers the absolute amount of NO_x emissions from the aircraft engines within the ICAO certification LTO-cycle (Landing and Take-Off) and contains a potential HC (hydrocarbon) correction factor for very old engines. The resulting "Emission Value" is on a continuous scale and therefore reflects both the transport capacity and the engine technology of the aircraft. The model applies to aircraft of >8,618 kg maximum take-off weight (MTOW) with regulated and some unregulated engines. In order to avoid distortion of competition in commercial aviation, a simplified matrix with default emission values for all aircraft-engine types outside the ECAC scheme has been developed by the Swiss and Swedish civil aviation authorities.

Emission Charges Schemes in Europe

There are currently four countries in Europe with emission charges: United Kingdom, Switzerland, Sweden, and France. The main airports covered are London-Heathrow, London-Gatwick, Zurich, Stockholm, Geneva, and Basel (Figure 3).

As already discussed, Switzerland was the first country to introduce emission charges when it implemented them at Zurich airport in 1997. That scheme is based on a federal recommendation, legally backed by Swiss Aviation Law. The model is technology-based by considering NO_x and HC in the certification LTO cycle. Engines are ranked in five classes, with a surcharge of 0%-40% to the weight based landing fee. To ensure revenue neutrality in the beginning, the landing fees have been reduced by 5%. This model was subsequently introduced in Geneva (1998), and Bern (2001).

Figure 3 – Local Aircraft Emission Charging at European Airports.

Sweden developed and implemented a similar model in 1998, but with seven NO_x and HC technology classes. The landing fee was reduced to ensure a revenue neutral outcome. The model was applied at all Swedish airports and airfields. In March 2004, Sweden was the first country to change its model and implement the ECAC recommended methodology at all airports and for all aircraft types, charging SEK 50 per kg NO_x.

France introduced local emission charges at Basel airport, which is a Swiss/French bi-national airport. For political reasons the Swiss model was used. The landing fee multiplier (a factor multiplied with the weight base landing fee) is between 0.94 and 1.30, depending on the engine technology class.

The United Kingdom, facing challenges to meet the EU air quality standards in the larger metropolitan areas, started with emission charges at London-Heathrow in April 2004. Based on the ECAC recommendation and the Swiss/Swedish matrix, it applies to aircraft >8,618 kg MTOW. The system is based on a bonus/malus system with a charge of GBP 1.10 per kg NO_x above 23 kg and a rebate of GBP 1.10 per kg NO_x below 23 kg. London-Gatwick followed with the same system in 2005, but with a threshold value of 16 kg NO_x.

Germany is currently establishing the necessary framework to enable airports to implement local emission charging schemes. Some airports may not be able to fully comply due to current expansion programs, but are designing mitigation plans that set incentives for promoting best available technology. The basis for the German scheme will be the ECAC recommendation, combined with the Swiss/Swedish matrix for smaller aircraft. Frankfurt and Munich are the two largest airports that are currently working on an implementation plan for 2008.

Local Solution Embedded in Framework

Wherever implemented to-date, aircraft emission charges programs have been able to be customized to deal with local problems and circumstances as dictated by either environmental or political issues. Emission charges are but one of many measures that address emissions from airport-related sources, and emission charges are usually part of an overall mitigation plan. While many measures are designed for the local sources, emission charges address aircraft emissions that are relatively the same at various airports. As such, deliberate harmonization of the charges models used is a paramount for effective financial budgeting and easy adoption by aircraft operators. Local emission charges is one of the few measures under the control of an airport operator or local authority that can have a direct impact on aircraft emissions.

It should be noted that such measures only have local impact. To achieve more global effects, a different approach is needed. Emission standards applied to a variety of pollution emitters (i.e. aircraft, APU, GSE, vehicles) are the only means to create global benefits. Such standards need to be revised regularly and should be responsive to the environmental need and not to the technological capabilities as is the case today.

Conclusions

Based on the experience to-date in Europe with respect to local aircraft emission charges the following overall conclusions can be drawn:

- There is environmental and/or political pressure to take action through mitigation plans that include aircraft operations as one of the emission sources at airports.

- The first applications of emission charges in Switzerland and Sweden consist of legally robust, revenue-neutral systems based on technology classes reflecting NO_x and HC emissions in the LTO-cycle.

- With other European countries or airports following suit, with partly modified systems, efforts to harmonize systems as much as possible is recommended in order to enhance transparency and predictability.

Ongoing discussions of air quality issues - not only on a global climate level - shows the major importance that the aviation industry places on taking measures that will yield direct environmental benefits, while also adding value to the further development of the civil aviation infrastructure.

A Cost-Effectiveness Analysis of Local Air Quality Charges At Zurich and Stockholm Airports

By Roger Roy

Roger Roy is Director General of Economic Analysis at Transport Canada. He holds a degree in economics from the University of Ottawa. He has worked for over 30 years in the field of transportation at Canada's transportation regulatory agency and department of transport, where he has been involved in a range of diversified analytical work related to air transportation. He served for over 17 years on the board of the Canadian Transportation Research Forum in various positions, including President. During CAEP 6 and 7, Mr. Roy served as co-rapporteur of the Forecast and Economic Analysis Support Group.

The ICAO Council tasked the Committee on Aviation Environmental Protection (CAEP) to study the effectiveness of emission levies related to local air quality. It was decided to focus on NO_x emissions at two airports – Zurich, Switzerland and Stockholm, Sweden - where aircraft emission charges had been in-place since the late 1990s. Local emission dispersion, health effects, and the relative importance of air transport emissions, were outside the scope of the analysis. The analysis neither considered the relative contributions of the different sources of emissions nor the political and legal obligations in-place that were used to justify the introduction of the charges.[1] This article provides an overview of that study.[1]

Background

Ideally, the analytical framework for this study should allow one to: determine the change (reduction) in NO_x emissions and isolate those attributable to the introduction of the charge(s); establish the costs of mitigation measures introduced by airlines in response to the charge, by airports funded out of the revenues from the charge and for the administration of the charge; and establish the relative cost/effectiveness of the charge(s). The analysis also had to accommodate practical limitations in data. The terms and conditions of the charges introduced were important to define the data needed and requested.

The costs to airlines (both individually and as a whole) due to the charge(s) must be based on the direct causality between the change in emissions, the changes in the carriers' operations (at the airports with emission charges), and the charge itself. The level of emission changes at the airports with the charges compared to other airports without charges are relevant to the causality question. This question would also take into account the 'revenue neutrality' feature of the charges at the two airports.[2]

Analysis of the NO_x Emission Charges at Zurich and Stockholm Airports

The overall study involved a number of phases: data collection, data analysis, assessment of impact on carriers, and the overall impact of the emission charges at Zurich and Stockholm airports. These phases are addressed in the following paragraphs.

Data Collection Phase

Data was gathered on movements by aircraft type and engine combination; NO_x emitted by year for each aircraft type/engine combination as well as for the total movements; and the landing fee (for Zurich only) and the NO_x-charge paid by year for each aircraft type/engine combination and for the total movements for the period 1991 to 2004 for Zurich, for the year 1997 and 1999 to 2004 for Stockholm. For confidentiality reasons, the data received was not as detailed as needed.

[1] Since this article only represents an overview of that study, some points may not be as clear as desired. It is for this reason, the reader is encouraged to read CAEP7/IP4 for a more detailed discussion.

[2] Revenue-Neutrality in this context represents the practice by which revenues collected from aircraft emissions charges from aircraft operators below a given emissions compliance threshold would be offset by revenues paid for mitigation measures and/or as compensation to aircraft operators above that same compliance threshold. Such aircraft emissions charges are typically imposed and collected by airports. At the end of a given period (say, one year), the revenues collected must be offset by the revenues paid out.

At both airports studied, emission charges[3] introduced were in relation to landing fees. For Zurich only, some aggregate level information on the charges paid, coupled with carrier-specific information on movements allowed the study to separate carriers into those from developed countries and those from developing countries. A survey of carriers conducted by IATA was helpful in assessing the impacts of the charges on the behaviour of carriers.

Since 1997-1998, the years of introduction of the NO_x charges at Zurich and Stockholm, respectively, a number of significant events impacted on the number of aircraft movements and emissions at airports, including Zurich and Stockholm, most notably: the September 11, 2001 terrorist attacks in the U.S.; the collapse of Swissair; the outbreak of SARS[4] in Asia; and the outbreak of the war in Iraq – these events are also considered as external factors (or shocks).

For example, at Zurich in 2004, the total number of aircraft movements was actually less than in 1997, after having increased steadily between 1992 and 2000. The events just listed led to a reduction in aircraft movements between 2001 and 2004 and a matching downward trend in total NO_x emissions was accentuated due to a shift in aircraft types used. NO_x emissions at Stockholm airport in 2004 was back to its 1995 levels despite having 20,000 additional aircraft movements.

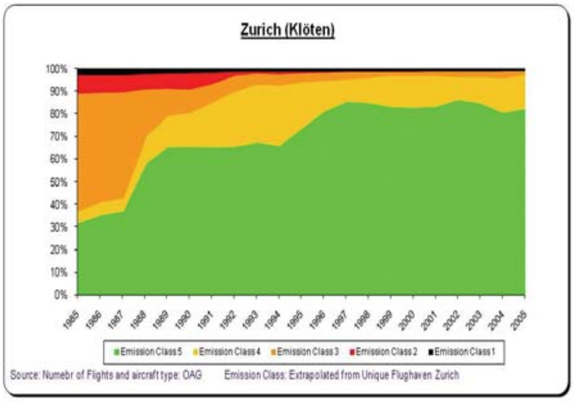


Figure 1 – NO_x emissions by classes of charges at the Zurich Airport.

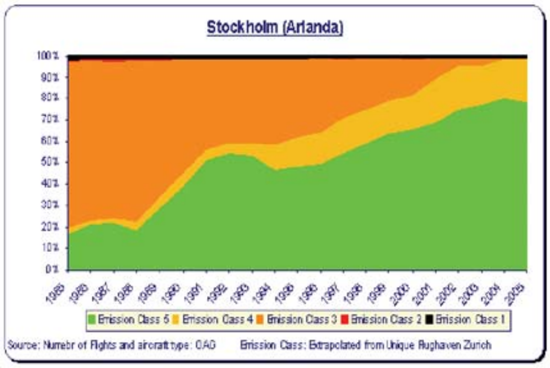


Figure 2 – NO_x emissions by classes of charges at the Stockholm airport.

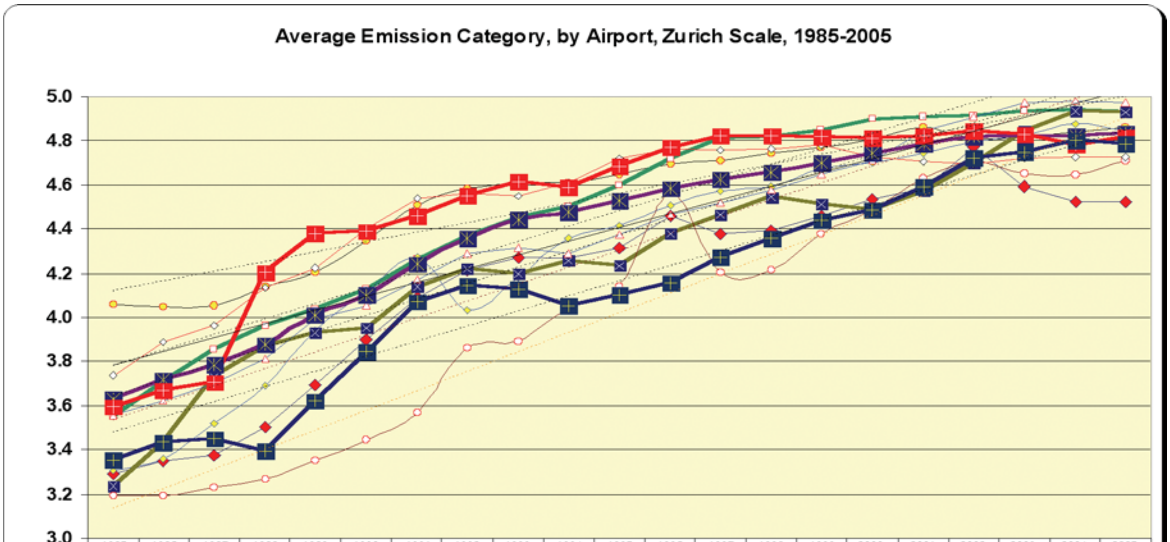
Data Analysis Phase

Changes in aircraft types used to serve the two airports with charges were compared with the changes in aircraft at other airports with similar/comparable air services, using the Official Airline Guide (OAG) service information. Figure 1 shows a shift for Zurich over the years towards the less NO_x emitting aircraft classes. Figure 2 indicates the same trend for the Stockholm airport after normalizing for the Zurich airport emission classes of charge.

Four airports were compared with Zurich: Copenhagen (Kastrup), Madrid (Barajas), Rome (Fiumicino) and Vienna (Schwechat). They are Western Europe airports receiving both intercontinental and intra-European services and hubs of a second-tier (size wise) European carrier. For Stockholm, the four airports identified were: Düsseldorf, Göteborg, Helsinki, Oslo, Western North European airports serving as regional/national hubs with some intercontinental services. The changes in aircraft used to serve

[3] Prior to the introduction of the charge at Zurich, a 5% reduction of the landing fees was introduced. The decrease in landing fees was calculated so that the introduction of the emission charge would translate into unchanged total revenues for the airport, e.g. the emission charge was to be revenue neutral to the airport as its revenues were to just offset the airport's overall reduction in the landing fees. The emission charge introduced at Zurich was in terms of a percentage of the landing fees between 0 and 40% depending on which one of five classes the engines of any given aircraft belong. In Sweden, a Swedish State enterprise introduced an emission charge at its 19 airports, including the Stockholm Airport. The charge introduced was for aircraft with a maximum take-off weight (MTOW) exceeding 9.0 tonnes, was linked to the landing charge, and was revenue-neutral to the State enterprise. The revenue neutrality was achieved through the lowering of the landing charge by 12 percent to offset the revenues to come from the emission charge. The objective behind the charge was to influence the nitrogen oxide (NO_x) and hydrocarbon (HC) emissions. Carbon dioxide (CO2) was left out, as it was felt that airlines would already have the incentive to reduce their CO2 emissions since they are directly related to fuel consumption. The emission classes at Stockholm ranged between the worst, e.g. category 0 and a 30% landing charge supplement, to the best, e.g. category 6, with a 0% landing charge supplement. The NO_x charge approach differed at the two airports — both in terms of classes of charge and in terms of levels.

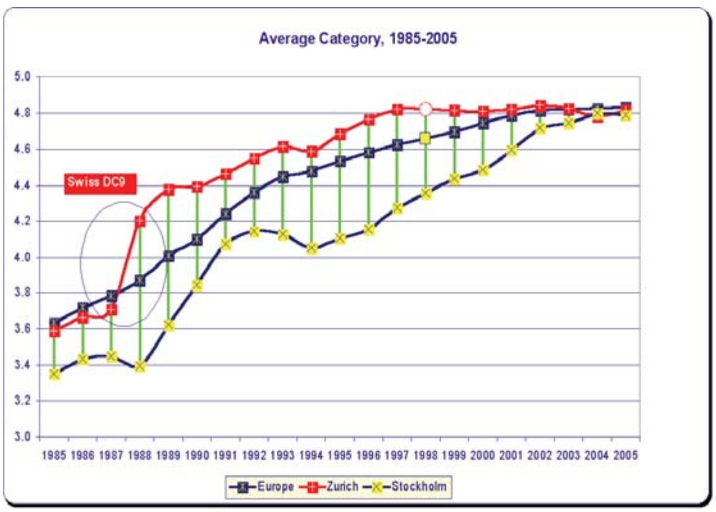
[4] SARS- Severe Acute Respiratory Syndrome



	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
CPH	3.3	3.3	3.4	3.5	3.7	3.9	4.1	4.2	4.3	4.3	4.3	4.5	4.4	4.4	4.5	4.5	4.6	4.8	4.6	4.5	4.5
DUS	4.1	4.0	4.1	4.1	4.2	4.3	4.5	4.6	4.6	4.6	4.6	4.7	4.7	4.7	4.8	4.8	4.9	4.8	4.8	4.8	4.9
FCO	3.5	3.7	3.9	4.0	4.0	4.1	4.3	4.4	4.5	4.5	4.6	4.7	4.8	4.8	4.8	4.9	4.9	4.9	4.9	4.9	4.9
GOT	3.3	3.4	3.5	3.7	3.9	4.1	4.3	4.0	4.2	4.4	4.4	4.5	4.6	4.6	4.7	4.7	4.7	4.8	4.8	4.9	4.8
HEL	3.2	3.4	3.7	3.9	3.9	3.9	4.1	4.2	4.2	4.3	4.2	4.4	4.5	4.5	4.5	4.5	4.6	4.7	4.8	4.9	4.9
MAD	3.2	3.2	3.2	3.3	3.4	3.4	3.6	3.9	3.9	4.0	4.1	4.6	4.2	4.2	4.4	4.5	4.6	4.7	4.7	4.6	4.7
OSL	3.6	3.6	3.7	3.8	4.0	4.1	4.2	4.3	4.3	4.3	4.4	4.5	4.5	4.6	4.6	4.7	4.8	4.9	5.0	5.0	5.0
VIE	3.7	3.9	4.0	4.1	4.2	4.4	4.5	4.6	4.6	4.6	4.7	4.8	4.8	4.8	4.8	4.7	4.7	4.7	4.7	4.7	4.7
EUR	3.6	3.7	3.8	3.9	4.0	4.1	4.2	4.4	4.4	4.5	4.5	4.6	4.6	4.7	4.7	4.7	4.8	4.8	4.8	4.8	4.8
ZRH	3.6	3.7	3.7	4.2	4.4	4.4	4.5	4.6	4.6	4.6	4.7	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8
ARN	3.4	3.4	3.4	3.4	3.6	3.8	4.1	4.1	4.1	4.1	4.1	4.2	4.3	4.4	4.4	4.5	4.6	4.7	4.7	4.8	4.8

Source: Number of Flights and aircrafts type: OAG *Emission Class: Extrapolated from Unique*

Figure 3 – Classification under the Zurich emission charge classes of aircraft landings at 10 airports and at Western Europe airports.



Source: Number of Flights and aircraft type: OAG
Emission Class: Extrapolated from Unique

Figure 4 – Comparison of changes in average aircraft classification serving Zurich and Stockholm Airports with the ones serving Western Europe Airports.

Zurich and Stockholm airports were not significantly different to the ones observed at the other comparable airports, an indication that NO_x emission charges did not induce the change of aircraft, since similar changes were observed at other comparable airports with no NO_x emission charges. An average aircraft emission charge classification concept for all 10 airports confirmed this finding (Figure 3). When compared with aircraft used for services at all Western Europe airports[5], the same conclusion can be drawn (Figure 4).

To test this, a linear regression between landings and emissions was estimated for each of the two airports with NO_x emission charges (i.e. Zurich and Stockholm), for each of the eight airports used for the comparison purposes, as well as for the Western Europe aggregated airports. The slope of the lines were not statistically different from one airport (group of airports) to another, an additional indicator of a lack of influence of the charges on the choice of aircraft used to serve the

[5] Services to all airports in Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom.

airports. A statistical test (Chow test) was used to determine whether the regression model estimated parameters were the same before and after the introduction of the charge, but the results did not indicate a statistically supported conclusion for Zurich and Stockholm. But that test did show that the time series behaved differently before and after the introduction of the charges; thus implying external factors influencing the time series. But clearly, the emission charges were not the only external factors. In all likelihood, those external influences came from the introduction of less polluting aircraft across Europe — not only at the two airports under study — the charge per se not being instrumental in influencing the change of aircraft captured by the linear model. A correlation analysis showed the changes in the average aircraft classes at airports with charges and the average at other airports without charges behaved the same way, also indicating a lack of influence by the charge.

This statistical analysis supported the conclusion that the introduction of the charges had a limited influence in inducing a switch to aircraft with better NO_x emission technology. This meant that the causality between the change in NO_x emissions and the charge could not be established, implying that costs encountered to reduce the level of NO_x emissions could not be associated with the charge.

Impacts On Air Carriers

The International Aviation Transport Association (IATA) conducted a survey of air carriers affected by the charges to determine the impact of the emissions charges on them. IATA's survey gathered information on the reaction of air carriers to the charge. Responding airlines all stated that the charge had no impact on their fleet-related decisions. SAS analysis software provided insights on how a NO_x-charge could impact on carriers' behavior. The information presented by SAS, seen in Table 1, shows that, for the smaller aircraft the importance of the emissions charge is a minor component of total direct operating costs (DOC), but is much more significant for larger aircraft. Replacing an older aircraft with a newer one reduces the relative importance of the charge in total DOC, but substantially increases the total DOC due to the heavier burden of the capital costs. This indicates that a carrier's reaction to a charge must be assessed in light of that reaction's impact on the total DOC. From the industry information obtained, it can be inferred that there was no change in airline purchase behavior as a result of the introduction of the charge. Consequently, carriers simply paid the charge as just another cost of doing business.

Table 1: Relative Operating Costs

(expressed as a percentage of the total DOC of the reference aircraft type)

Aircraft Type	**NEW**	**OLDER**	**SMALLER**	**BIGGER**
Number of seats	123	125	72	198
Operating Costs	Reference			
Maintenance	21.5	22.9	9.3	27.1
Fuel costs	13.4	14.8	6.8	16.8
Cockpit crew	14.3	14.3	11.5	14.3
Cabin crew	8.7	8.7	5.7	11.0
Navigation fees	4.8	5.0	3.4	5.8
Landing fees	7.2	7.8	2.7	11.4
Ground handling	13.4	13.9	10.3	18.4
Emission NO_x-charge	0.5	1.1	0.3	1.5
Capital costs per trip	16.2	5.2	10.4	23.5
Total DOC	100.0	93.7	60.4	129.7
Total operating costs	plus 33%			

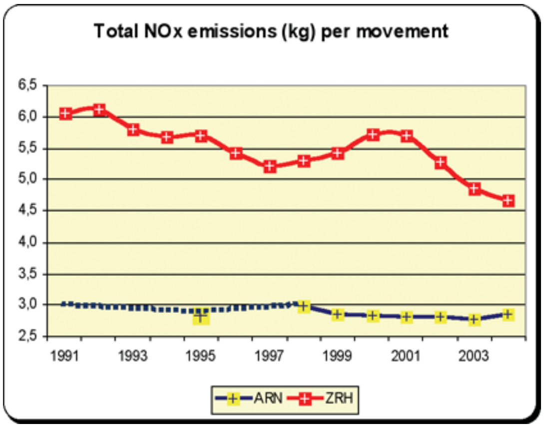
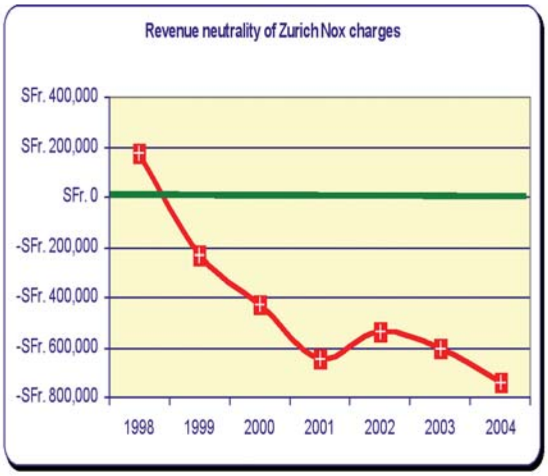


Figure 5 – Average kilograms of NO_x emissions per aircraft movements at Zurich and Stockholm airports.



Source: Unique Flughafen Zurich

Figure 6 – Revenues generated from the emission charge at Zurich airport.

Impacts On Air Carriers From Developing Countries

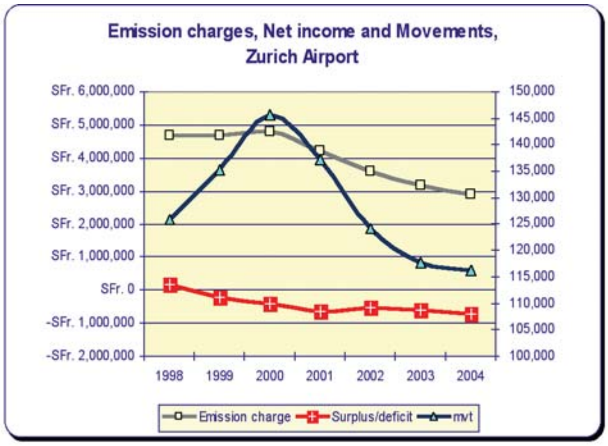
At Zurich, developing country carriers operations varied between 4% and 7.5% of total flights at the airport over the period studied. Developing country carriers that operated less emission-efficient aircraft, faced marginal increased costs on a per passenger basis, with no detrimental competitive disadvantages for them. Carriers with the most significant presence at Zurich airport – be it developed or developing country carriers – used the more modern and less emitting aircraft to serve the airport, offsetting the impact of the charge on their operations.

On a per aircraft movement basis, NO_x emissions have been reduced at Zurich by 18% but have increased slightly by 0.7% at Stockholm airport, as shown in Figure 5. This outcome was influenced largely by the types aircraft previously shown in Figures 1 and 2 under data analysis phase.

Impacts of the Emission Charges

The revenue neutrality of the emission charge came from a reduction in the landing fees prior to the introduction of the emission charges of 5% at Zurich and 12 % at Stockholm; in each case a reduction equivalent to the expected additional revenues from the emission charge in its first year of implementation. The reduction to the landing fees was done once and was not further adjusted subsequently to reflect changes in aircraft types landing at the two airports. The net charge paid for each individual aircraft landing could be estimated by subtracting the percentage reduction of the landing fee from the NO_x-emission charge paid for that aircraft/engine combination. This shows some aircraft/engine combinations benefiting over time from a reduction in their landing fees at the airports with emission charges. At Zurich, total net revenues from the charge (i.e. the sum of all net charges paid for each aircraft/engine combination after removing the 5% reduction in landing fees) declined since the introduction of the charge (Figure 6's green line represents emission charge revenues equal to the 5% landing fee reduction). Already in its second year of implementation, the NO_x emission charge generated revenues less than the landing fee reduction.

Figure 7 relates the revenue trend at Zurich to aircraft movements, showing net positive income for emission classes 1 to 3 and net negative income for emission classes 4 and 5, leading to an overall decline in revenues from the emission charge due to the landing fee reduction incentive. Figure 8 shows the distribution of net costs over individual aircraft movements, a negative value indicating a benefit to the airline and a positive figure an additional cost due to the introduction of the charge, the number of movements benefiting from a net reduction of their charge at the airport in 2004 being larger than in 1998. A carrier landing at Zurich with a class 5 engine/aircraft pair would be a "winner", paying less in landing fees than before the introduction of the NO_x emission charge. A class 4 aircraft operator would pay exactly the same amount of fees as before the introduction of the NO_x-charge. A carrier using a class 1 to 3 engine/aircraft pair for its services to Zurich, would be a "loser", paying more on a "net" basis than before the emissions charge.

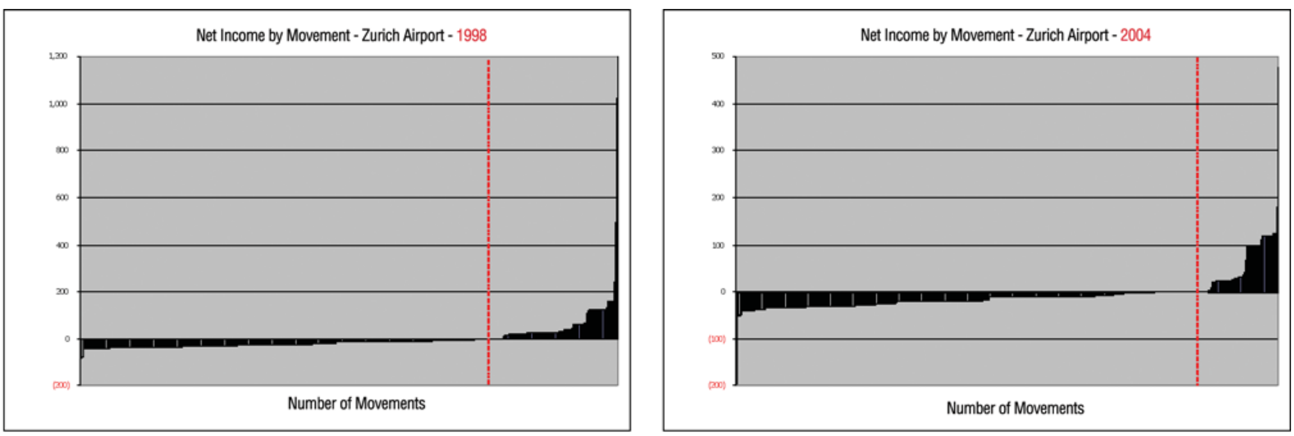


Source: Unique Flughafen Zurich

Figure 7 – Emission charge, net income and aircraft movements at Zurich airport.

At Stockholm, the last year before the shift in 2004 to the ERLIG[6] approach for the emission charge, 81% of aircraft types flying into that airport paid less than 40 Kroner per kg of NO_x. The average emission charge per kg of NO_x in 2003 was 19.2 Kr, and 73.9% of aircraft movements at that airport paid less than that amount that year. The average emission charge paid per kg of NO_x declined by 22.9% between 2000 and 2003 at Stockholm airport.

The limited influence of the emissions charge in inducing changes to aircraft with better NO_x emission technology, coupled with the net negative proceeds from the charge at Zurich, made it impossible to establish the cost/effectiveness of the charge.



Source: Unique Flughafen Zurich

Figure 8 – Ranked Net charge paid at Zurich by each individual movement for 1998 and 2004.

[6] In 2003, the European Civil Aviation Conference adopted recommendation 27-4 on a NO_x emissions Classification Scheme, developed by the Emissions-Related Landing Charges Investigation (ERLIG) subgroup.

Use and Cost-Effectiveness of "Net Revenues" from Emission Charges

In the report: "Emission Charges Zurich Airport Review 2003" the Swiss airport authority Unique gives a summary of the mitigation measures that have been taken with the proceeds of the charge.

The report gives an overview of the measures that have been paid out by the charge; measures mentioned have to do with the establishment of an air quality monitoring network for the airport region, development of a required emission inventory calculation and dispersion modeling approach; air quality management and research work; the construction of required fixed ground power for aircraft at piers, contribution to compressed natural gas fuel station for handling equipment and airside traffic, and the contribution to aircraft ground systems to enhance taxiing. The first three types of measures do not contribute to any additional NO_x-reduction. Therefore, they are not further considered here. From the last three measures, only for the fixed ground power at piers, is enough information available to warrant a closer investigation.

The report indicates that the airport spends, from the charges collected, 3 million CHF per year on investment on the fixed ground power installations. The report is not very clear about the additional charges airlines have to pay when using these power installations and how this relates to the investment and running costs. With the introduction of these fixed installations, an amount of 75 ton of NO_x is forgone and 12,170 ton of kerosene saved. Based on the current prices (which assumes US$1.80 per US gallon) that would mean roughly 7 million US dollars. If we assume that these cost savings cancel out the electric energy costs needed to run these fixed installations, it gives a cost/efficiency of roughly 30 US dollars[7] per kg of NO_x-saved. If this is compared with other NO_x-reduction measures in general, this is on the high side, though it does not seem to be extreme.

Conclusions

The following conclusions can be made based on the analysis described above.

- The impact of the emission charge on NO_x emission levels was found to be at best marginal. The shift towards aircraft with better NO_x-technology that took place at Zurich and Stockholm airports, was also observed at other comparable airports in Europe.

- An analysis of direct operating cost figures for different aircraft types showed that the level of the charge applied at the two airports studied was not high enough to create an incentive for the carriers to change their operations and/or their fleet purchase plans. How much higher the charge would have to be, and/or how many airports to which it would have to apply (within a broad region of the globe) to have an influence on airline behavior was not assessed.

- Studying the changes in costs due to the charge for the different aircraft/engine combinations in Zurich showed winners (use of aircraft with net fees less than before the introduction of the charge) and losers (use of aircraft with net fees higher than before the introduction of the charge). The analysis showed that carriers serving Zurich, as a whole, have benefited from an overall net airport charge/fee reduction since year two of the introduction of the NO_x charge. Due to some Swedish data limitations, the same assessment was not possible for Stockholm.

[7] An exchange rate of 1,23 CHF to the US dollar was used.

- Assessment of the impact of the charge on developing country airlines showed that the number of movements by these airlines was relatively small at the two airports studied. The developing country carriers with minimal operations at these airports operated older aircraft and faced increased landing fees. Carriers with more significant operations, like developed country carriers, tended to operate more modern and less emitting aircraft. Consequently, the effect of the emissions charge on developed country carriers was marginal at most.

- The additional NO_x-reduction measures at Zurich airport, which are said to have been paid for from the proceeds of the NO_x-charge, were assessed as to their possible additional NO_x -emission reduction benefits. Although some of these measures fell within the ICAO definition of being cost-related, they were not generating additional NO_x-reductions. For one measure, the information available permitted some minimal assessment of its cost-effectiveness. The costs of this measure were paid out of the revenues of the NO_x-charge, though the overall proceeds of the charge were negative. Overall, the measure was judged as low in terms of its cost-efectiveness, though it still falls within the range of other NO_x-reduction measures.

Overall, the ICAO's CAEP Forcasting Economic Analysis and Support Group (FESG) analytical work on the cost/effectiveness of the NO_x-charges revealed that the impact on NO_x-emissions directly attributable to the charge has been marginal at both Zurich and Stockholm airports. At the same time, the overall additional costs to the airlines from the introduction of the charge at Zurich were negative. In light of the limitations of the analysis conducted, definite inference as to the cost-effectiveness of local air quality charges cannot be made.

Reference

1 This section and the remainder of the article are based on the work of ICAO's CAEP Forecasting Economic Analysis and Support Group entitled, "Cost-Effectiveness of Local Air Quality Charges,"as contained in CAEP/7 IP/4.

Airport Air Quality and Aircraft Emissions Charges Guidance

Overview of ICAO Airport Air Quality Guidance Manual

By ICAO Secretariat

ICAO has been involved with airport-related emissions for many years, and initially developed aircraft engine emission Standards to respond to concerns regarding emissions that affect local air quality in the vicinity of airports. The Organization has also produced several guidance documents related to aircraft emissions including: the *Airport Planning Manual* (Doc 9184) and the ICAO Circular - *Operational Opportunities to Minimize Fuel Use and Reduce Emissions* (Cir 303, 2004). This article describes recent efforts by ICAO to develop guidance material to assist Contracting States and local authorities to implement best practices related to assessing airport-related air quality. Since this material covers an evolving area of knowledge, it represents currently available information that is sufficiently well-established to warrant inclusion in international guidance. The guidance will be updated periodically and expanded in the future.[1]

Background

Interest in air pollutant emissions from aircraft and airports has been rising ever since the substantial increase in commercial turbojet traffic in the 1970's. For example, aircraft emissions contain air contaminants such as nitrogen oxides (NO_x), hydrocarbons (HC), and fine particulate matter (PM), which in turn can become involved in broader environmental issues related to such phenomena as: ground level ozone (O_3), acid rain, and climate change. They can also pose potential risks related to public health and the environment in general. Unlike other transportation modes, aircraft travel great distances at a variety of altitudes, generating emissions that have the potential to impact air quality in the local, regional and global environments.

ICAO recognizes that airport-related sources of emissions have the ability to emit pollutants that can contribute to the degradation of air quality in nearby communities. National and international air quality programmes and standards are continually requiring airport authorities and government bodies to address air quality issues in the vicinity of airports. Similarly, attention must also be paid to other possible airport-related environmental impacts associated with such things and noise, water quality, waste management, energy consumption and local airport ecology. All of this to help ensure both the short- and the long-term welfare of airport workers, users, and surrounding communities.

Although significant improvements have been made over the past two decades in aircraft fuel-efficiency and other technical refinements have been made to reduce emissions, these advancements may be offset in the future by the forecast growth of airport operations and other aviation activities. Because aircraft are only one of several sources of emissions at an airport, it is also considered essential to manage emissions from: terminal, maintenance and heating facilities; airport ground service equipment (GSE); and various types of ground transport operating at and around airports. Optimizing airport design, layout, and infrastructure; modifying operating practices for greater efficiencies; retrofitting the GSE fleet with "no-" or "low-" emitting technologies; and promoting other environmentally-friendly modes of ground transport are some of the actions that airports and the rest of the aviation industry can take to help meet environmental goals while encouraging sustainable development in commercial air transport.

Development of Guidance Material

The new guidance document is being developed in two-phases. The first phase was completed by CAEP/7 and made available on CAEP's website. The second phase will be completed for CAEP/8 in the form of a published ICAO document (Doc 9889) which can be amended in the future as developments in "best practices" occur. In other words, the new guidance is intended to be an evolving "living document." Because of the scale and complexity of future work, it is anticipated that some later chapters of the guidance will, out of necessity, have to be finalized after CAEP/8.

Progress To-Date

So far, the first phase of the guidance has been completed in the form of a framework for the whole document with detailed text that includes an Introduction and the first three chapters: *Regulatory Frameworks and Drivers* (Chapter 1), *Emissions Inventories* (Chapter 2), *and Emissions Temporal and Spatial Distribution* (Chapter 3). The second phase, under development for CAEP/8, includes the chapters on Dispersion Modelling (Chapter 4) and Airport Air Quality Measurements (Chapter 5), as well as further development of the "sophisticated" approach for aircraft source emission inventorying. The remaining chapters, Mitigation Options (Chapter 6) and Interrelationships (Chapter 7), will most likely be completed for CAEP/9. A Glossary and a set of References also were developed for CAEP/7, and will be updated in the future to reflect the content of additional chapters.

The following paragraphs present brief summaries of the material covered in the first three chapters of the guidance document.

Chapter One: Regulatory Frameworks and Drivers

This chapter discusses the historical reasons that have driven States (and their delegates) to adopt local air quality regulations and provides examples of the various regulatory criteria already in place in specific States. These regulations, as well as increased public awareness and expectations regarding air quality, serve as the drivers pushing the aviation industry to inform, and where appropriate, attempt to meet those expectations. One obvious response of the aviation industry to these drivers, is to develop ways to control emissions from aircraft engines. This is achieved through the development of uniform international certification Standards, contained in ICAO *Annex 16 – Environmental Protection, Volume II – Aircraft Engine Emissions to the Convention on International Civil Aviation*.

Airport studies confirm that aircraft continue to be a relatively small contributor to regional pollution, although aircraft-related NO_x contributions could increase as air traffic increases and other non-aircraft emission sources become progressively cleaner. Therefore, although reductions in aircraft emissions (through operational and air traffic measures and/or more stringent ICAO engine Standards) can help to improve local air quality in the vicinity of airports, further growth and expansion means that it will become increasingly necessary for all sectors to improve their performance.

For determining compliance with local air quality regulations, comparing the emissions from aircraft with those from other sources, and for estimating future emissions concentrations, the development of emissions inventories is an essential step.

Chapter Two: Emissions Inventories

The second chapter describes the parameters and steps involved in preparing an inventory of the pollutant species of interest. Airports and their associated activities are sources of an assortment of gaseous and particulate emissions. It is important to know the total amount of each pollutant species (e.g. NO_x, HC, etc.) emitted by the sources at an airport in order to properly assess relative impacts and the degree of regulatory compliance. This information is determined through the completion of an emissions inventory. Emissions inventory objectives can include, but are not necessarily limited to, the following:

- Collecting information on emissions while monitoring trends and assessing future scenarios;
- Benchmarking emissions against legal requirements (e.g. thresholds);
- Creating input data for dispersion models in an effort to determine pollution concentrations; and
- Establishing mitigation programme baselines.

In order to develop an emissions inventory, the following six steps are necessary:

1. Define the general inventory parameters such as: purpose, spatial and functional perimeters, and frequency of updates;
2. Determine the emission species to be considered;
3. Determine existing emission sources;
4. Quantify the emissions from those sources;
5. Consider the macro-scale issues (regional emission inventories) to the extent relevant;
6. Implement quality assurance and control measures (to characterize uncertainties and limitations of data).

A wide assortment and number of emission sources can be found at airports, and all of these sources contribute to local air quality. However, depending on the specific activities at individual airports, not all types of emission sources are actually present (i.e. some are located off-airport). To better account for this variability, the emission sources have been grouped into four categories, as shown in the following table:

Typical Sources of Emissions At and Around An Airport

Emission sources directly from the aircraft are:	
Aircraft Main Engine	Main engines of aircraft within a specified operating perimeter (from start-up to shut-down).
Auxiliary Power Units	APU located on-board aircraft providing electricity and pre-conditioned air during ground times and bleed air for main engine start.
Aircraft handling emission sources are typically comprised of the following:	
Ground Support Equipment	GSE necessary to handle the aircraft during the turnaround at the stand: ground power units, air climate units, aircraft tugs, conveyer belts, passenger stairs, fork lifts, tractors, cargo loaders, etc.
Airside Traffic	Service vehicle and machinery traffic: sweepers, trucks (catering, fuel, sewage) cars, vans, buses, etc., that circulate on service roads within airport perimeter (usually restricted area).
Aircraft Refuelling	Evaporation through aircraft fuel tanks (vents) and from fuel trucks or pipeline systems during fuelling operations.
Aircraft De-icing	Application of de-icing and anti-icing substances to aircraft during winter operations.
Stationary- or infrastructure-related source categories of emissions comprise the following:	
Power/heat Generating Plant	Facilities that produce energy for the airport infrastructure: Boiler house, heating/cooling plants, co-generators.
Emergency Power Generator	Diesel generators for emergency operations (e.g. for buildings or for runway lights).
Aircraft Maintenance	All activities and facilities for maintenance of aircraft, i.e. washing, cleaning, paint shop, engine test beds, etc.
Airport Maintenance	All activities for maintenance of airport facilities: cleaning agents, building maintenance, repairs, grounds maintenance, and machinery (vehicle maintenance, paint shop).
Fuel	Storage, distribution and handling of fuel in fuel farm and vehicle fuel stations.
Construction Activities	All construction activities in airport operation and development.
Fire Training	Activities for fire training with different fuel (e.g. kerosene, butane, propane, wood).
Surface De-icing	Emissions of de-icing and anti-icing substances applied to aircraft moving areas and service and access roads.
Landside traffic emission sources are comprised of the following:	
Vehicle Traffic	Motor bikes, cars, vans, trucks, busses and motor coaches associated with the airport on access roads, curbsides, drive-ups, and on- or off-site parking lots (including engine turn-off, start-up and fuel tank evaporative emissions). *Trains are not currently included.*

An emissions inventory can be conducted at various levels of complexity, depending on the required accuracy of the results, as well as the availability of supporting knowledge, data, and other resources. The guidance is intended to be a general framework for conducting studies at various levels of complexity. Whenever possible, guidance is given for three different levels of complexity (e.g. Simple, Advanced and Sophisticated). When conducting an analysis, the applied approach should also be stated.

The document provides guidance for calculating emissions from all of the airport sources identified above. The calculation of emissions from the aircraft fleet is dealt with in considerable detail. Three approaches to quantifying aircraft fleet emissions are described – the three methods having a progressively greater degree of accuracy (or smaller degree of uncertainty), with a correspondingly greater degree of complication. The three approaches are:

1. **Simple Approach:** This is the most basic approach for estimating aircraft engine emissions. The only airport-specific data required are the number of aircraft movements (over a certain period such as a year) and the type of each aircraft involved in each movement. This airport-specific information is combined with pollutant emission factors for each aircraft-type published by the United Nations Framework Convention on Climate Change (UNFCCC). They have been calculated based on the representative engine type for each generic aircraft-type, using basic assumptions. This simplified technique should only be used as means for conducting an initial assessment of the aircraft engine emissions at an airport. For most pollutant species, the approach is generally conservative; meaning that the outcome will often overestimate the total level of aircraft engine emissions. However, for some emission species and less common aircraft, the resultant emissions may be underestimated. As such, it is unclear how accurately the Simple Approach accounts for actual aircraft engine emissions at a given airport. ICAO advises that if an emissions inventory involves policies that will affect aircraft operations at a particular airport, then the calculations should be based on the best data available, and the Simple Approach should not normally be used. When further information on the aircraft operations at an airport is available, one of the more advanced approaches would be more appropriate.

2. **Advanced Approach:** This approach results in more accurate emissions estimates because it attempts to account for the specific engine model on the aircraft under study, compared with the Simple Approach which uses only the representative engine type for each generic aircraft type. The Advanced Approach also calculates the emissions from each phase of the landing and take-off cycle (LTO) individually, which makes it possible to allow for the time spent in each phase of flight at the particular airport more precisely. These improvements in the Advanced Approach result in a more accurate reflection of main engine emissions over the simpler method, yet the total emissions are still considered conservative, given the reliance on certification data to represent LTO emissions.

3. **Sophisticated Approach:** This approach should be used where a high level of accuracy is required. The approach goes beyond LTO certification data and flight mode times, and utilizes actual engine/aircraft operational performance data. Use of the Sophisticated Approach requires a greater knowledge of aircraft and engine operations, and in certain instances will require the use of proprietary data, or data or models that are normally not available in the public domain. In most instances it requires users to perform higher levels of analysis.

There are a variety of air pollutants present as gaseous and particulate emissions from aviation-related activities that can potentially impact human health and the environment. However, data on all of them are not always relevant or needed for emission inventories. Government (i.e. State) requirements will normally indicate which emission species are actually necessary for the inventory. Generally, the following common species could be considered the primary species in emission inventories:

- NO_x - Nitrogen oxides, including nitrogen dioxide (NO_2) and nitrogen oxide (NO);
- VOC - Volatile organic compounds (including non-methane hydrocarbons (NMHC));
- CO - Carbon monoxide;
- PM - Particulate matter (fraction size $PM_{2.5}$ and PM_{10});
- SO_x - Sulphur oxides.

Carbon dioxide (CO_2) is sometimes included in inventories (using the total fuel burn as a basis for calculation). It has to be recognized that CO_2 is of a global rather than strictly local concern, but local CO_2 inventories can feed into global inventories where required.

Additional emission species of potential health and environmental concern may also need to be considered in emission inventories including so-called hazardous air pollutants (HAPs). Low levels of HAPs are also present in aircraft and ground support equipment exhaust in both gaseous and particulate forms. HAPs research is at an early stage and it should to be noted that knowledge of emission factors is therefore very limited for many of these species. Therefore, the creation of an inventory of HAPs might not be possible, or such an inventory cannot be expected to have the same level of accuracy as other, more common species. In such cases, the proper authorities would have to provide further guidance. Examples of HAPs that have been identified as being representative of airport sources of air emissions include (but are not necessarily limited to): Acetaldehyde, Benzene, Diesel Particulate Matter, Formaldehyde, Lead, Toluene, and Xylene.

Chapter Three: Temporal and Spatial Distribution of Airport Emissions

The third chapter of the guidance manual is devoted to the "temporal and spatial distribution of airport emissions". This is necessary because, at an airport, emissions occur at various locations and during different time-periods, depending on the purpose and operational characteristics of the source. This results in the dispersion of emissions becoming not only a temporal distribution (i.e. an accounting of emission variations over time) but a spatial three-dimensional (i.e. "3-D") consideration as well. The assessment of this variability of location and emission density over time must be done by spatial and temporal analysis of the emissions. This is especially true if dispersion modelling is to be performed as part of the overall air quality analysis. This chapter of the guidance document describes the emission distribution process that occurs in the general vicinity of airports.

Conclusions

The publication of this ICAO guidance material will assist States, local authorities and airports that have to perform emissions assessments to do so using the best international practices available.

Although the material is not yet complete, enough information has already been prepared and published to be of significant value. The work is expected to be largely completed in about three year's time (CAEP/8). However, the final guidance document chapters on Mitigation Options (Chapter 6) and Interrelationships (Chapter 7) will most likely be completed for CAEP/9.

Reference

1. This and the remaining sections of this article are based on the work of CAEP's Task Group 4 (Airport Air Quality) focal points (Ms. Julie Draper and Mr. Gardner) of Working Group 2, as contained in CAEP/7 WP/28 entitled, "*Report of WG2 TG4 – Airport Air Quality: Emissions LAQ Guidance*."

Overview of ICAO Guidance On Aircraft Emissions Charges Related To Local Air Quality

By Archie Muckle, Jr.

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This article presents an overview of the new guidance on aircraft emissions charges related to local air quality (LAQ). This guidance, which was recently published as document 9884, represents the first ever publication by ICAO devoted exclusively to aircraft emissions charges (or levies) dealing with local air quality issues related to aviation. This guidance pertains to a "best practice" framework of implementing emissions charges aimed at mitigating the adverse effects of aircraft emissions on local air quality, in ways that are consistent with ICAO policy, for those States that wish to adopt emissions charges.[1]

This article is divided into three sections, Background, Overview of Guidance, and Conclusions.

Background

Traditionally, technology and operational measures have been the primary means for limiting or reducing aircraft noise and aircraft engine emissions. Such measures have been promoted and fostered through ICAO's noise and emissions certification standards for aircraft, and through ICAO recommended practices and guidance.

In the mid-1990s, the potential for employing emissions-related levies to further address aviation emissions was raised. After significant discussion, the ICAO Council, in December 1996, adopted a resolution on Environmental Taxes and Charges (henceforth referred to as Council Resolution). A key aspect of that Resolution was the strong recommendation from the Council "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." The Council also urged "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" ICAO charging policies.

Since the mid-to-late 1990s, aircraft emissions charges have been implemented locally at some European airports. There has been much debate within and outside of ICAO as to whether or not existing aircraft emissions charges by some States are consistent with ICAO policy and whether the general ICAO charging policies are sufficiently detailed to fully address emissions charges. As a result of such discussions, the 35th Assembly of ICAO requested that the ICAO Council develop further guidance on emissions levies related to local air quality (LAQ), while recognizing the continued validity of the Council's Resolution. In response to the Council's request, ICAO's CAEP started to develop new guidance on aircraft emissions charges (related to LAQ) for delivery at CAEP/7 in February 2007.

While there continued to be differing viewpoints among States and CAEP participants as to whether emissions charges are a cost-effective and appropriate means of addressing aircraft emissions, there was strong agreement that additional guidance was needed for those States who decide to implement such measures. Thus, the effort to develop guidance was focused on the question of "how" charges might be implemented, rather than "whether" such measures should be adopted.

Overview Of Emissions Charges Guidance

The guidance is composed of five chapters, followed by two appendices. The first appendix is a glossary of terms, and the other presents the European Civil Aviation Conference approach to charges for aircraft powered by non-certified aircraft engines. Each of the five main chapters in the guidance document is discussed in the following paragraphs.

Chapter 1 - Scope of Guidance and Application of Existing ICAO Policies To Charges For Aircraft Emissions Charges Related to Local Air Quality

This chapter focuses on following four key items:

The first item pertains to scope of the guidance. Aside from what has already been noted in the background section, the appropriate scope of the guidance (as determined by CAEP) focused only on emissions charges related to local air quality concerns.

The second item relates to the working assumptions used in developing the guidance. The guidance assumed (and acknowledged) that a State (or its delegated authority) that had chosen to proceed with a local charge on aircraft emissions would have undertaken the necessary analysis to confirm that such a charge is an appropriate policy measure to address the local air quality situation.

The third item focuses on emphasizing the use of existing ICAO policies on emissions charges as part of the new guidance. This item includes information that makes the distinction between a local emissions charge and a tax, as well as a discussion of the application of ICAO's existing policies on emissions charges in the context of LAQ. These policies pertain to:

(1) Non-Discrimination: The ICAO Council urges States that are considering the introduction of emissions-related charges to take into account the non-discrimination principle in Article 15 of the Convention on International Civil Aviation. Further, charges must be non-discriminatory both between foreign users and those having the nationality of the State in which the airport is located and engaged in similar international operations, and between two or more foreign users.

(2) Potential Impacts on the Developing World: When market-based measures, such as emissions charges, are adopted, Contracting States are encouraged to take into account the potential impacts on the developing world.

(3) Transparency: Charging authorities are urged to ensure transparency as well as the availability and presentation of all financial data required to determine the basis for charges.

(4) Cost-Basis: States that are considering the introduction of emissions-related charges are urged to take into account the principle that "the charges should be related to costs. Further, charges should be based on the costs of mitigating the environmental impact of aircraft engine emissions to the extent that such costs can be properly identified and directly attributed to air transport.

(5) Cost-Effective Measures: When market-based measures, such as emissions charges, are adopted, States are encouraged to evaluate the costs and benefits of the various measures, including existing measures, with the goal of addressing aircraft engine emissions in the most cost-effective manner.

(6) Minimize Competitive Distortion: States that are considering the introduction of emissions-related charges are urged to take into account the principle that the charges should not discriminate against air transport compared with other modes of transport. In addition, authorities are urged to ensure there is no overcharging or other anti-competitive practice or abuse of dominant position.

(7) No Fiscal Aims: States that are considering the introduction of emissions-related charges are urged to take into account the principle that "there should be no fiscal aims behind the charges".

(8) Charges, Rather Than Taxes: The ICAO Council strongly recommends that any environmental levies on air transport which States may introduce should be in the form of charges rather than taxes.

The fourth item in Chapter 1 pertains to other existing ICAO guidance. This section recognizes guidance not noted previously in this chapter. It reminds States that:

- In Appendix A of ICAO Assembly Resolution A35-5, ICAO agreed to strive to "limit or reduce the impact of aviation emissions on local air quality."
- Appendix I of ICAO A35-5 states that 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.

- Appendix I of ICAO A35-5 contains Principle 16 of the Rio Declaration on Environment and Development (1992). It states that "national authorities should endeavour to promote the internalization of external costs and the use of economic instruments, taking into account the approach that the polluter should, in principle, bear the cost of pollution, with due regard to the public interest and without distorting international trade and investment."

Chapter 2 - Process for Implementing Local Emissions Charges

First; this chapter of the guidance acknowledges that implementing charging policies with due regard to ICAO policies and guidance is the responsibility of ICAO Contracting States, although they may delegate this responsibility to responsible authorities. At the same time, the guidance notes that Appendix I of Assembly Resolution A35-5 recognizes in the context of market-based measures that Contracting States have legal obligations, existing agreements, current laws and established policies.

Second; the chapter notes that local emissions charging schemes should be tailored to the specific characteristics of the airport air quality situation of concern, by means of an airport-by-airport approach. Nonetheless, it recognizes that a general framework may be implemented at a State-level in order to set up a common methodology for the implementation of the scheme.

Third; Chapter 2 notes that ICAO urges States to institute or oversee an inclusive and transparent process when adopting and implementing local emissions charges. The chapter also provides an overview of the steps in such a process (similar to the process in the balanced approach guidance on aircraft noise). The detail of this step-by-step approach is given in the remaining chapters of the guidance.

Chapter 3 - Local Air Quality Assessment

This chapter of the guidance identifies and summarizes the relevant steps in undertaking a local air quality assessment on which emissions charges may be based. It cross-references to the Airport Air Quality Guidance Manual (Doc 9889) wherever possible to avoid duplicating this separate work. The recommended process involves four steps as follows:

Step 1: Identify Relevant Local Air Quality Standards and Regulations

Responsibility for defining and achieving acceptable air quality in and around airports rests with the State. In assessing local air quality in the vicinity of airports, it is important to identify any relevant local air quality standards and goals established by the State (or its delegate) to protect public health and welfare and the environment in general.

Step 2: Determine Current Airport Air Quality

Airports and their associated activities are sources of different gaseous and particulate emissions. There are many air pollutants present in gaseous emissions from aviation-related activities that impact the environment. Local air quality in and around an airport is quantified in terms of pollutant concentrations. These concentrations can be calculated from airport activity data and numerical models of the emissions of each source and their interaction with the physical environment. Existing and/or predicted future concentration levels can be calculated utilizing software tools (numerical models). Local air quality modelling consists of two basic elements: 1) preparation of an emissions inventory and 2) dispersion modelling to assess emission concentrations and impacts.

Step 3: Verify Compliance and Conduct Impact Assessment

The next step is to compare the measured and/or calculated existing and forecast pollutant concentrations with the concentrations specified in applicable State regulations in order to assess existing and future compliance with the standards and requirements.

Step 4: Quantify the Relative Contribution of Aircraft

To determine the relative contribution of aircraft to the LAQ situation, that contribution needs to be put in context with other airport sources. Further, all airport sources may need to be put into the larger context of whatever local area is subject to the emissions standard or requirement. The contribution of an airport source's emissions to the airport's total emissions and its overall impact is dependent on the amount, time, and location of the emissions

Chapter 4 - Designing A Local Emissions Charges Scheme

This chapter addresses the steps that a State (or its delegate) might take in designing a specific emissions charging scheme once the LAQ situation and the aircraft contribution to adverse impacts have been determined. First, to enhance consistency, the guidance recommends use of an aircraft emissions classification scheme incorporating a recognized means of quantifying the amount of emissions emitted by each aircraft during a landing and takeoff (LTO) cycle. Second, the guidance addresses how a cost-basis may be established for a specific charge, that reflects the damage, and/or mitigation/prevention costs to address the environmental impact of the aircraft engine emissions; to the extent that such costs can be properly identified and directly attributed to air transport. Third, this chapter discusses the use of funds from LAQ charges levied on aircraft. Finally, this chapter provides guidance on how the charging level might be set and the ways in which the various charges might be collected.

This chapter covers key points about determining the cost-basis for a charge. As previously noted, if local emissions charges are to be applied to aircraft, those charges should be based directly on the costs of mitigating or preventing the environmental impact of aircraft engine emissions. In determining the cost-basis, States may find it beneficial to consider several guidelines. The costs at issue are the costs that are properly identified and directly attributable to the aircraft contribution to LAQ adverse impacts. These costs can be quantified in terms of damage, mitigation and/or prevention costs. There are different ways in which a State (or its delegate) might levy an aircraft emissions charge. This guidance describes some of the concepts and possibilities; in practice schemes may be a hybrid of these. Such schemes may include a direct charge, a modified landing fee, etc.

Chapter 5 – Administration of Emissions Charges

This chapter deals with the administration of emissions charges, particularly with respect to consultation with relevant stakeholders and States regarding the various facets of instituting emission charges, ranging from consideration for adoption, through implementation tasks, to post implementation activities. Specifically, the guidance recommends the use of open forums to allow stakeholders a chance to actively participate in the emissions charges process. Further, it suggests that ICAO be kept informed of LAQ charges and that those bodies levying such charges should keep records regarding the collection of charges and the use of funds generated. The key benefits of these actions will be to enhance mutual trust through transparency, and encourage cooperation in dealing with LAQ concerns.

Conclusion

While there are differing views as to whether aircraft-related LAQ emissions charges are a cost-effective and appropriate means of addressing aircraft emissions, if a State wishes to adopt and implement such charges, it should do so in a manner consistent with ICAO policy.

Reference

1. This and the remaining sections of this article are based on the work of ICAO/CAEP/7 Emissions Charges Task Force's Working Paper/36 entitled, "The Emissions Charges Task Force: Guidance on Emissions Charges Related to Local Air Quality."

ICAO Policy on Engine Emission Charges and Taxes

By ICAO Secretariat

The use of levies – charges or taxes – to deal with environmental problems is not the preferred option of a number of States, for various reasons. However, mounting pressure from the general public and environmental non-governmental organizations, coupled with recently well publicized reports by experts from the Intergovernmental Panel on Climate Change (IPCC) have drawn the attention of policy-makers to this type of economic instrument. This article explains how ICAO has responded to these concerns when developing policies on environmental charges and taxes.

Background

The issue of imposing levies to address the impact of aircraft engine emissions on the environment was first discussed in ICAO at the Conference on Airport and Route Facility Management (CARFM), held in 1991 in Montreal. The Conference recommended that ICAO should conduct "a study of whether charges could be an effective means of eliminating or reducing the adverse environmental consequences of aircraft engine emissions." In doing so, the following principles were to be taken into account:

- there should be no fiscal targets behind the charges;
- charges should not distort competition with other modes of transport;
- charges should not prevent the efficient use of existing aircraft capacity; and
- charges should be related to costs.

These were the basic principles that guided ICAO's first attempts to draft policy on emissions levies.

The Evolution of a Policy

The subsequent policy-making process included several working groups that produced studies and reports that were discussed at several CAEP meetings during the 4th to 7th CAEP cycles. These triennial CAEP meetings produced reports that were presented to the ICAO Council which in turn informed the relevant Assembly Sessions of the work accomplished by the Organization on environmental levies.

The Assembly then adopted, at each Regular Session, a Statement of continuing ICAO policies and practices related to environmental protection. Appendix I of that document is devoted to market-based measures, which includes environmental levies. The latest Assembly Resolution on this will be revised in September 2007, at the 36th Session of the ICAO Assembly.

Another major event in the ICAO policy-making process related to environmental protection was the adoption in December 1996 of a Resolution on environmental charges and taxes. This interim resolution was primarily aimed at assisting ICAO in its relations with other international bodies involved in environmental matters.

Finally, the Organization's policy that details the principles to apply to aviation charges in general is contained in the document called *ICAO's Policies on Charges for Airports and Air Navigation Services* (Doc 9082). On the subject of environmental protection, this document contains policies dealing with noise-related and local air quality emission-related charges, but it does not consider all facets of emission-related charges. The Organization's policy on emission-related taxes is expressed in the document, *ICAOs'Policies on Taxation in the Field of International Air Transport* (Doc 8632).

There is no specific ICAO policy on environmental charges. However, Document 8632, which expands on Article 24 of the Chicago Convention, prohibits taxation of fuel used for international air transport, a measure which is generally implemented by Contracting States and included in their air services agreements with other States. Moreover, the Council Resolution of December 1996 explicitly recommends that States wishing to introduce environmental levies do so in the form of charges rather than taxes.

ICAO's policies on emissions-related charges are contained in the three documents already mentioned: Assembly Resolutions in force, Council Resolution of December 1996, and Doc 9082. These environmental policies complement ICAO's general policies on charges which have their legal basis in Article 15 of the Chicago Convention. Currently, there is no single document that groups the various policy elements in a structured and comprehensive way.

During preparation leading to the CAEP/7 meeting, it was decided that aircraft engine emissions would be addressed in a different manner, based on the location where they occur. Guidance material was consequently developed to address aircraft engine emissions that affect local air quality (LAQ) at or around airports, and how emission-related charges could be used to deal with those local emissions.

However, with respect to greenhouse gas (GHG) emissions that affect global climate change, it was decided not to develop guidance on the possible use of GHG-related emissions charges. The difficulties associated with tackling the problem at a global level without consensus among the parties concerned were thought to be too great. It was considered more effective to address the global climate change issue by other means which were already generally accepted, such as emissions trading.

Current Emission Policy Features

The main characteristics of ICAO's policies on emissions-related charges, as gathered from the various documents mentioned above can be summarized as follows:

- Charges should be directly **related to costs**. These are the costs of mitigating the environmental impact of aircraft engine emissions to the extent that such costs can be properly identifiable and directly attributed to air transport.

- There should be **no fiscal targets** behind the charges; that is to say that environmental levies should be in the form of charges rather than taxes.

- Charging authorities should ensure **transparency** by making available all financial data required to determine the basis for charges.

- **All funds** collected through emission-related charges should be **used to mitigate the environmental impact**, through addressing the specific damage caused by these emissions, if that can be identified, or by funding emissions-related research.

- The establishment of charges should respect the **non-discrimination** principle among categories of users enunciated in Article 15 of ICAO's Chicago Convention.

- Charges should **minimize competitive distortions** by not penalizing air transport compared with other modes of transport.

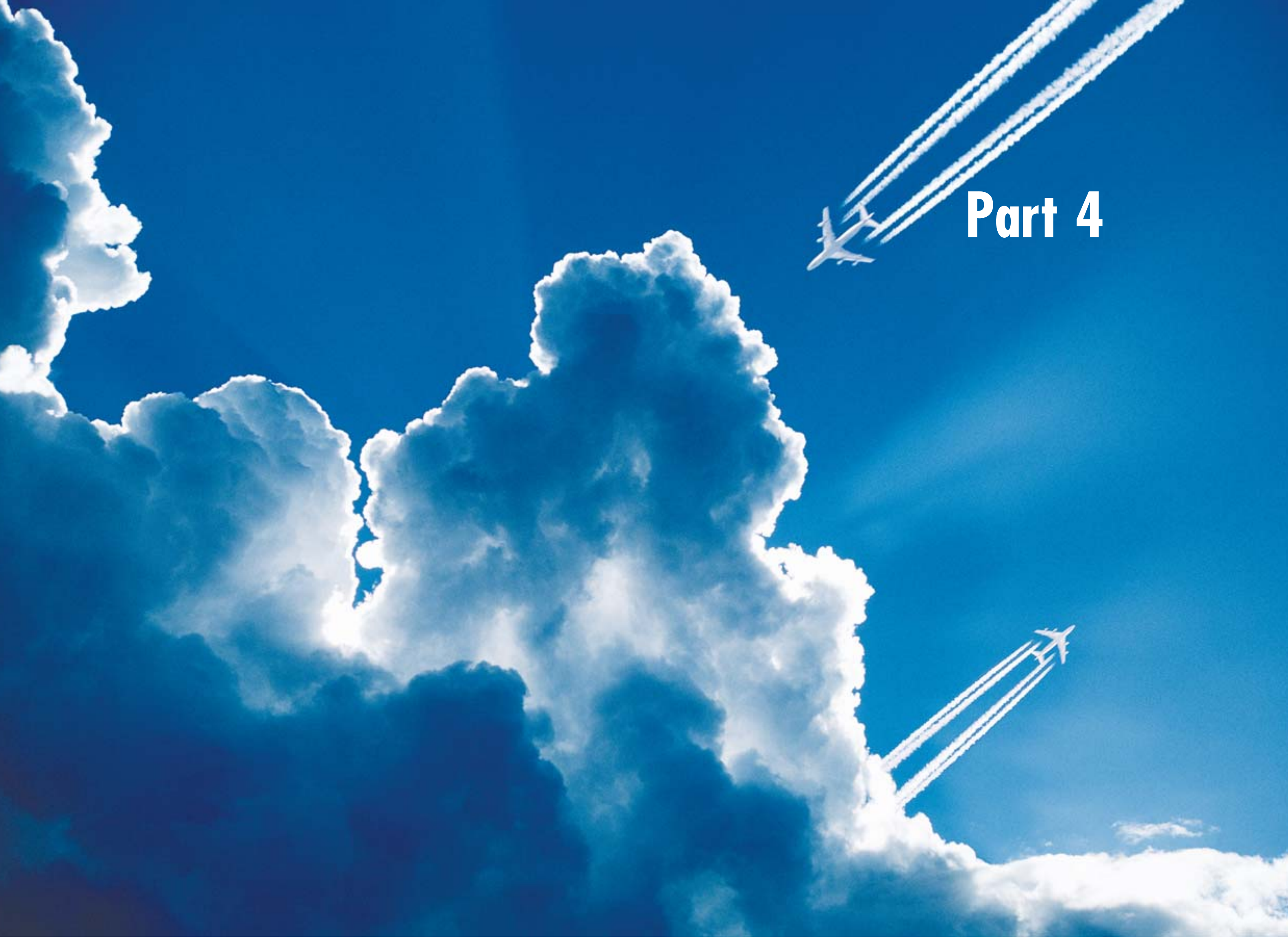
- When charges are established, the **interests of all parties concerned** should be taken into account, notably the potential impacts on the developing world.

- When charges are being considered, States are encouraged to evaluate the costs and benefits of the various proposed measures, including existing measures, with the goal of addressing aircraft engine emissions in the most **cost-effective** manner.

In theory, all of these principles could be applied equally to both local (LAQ) and global (GHG) emission-related charges. For the time being however, the only application is local emission-related charges, for reasons explained in a later article.

Conclusion

The issue of global emission-related charges is likely to resurface some day because of the difficulties encountered in setting up other mechanisms, and/or the fact that other market-based measures may not be sufficient to completely address the problem. Otherwise, taxation is still an option which is being seriously considered by many States which may decide to adopt that approach on a unilateral basis if they are frustrated by lack of consensus at a multinational level.



Global Emissions

Global Emissions Overview

By ICAO Secretariat

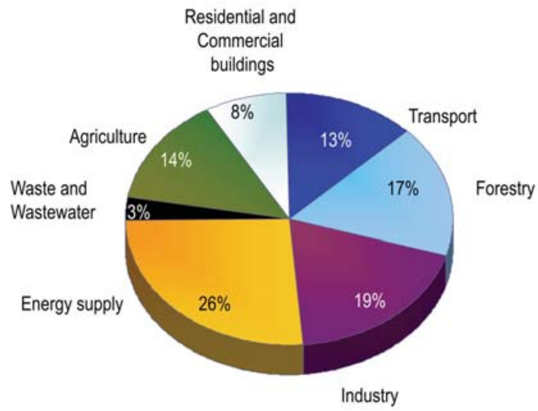
Aircraft engines produce emissions that are similar to other emissions produced by fossil fuel combustion. At present, aviation is a relatively small contributor of greenhouses gases; however, the latest scientific findings of the Intergovernmental Panel on Climate Change (IPCC) indique a clear urgency for action from all sectors.

In keeping with its mandate as the lead organization for international civil aviation, ICAO establishes policies, adopts standards, and develops supporting guidance, that provide an internationally harmonized regulatory process for the implementation of measures to limit or reduce the impact of aviation greenhouse gas emissions on the global climate.

Recognizing the global nature of this issue, ICAO coordinates its environmental activities on global climate with other UN bodies. For example, ICAO reports periodically to the United Nations Framework Convention on Climate Change (UNFCCC) process on its activities to limit or reduce emissions from aviation, and cooperates with the IPCC on improving methodologies used for calculating aviation emissions and on other aviation-related matters (see *International Cooperation* on Part 6 of this report).

One important milestone on the path to improving the knowledge base on aviation emissions was the IPCC 1999 special report on "Aviation and the Global Atmosphere". Following a request from ICAO, IPCC developed for the first time a report addressing a sector-specific impact. This special report assessed the consequences of greenhouses gases from aircraft engines and the potential effects from aviation on both stratospheric ozone depletion and global climate change. In 1999 it was estimated that the contribution made by aviation to the total radiative forcing (a measure of change in climate) from all human activities was about 3.5%, and this percentage which excluded the effects of possible changes in cirrus clouds was expected to grow. A more recent IPCC assessment, the IPCC Fourth Assessment Report (AR4), revised aviation's estimated contribution to about 3%.[1] The report also estimated that aviation was responsible for approximately 2% of the world's carbon dioxide (CO_2) emissions, from which just part is attributed to international traffic.

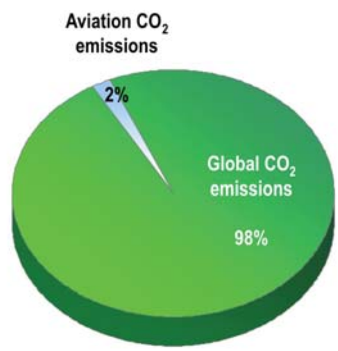
[1] More information on the IPCC AR4 report is available at http://ipcc-wg1.ucar.edu/wg1/wg1-report.html



Global GHG by Sector, 2004 (IPCC)

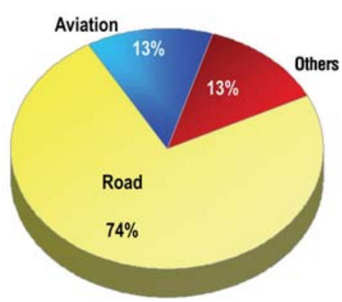
In 2004, the entire global transport sector was responsible for 13% of all greenhouse gases emissions.
Source: IPCC, 4th Assessment Report, 2007, WGIII, Technical Summary.

Aviation Contribution Global CO_2 Emissions



Aviation (Domestic and International) accounts for about 2 % of all global CO2 emissions
Source: IPCC, 4th Assessment Report, 2007, WGIII, Technical Summary

Global CO_2 Emissions per Transport Sector (%)



Total aviation accounts for about 13% of CO_2 emissions from transport sources compared to 74% of total transport CO_2 emissions from road transport.
Source: IPCC Special Report on Aviation and the Global Atmosphere (1999)

The science behind climate change effects from aviation is complex and evolving. This complexity can give rise to inaccurate and misleading interpretation of the dimension of current and future contributions from aviation to climate change.

The Science of Climate Change

As explained in the IPCC Fourth Assessment Report (AR4), greenhouse gases (GHG) trap heat in the Earth's atmosphere, leading to the overall rise of global temperatures, which could disrupt natural climate patterns (Figure 1). During the last century, the average global temperature rose by 0.74°C and current projections show that it will continue to rise in the future. During this century the Earth could warm by 3°C. Scientists are now certain that human activities that emit greenhouse gases have contributed to that change.

According to IPCC, climate change is already having significant impacts in certain regions and on most ecosystems, particularly in developing countries. Economic assessment of climate change indicates that the cost of inaction will most probably exceed the cost of taking early action.

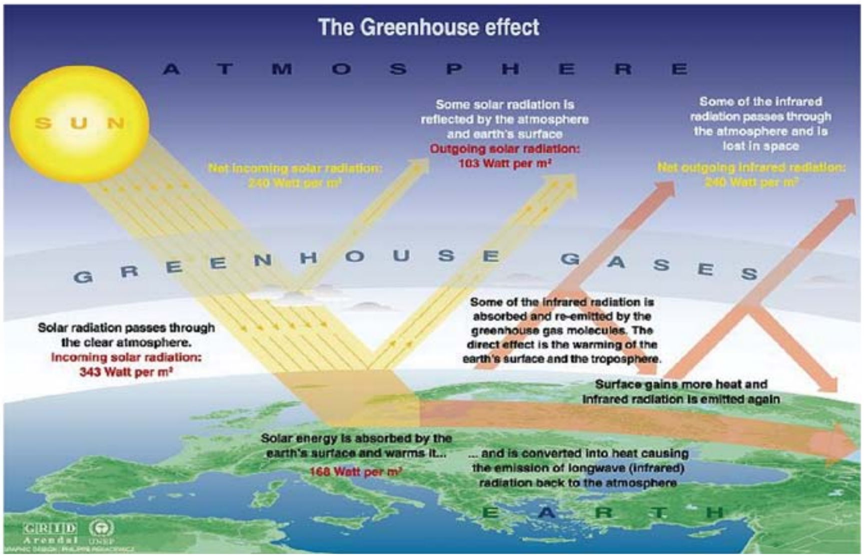


Figure 1 - The greenhouse effect on the atmosphere.

Sources: Okanagan university college in Canada, Department of geography, University of Oxford, school of geography; United States Environmental Protection Agency (EPA) Washington; Climate change 1996, The science of climate change, contribution to working group 1 to the second assessment report of the Intergovernmental panel on climate change; UNEP and WMO, Cambridge University press, 1996.

Climate Change
Climate change refers to any change in climate over time, whether due to natural variability or as a result of human activity (IPCC).

As pointed out in the report , there is major potential for mitigation, including increasing the use of clean technologies and improving end-use efficiency and there is important economic potential for all sectors that get involved in the mitigation over the coming decades. This potential is estimated to be sufficient to offset the projected growth of global emissions, or even to reduce emissions below current levels. The ultimate objective of the United Nations Framework Convention on Climate Change (UNFCCC) is to achieve stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous human interference with the global climate system.

Aviation Contribution To Climate Change

Aircraft emit gases and particles directly into the upper troposphere and lower stratospheres where they have an impact on atmospheric composition. The climate impacts of these gases and particles emitted and formed, are difficult to quantify. Global climate change is caused by the accumulation of greenhouse gases (GHG) in the lower atmosphere. The aviation greenhouse gas of most concern is CO_2. ICAO/CAEP's initial estimate is that the total amount of aviation CO_2 emissions in 2005 is about of 600 million tonnes (see article *Environmental Goals Assessment*, Part 5 of this report).

CO_2 has the same effect on the environment, no matter what the source, or from where in the atmosphere it is emitted. However, aircraft, like cars, trucks, ships and trains, emit other gases that may also affect the climate, and some may have a greater effect at altitude than at ground level.

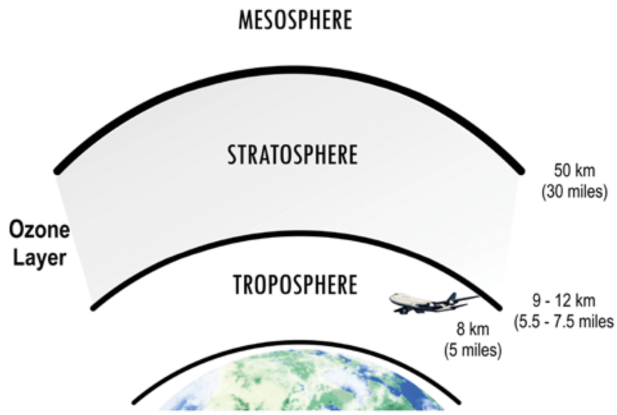


Figure 2 – Layers of the Earth's atmosphere.
Source: ICAO.

As shown in Figure 2, aircraft typically operate at cruising altitudes of 8 to 13 km, where they release several gases and particles which may alter the composition of the atmosphere.

The most comprehensive assessment to-date concerning aviation's impact on the upper atmosphere is contained in the *Special Report on Aviation and the Global Atmosphere* (1999).The emissions considered in that report were: carbon dioxide, water vapour, carbon monoxide, hydrocarbons, particles, oxides of nitrogen, and sulphur compounds. The base year for the study was 1992 and it contained forecasts for 2015 and projected scenarios for 2050.

Main Gases and Particles Emitted From Aircraft

Carbon dioxide (CO_2) is the most important greenhouse gas because of the large quantities released and its long residence time in the atmosphere. Increasing concentrations have a well-known direct effect which warms the earth's surface.

Nitrogen Oxides (NO_x) have two indirect effects on the climate. Nitrogen oxides produce ozone under the influence of sunlight, but they also reduce the atmospheric concentration of methane (these reduction of methane tend to cool the surface of the Earth). Both ozone and methane are strong greenhouses gases. They have opposite effects but the net result is that the ozone dominates the methane effect, thus warming the Earth.

Water vapour released by aircraft has a direct greenhouse gas effect, but because it is quickly removed by precipitation, the effect is small. However, water vapour emitted at high altitude often triggers the formation of condensation trails, or "contrails", (i.e. white-line clouds often visible behind aircraft). These contrails can have a warming effect on the Earth's surface. Moreover, contrails may develop into cirrus clouds (i.e. thin, wispy high clouds), which also tend to warm the Earth's surface.

Sulphate and soot particles have a smaller direct effect compared with other aircraft emissions. Soot (Carbon-containing particles produced as a result of incomplete combustion processes) absorbs heat and has a warming effect. Sulphate particles reflect radiation and tend to deplete ozone, having a small net cooling effect. In addition, they can influence the formation and properties of clouds.

Based on : IPCC 1999 Special Report on Aviation and the Global Atmosphere, and European Union.

The IPCC AR4 revision of 2007 includes an update of the main findings of the special report as well as new findings related to aviation emissions. In addition, a range of technological options were examined by IPCC showing possible progress through substantive reductions in fuel usage that could arise from the introduction of more radical technologies.

That report also includes a revision on contrails and contrails-cirrus effects. The estimated of radiative forcing by contrails was reduced but that of aviation cirrus potentially increased, although significant uncertainties remain.

Limiting or Reducing Aircraft Global Emissions

Overall fuel efficiency of civil aviation can be improved through a variety of means such as: increased aircraft efficiency through technology, improved operations, and efficient air traffic management. In 2001, the ICAO Assembly requested the Council to continue studying policy options to limit or reduce the environmental impact of aircraft engine emissions and to develop concrete proposals. It called for special emphasis to be placed on the use of technical solutions, while continuing consideration of market-based measures, and taking into account potential implications for developing, as well as developed countries. ICAO's work on each of these elements is described below.

Technology

Conscious of technology developments and the environmental needs, ICAO continuously reviews its environmental standards, promoting more efficient, and cleaner aircraft. ICAO has produced standards for NO_x emissions that have helped minimize the effects on climate (see Part 3 of this report). Throughout the years, technology improvements have been made to engines to make them more fuel efficient. Also, in the 1990s, the engine manufacturer CFM International pioneered the development of an ultra-low NO_x combustor for aircraft, reducing NO_x emissions by up to 40%. There are multiple paths that can lead to additional reduced emissions, which are either in development, under exploration, or at the concept stage. Another example is the Rolls-Royce's Trent 1000 engine, designed and built for the Boeing B787 Dreamliner. That engine is designed for 15% lower fuel burn than comparable engines of a decade ago, and will deliver 40% lower emissions than required by current international legislation.

The aircraft delivered today are substantially more fuel efficient than the ones delivered early in the 1980's as shown in Figure 3.

Passenger jet aircraft produced today are 70% more fuel efficient than the equivalent aircraft produced 40 years ago, and continued improvement is expected.

Fuel Efficiency Rules of Thumb:

- On average, an aircraft will burn about 0.03kg of fuel for each kilogramme carried per hour. This number will be slightly higher for shorter flights and for older aircraft, and slightly lower for longer flights and newer aircraft.
- Reducing the weight of an aircraft, for example by replacing metal components with composites, could reduce fuel burn by as much as 5%.
- Average fuel burn per minute of flight : 49 kg.
- Average fuel burn per nautical mile of flight : 11 kg.

Later in this Part of the report, technological improvements to reduce emissions are explored under six areas: propulsion systems, materials, structure, design and methods, manufacturing processes aircraft system, and operational procedures (see article *Reducing Aviation Global Climate Emission: The Role of Manufacturers and Technology*)

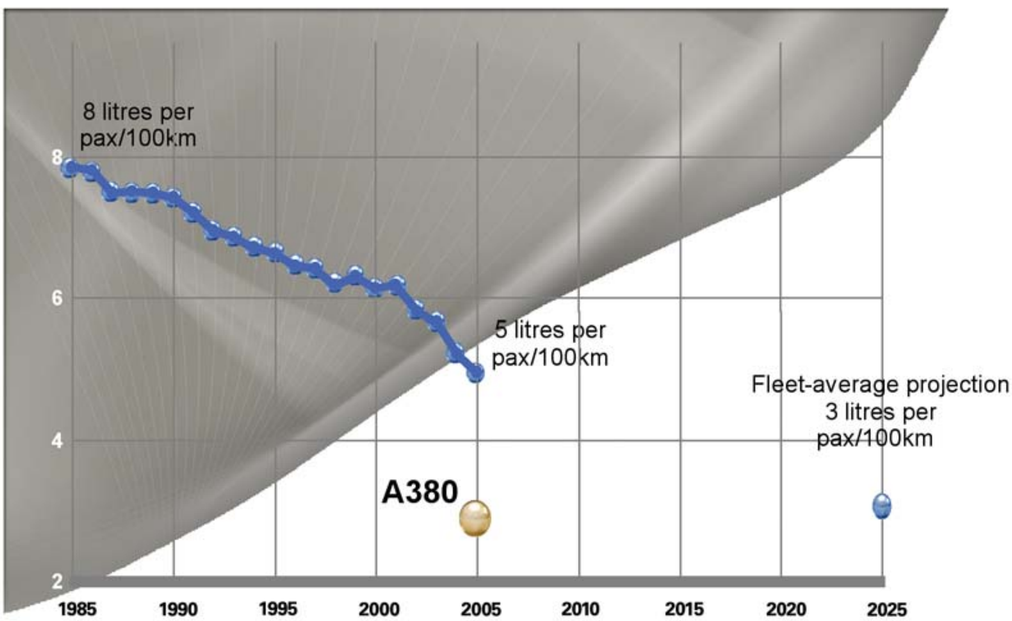


Figure 3 – Worldwide passenger air traffic fuel consumption (litres per passengers (pax) per 100 km). The new Airbus A380 has the lowest fuel consumption per passenger of any large commercial airliner yet built.
Source : Airbus

In 2001, ICAO/CAEP discussed the question of whether developing an ICAO Standard to limit aviation CO_2 emissions would be appropriate, or particularly relevant. After considering the different technical alternatives the group concluded that "the definition of a representative point or mission on which to base a CO_2 certification scheme would be very difficult in view of the great diversity of aircraft operations. There is also the danger that point certification would drive manufacturers to meet compliance at the reference point at the expense of overall CO_2 reduction"[2]. For the foregoing reasons CAEP members did not consider it desirable to pursue the possibility of developing a CO_2 emissions standard.

In addition, the group noted that the market pressure already ensured that aircraft would become more fuel efficient. Since CO_2 production was directly related to fuel consumption, these economic pressures were also serving to minimize CO_2 emissions. ICAO continues to explore the possibility of establishing a CO_2 parameter and is currently working on the definition of medium-term (10 years) and long-term (20 years) goals for fuel burn.

Operational Measures

ICAO encourages the development of operational measures and the improvement of air traffic management (ATM) to reduce aviation emissions. The United States and Europe have started a transition towards the next generation of ATM Systems.

The most important fuel saving opportunities come from ATM systems that permit more direct routings and the use of more efficient conditions such as optimum altitude and speed. Shortening routes can indeed significantly reduce CO_2 emissions.

Impact of ATM Improvements

- Improvements in ATM operational procedures could reduce aviation fuel burn by between 6 and 18%.
- A further 2-6% could come from improvements in other operational measures.

Source: 1999 IPCC Special Report.

ICAO guidance on achieving fuel efficiency through operational measures is provided in the *Circular 303 - Operational Opportunities to Minimize Fuel Use and Reduce Emissions*. That document identifies and reviews various operational opportunities and techniques for minimizing fuel consumption, and therefore emissions, in civil aviation operations. Operations covered in the guidance are: aircraft ground-level and in-flight operations, ground service equipment (GSE), and auxiliary power units (APUs), with potential actions to facilitate their broader application.

ICAO supported the development of Reduced Vertical Separation Minimum (RVSM) which was first implemented in 1997. RVSM will soon cover all airspace around the world. RVSM has led to significant environmental benefits. For example, studies in the European region[3] showed that it results in a reduction of NO_x emissions, sulphur oxide emissions, and the reduction of total fuel burn (average of 80 kg fuel saving per flight).

Market-Based Measures

Market-based measures are policy tools that are designed to achieve environmental goals at a lower cost and in a more flexible manner than traditional command and control regulatory measures. In 2001, the ICAO Assembly requested the Council to continue to develop guidance for States on the application of market-based measures aimed at mitigating the impact of aviation on climate change. Three market-based measures have been under consideration: emissions trading, voluntary measures, and emissions-related charges.

Emissions trading

Emissions trading schemes can be a cost effective measure to reduce CO_2 emissions. One approach sets an overall limit on emissions, then allows companies to buy and sell emission "allowances" to meet their reduction targets. One of the highlights of the ICAO/CAEP meeting in February 2007 was the development of guidance material for including international aviation emissions into the emissions trading schemes of States, consistent with the United Nations Framework Convention on the Climate Change process.

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2 Report of the Committee on Aviation Environmental Protection, Fifth Meeting, Montréal, 8– 17 January 2001, (Doc 9777, CAEP/5).

3 EUROCONTROL January 2002.

The draft guidance document (ICAO Doc 9885) identifies a range of emission trading issues and is based on contributions from a wide range of aviation, climate change, and emissions trading experts from around the world. This draft guidance focuses on aviation-specific issues, identifies options and offers potential solutions. It addresses the various elements of a trading system, such as:

- ✔ Accountable entities;
- ✔ Emissions sources species (gases) to be covered;
- ✔ Trading units;
- ✔ Base-year and targets;
- ✔ Allowance distribution;
- ✔ Monitoring and reporting; and
- ✔ Geographic scope.

On the subject of geographic scope, the draft guidance recommends that States take into account an ICAO Council request that ICAO/CAEP include the different options regarding the geographical scope describing their advantages and disadvantages and start to address the integration of foreign aircraft operators under a mutually agreed basis, and continue to analyze further options. The draft guidance includes an introduction addressing the views of the ICAO Council on this subject.

In addition to the draft guidance, ICAO/CAEP prepared a "Report on Voluntary Emissions Trading for Aviation" describing the general nature and practical experiences of various types of voluntary emissions trading schemes. This information has been available, since April 2007, on the ICAO website[4] (see article *Voluntary Emissions Trading For Aviation* later in this Part of the report).

Voluntary measures

In 2004, ICAO/CAEP made a template for voluntary agreements between the aviation sector and public sector organizations available on the ICAO website. Further, ICAO has collected information on voluntary activities, and made it available as feedback to States and the aviation community in general, with the aim of widely disseminating information on such activities. It was expected that collecting and providing information on the experience of their organizations with the various voluntary activities would encourage the implementation of such measures.

Carbon Offsets

Carbon offsetting involves calculating the emissions created by one activity (e.g. aviation) and then compensating for the emissions produced with an equivalent amount of carbon dioxide (CO_2) savings from emission-reduction projects. These projects will have prevented or removed an equivalent amount of carbon dioxide elsewhere, and in that way "offset" the emissions activity.

Examples of typical carbon-offset projects to compensate for the CO_2 emissions are:

- Forestation projects.

- Land-use improvement options such as: agroforestry, reforestation, soil conservation.

- Reducing energy-related emissions in non-company facilities, through, for example, energy efficiency, green-power purchases, or fuel-switching (e.g. replacing oil-fired burners with natural gas ones).

Carbon-offsetting is not a substitute for reducing emissions at source. Nevertheless, it is a possible short-term solution for mitigating emissions from activities on an individual or corporate basis. Many companies exist that will sell carbon-offsets to individuals or organizations interested in paying voluntary compensation to reduce the carbon footprint made by their activities, including air travel. The practicality and the simplicity of this approach (most of these initiatives are available on the Internet) has made it an attractive voluntary option to be considered by the public. However the transparency, costing practices, and reliability of this schemes remain to be improved.

Existing methodologies differ in their assessment of the emissions produced by a passenger for one trip. The correct estimation of emissions from travel is key to identify the amount of CO_2 to be offset. With a view to provide appropriate information on emissions from aviation ICAO is currently developing a methodology and a guidance for the calculation of air travel CO_2 . When completed, these will be made available to the public on the ICAO website.

[4] http://www.icao.int/icao/en/env/vets_report.pdf

Alternative Fuels

Currently, most civil aviation aircraft around the world use kerosene derived from on crude oil. This fuel provides a good balance of properties required for an aviation fuel, such as energy density, operational issues, cost and safety. Given these characteristics, aircraft operations and their supply infrastructures on the ground are fully adapted to its use.

However, concerns over rising fuel costs, energy supply security, and the environment, have led to the need to investigate the development of alternative fuels. A viable alternative aviation fuel could offer important benefits such as stabilizing world fuel price fluctuations and reducing the uncertainty and vulnerability that comes from too much reliance on crude oil as the one main fuel source. In addition, alternative fuels could increase the environmental performance of air transport, allowing it to substantially reduce CO_2 emissions.

Aircraft and engine manufacturers are currently investigating synthetic jet fuels (e.g. from coal, natural gas, or other hydrocarbon feedstock) as well as bio-fuels. The type of fuel that is of immediate interest to aviation is termed a "drop-in" fuel, (i.e. a direct substitute fuel) that can be used without substantial modification to engine or aircraft (see articles on *Alternative Fuels* later in this Part of the report).

Evolution of Alternative Fuels

- ***Present and short-term*** - synthetic jet fuel processed using the Fischer-Tropsch process.

- ***Medium-term*** – possible use of bio-fuels with necessary changes in the engine configuration.

- ***Longer-term*** - cryogenic hydrogen and liquid methane are being considered, but a number of technological challenges have to be solved prior to their use.

Further steps on Global Emissions

Among the main issues considered by ICAO/CAEP during the last CAEP meeting in February 2007, were the assessment of the evolution of emissions over the years and future trends; and items related to market-based measures to reduce emissions, such as aviation emissions trading.

Much effort is being channelled to the modelling activities and to the better understanding of the interdependencies of actions to reduce aviation emissions. All the work done by ICAO/CAEP and the information accrued from the scientific advances in the understanding of aviation impacts on the environment will be brought to the attention of the next ICAO Assembly.

Characterization of Aviation Emissions Climate Change - Impact Assessments

Effect of Aviation Emissions on the Global Atmosphere

By ICAO Secretariat

At ICAO's request, the Intergovernmental Panel on Climate Change (IPCC) prepared a Special Report on Aviation and the Global Atmosphere, in 1999. The request was made in order to establish the global impact of aviation on the earth's atmosphere, based on the best information and forecasts available at the time. The objective was to place ICAO's work to-date on engine emissions, in a proper global perspective. The findings of that seminal report are summarized in the following article.

IPCC Special Report on Aviation (1999)

Background

IPCC had been requested by ICAO to prepare the report to assist it in its policy and decision-making in matters relating to aviation and the global environment. It was intended to be a review and summary of the best available international understanding of atmospheric science, aviation technology, and operating practices in effect at that time. It was also to include forecasts of the future situation and potential climate mitigation options, but to remain neutral concerning future policies on the matter.

The emissions it considered were: carbon dioxide, water vapour, carbon monoxide, hydrocarbons, particles, oxides of nitrogen, and sulphur compounds. The base year for the study was 1992 and it contained forecasts for 2015 and scenarios for 2050. The Report dealt with aviation's effects on the climate and on ultraviolet radiation, and considered mitigation options related to technology, and fuel and operations, in terms of regulation and market-based activities. It considered only global impacts and did not look into local air quality issues.

The commonly used measure of the climatic effect of an action is its radiative forcing. Radiative forcing is defined as the change in the energy balance of the earth-atmosphere system — measured in watts/square metre. The Report studied the effect of each of the aviation emissions mentioned above on the radiative forcing for 1992 and for future forecasts/scenarios, as shown in Figure 1.

Summary of Findings

The study concluded that, overall, aviation increased radiative forcing in 1992 by about 0.05 watts/sq.m., with about 40% of this total being due to carbon dioxide.

Oxides of nitrogen lead to the formation of ozone and the reduction of methane in the upper atmosphere, both of which in turn affect radiative forcing. The warming effect of the ozone is in fact greater than that of carbon dioxide, but this is partially offset by the cooling effect of the methane. The effect of water vapour, in the form of contrails, is very similar in magnitude to that of the carbon dioxide.

Estimates projected for 2050 were relatively similar for each constituent, but the total radiative forcing is considerably greater. For all the species of emissions there is a considerable degree of uncertainty in the results. The results illustrate that, although in general carbon dioxide is considered to be the primary global cause of increased radiative forcing, in the case of aviation, other species are equally important. The future estimates indicate a steady increase in the aviation-induced radiative forcing out to 2015, followed by possibly much more dramatic increases thereafter, depending on the aviation activity growth scenario chosen.

The IPCC Report estimates that there will be a small reduction in ultraviolet light reaching the earth's surface as a result of the expected increase in subsonic aircraft operations. However, if a significant fleet of supersonic aircraft were to be introduced, the combined effect could be a slight increase in the uv radiation at the earth's surface.

The Report notes that there had been significant advances in aircraft and engine technology which had reduced emissions on a passenger mile

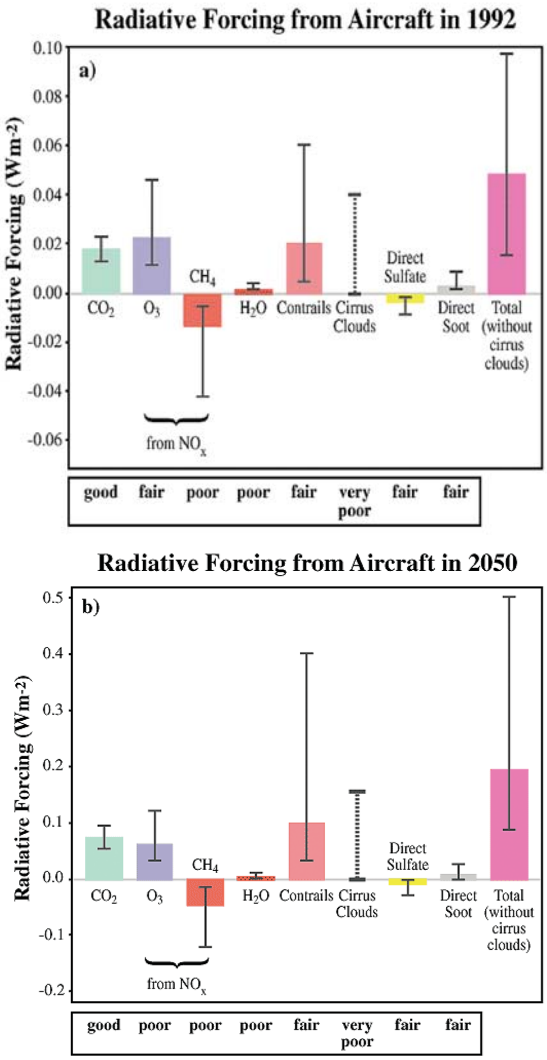


Figure 1 – Radiative forcing from aircraft activity in 1992 and in 2050.

basis, and that further improvements could be expected. However, it also notes that improvements in oxides of nitrogen emissions in particular require significant advances in combustor technology. The need for careful balancing of technological advances is stressed in view of the danger of developments which might reduce the production of one emission at the cost of increasing another.

There did not appear to be any likelihood of an alternative fuel becoming available in the near future. Hydrogen, which would increase water vapour production but not produce any carbon dioxide, was recognized as a long-term possibility, but its use would involve significant design changes to airframes as well as engines.

Improvements in air traffic management and other operational procedures could reduce fuel consumption by between 8 and 18%, with a 6 to 12% reduction coming from improved traffic management. However, it should be noted that progress in improving air traffic management has in practice been much slower than had been anticipated at the time the report was prepared. There was also the danger that, from an environmental viewpoint, significantly improved traffic flows might attract increased traffic and thus cancel out any environmental gains.

The Report recognized that technological and operational improvements alone would be unable to prevent an increase in aviation emissions in light of the expected increase in traffic over the coming years. It was clear that other non-technical measures would also be necessary. Such measures might include the removal of subsidies and other incentives fostering aviation growth, market-based options, voluntary agreements to limit growth, and encouragement of travel on alternative modes of transport. It was acknowledged that most of these options would probably lead to increased fares and rates.

Conclusion

In summary, the IPCC Report noted that there remained many uncertainties of a scientific, technical and socio-economic nature which could influence future developments. Nevertheless, the Report was the most comprehensive study of aviation's effect on the environment conducted to-date. It had drawn together the relevant atmospheric scientists and aviation experts and was the first time that the IPCC had studied a particular mode of transport. As a result of the study, it has been possible to focus subsequent research on specific areas of high uncertainty.

The last formal appraisal of aviation's contribution to climate change was made by IPCC in 1999, using a base year of 1992. Our knowledge of atmospheric science has improved since then. Aircraft fleets have changed, and consequently, so have emissions inventories. Meanwhile ICAO, through its CAEP, has continued to examine the future effects of aviation on the environment and also to update aircraft emissions databases.

References

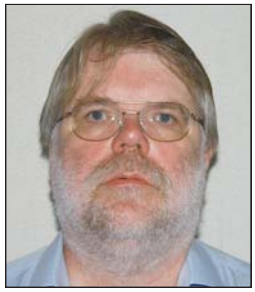
This article is based largely on the work developed for the ICAO/CAEP, by its CAEP/Working Group 3.

All charts and graphs were taken from the presentation of Dr. D. Lister, Emissions Specialist with the UK Civil Aviation Authority, in the ICAO Environmental Colloquium on Aviation held in Montreal in May 2007.

IPCC special reports "Aviation and the Global Atmosphere" 1999 www.ipcc.ch/pub/online.htm

IPCC Guidelines for Estimating National Greenhouse Gas Inventories

By Simon Eggleston



For the past 3 years, Dr. Simon Eggleston has been Head of the Technical Support Unit of the IPCC's National Greenhouse Gas Inventories Programme, based in Japan, where he managed the production of the IPCC 2006 Guidelines for National Greenhouse Gas Inventories. Earlier, Simon developed and managed the UK's National Atmospheric Emission Inventory (NAEI) for 15 years covering emissions of local and regional air pollutants as well as greenhouse gases. Simon has contributed to the development of emission inventories in Europe and China, especially regarding methods for energy use and road transport and ways to estimate uncertainties.

In order to develop cost-effective strategies and policies to mitigate climate change it is important to have a clear understanding of the current emissions and removals of greenhouse gases (GHG), including their sources and means of removal. Complete estimates of emissions and removals, called emission inventories, are thus an essential part of any response to climate change. It is very difficult to undertake successful international negotiations without a clear understanding of the sources and removals of the greenhouse gases. Inventories also provide a reliable way to monitor progress on addressing climate change; they are important in informing the public; and they are a key input to scientific studies of the issues. National GHG inventories provide the link between human activities and the greenhouse gases that impact on the environment.

It is important to gain a common understanding so that the national GHG inventories compiled in different countries and/or for different years are comparable and consistent. This facilitates a universal understanding of emissions and removals. This common knowledge and approach is enhanced by making inventories transparent and well-documented which in-turn increases the credibility of the inventory results. All of this needs clear guidelines to be agreed by all parties, which provide not just methods but also guidance on inventory quality, often called "good practice guidance".

Background

Parties to the UN Framework Convention on Climate Change (UNFCCC) have agreed (amongst other things) to "*Develop, periodically update, publish and make available … national inventories of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol, using comparable methodologies to be agreed upon by the Conference of the Parties;*" (Article 4, Para 1(a)). The "comparable methodologies" agreed on are those produced by the Intergovernmental Panel on Climate Change (IPCC).

The *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories[1]*, together with the two volumes on inventory good practice, *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories[2]* and *Good Practice Guidance for Land Use, Land-Use Change and Forestry[3]* have to be used by so-called ICAO "Annex I" parties (i.e. developed countries). All other parties to the convention should use the Revised 1996 Guidelines, but the use of the Good Practice Guidance is encouraged.

The 2006 IPCC Guidelines for National Greenhouse Gas Inventories[4] (2006 Guidelines) represent a significant step forward in producing reliable, accurate, consistent and comparable inventories of emissions and removals of greenhouse gases. These new guidelines were produced at the invitation of the UNFCCC in 2001 to update the Revised 1996 Guidelines and associated good practice guidance by 2006. The IPCC's Task Force on Inventories undertook this task and the IPCC Panel XXV, (Port Louis, Mauritius, April 2006) accepted and adopted the 2006 Guidelines. The UNFCC is currently considering the 2006 Guidelines. However, the 2006 Guidelines contain many improved default parameters and methods that can be used in the context of the current UNFCCC reporting guidelines.

The 2006 Guidelines update earlier guidance by combining experience using earlier guidelines with new scientific and technical information. They are the work of over 250 authors nominated by governments and international organisations (ICAO and FAO provided authors for relevant sections). The final list of authors was selected to ensure as wide a geographic representation as possible, as well as to ensure sufficient coverage of all potential sources and sinks. Sectoral meetings were held enabling authors to discuss and agree on common approaches, followed by drafting and email exchanges to produce the completed guidelines. Following drafting, the complete document was peer reviewed twice, first by experts alone and the second time by experts and governments. After each review, a meeting of experts considered the comments and edited the text, when necessary. In total, more than 6000 comments were received. Following a period of government[1] consideration the final draft was approved and adopted by the IPCC in April 2006.

[1] The Governments are all members of the IPCC- membership is open to all member countries of the UNEP and the WMO (virtually all countries in the world).

ICAO assisted the IPCC through the provision of expert authors and access to data and model outputs in the production of the chapter on aviation. This long-standing co-operation between ICAO and the IPCC is valued as it ensures that the final results are the best possible.

Emission Inventories are complete estimates of all emissions (and removals) of specified gases from a specified region in a specified time-frame. Under the UNFCCC we are concerned with anthropogenic, national, annual, emissions and removals of greenhouse gases not covered by the Montréal Protocol. Determining "anthropogenic" emissions (i.e. caused by humans) is possible for emissions from energy use; however it is sometimes impossible to disentangle natural and anthropogenic components of some land-use emissions. For example, emissions from wild fire may be initially caused naturally (e.g. by lightning), but then be influenced by local management practices (e.g. fire suppression activity and harvesting regimes). Conversely, determining "national" emissions is usually straightforward for land-use emissions, but causes problems for emissions from fuel combustion in transport such as aircraft and shipping, since these emissions often occur in international airspace or waters. Thus, inventory guidance often involves preset pragmatic solutions that can be universally applied and understood.

The gases covered by the guidelines are shown in Table 1. The Revised 1996 Guidelines only gave guidance on six gases (or groups of gases) as shown. The Kyoto Protocol covers these six gases. These gases are those that have Global Warming Potentials (GWP) in the IPCC's Second Assessment Report[5]. GWP is a comparative measure of the warming impact of a unit mass of each gas with the GWP of CO_2 = 1[2]. Thus, the mass emissions of each gas can be multiplied by their respective GWP to compare their impact. Emissions converted by the GWP are referred to as "CO_2 equivalent" and can then be added to give an overall measure of the impact of the emissions of all the gases. For example, the GWP of CO_2, CH_4, N_2O, and SF6 are 1, 21, 310 and 23,900 respectively[3].

Table 1 – List of Greenhouse Gases Covered by 2006 Guidelines.

Name of Gas	Symbol	Revised 1996 Guidelines	Gases with GWP in the TAR
Carbon Dioxide	CO_2	✔	✔
Methane	CH_4	✔	✔
Nitrous Oxide	N_2O	✔	✔
Hydrofluorocarbons	HFCs (e.g.,HFC-23 (CHF_3), HFC-134a (CH_2FCF_3), HFC-152a (CH_3CHF_2))	✔	✔
Perfluorocarbons	PFCs (CF_4, C_2F_6, C_3F_8, C_4F_{10}, c-C_4F_8, C_5F_{12}, C_6F_{14})	✔	✔
Sulphur Hexafluoride	SF_6	✔	✔
Nitrogen Trifluoride	NF_3		✔
Trifluoromethyl Sulphur Pentafluoride	SF_5CF_3		✔
Halogenated Ethers	e.g., $C_4F_9OC_2H_5$, $CHF_2OCF_2OC_2F_4OCHF_2$, $CHF_2OCF_2OCHF_2$		✔
Other halocarbons	e.g. CF_3I, CH_2Br_2, $CHCl_3$, CH_3Cl, CH_2Cl_2		✔
Other Fluorinated Gases without GWP available	$C_3F_7C(O)C_2F_5$, C_7F_{16}, C_4F_6, C_5F_8, c-C_4F_8O		

[2] More precisely: An index, based upon radiative properties of well-mixed greenhouse gases, measuring the radiative forcing of a unit mass of a given well-mixed greenhouse gas in today's atmosphere integrated over a chosen time horizon, relative to that of carbon dioxide. The GWP represents the combined effect of the differing times these gases remain in the atmosphere and their relative effectiveness in absorbing outgoing infrared radiation. The Kyoto Protocol is based on GWPs from pulse emissions over a 100 year time-frame, using the values given in the IPCC's Second Assessment Report (1995).

[3] These are the values used for reporting to the UNFCCC and come from the IPCC Second Assessment Report with a 100 year time horizon. Use of a different time horizon gives different values and more recent calculations have changed these values. See the IPCC Third and Forth Assessment Reports [6, 7] (2001 and 2007).

The IPCC's Third Assessment Report[6] (TAR) extended the list of gases that have GWP calculated to ten, and the 2006 Guidelines extend the coverage to these gases as well. In addition, methods are given for a few gases that may be used as substitutes for gases already included in the guidelines but which did not have a GWP available in the TAR.

Estimating Emissions

Not all emissions can be measured. While large factories can be fitted with automatic monitoring equipment (and often are), this is not practical for the large number of smaller sources that produce many of the emissions, such as motor vehicles, small domestic water heaters, etc. So to cover most emission sources, estimation methods are required that enable the emissions (or their removal) to be calculated. This is often done by making estimates based on parameters directly associated with the emissions, such as "activity data". Fuel consumption is often used. This "activity data" then has to be multiplied by an "emission factor" to give an emission estimate. Carbon content of the fuel is often used as the basis of an emission factor as it is directly related to the emission of CO_2 (except for a very small amount that is incompletely oxidised and is either emitted as CO, CH_4 or a hydrocarbon, or remains as particulate carbon that can be emitted as an aerosol or retained as ash).

Methane (CH_4) emissions are often proportional to fuel use as well, but here the emission rate is dependent on a range of factors such as technology, combustion rate (load), and maintenance variables. CO_2 emissions from forests are estimated from the changes in the various stocks of carbon in the forests taking account of re-growth and harvesting and other removals from the forests. A further complication for some sources is that the emissions may continue for many years after the activity that causes the emissions. For example, CH_4 from waste disposal landfills can occur over decades after the waste is deposited, so a first-order decay model is used to simulate this. PFC and HFC gases emitted from foams and refrigeration are other sources where leakage can occur over many years.

Clearly some of these estimation methods can become complex and require considerable data and resources to complete. In order to focus resources on those sources that are significant in an individual country, inventory compilers are instructed to undertake a "key category" analysis of their inventory. This Key Category analysis identifies significant sources in each country in a systematic way across all emitting parties. A simple first-pass is to identify those major sources that cumulatively account for 95% or more of total emissions. In a second-pass, additional sources that make a significant contribution to the emissions trends can be included, as well as estimates to cover uncertainty in more complex situations.

Methods of differentiating levels of complexity and resource requirements, called "Tiers", are given in the guidelines:

Tier 1: These are simple methods with defaults provided in the guidelines for all the required parameters. These methods are suitable for minor sources in all countries. Typically all that is needed is for some basic "activity data" (e.g. fuel use) to be provided by the inventory compiler.

Tier 2: These are generally similar to Tier 1 but require country-specific data for the parameters instead of the defaults in Tier 1. They are generally suitable for significant sources (i.e. "key categories") or where abatement needs to be treated.

Tier 3: More complex, resource-intensive methods, often computer-based simulation models, can be used if a country wishes. The guidelines only sketch out what may be included in the methods but the results must be compatible with Tiers 1 and 2 in their coverage completeness.

These 2006 Guidelines are the most up-to-date guidance available for inventory compilers. They are the latest in a series of publications started in 1994 and supersede all earlier guidance. The 2006 Guidelines provide users with a number of key advantages compared to earlier guidance: they should improve accuracy and reduce the scope for errors, they are more complete, they integrate good practices that make the guidelines clearer, and they allow for differing levels of resources and expertise.

Aviation Emissions

Emissions from global aviation activity currently contribute about 2% of both total anthropogenic emissions of greenhouse gases and global anthropogenic CO_2 emissions[4]. However, this is forecast to rise, both in terms of absolute emissions and as a percentage of the total. Meanwhile, many countries are planning for significant reductions in other emissions. Demand for aviation is increasing faster than anticipated improvements in fuel efficiency, hence increasing emissions, while, in other sectors, much larger emission reductions are possible through a wide range of measures such as energy efficiency, alternative fuels, carbon capture and storage and demand management.

Emissions from aviation come from the combustion of jet fuel and aviation gasoline; the latter which generally accounts for less than 1 percent of fuel used in aviation. The exhaust gas is roughly about 70 percent CO_2, a little less than 30 percent H_2O, and less than 1 percent each of NO_x, CO, SO_x, NMVOC, particulates, and other trace components including hazardous air pollutants. Little or no N_2O emissions come from modern gas turbines. Methane may be emitted by gas turbines during idle and by older technology engines, but recent data suggest that little or no CH_4 is emitted by modern engines (see [8]). Currently neither the UNFCCC guidance nor the IPCC guidelines requires reporting of NO_x[5] or H_2O both of which can have a warming impact if emitted at altitude.

Total emissions of CO_2 depend solely on the amount of carbon in the fuel (the fraction not oxidised to CO_2 is negligible compared to the other uncertainties), and so the amount of fuel used, multiplied by the carbon content, gives the emission of carbon as CO_2. For Tier 2 estimates, data on fuel consumption and CO_2 emissions during the landing and takeoff (LTO) phases of flights for different aircraft types has been taken from the ICAO Engine Emissions Data Bank [9]. CO_2 cruise emissions are estimated from the carbon content of the fuel. Tier 3 Estimates require the use of more sophisticated models such as SAGE[10, 11] and AERO2K[12]. The IPCC guidelines also give emission factors for CH_4 and N_2O shown in Table 2. The CO_2 equivalent emissions (the mass of a gas converted to the mass of CO_2 that has the same climatic effect) of CH_4 and N_2O are only 0.02% and 0.6% of the CO_2 emissions.

Table 2 – Default (Tier 1) Aviation Emission Factors from 2006 IPCC Guidelines.

	Emission Factors (kg/TJ)		
Fuel	**CO_2**	**CH_4**	**N_2O**
Aviation Gasoline	70 000	0.5	2
Jet Kerosene	71 500		

However, following decisions by the UNFCCC, the guidelines state that emissions from fuel for use on ships or aircraft engaged in international transport should not be included in national totals. To ensure global completeness and avoid double-counting, these emissions should be reported separately. International transport is defined as a trip between different countries. Thus, until the UNFCCC decides otherwise, emissions from international aviation should not be included in the national total emissions, but are to be reported as a "memo" item. Accordingly, in order to meet the UNFCCC reporting requirements, inventory compilers must distinguish between international and domestic flights – in other words, they must differentiate the fuel used for an international journey from that used for domestic flights.

This information can be derived from a knowledge of the start and end points of all the flights, and fuel consumption information for a range of aircraft types, both for cruise and LTO. Estimates can then be built-up from this traffic data. Thus, the split in fuel use between domestic and international can be determined. However this can be a time and resource consuming task, and because of this, many parties have used general assumptions based on knowledge of the airline industry in their country and the experience of those involved.

[4] http://www.mnp.nl/edgar/model/v32ft2000edgar/Citation: Olivier, J.G.J., Van Aardenne, J.A., Dentener, F., Ganzeveld, L. and J.A.H.W. Peters (2005). Recent trends in global greenhouse gas emissions: regional trends and spatial distribution of key sources. Pdf-document (169Kb) In: "Non-CO2 Greenhouse Gases (NCGG-4)", A. van Amstel (coord.), page 325-330. Millpress, Rotterdam, ISBN 90 5966 043 9.

[5] The 2006 Guidelines do give emission data for NO_x, and under current reporting guidelines NO_x can be optionally reported as a precursor gas. However, there is not a mandatory requirement to report NO_x nor is it included under the Kyoto Protocol.

Conclusions

National greenhouse gas emission inventories are essential tools in understanding and responding to the problem of climate change. The guidelines developed by the IPCC are mandated for use by parties to the UNFCCC. They provide guidance on not just methodologies to estimate emissions but also on a range of good practice to ensure that the resulting estimates are: complete, consistent over time, comparable between parties, transparent, and as accurate as possible.

The latest IPCC guidelines, the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, provide the most complete, accurate and consistent guidance that is globally applicable, since they take into account the varying levels of resources and experience of the different countries.

The IPCC guidelines are suitable for estimating national emissions of greenhouse gases from the aviation sector for reporting to the UNFCCC. The simplest method is suitable for use by those with limited resources, however the guidelines also show how much more detailed, nationally-specific, methods can be utilised if so desired.

All of the guidelines, (the Revised 1996 Guidelines, Good Practice Guidance and the 2006 Guidelines), are available for free download at the following website :
http://www.ipcc-nggip.iges.or.jp/

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Assessment of Aviation Cloudiness

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Dr. David Fahey is a research physicist in NOAA's Earth System Research Laboratory in Boulder, Colorado, USA. He holds advanced degrees in physics and his specialty is the measurement of trace gases and aerosols in the troposphere and lower. His studies have addressed stratospheric ozone depletion, the photochemistry of nitrogen oxides, the formation of nitric acid containing aerosols, and the role of black carbon aerosol in climate. He has served as a senior scientist for NASA in several international scientific assessments of ozone depletion and climate. Dr. Fahey has received numerous awards for his work related to climate and the environment.

Aircraft in flight emit gases and particles into the atmosphere and increase cloudiness through the formation of contrails in the Earth's atmosphere. This "aviation cloudiness" has two components: persistent linear contrails and an induced cirrus component often called contrail cirrus. The latter comes from the spreading of contrails in the atmosphere for periods of minutes to hours after their formation. Aviation increases global cloud cover, an important component of Earth's climate system.

Intergovernmental Panel on Climate Change

The Intergovernmental Panel on Climate Change (IPCC) evaluated the contribution to climate change from many aspects of 1992 aircraft operations in a special report in 1999 (IPCC, 1999). Included here are results from the recently released 2007 IPCC assessment, in which the contributions of aviation cloudiness were reevaluated along with other principal anthropogenic and natural sources of climate change.

IPCC's unique role in the landscape of global environmental science is carried out under the auspices of both the United Nations Environment Program and the World Meteorological Organization. Its mandate is "*...to assess scientific, technical and socio-economic information relevant for the understanding of climate change, its potential impacts and options for mitigation and adaptation*" (www.ipcc.ch). IPCC provides information to policymakers following a policy-neutral, but policy-relevant, process. Broad agreement approaching or reaching consensus is sought within an international group of scientists on aspects of climate change related to science, mitigation, and adaptation.

The IPCC reports are improved and strengthened by multiple expert and government reviews during the formation process. The new results presented here come from the *Climate Change 2007 Report: The Physical Science Basis* (IPCC, 2007), which is a product of Working Group I. More specifically, they are drawn from Chapter 2 of the 2007 report, *Changes in Atmospheric Constituents and in Radiative Forcing*, which assesses human and natural contributions to radiative forcing from pre-industrial times to the present.

Formation of Contrails and Contrail Cirrus

Persistent linear contrails and contrail cirrus are ice clouds in the category of thin cirrus. Contrails are formed several miles above Earth's surface in the exhaust of jet engines and consist primarily of condensed atmospheric water vapour. Persistent contrails are those that last for minutes to hours after formation, which requires high humidity in the air surrounding the flight track. As a consequence, contrails generally form at low atmospheric temperatures (lower than 40°C). Small particles in the atmosphere or those emitted in the engine exhaust are also required for contrail formation. Since small particles are ubiquitous in the atmosphere, it is the humidity in the atmosphere along an aircraft flight track that primarily determines when and where persistent contrails form. The formation of a persistent contrail can be accurately predicted for individual aircraft if the engine type and atmospheric conditions are known (e.g., IPCC, 1999). Contrail cirrus, sometimes called induced cirrus, is defined as cloudiness that evolves or spreads from persistent linear contrails, creating cloud cover that exceeds that of the initial contrail. The spreading can only occur in regions that have high humidity similar to that where the contrails are formed.

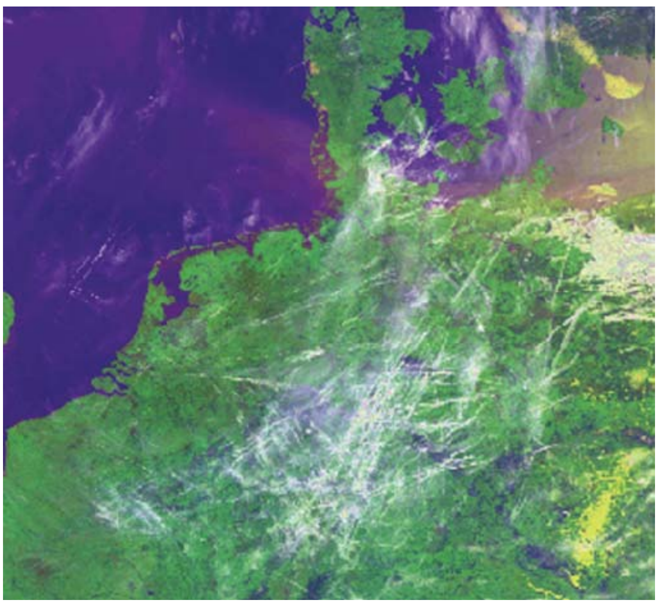

Figure 1 – Contrails and contrail cirrus cloudiness over Europe as viewed by the NOAA-12 AVHRR satellite on 4 May 1995 (IPCC, 1999).

IPCC Results

The principal graph from the IPCC special report on aviation (IPCC, 1999) summarizing climate effects for the 1992 global fleet is shown in Figure 3. The bars in the figure represent the best estimate of the radiative forcing[1] for each contributing factor, and the error bars show the estimated uncertainty. Radiative forcing is a formal, quantitative measure of the potential of climate change from each contributing factor (IPCC, 2007). Positive radiative forcing leads to heating of the Earth's atmosphere and surface, and a negative forcing leads to a cooling.

Clouds can both heat and cool the atmosphere and Earth's surface, depending on their altitude and radiative properties. The net effect of cirrus and contrail cirrus at aircraft cruise altitudes is generally to trap Earth's thermal radiation, leading to a warming. In 1992, contrails had an estimated positive forcing of 0.02 W m^{-2} with a large uncertainty (0.005 – 0.06). The contrail percentage of the total radiative forcing from aviation was about 40%. Although no best estimate was established then for contrail cirrus, labeled as 'cirrus clouds' in Figure 3, the dashed line shows the expected range of the best estimate.

Since 1999, aviation emissions have grown as a result of increases in air traffic. Aviation impacts have been reassessed in whole or part in a number of studies. Notable among these is the European Union TRADEOFF project that reevaluated all of the factors in Figure 3 (Sausen et al., 2005). The updated radiative forcing values for contrails decreased from the 1999 values, primarily as a result of more accurate methods of calculating contrail cover and estimating their radiative properties. The 2007 IPCC assessment included a new value for contrail radiative forcing, which is shown in the summary in Figure 4. This figure shows the important human and natural terms in climate forcing from pre-industrial times to 2005, categorized here as cooling terms and warming terms. Accumulated carbon dioxide (CO_2) is the primary warming term, but there are significant cooling terms associated with clouds and aerosols. The persistent contrail term is less than 1% of the total from human activities.

Figure 2 – Persistent contrails spreading to form contrail cirrus as viewed from the ground from a location in suburban Washington, DC, USA (EPA Contrail Factsheet).

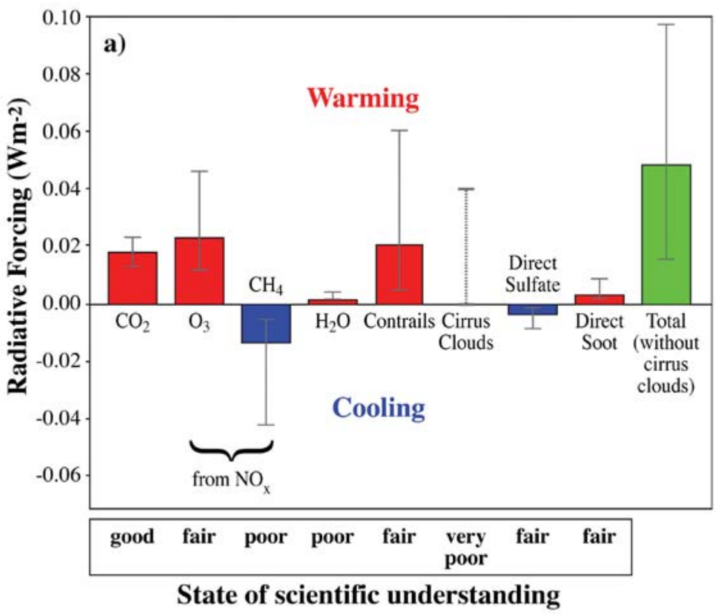

Figure 3 – Estimates of radiative forcing from subsonic aircraft emissions in 1992. Bars are best estimates of globally and annually averaged values. Error bars are the 67% probability range for each estimate. No best estimate is available for contrail cirrus (labeled cirrus clouds). The scientific understanding for each component is indicated at the bottom of the graph. (IPCC, 1999).

[1] Radiative forcing: a measure of change in climate impact. A parameter often used to compare the climate impact of the different gases and particles.

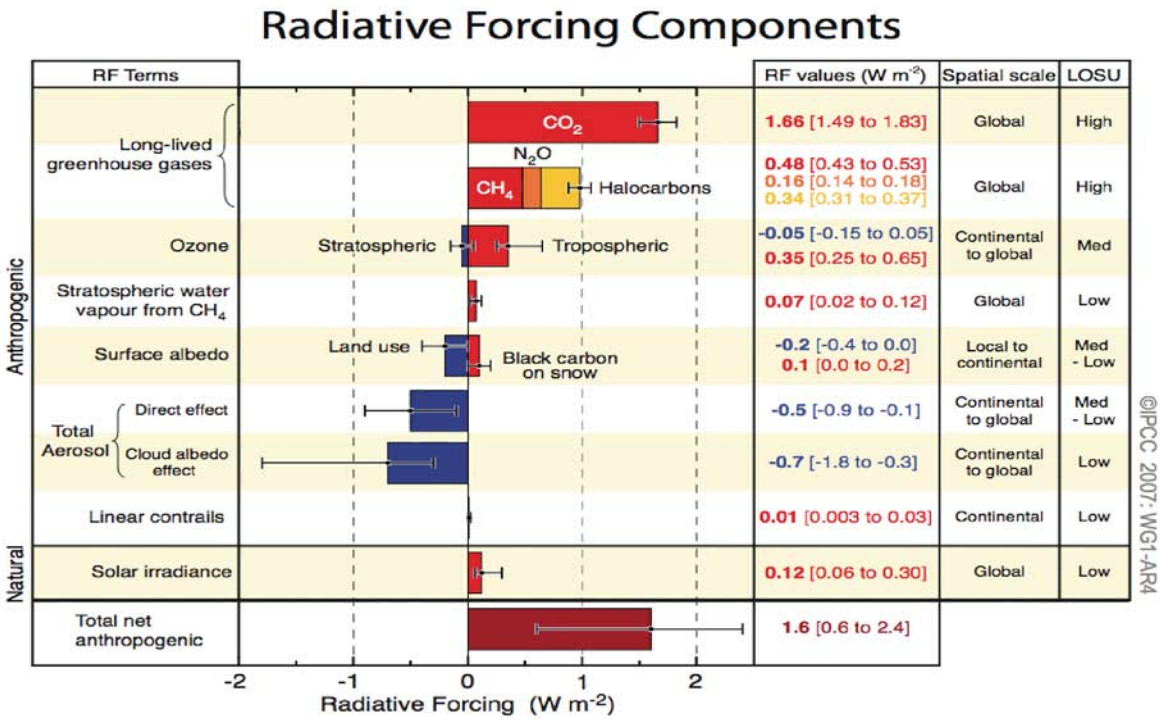

Figure 4 – Globally averaged radiative forcing estimates and ranges for anthropogenic increases in principal greenhouse gases (carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N2O)) and for other important agents and mechanisms between pre-industrial times and the present (2005). Also shown are the typical geographical extent (spatial scale) of the forcing and the assessed level of scientific understanding (LOSU). The total net anthropogenic radiative forcing and its range are also shown. The change in solar irradiance represents a natural climate-forcing agent. (IPCC, 2007; Figure SPM-2).

IPCC 2007 Estimates of the Radiative Forcing From Aviation Cloudiness

Radiative forcing estimates of aviation cloudiness depend on two key factors: the geographic extent of cloudiness and the contrail radiative properties. To estimate persistent contrails cover one needs to know the formation conditions and traffic amounts along aircraft routes. Estimating total contrail cover is generally done by careful evaluations in selected regions that are then extended to the globe. Europe is an important example of a well-studied region for air traffic effects as highlighted in Figure 1. Global cover requires predicting humidity distribution at cruise altitudes because contrail formation depends on humidity. The uncertainty in predicting humidity causes global contrail cover to be uncertain. The radiative forcing or climate impact from contrail cover requires defining the radiative properties of the calculated contrail cover. These properties account for how contrail ice particles absorb and/or reflect solar radiation and heat radiation from Earth's atmosphere and surface. These properties are also uncertain, in part because of the variability in contrail properties that results from the variability in formation conditions (*e.g.*, temperature, humidity, winds) in air traffic regions.

In the 2007 IPCC assessment, the estimated radiative forcing of the 2005 aviation fleet is 0.01 W m^{-2} with a factor-of-three uncertainty (see Figure 4). The new value is one half of the 1999 IPCC estimate, as illustrated in Figure 3, and also has a lower uncertainty. The downward adjustment is due to refined estimates of contrail cover from satellites and cloud radiative properties. It is important to note that the 1999 and 2007 estimates are for air traffic in 1992 and 2005, respectively. Since air traffic increased substantially between 1992 and 2005, the climate sensitivity to contrail cloudiness decreased by more than the reduction in radiative forcing estimates.

Predictions of the climate impact of contrail cirrus are more difficult than predicting persistent contrails. The latter spread to form contrail cirrus due to winds and wind shear along aircraft flight tracks. Predicting precise wind conditions in flight corridors is an uncertain process. The uncertainties in the radiative properties of contrail cirrus are similar to those of persistent contrails. As a result, estimates for contrail cirrus cover are sufficiently uncertain that only a range of best estimates was provided in IPCC 1999 (0 - 0.04 W m^{-2}) and no best estimate was provided in IPCC

2007. However, current estimates of contrail cirrus are near 0.030 W m^{-2} with a range of 0.01 – 0.08 W m^{-2}, strongly reinforcing the IPCC 1999 conclusion that the climate contribution of contrail cirrus cannot be neglected. A major limitation in the evaluation of contrail cirrus is that, as contrail spreading continues, contrail cirrus eventually becomes indistinguishable from background cirrus cloudiness. Furthermore, scientists cannot be certain that clouds would not have naturally formed in the region of contrail cirrus if a persistent contrail had not been formed.

Aviation Aerosol

Aviation aerosol[2] is a source of sulfate and black carbon (soot) aerosols found in the upper troposphere and lower stratosphere. Aviation aerosols accumulate in these regions before natural processes remove them. Increased aerosol acts to warm or cool the atmosphere depending on aerosol composition and can also alter cloud processes in the atmosphere. The aviation aerosol sources of both soot and sulfate have been evaluated in mass units as small in comparison to the total masses present from other natural and human sources. As a consequence, the direct warming or cooling of climate is small from the accumulation of these aerosols, as shown in IPCC 1999 and in Figure 3. In IPCC 2007, no separate evaluation was made of the direct aerosol effects of aviation.

In contrast to aerosol mass, the increase in the number of aviation soot aerosols is significant in comparison to other natural and human sources. Studies show that aviation increases the number of particles in large regions of the upper atmosphere, particularly in flight corridors. Further, these studies indicate that increases in soot aerosol numbers can potentially change how clouds form and the optical properties of the clouds. Cloud effects are considered an indirect effect on climate, similar to the formation of contrail cirrus. Large uncertainties are associated with these indirect effects. Reducing these uncertainties is important for our understanding of the effects of black carbon from aviation and from all other anthropogenic and natural sources of black carbon, such as burning of fossil fuels and biomass burning.

Conclusion

The IPCC international assessment process has significantly contributed to the evaluation of the effect of aviation on the Earth's atmosphere. Increased cloudiness from persistent contrails and contrail cirrus is a fixture of global aviation operations and will remain so in the foreseeable future.

For 2005 aircraft operations, persistent contrails added about 0.01 W m^{-2}, with about a factor-of-three uncertainty, to climate forcing from human activities. This is less than 1% of the total climate contribution from CO_2 increases and of the total anthroprogenic radiative forcing. The contrail contribution has been revised downward by about a factor of two from the 1999 IPCC assessment due to improved estimates of contrail cover and cloud radiative effects.

Contrail cirrus is an additional radiative forcing component, but currently has no best estimate.

Finally, aviation soot aerosol is expected to increase the number of atmosphere particles in the upper atmosphere, which can potentially change cirrus cloud properties.

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Climate Impact of Aviation

By Robert Sausen and Ulrich Schumann

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The climate impact of aviation[1] has been receiving increased attention, in particular, since the European Commission published a proposal to include aviation in the European Emission Trading System, and even more, since IPCC published its Fourth Assessment Report on Climate Change. The global aviation fleet currently contributes about 2% of all man-made carbon dioxide (CO_2) emissions. However, like other sources, aviation also emits other gases and particles affecting the climate.

Therefore, several questions arise: How can aviation impact climate? What is particular about aviation-induced climate change? What is the ratio between the total contributions and those from CO_2? How can we reduce the climatic impact of aviation?

Radiative Forcing

Aviation emits gases and particles which change the composition of the atmosphere or change clouds and hence disturb the radiation balance of the Earth. In particular, aviation emits the greenhouse gases CO_2 and H_2O (water vapour). Aircraft also emit nitrogen oxides (NO_x). Through photochemistry in the atmosphere, the additional NO_x enhances the formation of ozone (O_3) and destroys methane (CH_4). Both, O_3 and CH_4 are greenhouse gases.

The water vapour emitted by an aircraft at cruise altitude can trigger the formation of contrails. Contrails are initially visible as line-shaped clouds. In cold and moist air masses, contrails may spread and in some cases eventually form so-called contrail cirrus, which resemble natural cir-

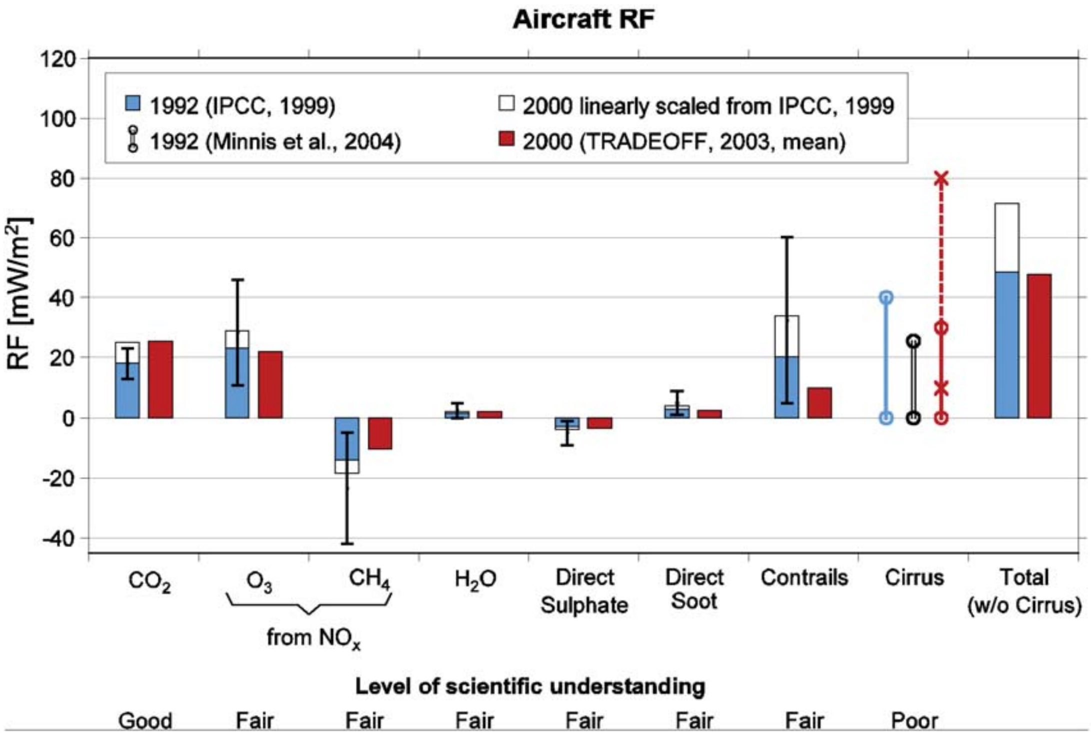

Figure 1 – Aviation-Related Radiative Forcing.
RF [mW/m^2] from aviation for 1992 and 2000, based on IPCC (1999) and results of the TRADEOFF project (Sausen et al., 2005). The whiskers denote the 2/3 confidence intervals of the IPCC (1999) value. The lines with the circles at the end display different estimates for the possible range of RF from aviation-induced cirrus clouds. In addition, the dashed line with the crosses at the end denotes an estimate of the range for RF from aviation induced cirrus. The total does not include the contribution from cirrus clouds. The level of scientific understanding is indicated by the subjective grades "Good", "Fair" and "Poor".

[1] This article was produced initially for ASD Focus, Summer 2007 "Meeting the Challenges".

rus clouds. Finally, aviation induces aerosols (soot and particles formed from sulfur oxides). These aerosols may interfere with the atmospheric radiation directly or indirectly after modifying clouds.

The magnitude of the perturbation of the atmosphere's radiative budget is measured by radiative forcing (RF). A positive RF warms the atmosphere, a negative RF cools. For constant RF, after many decades, the Earth approaches a new climate, with a changed global mean temperature at the Earth surface approximately proportional to RF. Therefore, RF is used as a metric to compare the relative strengths of various perturbations to the atmosphere.

In 1999 the IPCC Special Report "Aviation and the Global Atmosphere" showed a first estimate of the aviation related radiative forcing. An update to those estimates was provided in 2005[2]. Figure 1 displays the results; the red bars show the most recent estimate. The largest contributions come from CO_2, O_3, contrails (all positive, warming) and CH_4 (negative, cooling). Small contributions are from H_2O, direct sulfate aerosol and direct soot aerosol. As can be seen from Figure 1, the total aviation-induced radiative forcing RF is about twice that from CO_2. Note that no best estimate for RF from cirrus clouds (beyond contrails) is provided due to presently poor knowledge. The total amounts to about 3% of the radiative forcing from all man-made activity since the 18th century, with a substantial uncertainty. The largest uncertainty comes from aviation contributions to changes in cirrus clouds, which are therefore not included in the total.

Impact of Emissions

Carbon dioxide has an atmospheric lifetime of more than 60 years and becomes well-mixed during this period regardless of where the emission occurred. Hence, CO_2 emissions from aviation have the same effect as CO_2 emissions from other sources. However, the RF caused by other emissions depends strongly on where and when they are emitted.

Because of a longer lifetime and lower ambient pollution, a NO_x molecule emitted at cruise altitude (8 - 14 km) produces a larger amount of O_3 than when emitted at the Earth's surface. As the atmospheric temperature at cruise altitude is lower than at the Earth's surface, the radiative forcing per unit ozone is larger than the RF from the same amount of ozone near the surface (e.g., from road transport).

Contrails and cirrus clouds only form at the low temperatures typically occurring at cruise altitudes. Long-lived contrails occur mainly in the humid and cold regions near and below the tropopause. Thin cirrus clouds and contrails most probably cause a positive RF.

Non CO_2 Effects Under Scrutiny

International aviation and international shipping are not included in the Kyoto Protocol because the parties could not agree on a national allocation of emitters during the negotiation of the Kyoto Protocol. Therefore, the parties asked the respective UN specialized agencies, ICAO and IMO to find a solution to the allocation problem, which has not yet been achieved.

Recently, the European Commission has developed a scheme on how to include aviation (domestic and international) in its Emission Trading Scheme. In this context, how to include the non-CO_2 effects of aviation into such a scheme, has been discussed.

Is there a good method to account for the non-CO_2 effects of aviation? One question is how to weigh the non-CO_2 effects in relation to the CO_2-induced climate change. One might be tempted to use the ratio between the total aviation-induced RF, relative to the RF only from the CO_2 emissions of aviation, the so-called Radiative Forcing Index (RFI). However, RF is a backward looking metric, i.e., it accounts for all the effects of processes that happened in the past. For example, aviation RF for the year 2000, as displayed by the red bars in Figure 1, accumulates all

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2 Sausen, R., I. Isaksen, V. Grewe, D. Hauglustaine, D.S. Lee, G. Myhre, M.O. Köhler, G. Pitari, U. Schumann, F. Stordal and C. Zerefos, 2005: Aviation radiative forcing in 2000: An update on IPCC (1999). *Meteorol.* Z. 14, 555-561.

contributions of aviation since 1940 weighted with the lifetime of the various emission species. While RF from NO_x-induced ozone and contrails was essentially only from air traffic in 2000, RF from CO_2 is from the accumulated CO_2 since 1940. For constant air fleet and aviation emissions, RF from ozone and contrails were constant, but aviation CO_2-induced RF would grow because CO_2 would further accumulate. Therefore, neither the total aviation-induced RF nor the RFI are suitable measures to weigh the non-CO_2 climate effects of aviation.

The fact that RF at a given time does not include any information about the atmospheric lifetime of a perturbation to the atmosphere, is one of the reasons why RF was not used in the Kyoto Protocol to weigh non-CO_2 gases, i.e., to transfer them into equivalent CO_2. The Kyoto Protocol rather makes use of the Global Warming Potential (GWP), which is the time-integrated RF arising over a given time horizon (100 years) from a unit emission of a particular gas, normalized by the time-integrated RF from unit CO_2 emission. In this way the individual lifetimes of the various gases are considered.

Further Research

The GWP concept cannot be applied directly to aviation, mainly because the atmospheric lifetimes of important aviation effects are much smaller than the lifetimes of the Kyoto gases. Among the Kyoto gases, CH_4 has the shortest lifetime, in the order of 10 years. In the case of aviation we also deal with phenomena, which only last for a few hours, such as contrails. Moreover, the aviation-induced climate effect depends not only on the magnitude of the emissions but also on geographical region and altitude, and daytime and season of the emissions.

Currently, several proposals for the inclusion of the non-CO_2 effects are being discussed in the science community, including time-integrated RF from an aviation induced perturbation of the atmosphere or the temperature change resulting from such a perturbation after a certain time, e.g., after 100 years. The integrated RF would be in analogy to the GWP currently applied by the Kyoto Protocol. The temperature change would more directly measure the contribution of the perturbation to long-term global climate change. Proper methods to account for the climate effects of non-CO_2 effects have still to be established, and further research must be undertaken to reduce uncertainties.

A scientifically sound solution for the inclusion of non-CO_2 effects in an emissions trading scheme (or other approaches) would eventually call for something other than a simple multiplication factor. Such a simple multiplication factor would weaken incentives to reduce the total climate impact beyond a reduction of the fuel consumption, i.e., there would be no benefit in reducing non-CO_2 effects.

Comparing Effects of Different Aircraft Emissions on Climate

By Claus Brüning
and Malcolm Ko

This article presents an overview of the scientific consensus to-date of the effects of aviation emissions on climate change in the context of how the information should be used in evaluating the environmental benefits of technology improvements and changes in operations.

There are three steps in the process of evaluating climate impacts, each with uncertainties: the emissions, the changes in ambient air concentrations of greenhouse gases or cloud cover, and the actual climate impacts (i.e. radiative forcing and/or responses such as change in surface temperature).

Background

The Intergovernmental Panel on Climate Change (IPCC) is the premier international organization established by the World Meteorological Organization (WMO) and United Nations Environmental Program (UNEP) to assess the problem of global climate change. It provides a consensus view and policy-relevant scientific information on our latest understanding of causes and impacts of climate change including mitigation options and measures.

The impact of aviation on climate was addressed by the IPCC Special Report on Aviation (IPCC, 1999). The issues were revisited briefly in subsequent climate assessment reports (IPCC, 2001; IPCC, 2007). In the IPCC process, expert panels review the peer-reviewed results from top research groups to synthesize a consensus view on different aspects of climate change. An individual chapter usually involves many contributing authors, and is twice reviewed by a wider scientific community and finally discussed and agreed on by government representatives.

This article includes updated results from peer-reviewed literature. However, one should keep in mind that those results have not gone through the more rigorous process as implemented by IPCC. Currently, project ATTICA commissioned by the European Commission is in the process of reviewing the impact of the transport sector (including aviation) on climate change and ozone depletion. Findings from the ATTICA could provide additional inputs for the ICAO/CAEP impact assessment activity.
(http://www.pa.op.dlr.de/attica/)

Radiative Forcing and Climate Change

Radiative forcing (RF) is a parameter often used to compare the climate impact of different gases and particles (see e.g. IPCC, 1999). RF (here measured in milli Watts per square meter, $mW\ m^{-2}$) expresses an instantaneous change in the energy balance of the earth-atmospheric system resulting from a perturbation in concentrations of green house gases (GHGs) in the atmosphere. A sustained positive radiative-forcing imposes a warming effect, a negative radiative-forcing, a cooling one. Carbon dioxide is the most important GHG because of the large quantities released and the long residence time of this gas in the atmosphere. Its RF is well known.

Due to the long residence times (i.e. several decades or longer), GHGs such as CO_2 are well-mixed (WM) and the changes in concentrations are independent of where the gas is emitted. Once emitted, the forcing will persist for decades or centuries, and even if emissions were to cease, the temperature effects would persist even longer.

For reference; change in forcing due to accumulation of WM GHGs emitted from industrial activities is estimated to be 2500 $mW\ m^{-2}$. For example, it is estimated that a future doubling of CO_2 will lead to a change in forcing of about 4000 $mW\ m^{-2}$ and a global average surface warming of somewhere from 1.5 to 4.5 degree Celsius.

For these long-lived GHGs, the steady state temperature change for a sustained forcing is expected to be proportional to the RF, with approximately the same (~20%) proportionality constant for all WM GHGs. The CO_2-equivalent impact of other long-lived GHGs, developed under UNFCCC and as used in European Emissions Trading Schemes (ETS), is based on global warming potential (GWP) with a specific integration time horizon. For example, an integration time horizon of 100 years (GWP-100 weighted) gives the equivalence mass of CO_2 that would have the same cumulative forcing 100 years following the emission.

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Dr. Ko has more than 25 years of experience modelling the distributions of trace gases and their photochemical and climatic impacts on the environment. His specialty is the study of the response of ozone to natural and anthropogenic activities such as emissions of halocarbons; operation of space shuttle, and supersonic and subsonic aircraft. He has provided results for, and participated in the preparation of many national and international reports, including: the World Meteorological Organization reports on Scientific Assessment of Ozone Depletion, the Intergovernmental Panel on Climate Change (IPCC) special report on Aviation, and the IPCC Climate Change reports.

IPCC acknowledges that there are much greater uncertainties associated with evaluating the climate impacts from short-lived gases with a lifetime typically less than 1 year. RF of short-lived gases depends also on the spatial pattern of the emissions and when the emissions occur. Because only a small fraction of the NO_x emitted at the ground is transported to the upper troposphere, NO_x emitted by aircraft at cruise altitudes has a much larger impact on ozone in the upper troposphere than the same amount emitted at ground level.

Changes in concentrations will also be most significant near flight routes and therefore have a more regional effect on climate. It is unclear whether the global average temperature response to the global average forcing will bear the same relationship as the long-lived GHGs. For these reasons, there are conceptual difficulties in using a GWP for NO_x/O_3 as the chemical (and thus RF) effect varies in space (i.e. location, altitude). Finally, using 100-year integrated forcing would artificially spread the effects over 100 years and would not capture the short-term impacts of those forcings that really occur only in the first couple of years.

Radiative Forcing From Cruise Emissions

Emission inventories for aviation emissions at cruise altitude are calculated using fuel use and emission indices (g of pollutants emitted per Kg of fuel use). Aircraft engine emissions consist of (by mass) 70% CO_2 (carbon dioxide), 30% H_2O (water), and less than 0.5% NO_x (nitrogen oxide), CO (carbon), SO_2 (sulphur), UHC (unburned hydrocarbons), and soot. These emissions lead to changes in ambient concentration of the emitted species (e.g. CO_2), and indirectly to changes in concentrations of other species through photochemical interactions (changes in concentration of O_3 and CH_4 as a result of NO_x emissions). For CO_2, H_2O, and essentially for SO_2, the amount emitted into the global atmosphere is directly proportional to fuel use, implying that 90% of the emission occurs during, other than landing and takeoff operations (LTO). NO_x emissions depend strongly on engine power settings, with much larger emission indices occurring during LTO operations. Approximately 60% is emitted at cruise altitudes. It is likely that LTO emissions around specific airports only have a small effect on global concentrations of O_3 (Tarrason et al., 2004). In addition, aircraft in the cruising phase of flight cause contrails under certain environmental conditions that may, in turn, develop contrail cirrus, enhancing cirrus cloud cover. Contrails occurring at night have a larger net forcing than those during the day because the compensation from reflected sunlight is absent.

CO_2 emitted by aircraft at cruise altitudes has the same effect as CO_2 emitted by a source at ground level. Fuel use for aviation in 2000 was 2% of all combustion sources, and accounted for 12% of the emissions for the transport sector alone. RF associated with CO_2 is well understood and its effects can be directly related to CO_2 emitted by other sources.

For the following three short-lived species, the RF will depend on the location of emission (flight path) in addition to the total fuel use:

Water Vapour

The release of water vapour into the free troposphere by subsonic aircraft has little effect on RF because of the copious amount of water already in this part of the atmosphere. However, water vapour (and particulate matter) emitted into the upper (cold) regions of the troposphere often triggers the formation of line-shaped contrails, which tend to warm the earth's surface. Persistent contrails may also disperse to form (optically thin) cirrus clouds (called contrail cirrus), which could have an additional warming effect. The direct RF of H_2O and the RF of linear contrails (for a given contrail coverage) is fairly well known, however, the RF associated with contrail cirrus is highly uncertain. In addition, prediction of contrail coverage and cirrus remain a challenge. The residence times of water and contrail in the upper troposphere are of the order of days, and hours respectively.

Sulphate and Soot Aerosols

These have a much smaller direct forcing effect compared with other aircraft emissions. Soot absorbs heat and has a warming effect; sulphate reflects radiation and has a small cooling effect. In addition, accumulation of sulphate and soot aerosols might influence the formation and the radiative properties of clouds. Direct RFs are fairly well known; however, indirect RF through changing cloud properties is highly uncertain. Additional uncertainties are due to the lack of knowledge about the emission indices of soot.

Table 1– Radiative forcing (RFs) [mW/m2] due to aviation CO_2 emissions from historical operation of the subsonic fleet in the year 1992 as reported by IPCC (1999).

Emission/ Concentration	RF/Range* [mW/m2]	Remarks
CO_2/CO_2	18 / 13 to 23	Instantaneous forcing due to a change in CO_2 concentration of 1 ppmv resulting from cumulative CO_2 emission from historical operation of the fleet to 1992. For comparison, the change in CO_2 concentration from 1992 emission is 0.07 ppmv.
NO_x/O_3	23 / 13 to 45	Instantaneous forcing from changes in concentration due to the steady-state response of the atmosphere to a persistent operation of a fleet with 1992 emissions. Typical time to reach steady-state is a few months for O_3, about 10 years from CH_4.
NO_x/CH_4	-14 / -44 to -4	
H_2O/ H_2O	1.5 / 1.5 to 3	Instantaneous forcing from changes in concentration due to the steady-state response of the atmosphere to a persistent operation of a fleet with 1992 emissions. Typical time constant is weeks.
SOx,PM/SO_4	-3 / -.5 to 0	
Soot/ Soot	3 / 2 to 8	
H_2O, PM/ Contrails, cirrus	20 / 0.5 to 60	

*The ranges shown represent a subjective estimate (as cited in the IPCC report) that there is a 67% probability that the true value falls within the range. The uncertainties arise from a combination of the uncertainties in predicting the change in concentration and in predicting the environmental impact from a given concentration change.

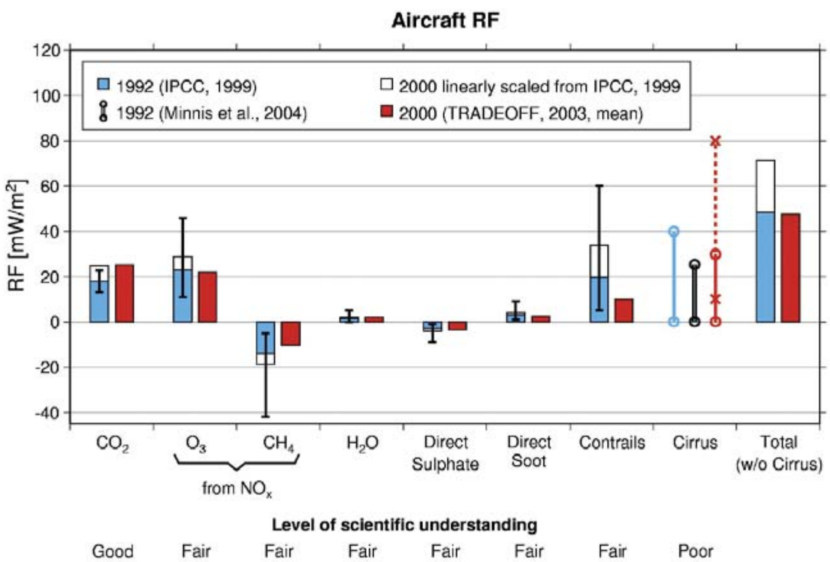

Figure 1 – Instantaneous radiative forcing (RF) [mW/m2] from cumulative emissions of the historical fleet for 1992 and 2000, based on IPCC (1999) and TRADEOFF results (Sausen et al., 2005). The whiskers denote the 2/3 confidence intervals of the IPCC (1999) values. The lines with the circles at the end display different estimates for the possible range of RF from aviation induced cirrus clouds. In addition, the dashed line with the crosses at the end denotes an estimate of the range for RF from aviation-induced cirrus. The total does not include the contribution from cirrus clouds. Figure taken from Sausen et al. (2005).

Nitrogen Oxides

Although nitrogen oxides are not in themselves GHGs, they produce an indirect radiative forcing by changing O_3 (Ozone) and CH_4 (Methane) concentrations in the atmosphere. Nitrogen oxides are chemically reactive gases, which produce O_3 under the influence of sunlight. As a consequence of complex tropospheric chemistry, NO_x, also reduces the ambient atmospheric concentration of CH_4. The RFs of O_3 and CH_4 are fairly well known, of similar magnitude but opposite sign.

Table 1 and Figure 1 summarize estimates of instantaneous RF and the uncertainties from changes in concentrations of CO_2 from historical aircraft emissions reported by IPCC (1999), and from changes in concentrations of other species corresponding to the steady-state response to the persistent application of the 1992 fleet emission. A recent study by Sausen et al. (2005) showed that the magnitude of the O_3 and CH_4 responses are respectively 25% and 50% smaller than those estimated by IPCC (1999). The results for soot and contrails are 1.6 and 3 times smaller, respectively. These values are consistent with the uncertainty estimates provided in the IPCC report.

Tradeoffs

Reducing emissions across the board is one way to minimize climate impacts. Unfortunately, designs and/or operations that reduce one emission may have negative impacts on other emissions. This is the reason why one must consider trade-offs in such designs. Uncertainties associated with estimating the impacts play an increasingly important role in trade studies as one includes more dissimilar forcing (e.g. long-lived vs short-lived, etc.) in the trade space. The scientific consensus that warming from well-mixed GHGs is proportional to radiative forcing allows one to consider the trade-off among well-mixed GHGs without having to account for the uncertainties associated with the relation between forcing and the climate impact. If one considers the trade-offs among CO_2, NO_x, H_2O and PM emissions at cruising altitude, the outstanding science question is whether RF (instantaneous or cumulative) from short-lived GHGs (NO_x, H_2O, and PM emissions), and their effects on ozone and contrails, can be used as a proxy for temperature response in the same way as it is done for well-mixed GHGs (CO_2). Therefore, the development of a separate metric for short-lived GHGs was necessary to address policy questions regarding their environmental impact. Wit et al. (2005) provided an example of how this problem could be approached. This is one area where Science must provide critical input.

There have been discussions on how to use the forcing values given in Table 1 in trade-off studies. In any case, the figures provided in Table 1 must be used with care for two reasons:

1. The numbers are RF related to the changes in concentrations associated with cumulative emissions from the historical fleet or steady-state response to persistent application of the annual emissions, rather than annual emissions.

2. They are based on instantaneous forcing and do not account for the difference in persistence between long-lived and short-lived GHGs.

An alternative way to look at relative impacts of long-lived and short-lived GHGs is to compare the effects of emissions associated with one year of operation of a fleet.

With appropriate scaling, the values in Table 1 and Figure 1 confirm that instantaneous forcing from either the ozone effect of NO_x emissions, or the forcing of contrails is much larger than the forcing from the annual CO_2 emission. Yet if one integrates the forcing long enough (say over 20 years), the integrated CO_2 forcing will be larger. If one uses integrated temperature response (see e.g. Lim et al. 2007; Shine et al. 2007), the cross-over point will occur after 50 years. Thus, whether CO_2 or NO_x emission has a larger climate impact depends on the choice of integration time horizon. This choice is a policy decision.

Conclusions

Based on the foregoing discussion, a number of conclusions can be drawn about the effects of aircraft emissions on climate:

- Both CO_2 and NO_x emissions remain important.
- The climate impact of a pulse emission of a GHG should be integrated over time to properly capture its long-term effect. If the integrated temperature response is used as the metric, there is evidence that the warming from O_3 production associated with NO_x emissions could be more important in approximately the first 50 years, while over longer timescales CO_2 becomes more important. The choice of period for integration time is a policy decision.
- There are significant uncertainties associated with the predicted climate impact of contrail and contrail cirrus, which could potentially be important. It is apparent that technological changes in engine development offer little scope for mitigating against these effects, since contrails are largely a function of atmospheric conditions for which aircraft emissions provide the 'trigger'.
- Contrail formation and persistence are influenced by a combination of environmental and operational conditions, but the potential trade-offs associated with contrail avoidance, such as increased fuel burn, increased ground delays, etc. require additional studies.

Acknowledgement

This report draws on materials that were previously submitted in a paper to CAEP 7 and is based largely on the work developed for the ICAO/CAEP, by its CAEP/Working Group 3.

The contributions from the co-authors in that paper, Dr. David Lee and Dr. Richard Miake-Lye, are acknowledged here.

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Technology

Reducing Aviation Global Climate Emissions: The Role of Manufacturers and Technology

By International Coordinating Council of Aerospace Industries Associations (ICCAIA)

Aircraft engine and airframe manufacturers, in collaboration with research organizations and other stakeholders, continuously strive to develop innovative technology and design highly performing products to respond to the evolving demand for transporting people, goods and services, while achieving this mission in the safest and most cost-effective and environmentally-friendly manner. This task involves the compromise of many challenges of differing natures, related in particular to technical, safety, economic and environmental issues. Nonetheless, noteworthy progress has been made to reduce the effects of aviation emissions on global climate largely through technological innovations. This article discusses the role manufacturers have played and continue to play towards achieving such improvements.

Aircraft Fuel Efficiency Improvements

In parallel with the aviation industry's natural vocation to develop high-performing products that respond to ever-increasing demands, market forces have always ensured that fuel burn and associated CO_2 emissions have been kept to a minimum for reasons of efficiency. Designing a product able to fulfil its mission safely with the lowest fuel consumption is a fundamental impetus behind reducing CO_2 (and other) emissions for each new aircraft type. This is the reason why aircraft engine and airframe manufacturers are always looking ahead at technological solutions that will enable significant environmental improvements. This is supported by extensive, continuous, and consistent research programmes. In fact, generation after generation of aircraft have shown impressive weight reduction results due to improvements in: materials, manufacturing processes and systems, aerodynamics, engine performance, and advances in specific combustion and acoustic focused technologies.

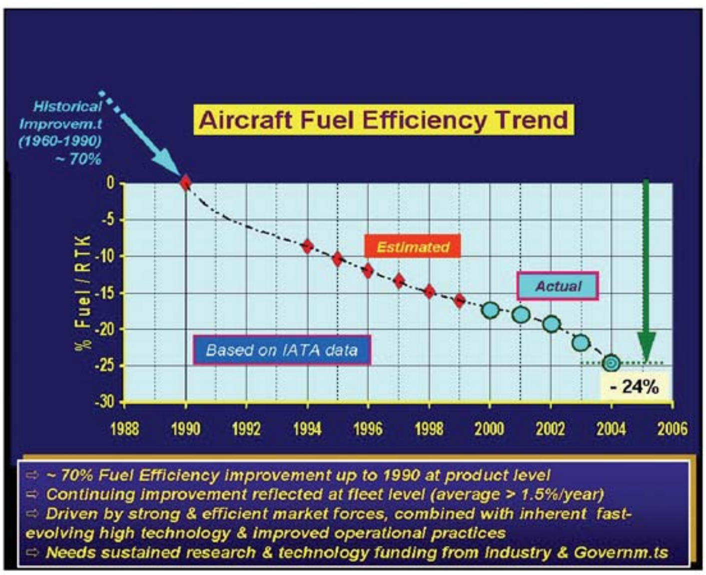


Figure 1 - Aircraft fuel efficiency trends.
Source: IATA

As a result, remarkable results have been achieved, not only without compromising the standards of safety and reliability, but by actually raising those to the highest levels. To give an order of magnitude of the reductions in CO_2 emissions; a 70% reduction in fuel consumption was achieved between 1960 and 1990, thus more than tripling fuel efficiency during that period. From 1990 to 2004, that trend continued to the point where it is estimated that fuel efficiency in the commercial aviation fleet quadrupled from 1960 to 2004 (Figure 1).

As mentioned above, fuel efficiency gains result from a continuous flow of new and improved design features and technologies, which are hallmarks of the constantly evolving and innovative high-technology focused aviation industry. The mindset of continuous improvement through innovation is one that is deeply ingrained in the cultures of both manufacturers and operators in the aviation industry. Improved operational practices and enhanced air traffic management (ATM) systems and procedures also contribute to the overall efficiency improvements.

The most recent results from the International Air Transport Association (IATA) (Figure 1) show that the improvement trend continues. In addition to acquiring new modern high performance aircraft and engines, operators are investing in various fuel economy-related operational measures as another way to deal with challenging economic times in the industry. There is believed to be significant potential there, with manufacturers, ICAO and other stakeholders, striving to exploit all available means.

An additional example of technological progress with respect to reducing aviation emissions is shown in Figure 2. This figure illustrates progress of actual and projected specific fuel consumption (SFC) improvement trends from 1980 to 2010. As can be seen, the SFC of engines is projected to be significantly lower than it was in 1980.

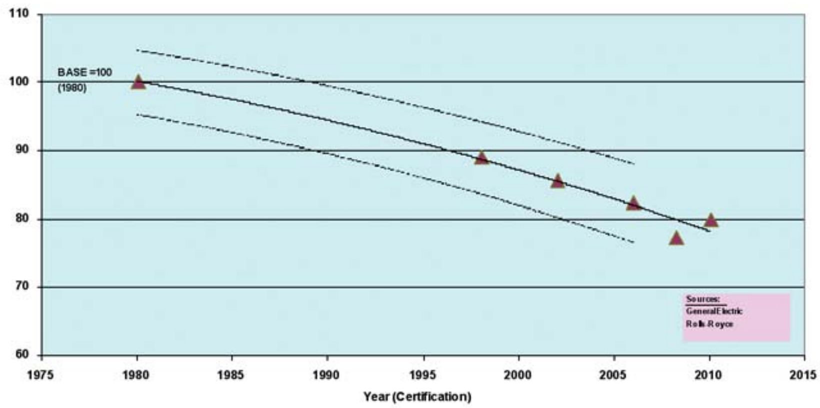


Figure 2 – Typical SFC Trend Line Over Time
Source: General Electric and Rolls-Royce.

Design Considerations of Manufacturers

Improvements in aircraft fuel efficiency are inextricably linked to how aircraft engine and airframe manufacturers design their products. The concepts, the design criteria, the design optimization and the technology transition processes, are all tightly interconnected. Design features are generally linked to products and the associated aircraft configuration. There is a fine line between technology and design, since both often evolve in tandem, rely on each other, and interact through multiple interconnected domains and disciplines. These interactions usually increase as a product is developed. Simultaneously, product innovations are permanently introduced through design, simulation, modelling, testing, and validation tools. The optimization processes and trade-offs involve iterative loops at the technology, design, and product levels.

Throughout the process of merging technology elements and design features that lead to final product optimization, fuel efficiency and emission considerations, as well as noise, are major drivers. However, environmental solutions must remain compatible with all other major design requirements (i.e. performance, operability, reliability, maintainability, durability, costs, comfort, capacity, timing), with safety obviously remaining the overarching requirement.

Any new aircraft-related component designs need to strike a balance between being technologically feasible, economically reasonable, and environmentally beneficial. Focusing on the environmental requirements, there is also a balance needed in order to ensure that each new aircraft will bring environmental performance improvements across three dimensions: noise reduction, emissions reduction, and minimized environmental life-cycle impacts. For instance, increasing the fan diameter of an engine would normally result in a noise reduction. However, since this implies adding weight and drag, it may also result in an increase in fuel consumption. Similar balances would have to be addressed for other requirements.

Stable Regulatory Framework and Dependable Scientific Knowledge

It takes approximately 10 years to design an aircraft. An aircraft type can be produced for 20 to 30 years with each aircraft being in service for 25 to 40 years. In such a long life-cycle industry, today's choices and solutions must be sustained over decades. Therefore, in order to make decisions to invest in future technologies, aircraft engine and airframe manufacturers need a stable international regulatory framework based on dependable scientific knowledge. This will enable the best technology balance to deliver the largest environmental improvements across the noise, emissions, and life-cycle dimensions. Improving the scientific understanding of the atmosphere and the impact of aviation emissions is key to optimizing priorities and assigning weight factors in prioritizing research, trade-offs, and mitigation measures.

The role of the manufacturers is stimulated and enhanced by their deep involvement in ICAO's CAEP activities and by participating in the achievements of that group in developing standards and recommended practices. The ICAO/CAEP process provides a highly effective international framework that facilitates harmonization and fruitful cooperation at the global level. Aircraft engine and airframe manufacturers and their airline customers, therefore support scientific research and contribute to atmospheric studies by enabling the collection of data through the placement of atmospheric measurement devices on their aircraft to meet the needs of research scientists. The manufacturers and research organizations are also plan, create and share their technological programmes and goals with regulatory authorities and decision-makers, and seek the collaboration of scientists whenever appropriate. Research funding is obviously key in this process.

Six Elements Towards Technology Improvements

While the preceding text describes what technology has permitted industry to accomplish globally to-date, this section focuses on six key ways (or strands of progress) in which technology plays a role in reducing aircraft emission impacts on global climate. These key elements explain how past technological achievements were accomplished and also cover some of the potential areas for future improvements. The six key elements are: 1) *Propulsion Systems*, 2) *Materials*, 3) *Structure, Aero & Systems Design & Methods*, 4) *Manufacturing Processes*, 5) *Aircraft Systems and* 6) *Operational Procedures*. Table 1 describes each of these elements and shows how they interact with corresponding factors such as weight reductions, aerodynamic and engine performance improvements, and operations - all towards achieving reductions in aircraft emissions. These elements illustrate the multiple paths and opportunities often adopted by manufacturers to reduce emissions (e.g. propulsion system, materials, systems design, etc.).

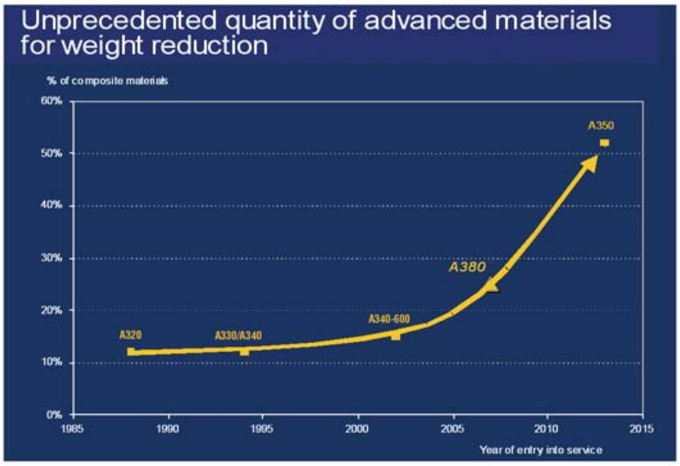


Figure 3 - Example of trend in the percentage of composites used. *Source: Airbus.*

Although all six strands are of significant importance, the rest of this article focuses on Weight Reductions as a typical example, illustrating the progress achieved in reducing the impact of aviation emissions (namely, CO_2) on climate change.

Structural Weight Reductions

Figure 3 illustrates the increasing use of composite materials on successive airplane generations, using the Airbus as a typical example. The use of composites coupled with: other advanced materials, loads alleviation, other systems optimizations, and new manufacturing techniques; result in significant weight savings.

Table 1 – Six Strands of Technological Progress. *Source: ICCAIA*

	Weight Reductions	Aerodynamic & Engine Performance Improvts.	Operations
1. Propulsion System	- Engine, Nacelle & Propulsion System • Advanced lightweight materials • Weight optimized Configuration	-Engine turbomachinery efficiency - Cycle optimized (intercooler, HBPR, UHBPR, geared turbofan, contra-fan) -"Intelligent"systems/more integrated engine -Innovative/active engine systems (heat management, cooling, power transmission,...) - Enhanced modelling capabilities (numerical) - low emissions combustor	- FADEC - Enhanced Controls & Sensors - Optimized Engine Operating Procedures
2. Materials	- Composites - Advanced light Alloys (Ti, Al-Li, Mg), Hybrid alloys (glare) - Innovative, smart materials	*NOTE: Information provided in this table is very general, non-exhaustive*	
3. Structure, Aero & Systems Design & Methods	- Aero-elasticity (load alleviation & control) - Structural optimization, integration & new concepts - Smart, morphing structures, nanotechnologies (future) - Wing, fuselage, empennage, landing gear, pylon innovative features	- Wing, HLD, HTP, Winglets, Fuselage - Engine/nacelle/pylon integration - Flow control - New unconventional configurations & concepts (future) - Multi-disciplinary design methods - Virtual Engineering	- Systems Modelling - Systems Simulation & Virtual Testing - Adaptive flight path to reduce emissions (future)
4. Manufact. Processes	- Welding processes (EBW, LBW, FSW) - Innovative structures & processes	- Welding Processes (drag reduction)	
5. Aircraft Systems	- Fly by Wire - Optimized, integrated & simpler electrical & mechanical systems, less components - IMA - Fuel transfer/load alleviation	- Advanced flight controls, more electronic systems: optimized control surface deflections, level & trajectory control	- Advanced Cockpit, Flight Management & Navigation - Optimized Energy & Electric Power managt (generation/distribution)
6. Operational Procedures	*Some procedures are linked with minimizing TOW*	*Some procedures optimize operations based on Aircraft aerodynamic characteristics*	- Optimized ground & flight, Maintenance procedures - ATM

Figure 4 shows an example of structural improvements, involving the use of composites, other advanced materials, and improved processes.

The subject of weight reduction is more complex than it first appears, for a number of reasons:

- Composites are not the only important factor involved in structural weight reduction. Experience shows that the optimum weight reduction depends on a combination of composites, advanced alloys, advanced processes, as well as improved overall structural architecture.

- Important contributors, other than materials and processes can also reduce the weight of an airplane. For example, load alleviation systems.

- Weight comparisons between different generations of airplanes are difficult to make and often not meaningful. This is because all technologies and design practices evolve over time, and the interpretation of gains estimated by projecting newer aircraft back to a past context is subject to interpretation. In addition, differences in design objectives at different points in time affect the characteristics and the optimization processes and trades.

What really matters is the overall environmental performance resulting from the combination of aircraft concepts, integration, and optimization; in relation to the product requirements.

Structural Weight Reduction Trends

Figures 5 and 6 illustrate, through some typical examples, showing the gains in terms of structural weight reduction and "structural productivity" increases over time.

Systems Weight Savings

Figure 7 shows examples of weight savings associated with aircraft systems.

Fuel Savings Associated With SFC, Drag and Weight Reductions

The fuel saving resulting from SFC or drag reduction is in a ratio of about 1 to 1; that is, about 1% block fuel saving or fuel efficiency increase for 1% SFC or drag reduction, although this varies slightly with the size of the airplane and the flight range. The fuel saving resulting from a structural weight reduction is in a ratio of about 0.6 to 1; or about 0.6% block fuel saving or fuel efficiency increase for 1% of MWE (Manufacturer Weight Empty), also varying slightly with the airplane size and range. It is important to note that, irrespec-

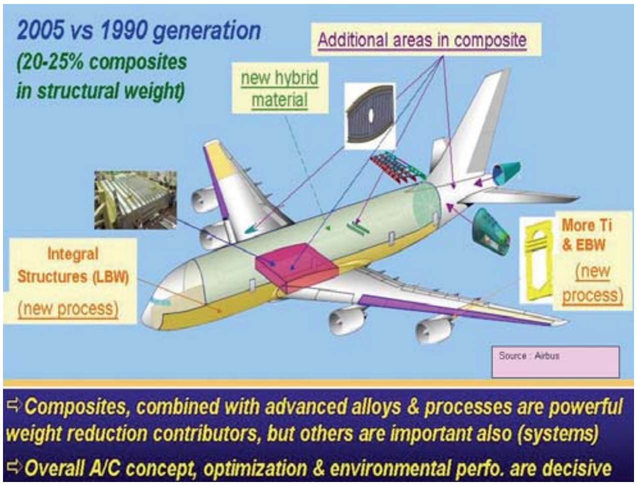


Figure 4 – Example of Structural Weight Reductions (A380).
Source: Airbus.

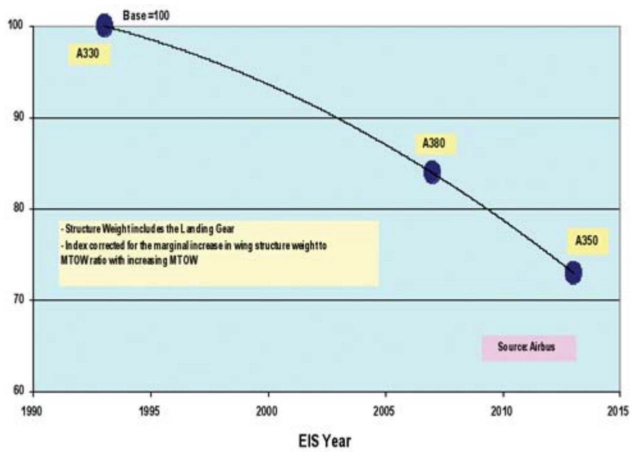


Figure 5 - Example of Structural Weight/MTOW ratio Trend vs. Time.
Source: Airbus.

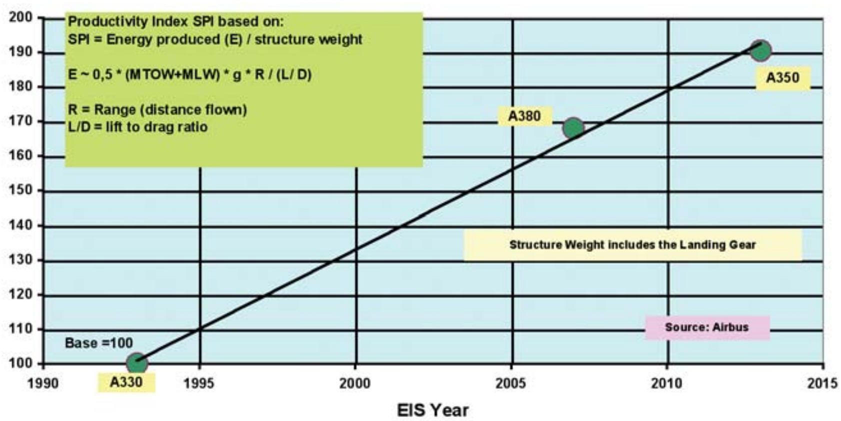


Figure 6 - Example of "Structural Productivity" Trend vs. Time.
Source: Airbus.

Figure 7 - Examples of Systems Innovations for Weight Saving (A380)
Source: Airbus.

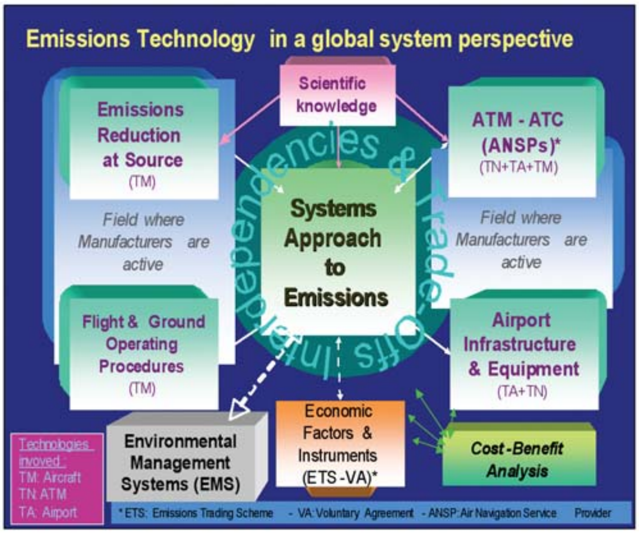
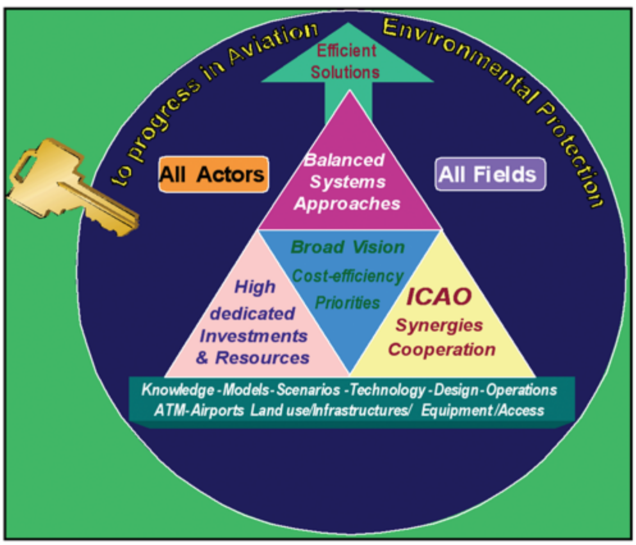


Figure 8 - A global perspective for emission reductions.
Source: ICCAIA.



tive of design trends, the weight, SFC and drag improvements are not independent due to the inherent physical relationships governing airplane performance and flight mechanics.

Global Systems Approach

Technology cannot be considered in isolation. In order to continue to benefit from the considerable efforts and resources invested to-date by the manufacturers in the development of emissions (and noise) reduction technologies and environmental-friendly designs, it is essential that these efforts be integrated with those of all stakeholders, working together on a global scale. Such a global systems approach is needed to identify and define globally optimized solutions that take into account all of the various interdependent factors. This requires an ongoing productive dialogue as well as extensive cooperation among stakeholders.

Technology is obviously a very important factor, but will not be enough to address air transport growth and environmental needs. All cost-effective means to improve environmental protection need to be explored and exploited, in combination with technologies, including operating procedures, land-use management, airport infrastructure and equipment, ground systems and ATM. This global systems approach which is illustrated in Figure 8, puts these elements into a broader perspective, together with other influencing factors including: scientific understanding, interdependencies and trade-offs, and economic factors. This actually defines a systems approach to emissions management, leading to an even wider concept encompassing all environmental aspects. This implies having proper criteria and weight factors defined, and developing proper methodologies to analyze interdependencies.

Conclusions

The quest for efficient environmental solutions and progress in aviation environmental protection depends on a comprehensive and robust knowledge base, complemented by technology enablers and modelling tools and capabilities in all relevant domains. This will require meaningful and consistent investments of financial and other resources to support the necessary research and technology development. This quest will benefit from combined synergies, cooperation, and an integrated and balanced systems approaches, on a global scale. This is a permanent dynamic process that does present challenges. To make it work, one must remain watchful, open, flexible, and determined, in order to ensure meaningful inputs at all time., This will enable efficient analysis in support of responsible decision-making for the future.

Operational Measures

Operational Measures for Fuel and Emissions Reductions Applicable to Global Emissions

By Ted Mc Donald

Ted McDonald is Manager of Environmental Protection for Transport Canada's Civil Aviation Directorate. He coordinates all civil aviation environmental protection issues for Canada. Domestically, he supports Canada's agenda for minimizing emissions from civil aviation including: the voluntary agreement with the Air Transport Association of Canada, environmental programs which promote the adoption of operational measures in ICAO Circular 303, and Canadian environmental research for the modelling and sampling of aircraft emissions. Internationally, Mr. McDonald serves as Canada's representative to ICAO/CAEP Working Group 3 – Emissions, and as the Secretariat for ICAO/CAEP Working Group 2 – Operations. Ted McDonald holds degrees in Environmental Science and Education.

Through its Committee on Aviation Environmental Protection (CAEP), ICAO has taken a number of steps to pursue the limitation or reduction of aviation emissions and to recommend appropriate action. Upon ICAO's request, the Intergovernmental Panel on Climate Change (IPCC) prepared a Special Report on Aviation and the Global Atmosphere, issued in 1999.

That report indicated that air traffic management (ATM) improvements and other operational measures could reduce total aviation fuel burn on a global basis by between 8 and 18 per cent. The report also identified existing national and international ATM systems constraints that result, for example, in aircraft having to fly in holding patterns (e.g. while waiting for permission to land), inefficient routings, and sub-optimal flight profiles. These constraints result in excess fuel burn and, consequently, excess emissions.

According to the IPCC Special Report, addressing only the ATM system constraints on the current aircraft fleet and operations could reduce fuel burned by 6 to 12 per cent. The Report stated that the improvements needed for these fuel-burn reductions were anticipated to be fully implemented within a twenty-year time horizon, provided that the necessary institutional and regulatory arrangements were put in place.

The IPCC Special Report identified other possible operational measures for reducing the amount of fuel burned per passenger-kilometre such as: increasing the load factor (carrying more passengers or freight on a given aircraft), eliminating non-essential aircraft mass/weight, optimizing aircraft speed, limiting the use of auxiliary power units, and reducing taxiing. The report concludes that potential improvements to these areas could reduce fuel burned and emissions by 2 to 6 per cent.

ICAO Circular 303 – Operational Opportunities to Minimize Fuel Use and Reduce Emissions

Recognizing the potential for emissions reductions from operational measures, ICAO/CAEP took it upon itself to ensure the development, dissemination, and to the maximum practical extent, the use of best operating practices to achieve near-term reductions in aircraft emissions. Operations covered are: aircraft ground-level and in-flight operations, ground service equipment (GSE), and auxiliary power units (APUs), with potential actions to facilitate their broader application. This task led to the preparation of ICAO Circular 303, and in 2001 the ICAO Assembly requested the Council to promote the use of operational measures as a means of limiting or reducing the impact of aircraft engine emissions.

The circular was developed by CAEP, with valuable contributions provided by representatives of the majority of aviation stakeholders, including the ICAO Secretariat, regulatory authorities, air traffic management providers, airport operators, manufacturers, airline associations and airlines.

The development of the circular focused on three key issues:

1. Quantification of the benefits of CNS/ATM measures;
2 Increased liaison with ICAO's planning and regional implementation groups to help maximize the emissions benefits of regional CNS/ATM implementation plans; and
3. Identification and discussion of operational opportunities in the air and on the ground for reducing fuel burn.

The circular identifies and reviews various operational opportunities and techniques for minimizing fuel consumption, and therefore emissions, in civil aviation operations. It is based on the premise that the most effective way to minimize aircraft emissions is to minimize the amount of fuel used in operating each flight. It is aimed at airlines, airports, air traffic management and air traffic control service providers, airworthiness authorities, environmental agencies, other government bodies, and other interested parties.

The circular begins by reviewing the impetus for minimizing fuel consumption in order to limit engine emissions. Next, opportunities for improvements at airports are considered. The circular then focuses on the historical record of fuel saving in the civil aircraft fleet and the anticipated continued improvement in aircraft fuel efficiency in future. This is followed by the identification of fuel-saving opportunities during ground-based activities before flight, including both maintenance and the reduction of aircraft mass. The possibilities for in-flight fuel saving are then considered, with particular focus on the input from airlines and air traffic services providers. The potential for increased efficiency through load factor improvement is then reviewed. Finally, some specific examples are provided of changes that each stakeholder (i.e. manufacturers, airlines, airports, air navigation service providers, airworthiness authorities, environmental agencies, other government bodies, and other interested parties) could consider in order to minimize the amount of fuel used.

Implementation of Circular 303

Each sector is responding to the challenge of the measures detailed in ICAO Circular 303, and a number of significant achievements have been made including:

Manufacturers:

Manufacturers of airframes and engines have a good record of environmental achievements. They are continually developing more efficient technologies and clean manufacturing processes, leading to the reduction and control of energy use, emissions, dangerous substances and waste.

The results have been substantial:

- 70% reduction in fuel consumption/CO_2 emissions per passenger/km;

- Oxides of nitrogen (NO_x) emissions have been progressively reduced to meet four successive increases in ICAO stringency standards;

- Carbon monoxide, hydrocarbons and smoke have been virtually eliminated.

These results have been achieved while pursuing noise reduction objectives and implementing noise reduction design features and technologies.

From a design and manufacturing standpoint, all manufacturers are pursuing technologies for reduced emissions in light of the environmental tradeoffs (e.g. noise). Improved aircraft and engine designs and methodologies, the use of composite and advanced materials and processes, and investigating options for alternative fuels are but a few of the many examples of how manufacturers are working to reduce aviation emissions.

From an operational standpoint, manufacturers are aware of and sensitive to the importance of the operational factors. Manufacturers provide guidance on optimal operating conditions so that the maximum environmental benefit from all design and technology advances incorporated into the product can be realized. This is achieved through several means, including: the design itself, ground and flight testing, training, specific documentation, as well as dedicated services to operators covering the domains of ground, flight, maintenance and overhaul procedures, and in particular:

1. Incorporating capabilities for monitoring, data analysis, collection and transfer into the engine and aircraft systems;
2. Supplying all relevant software tools, documentation and training (e.g. familiarization, starting before Entry Into Service);
3. Monitoring and supporting the in-service activities, including periodic and ad-hoc visits, audits and conferences, and taking any action necessary to adapt and improve further the product and procedures,
4. Supporting extensively the efforts made by ICAO to promote best practices to reduce fuel burn (e.g. documentation, workshops and other dedicated CAEP activities).

This of course also addresses the environmental interdependencies and tradeoff aspects in operations related to noise, fuel burn (climate), and NO_x (local air quality).

These efforts are part of the integrated systemic approach from the manufacturers to better manage the whole environmental subject, targeting simultaneously all fields of activity, every phase of product life, all parts of the aircraft, and every phase of aircraft operation (see previous article).

Airports:
One of the key environmental policies developed by member airports of the Airports Council International (ACI) is to minimize or mitigate the impact of aviation on climate change. ACI airports have committed to take action to minimize greenhouse gas emissions within their control and they support the development of technologies that will reduce aircraft emissions globally.

Some examples of actions being undertaken include:

- Hong Kong International experiences significant levels of air pollution from neighboring China. To reduce local contributions of emissions, the airport provides power and pre-conditioned air to aircraft at the terminal gates, significantly decreasing the need to run engines on the ground and the APU's (auxiliary power units). Such infrastructure is becoming commonplace at many Asian airports, following the lead of Europe and North America.

- In the US, many major airports are located in areas that do not comply with certain national ambient air quality standards. In these "non-attainment" areas, any airport capacity expansion project must be shown to not further impair a region's plans to achieve compliance. At Dallas-Fort Worth airport, 100% of the light and medium-size ground vehicles, including the bus and shuttle van fleet, and 72% of the heavy duty fleet, have been converted to alternative fuels. Together with the upgrade of the central heating plant, ground-based NO_x emissions have been decreased 95% in 10 years.

ACI intends to build on the considerable work being done at airports all over the world and, through encouraging the adoption of more environmental initiatives, play its own significant part in stemming the impact that aviation has on the environment. ACI, whose airport members account for over 95 percent of the world's passenger traffic, is in a position to continue making a real difference in this area.

Operators:
Currently, the single most effective way to limit aviation carbon dioxide (CO_2) emissions is to cut fuel consumption. On average, every minute of flight uses 60 litres of fuel and produces 160 kg of CO_2 emissions. Each kilogram of fuel saved reduces CO_2 emissions by 3.16 kg. Given that a US$ 1 per barrel increase in fuel prices adds US$ 1.4 billion to global aviation industry costs yearly, it is obvious that reducing fuel use brings both substantial environmental and economic benefits.

In 2000, member airlines of the International Air Transport Association (IATA) adopted a voluntary goal and committed to improving their fuel efficiency by 10% between 2000 and 2010. IATA airlines beat this goal ahead of time and in 2007 adopted a more ambitious goal to improve fuel efficiency 25% by 2020, relative to 2005. The saving in CO_2 emissions is projected to be about 345 million tonnes.

Achieving the IATA fuel efficiency goal will be predominantly driven by very significant investments in the continuous renewal of airline fleets. Increasing load factors also play an important part. The IATA goal does not however take into account additional operational and infrastructure improvements, which, if pushed beyond historical trends, could yield significant extra benefits. Recent initiatives, both by industry and by government, suggest that additional potential indeed exists.

IATA is compiling industry best practices, publishing guidance material, and establishing training programs for member airlines to improve existing fuel conservation measures.

IATA's Go Teams are at the heart of efforts to help airlines become more environmentally efficient. Since October 2005, Go Teams worked with 57 airlines to identify and implement fuel conservation initiatives that provided 6.6 Mt CO_2 savings. Each team consists of experts in the areas of flight operations, flight planning and ATC, and maintenance and engineering. Using IATA's manual, *Guidance Material and Best Practices for Fuel and Environmental Management*, the teams identify quick solutions and opportunities, including weight savings, reserve fuel planning, aircraft structure alignment (slats, flaps, doors), engine water wash, and aircraft flight management capability optimization.

In addition, IATA is working with ICAO, governments and air navigation service providers (ANSPs) to optimize flight routings. In 2006, this led to more than 350 route improvements in Africa, the Americas, Asia, and Europe, resulting in savings of 6 million tonnes of CO_2 emissions. Examples include:

- Shortened routes between Europe and China (IATA-1) eliminating 2,860 hours of flight time, 27,000 tonnes of fuel, and 84,800 tonnes of CO_2 per year.

- New route between Cairo and Tripoli, cutting 16 minutes of flight time and saving 7,000 tonnes of CO_2 per year.

- User-preferred routes for North Atlantic flights saving 4 to 7 minutes of flight time for some 180 flights per day, reducing 200 tonnes of CO_2 per year.

For 2007, IATA has identified 240 more routes where fuel and CO_2 benefits can be achieved.

IATA has also put the spotlight on efficiency gains in terminal operations: it has identified 80 airports where arrival, departure, and approach procedures can be improved using Required Area Navigation (RNAV) or Required Navigation Performance (RNP) resulting in significant environmental benefits.

Air Navigation Service Providers:
Air navigation service providers (ANSPs) are increasingly recognizing the importance of their contribution to mitigating the impact of aviation on the environment. They are fully committed to playing their part in minimizing the negative impacts of aviation on the local and global environment.

In May 2007, ANSP members of Civil Air Navigation Services Organization (CANSO) adopted a voluntary code of conduct which establishes a framework within which ANSPs can seek to offset the environmental impacts of growth through their own initiatives and collaboration with other industry stakeholders.

Over the last few years ANSPs have delivered substantial, quantifiable reductions in aircraft pollution levels through pioneering work to shorten routes, reduce delays, provide continuous descent approaches into airports, and optimize flight profiles through the introduction of reduced vertical separation minimum (RVSM).

Individually, their environmental programmes have provided major short-term gains in lowering fuel burn and decreasing emissions of greenhouse gases – examples include:

- In 2006 ANSPs cooperated with IATA to deliver improvements on over 350 routes yielding reductions in emissions of 6 million tonnes.

- Airservices Australia's "flextracks" programme enables aircraft to use the prevailing jet-stream conditions to fly more efficient routes. For example, one airline calculated it had saved 8 408 kg of fuel and 43 minutes of flying-time on a single service between the Middle East and Australia by diverting from the straight path to hitch a ride on the high-speed jet-streams.

- The use of continuous descent approaches/arrivals (CDAs) – allowing the pilot to set the aircraft engines to best-economy power setting using near minimum thrust during descent from cruise altitude and in the terminal area - can save between 100 and 300 kilos of fuel per flight. Forms of CDAs have already been implemented in a number of States and regions and are being tested for implementation in others

- The opening of new polar routes into Russian airspace has allowed aircraft to fly routes that are much shorter and more fuel efficient than previously. For example, a New York to Hong Kong flight routed over the Arctic will save five hours of flight time.

Government Regulators:
Many ICAO Member States are taking proactive approaches with ongoing work in areas related to en-route and terminal area operational measures to reduce aviation noise, local air quality impacts, and global climatic impacts. Specific examples include:

- Establishing multi-disciplinary domestic and international partnerships of aviation stakeholders and research institutions to do such things as expand the demonstration, implementation and adoption of operational measures. Examples include the Opportunities for Meeting the Environmental Challenge of Growth in Aviation (OMEGA) project in the United Kingdom, the Partnership for AiR Transportation Noise and Emissions Reduction (PARTNER) in the United States and Canada and, the European Network of Excellence, Environmentally Compatible Air Transport System (ECATS) in the European Commission.

- Including operational measures as part of domestic voluntary agreements for aviation emissions reduction. Canada, for example, has established a voluntary agreement for emissions reductions with its air carrier association. The agreement builds upon measures identified in the ICAO Circular and will result in a collective greenhouse gas emissions reduction of 24 per cent by 2012, when compared with 1990 levels.

- Conducting environmental studies to assess the domestic potential for improved operations. Italy, for example, has developed an environmental program to compute and assess that country's greenhouse gas emissions, in order to understand the extent of the problem, and to establish a baseline reference for assessing the benefits of implementating operational measures.

- Implementating air traffic efficiency measures. In the US, for example, measures implemented thus far have led to significant reductions including:
  1. Effective use of ground delays to balance demand versus capacity saved airlines approximately $150 million in fuel costs in 2006.
  2. Implementing the Airspace Flow Program (AFP) in 2006 saved customers more than 2.38 million delay minutes; equating to an estimated savings of about $98 million in delay costs, of which 20 to 30 percent of that cost was fuel.
  3. Installing the User Request Evaluation Tool (URET) at en-route air traffic control facilities in 2006 which has increased airspace capacity and enhanced fuel conservation, and saved customers more than 25.6 million nautical miles of distance traveled and $40 million in fuel expenditures in 2006 alone.

ICAO Member States are also conducting much needed research and testing to expand the scope of application for operational measures, both domestically and internationally.

Workshops and Colloquia

ICAO has been actively promoting measures referenced in Circular 303. Detailed presentations have been made at three ICAO Workshops on Aviation Operational Measures for Fuel and Emissions Reductions:

- Montreal, Canada, 20-21 September 2006.

- Ottawa, Canada, 5-6 November 2002.

- Madrid, Spain, 21-22 May 2002.

The workshops included panels on aircraft maintenance, air traffic management, flight operations and airport operations. Presentations from these workshops can be found on the ICAO website at http://www.icao.int/icao/en/env/workshops.htm

ICAO also promotes the benefits of operational measures when it is invited to speak at international forums on aviation environmental protection. A presentation on operational measures was also made at the May 2007, ICAO Colloquium on Aviation Emissions that focused on aviation emissions. Presentations from the colloquium can be found on the ICAO website at http://www.icao.int/EnvClq/Clq07/Index.html

An ongoing program of similar workshops and colloquia is currently under development.

Summary

As demonstrated in the foregoing article, operational measures present advantages over other methods of addressing aviation-related emissions in several important respects.

- Operational measures provide not only an effective and quantifiable means, but also a near-term way, of minimizing aircraft emissions.

- Operational measures may also present fewer of the legal, economic and technical challenges (e.g. engine redesign and replacement or modification) that are associated with other approaches.

- Adoption of the most efficient operational flight procedures may involve tradeoffs with other aviation environmental impacts. These tradeoffs can be significant and must be taken into account.

The identification, development and implementation of operational measures by aviation stakeholders are being actively promoted as part of the international effort to reduce the impact of emissions from civil aviation on the global atmosphere.

ICAO's ATM Operational Concept and Global Air Navigation Plan Support Fuel and Emissions Reductions

By ICAO Secretariat

ICAO is the driving force for the ongoing development of a global air traffic management (ATM) system that meets agreed levels of safety, provides for optimum economic operations, is environmentally sustainable, and meets national security requirements. Achieving such a worldwide ATM system will be accomplished through the implementation of many initiatives over several years on an incremental basis. With the increased focus on aviation environmental concerns in recent years, it is recognized that the ATM operational concept needs to contribute to the protection of the environment by considering noise, gaseous emissions and other environmental issues along with operational issues in the development, implementation and operation of the global ATM system. This article explains the background of the global operational concept and illustrates how it takes into account aviation environmental concerns and priorities.

Global ATM Operational Concept

ICAO efforts to continually improve the Air Traffic Management (ATM) system are focused on the Global Air Traffic Management Operational Concept. The vision of the operational concept is to achieve an interoperable global air traffic management system, for all users during all phases of flight, that meets agreed levels of safety, provides for optimum economic operations, is environmentally sustainable and meets national security requirements. The Concept was endorsed by the Eleventh Air Navigation Conference in 2003 and is now an important part of all major ATM development programmes including NexGen of the United States and the European SESAR. The operational concept contains an important performance measurement framework.

The global ATM system envisaged in the concept, is one in which aircraft would operate as closely as possible to their preferred 4-dimensional trajectories. This requires a continued effort toward removal of any and all ATM impediments.

Performance-Based Transition Guidance

The operational concept recognizes that reaching the desired "end-state" cannot be achieved by revolution; rather, it will be an evolutionary process, with an ultimate goal of global harmonization. This will allow States, regions and homogeneous areas to plan the significant investments that will be needed, and the timeframe for those investments, in a collaborative decision-making environment.

Rather than emphasizing improvements solely in the areas of efficiency or safety as the sought after outcome, the operational concept recognizes that competing interests for the use of airspace will make airspace management a highly complex exercise, necessitating a process that equitably balances those interests. Each of those interests must be considered on the basis of a weighted "desired outcome contribution". The environment is certainly one of the outcomes that must be considered.

In an effort to assist planners in weighing outcomes and making appropriate decisions, the manual on *Performance Based Transition Guidelines* (PBTG) was developed. The PBTG supports an approach to planning based on performance needs, expected benefits, and achievement timelines. Such explicit management and planning of ATM performance will be needed to ensure that throughout the transition process the expectations of the entire community are met.

The Global Air Navigation Plan and the Planning Process

To assist States and regional planning groups in identifying the most appropriate operational improvements and also to support implementation, the Global Air Navigation Plan has been revised so that it clearly describes a strategy aimed at achieving near- and medium-term ATM benefits on the basis of available and foreseen aircraft capabilities and ATM infrastructure. On this basis, planning will be focused on specific performance objectives, supported by a set of "Global Plan Initiatives". States and regions choose initiatives that meet performance objectives, identified through an analytical process, specific to the particular needs of a State, region, homogeneous ATM area, or major traffic flow. Development of work programmes must be based on the experience and lessons learned in the previous cycle of the CNS/ATM implementation process. The Global Plan therefore, focuses efforts toward maintaining consistent global harmonization and improving implementation efficiencies by drawing on the existing capabilities of the infrastructure and successful regional implementations over the near- and medium-terms.

Achieving the desired global ATM system will be accomplished through the implementation of many initiatives over several years on an evolutionary basis. The set of initiatives contained in the Global Plan are meant to facilitate and harmonize the work already underway within the regions and to bring needed benefits to aircraft operators over the near-and medium-term. ICAO will continue to develop new initiatives on the basis of the operational concept which will be placed in the Global Plan. In all cases, initiatives must meet global objectives. On this basis, planning and implementation activities begin with the application of available procedures, processes and capabilities. The evolution progresses to the application of emerging procedures, processes and capabilities, and ultimately, migrates to the ATM system based on the operational concept.

Table 1 – Global plan initiatives and their relationships to the major ATM functional areas.

GPI		En-route	Terminal Area	Aerodrome	Supporting Infrastructure
GPI-1	Flexible use of airspace	X	X		
GPI-2	Reduced vertical separation minima	X			
GPI-3	Harmonization of level systems	X			
GPI-4	Alignment of upper airspace classifications	X			
GPI-5	RNAV and RNP (Performance-based navigation)	X	X	X	
GPI-6	Air traffic flow management	X	X	X	
GPI-7	Dynamic and flexible ATS route management	X	X		
GPI-8	Collaborative airspace design and management	X	X		
GPI-9	Situational awareness	X	X	X	X
GPI-10	Terminal area design and management		X		
GPI-11	RNP and RNAV SIDs and STARs		X		
GPI-12	Functional integration of ground systems with airborne systems		X		X
GPI-13	Aerodrome design and management			X	
GPI-14	Runway operations			X	
GPI-15	Match IMC and VMC operating capacity		X	X	X
GPI-16	Decision support systems and alerting systems	X	X	X	X
GPI-17	Data link applications	X	X	X	X
GPI-18	Aeronautical information	X	X	X	X
GPI-19	Meteorological systems	X	X	X	X
GPI-20	WGS-84	X	X	X	X
GPI-21	Navigation systems	X	X	X	X
GPI-22	Communication infrastructure	X	X	X	X
GPI-23	Aeronautical radio spectrum	X	X	X	X

All regions have well established implementation plans in place and are progressing with their individual work programmes.

Performance and the Environment

A key tenet of the operational concept is its performance orientation. The concept contains 11 expectations of the international ATM Community which can also be described as key performance areas. The ATM system performance requirements should always be based on the key understanding that the ATM system is the collective integration of services, humans, information and technology.

Members of the ATM community will have differing performance demands of the system. All will have either an explicit or implicit expectation of safety. Some will have explicit economic expectations, others efficiency and predictability, and of course others will have as their main concern, the environment. For optimum system performance, each of these sometimes competing expectations will need to be balanced. Interests must be considered on the basis of a weighted "desired outcome contribution". As stated previously, the environment is certainly one of the outcomes to be considered. The operational concept outlines a total system performance framework to assist in the process.

The operational concept recognizes that the ATM system should contribute to the protection of the environment by considering noise, gaseous emissions and other environmental issues in the implementation and operation of the global ATM system.

The means and tools to establish performance targets and measure performance are under development by several groups both within and outside of ICAO. It is important now that these groups begin a dialogue where there is overlap in order to: make maximum use of available expertise, produce synergy, avoid misunderstanding and conflicting goals, and ensure the establishment of realistic targets and effective measurement.

Reduced Vertical Separation Minimum

Reduced Vertical Separation Minimum (RVSM) was first implemented in 1997 in the airspace of the North Atlantic followed by Europe, the Pacific, Asia, the Middle East, the Europe/South America corridor, the Caribbean and South and Central American Regions. RVSM facilitates a more efficient use of airspace and provides for more economical aircraft operations because it allows aircraft to operate closer to their preferred levels thereby reducing fuel burn. Implementation continues, and RVSM will soon cover all airspace around the world.

A cost-benefit analysis in the North Pacific showed a 0.5% to 1.0% reduction in fuel cost for a saving of approximately US $8 million per year for aircraft using this form of airspace. In Europe, it is estimated that RVSM saves airlines close to $60 million annually. In the Caribbean and South and Central American Regions, airlines will save approximately $400 million over a 15-year period for international flights due to RVSM, while for North America the fuel-saving benefits are estimated to be approximately US $5.3 billion for the same period.

Following the implementation of RVSM in the European Region in January 2002, the "Environmental Studies" Business Area of the EUROCONTROL Experimental Centre performed an analysis focusing on the environmental aspects and concluded that RVSM implementation led to significant environmental benefits. The report states that total NO_x emissions were reduced by 0.7 – 1% which represents about 3 500 tons less NO_x per year emitted by aviation into the atmosphere. Sulphur oxide emissions were reduced by around 260 tons per year and total fuel burn, CO_2 and H_2O emissions were reduced by 1.6 – 2.3%., which translates into reduced costs for airlines operating in the EUR RVSM area of up to 310,000 tons of fuel per year. The reports goes on to state that the environmental benefits were even more positive for the high altitude band along and above the tropopause, between 8 and 10 kilometres. At these flight levels NO_x emissions were found to be reduced by as much as 2.3 - 4.4%, fuel burn and directly proportional emissions like CO_2, SOx and especially H_2O were reduced by 3.5 – 5.0%.

ICAO's role in supporting the realization of RVSM was and continues to be significant. From the detailed safety related work of the Review of the General Concept of Separation Panel (RGCSP), now known as the Separation and Airspace Safety Panel (SASP), the development of standards and supporting guidance material, to the extensive planning and safety assessments conducted by the regional planning groups; RVSM could not have been implemented globally without ICAO leadership.

An important lesson learned from the success of RVSM is that improving efficiency leads to environmental benefits. We should therefore continue working toward the establishment of a common performance framework, establishing environmental and efficiency targets and developing the methods to measure outcomes.

Rules of Thumb For Emissions Modelling

ICAO/CAEP has been involved in the development of computer-based models to assess the environmental benefits for CNS/ATM Systems implementations since 1998, and the committee continues to support the development of the sophisticated models capable of undertaking these assessments (see Part 5 of this report).

However, to help States make initial estimates of savings accrued from the implementation of measures such as RVSM, and to harmonize the approaches for converting fuel savings into emissions savings, CAEP prepared some initial "rules of thumb" that are summarized below.

To gain a "first-order estimate" of the environmental benefits of potential CNS/ATM changes in order to assess which options to carry forward, a less accurate, rough-and-ready method may be all that is necessary. Statistics relating to fuel burn and emissions are critically dependent on aircraft and engine types, operating procedures, air traffic management constraints, passenger and cargo loading, maintenance procedures, fleet utilization, and other factors. Without more detailed analysis, it is impossible to be specific about the performance of any particular aircraft or airline. The first order approximation approach used is therefore only intended to provide broad-based information for very general planning and assessment purposes. The two general estimates provided below are based on common statistics and assumptions and were provided by IATA/ICCAIA. Each of these may be applied more broadly as a "rule of thumb" to obtain order of magnitude estimates:

Average fuel burn per minute of flight = 49 kg

Average fuel burn per nautical mile (NM) of flight = 11 kg

Table 1 shows average additional fuel burn for a change in flight level (FL)[1]:

Table 1 – First-order estimates of average fuel burn penalties for changes in flight level compared to an assumed optimum altitude.

FL change	Average S.R.* penalty	Average fuel burn penalty	Average fuel burn penalty per hour**	Average fuel burn penalty per 100 NM
ft	%	%	kg	kg
-6000	9,1	10,0	301	110
-5000	6,5	7,0	209	77
-4000	4,5	4,7	141	52
-3000	3,0	3,1	92	34
-2000	1,5	1,5	45	17
-1000	0,5	0,5	15	6
0	0,0	0,0	0	0
1000	0,5	0,5	15	6
2000	1,6	1,6	47	18

*S.R. = Specific Range = distance flown per unit weight of fuel burned ** time-corrected

[1] In order to minimize fuel burn, an aircraft should be flown at its optimum altitude. In reality, the optimum altitude changes during flight. In this table, the flight level change is relative to the optimum altitude (referred to as zero "0").

The average range in fuel burn increase mentioned in ICAO Circular 303 *Operational Opportunities to Minimize Fuel Use and Reduce Emissions* is generally in line with the estimated percentages shown in Table 1. When making fuel burn penalty estimations using Table 1, it should be noted that the numbers are based on the general assumption that the cruise phase of the flight is, on average, representative of the entire flight.

Detailed Modelling

Detailed modelling is appropriate when accuracy is essential; however, it is resource intensive and relatively complex. This methodology is distinguished by the calculation of fuel burn and emissions throughout the full trajectory of each flight segment using aircraft and engine-specific aerodynamic performance information. To use this methodology (IPCC Tier 3B), sophisticated computer models are required to address all the equipment, performance and trajectory variables and calculations for all flights in a given year. Models used for Tier 3B level can generally specify output in terms of aircraft, engine, airport, region, and global totals, as well as by latitude, longitude, altitude and time, for fuel burn and emissions of carbon dioxide (CO_2), carbon monoxide (CO), unburned hydrocarbons (HC), nitrogen oxides (NO_x), water (H_2O), and sulfur oxides (SOx calculated as sulfur dioxide, SO_2).

Examples of these types of modelling tools are AEM, AERO2K and SAGE. These, and other models are discussed in detail in Part 5 of this report.

Conclusions

The aviation community has been working on ATM operational improvements steadily since the 1920s. The work accelerated with the onset of CNS/ATM systems. Technology development has been more rapid in recent years and improvements are now occurring even more quickly.

A major operational improvement was the implementation of the Reduced Vertical Separation Minimum (RVSM) system, which yielded significant operational benefits to aircraft operators in terms of reduced fuel burn, availability of optimal flight levels, increased capacity, as well as significant spin-off environmental benefits.

ICAO has a central role to play in planning for the implementation of operational improvements. In addition to developing the necessary standards and guidance material, ICAO has developed a global ATM Operational Concept that has been widely endorsed and used as the basis for planning. ICAO also provides the planning framework through the Global Air Navigation Plan and several other documents and tools that support planning and implementation efforts. Sophisticated computer models are under development to assess the environmental benefits accrued through implementation of the various initiatives.

Every ICAO Region has a list of identified performance objectives and has developed work programmes to bring near- and medium-term benefits, while integrating those programmes with the extensive work already accomplished.

An important lesson learned from the success of RVSM is that the environmental and efficiency missions can be achieved in parallel. We should therefore, continue to work together even more closely towards the development of a common performance framework, establishing joint environmental and efficiency targets, and developing methods to measure performance outcomes.

Market-Based Measures

Overview Of CAEP/5 Analysis of Market-Based Measures

By Nancy Young and Michael Mann

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This article provides an overview of the economic analysis that was conducted by the Forecasting and Economic analysis Support Group (FESG) of ICAO's Committee on Aviation Environmental Protection (CAEP) for its fifth meeting (CAEP/5) in January 2001. That analysis was done into the various market-based measures that might be used to reduce carbon dioxide (CO_2) emissions from aviation.[1] The analysis focused on the economic and environmental impacts of three types of market-based measures: emissions trading, environmental levies, and voluntary measures. To conduct the analysis, ICAO/CAEP used the Aviation Emissions and Evaluation of Reduction Options Modelling System (AERO-MS), developed by the Government of the Netherlands (see Part 5).

The work was performed by ICAO/CAEP in response to provisions in ICAO Assembly Resolution A32-8, under which the ICAO Assembly called for the ICAO Council, through CAEP, to assess policy options, including "an en-route levy or a fuel levy to address global emissions ...and on other market-based measures such as emissions trading." Since no specific policy measure was defined by the ICAO Assembly for study, ICAO/CAEP established the parameters of the study through a consensus process.[2]

Background

For the purposes of the analysis, the three types of market-based measures were assessed against three alternative hypothetical emissions reduction targets, which were defined by ICAO/CAEP. The most stringent target was an actual overall reduction of 2010 emissions to 95% of their 1990 level, roughly in line with the average of targets for ICAO Member States under the Kyoto Protocol climate change treaty. The two other emission targets were 50% and 25% in projected emissions increase between 1990 and 2010. To perform the analysis, a base case was established first, projecting what fuel burn and emissions might be expected without market-based measures. Based on forecast inputs provided by ICAO/CAEP's FESG, the AERO-MS model estimated that in the base case (with no additional policy action) global air traffic would increase by 85% between 1992 and 2010, while total fuel use would increase by only 40%, reflecting improved aircraft fuel efficiency over that period. As the amount of fuel burned has a direct relationship to the amount of CO_2 that is released, projecting expected fuel burn and resulting emissions was important for identifying the potential effects of the various market-based measures.

To conduct the analysis, FESG had to identify and agree on various assumptions. Important among these was that total air transport demand (in the base case), measured in terms of revenue ton kilometres (RTKs), would increase at an average annual growth rate of 5.25%, while airport and airspace capacity to meet that projected demand would be unconstrained. The analysis also assumed that all cost increases to airlines due to market-based measures would be fully passed on to customers through higher passenger fares and freight rates. FESG also had to establish agreed figures for price elasticity of demand and projected fuel efficiency improvements. So as to not unduly complicate the analysis, and so that the potential effects of the market-based measures could be isolated, FESG assumed that fuel prices would remain constant over the study period.

[1] This article reports FESG's work, as presented in its CAEP/5 working paper, "Economic Analysis of Potential Market-Based Options for reduction of CO2 Emissions from Aviation," CAEP/5-WP/24.

[2] CAEP had established a dedicated working group, "Working Group 5," to study potential market-based options. This group developed the design parameters for the options subject to analysis. Working Group 5's work is presented in the information paper presented to CAEP/5 entitled "Market-Based Measures, report from Working Group 5 to the Fifth Meeting of the Committee on Aviation Environmental Protection," CAEP/5-IP/22.

Michael Mann is an independent economic consultant working mainly on aviation environmental issues. Before that, Michael worked in the UK Department for Transport for 18 years as head of the economics division covering aviation and maritime policy. He has been involved with ICAO's Committee on Aviation Environmental Protection (CAEP) since 1993, doing work on forecasting, modelling, and economic analysis of environmental policy options.

Measures Evaluated

Once the market-based measures and CO_2 reduction targets to be assessed were defined, and the study assumptions were agreed, the analysis of the three types of market-based measures commenced. Below is a description of these measures, followed by a summary of the study findings.

Emissions Trading

Under a CO_2 emissions trading system, an overall target or cap is set and a market for carbon is established, allowing participants to buy and sell permits, the price of which is set by the market place. If the CO_2 abatement costs that face participants are lower than the permit price, they will have an incentive to take abatement actions to meet any targets applicable to them and to try to generate permits they can sell. If abatement costs facing a particular participant exceed permit prices, that participant will have an incentive to buy permits to meet their targets, rather than taking the more expensive abatement actions. Under an open emissions trading system, aviation would be free to trade with other sectors that are included within the scheme. A closed trading system on the other hand, would be limited to the aviation sector. Under a trading system, the environmental impact will be determined by the cap that is set, while the economic impact will depend on the level of permit prices. The CAEP analysis assessed both open and closed emissions trading.

Environmental Levies

Environmental levies include taxes and charges with the objective of creating an economic incentive to reduce emissions. In essence, taxes and charges raise costs to the airlines. To the extent that these costs are passed on to the consumer, they can have the effect of reducing demand (i.e., reducing flying, and therefore the emissions from flying). Alternatively, or in addition, taxes and charges can induce the adoption of abatement measures, to the extent that those measures are less costly than enduring the full effect of the tax or charge that would otherwise be applied. So, in this case the economic impact will be determined by the level of the charge or tax set, while the environmental impact will depend on the extent to which the tax or charge induces emissions-reducing behaviour. The measures considered in the CAEP analysis included a fuel tax, an en-route emissions tax, and en-route emissions charges with proceeds recycled to the aviation sector. A revenue neutral en-route emissions charge was also tested.

Voluntary Measures

Voluntary measures can involve unilateral action by industry or agreement between industry and government to reduce emissions beyond a base case. They are similar to emissions trading in that they typically are based on an overall cap on emissions, but, unlike with trading, the cap is not always enforceable. Voluntary measures to limit or reduce emissions might include such things as voluntary emissions trading, carbon offsets, operational changes, and/or technology investments. However, given that the emission reduction targets set in the study were observed to require "very costly" measures that "would induce significant demand effects," specific voluntary measures were not fully analyzed, because it was believed that industry would not voluntarily agree to actually meet such targets. Thus, after initial screening analysis, only a "hybrid" voluntary agreement scenario, combining voluntary early aircraft retirement with open emission trading, was subjected to detailed analysis.[3]

Key Findings

The emissions trading measures were tested using several allowance prices, ranging from \$5 to \$100 per tonne of CO_2. Two alternative mechanisms for distributing allowances to airlines were used: auctioning (airlines must purchase all permits needed to cover their emissions, including baseline emissions), and grandfathering (distribution of permits up to a certain baseline free of charge). Of the market-based measures studied, an open emissions trading system, whereby aviation is free to trade with other sectors, was found to be the most economically efficient approach for achieving CO_2 emission reduction targets. The open system had relatively modest impacts on airline costs and demand, when compared with the impacts from taxes and charges. For example, with allowances auctioned at an allowance price of \$25, there would be a 2.5% demand reduction and \$17bn per year (1992 US\$) increase in airline costs to meet the least stringent target

[3] A description of the screening process and of the findings regarding the screening process are presented in FESG's detailed information paper, "Report on Economic Analysis of Potential Market-Based Options for Reduction of CO_2 Emissions from Aviation," CAEP/5-IP/9, which also was presented at CAEP/5. The quotations here are from Section 6.1.12 of that paper.

of a 25% reduction in the growth of emissions. With allowances grandfathered, the demand reduction for this target is estimated to be 1% and the cost penalty is reduced by 90%, with a \$1.6bn annual increase in airline operating costs.[4] Among the measures studied, an open emissions trading system was found to be the only way to achieve the most stringent targets under the assumptions applied,[5] with all other options giving rise to substantially greater increases in airline costs as well as demand reductions.

With aviation expected to be a net purchaser of permits due to the high cost of abatement action within the sector,[6] most of the emissions reductions would be achieved by other sectors, particularly under scenarios where allowance prices were assumed to be low. As noted above, including different sectors in one scheme encourages efficient behaviour (in this case, encouraging those who can reduce emissions at lower costs to do so), providing a more cost-effective way of reducing emissions than if the measures employed are limited to the aviation sector. This explains why the impact on airline costs and traffic levels is less pronounced under open emissions trading than with environmental levies.

A closed emissions trading system limited to the aviation sector was found to be less economically efficient and not capable of achieving stringent emissions targets under the permit prices assumed. Although this mechanism works differently from emissions-related levies, its economic and environmental impacts would be identical to that of environmental levies.

If environmental levies are used to achieve the study's CO_2 reduction targets, they would need to be set at very high levels. For example, to meet the most stringent Kyoto Protocol reduction target (a 5% reduction from 1990 emission levels), a fuel or en-route emissions levy would need to be set at around 8 times the fuel price used in the base year (1992). An environmental levy of this scale was found to have substantial implications for airline costs (up by almost 80%), with demand reductions of around one third, arising from higher ticket prices. Even under the most relaxed emission reduction target, a levy equivalent to doubling the fuel price would be required. Analysis showed that the cost of meeting the three targets was between \$47bn and \$245bn per year in 1992 US\$.

Where the proceeds of environmental levies were assumed to be re-channelled back into the aviation industry to provide an incentive for more rapid fleet replacement, the adverse effects on demand and airline operating costs were somewhat dampened. The analysis showed that such a system would be a viable option for achieving the less stringent targets analysed. Options identified, but not considered in any detail, for re-channelling proceeds included their use for: accelerated retirement of older aircraft, funding technology improvements, and improving ATC systems to reduce delays.

A revenue neutral CO_2 charge, whereby less fuel efficient aircraft would pay higher en-route charges, with compensating savings for more fuel efficient aircraft, was found to result in only modest reductions in CO_2 emissions. Such an instrument would only be feasible for achieving more relaxed emission reduction charges than considered in this study.

A combined/hybrid system of voluntary measures to retire old aircraft early and open trading was found to be less efficient than open trading on its own, but more efficient than environmental levies. Because of the high cost of implementing abatement measures within the aviation sector, the study found that voluntary measures on their own would likely achieve only the more relaxed targets.

To the extent that a particular market-based measure aimed at reducing CO_2 has the effect of reducing demand, the study noted that it would also result in a reduction of other emissions such

[4] To meet the Kyoto-like target of a 5% reduction in emissions from a 1990 baseline, open emissions trading was estimated to cost \$63 billion annually, if permits were auctioned.
[5] A key assumption in this regard was that the airlines would have full access to emissions permits, although the source of those permits was not identified.
[6] Abatement actions by the airlines are projected to be more costly due to several factors, including the fact that airlines already are motivated by the high cost of jet fuel (typically, the greatest or second greatest cost center for an airline, next to labor) to be highly fuel efficient, and the current unavailability of viable alternative fuels or carbon sequestration options.

as oxides of nitrogen (NO_x). However, the study noted that operational or technology-related abatement measures taken in response to such policies may have adverse effects in increasing NO_x and noise, as there are interrelationships between these parameters in aircraft operation.

Where targets are applied regionally, for example assumed to apply only to developed countries, environmental benefits were found to be correspondingly smaller, and the risk of economic distortions caused by such actions as destination switching and tankering of fuel, as well as potential competitive distortions, were identified.

Summary

In response to a request from the ICAO Assembly, CAEP performed an extensive assessment of the relative economic and environmental impacts of various market-based measures that might be employed to limit or reduce CO_2 emissions. While this analysis was concluded in 2001, CAEP has reaffirmed the validity of this work since, subject to the assumptions used.

Under the analysis, “open emissions trading” was found to be the most economically efficient approach, as compared with taxes and charges and voluntary measures for meeting the specified targets and the only viable one capable of meeting the most stringent (Kyoto Protocol) emission reduction targets. Under this measure, a significant part of the emissions reductions would be realized outside of aviation, with aviation likely to be a net buyer of emissions from other sectors, unless allowance prices were extremely high.

Environmental levies (taxes or charges) would need to be set at very high levels to meet stringent CO_2 reduction targets, with substantial increases in airline operating costs and demand reductions arising from higher ticket prices. Where the proceeds of levies were assumed to be re-channelled back to the airline industry, for example to enable more rapid fleet replacement, these impacts were somewhat dampened and this was found to be a potentially viable measures for achieving the less stringent targets.

For targets less restrictive than those used in the analysis, a revenue neutral charge and voluntary agreements were found to be viable options.

Overview of ICAO Guidance on Emissions Trading

By Andreas Hardeman
and Kalle Keldusild

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This article presents a brief overview of the guidance material that ICAO has developed on emissions trading to assist Contracting States in developing and implementing their own aviation emissions trading schemes, and it offers some advice and practical information they might be able to use.

International Aviation and Emissions Trading

Pressure on the world community to address climate change issues is continuously increasing. Although aviation's share is relatively small, the contribution from the aviation sector is growing in relation to the total global impact on climate change from other sectors. In evaluating alternative approaches to addressing aviation's impact on the global climate, relative to other market-based measures, it was decided at the fifth meeting of ICAO's Committee on Aviation Environmental Protection (CAEP) that an emissions-trading system would be a cost-effective measure to limit or reduce CO_2 emitted by civil aviation in the longer term, provided that the system is an open one across economic sectors[1]. This potential for open emissions trading was also recognized when the Kyoto Protocol to the UNFCCC laid the groundwork for an international open emissions trading scheme via the inclusion of Article 17.

There are a number of reasons why the inclusion of international aviation in an emissions trading scheme is challenging. One issue, which has been controversial throughout the work of ICAO CAEP, is the geographic scope. Including emissions from stationary sources is geographically simple, because emissions physically occur within the territory of a given State. However, this is not the case for emissions from non-stationary sources, such as from international aviation, which by definition is not geographically contained wholly within one State. This certainly adds complexity in designing an emissions trading scheme including aviation.

Furthermore, unlike domestic aviation, international aviation is not listed in Annex A to the Kyoto Protocol and is not a sub-category of any other source listed. Therefore, emissions from this activity are not taken into account in the calculation of assigned amounts of Annex I Parties and are not subject to the limitation and reduction commitments of Annex I Parties under the Kyoto Protocol. Article 2.2 of the Kyoto Protocol states that Parties "included in Annex I shall pursue limitation or reduction of emissions of greenhouse gases not controlled by the Montreal Protocol from aviation…bunker fuels, working through the International Civil Aviation Organization".

The exclusion of international aviation emissions from assigned amounts under the Kyoto Protocol means that their inclusion in emissions trading under Article 17 of the Kyoto Protocol is not provided for. In addition, the UNFCCC and Kyoto Protocol confer no guidance in relation to emissions trading schemes that are not provided for in either of these agreements, such as those developed by Parties or groups of Parties.

It is obvious from the description above that ICAO CAEP had a most challenging assignment and furthermore it was a complex and new area in many other ways, with little or no experience to build upon, in particular with respect to aviation participation. Nevertheless, it succeeded in presenting a clean draft guidance document to CAEP/7 (February 2007) thanks to the combination of mixed expertise, hard and constructive work and the willingness to compromise. CAEP agreed to recommend to the ICAO Council that it adopt the guidance on emissions trading for aviation and publish it prior to the forthcoming Assembly.

After subsequent intense discussions, the Council decided to publish the guidance document as a draft document with a foreword by the President of ICAO emphasizing that there are different views on the issue of geographic scope in the Council on whether Contracting States could integrate international aviation emissions from aircraft operators from other Contracting States without their agreement. The President concluded his foreword by stating that "In line with the emphasis from the last Session of the Assembly on ICAO taking a leadership role in all aviation matters related to the environment, I believe that this guidance material is an important step in advancing our knowledge of possible alternative

[1] "Market-Based Measures:" Report from Working Group 5 to the fifth meeting of the Committee on Aviation Environmental Protection. CAEP/5-IP/22. 5/01/01.

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measures to address aviation emissions and provides the basis for sound discussions, deliberations and decisions as a way forward on emissions trading at the upcoming 36th Session of the ICAO Assembly."

Guidance On Emissions Trading

The scope of the guidance material extends exclusively to international civil aircraft operations and does not include State aircraft, which covers military, customs, and police services. The guidance focuses on those aspects of emissions trading that require consideration with respect to aviation-specific issues; it identifies options and offers potential solutions where possible.

The guidance on emissions trading is not of a regulatory nature. It is recognized that the guidance material may not provide the level of detail necessary to assist ICAO Contracting States in addressing every issue that might arise, given that there may be unique legal, technical or political situations for particular States. It is therefore advised that ICAO Contracting States use the guidance material as supporting material, to be shaped and applied to specific circumstances. It is a new area and the guidance may need to be revised as the world of emissions trading and aviation develops over time.

> The guidance on emissions trading addresses the aviation-specific options for the various elements of trading systems, such as:
>
> - Accountable entities
> - Emission sources included
> - Emission species included
> - International and domestic emissions
> - Geographical scope (jurisdiction)
> - Trading units (integration and linking)
> - Types of trading systems
> - Allowance distribution (benchmarking)
> - Monitoring, reporting, verification, and enforcement

Each of these elements is briefly addressed below. For more detailed information the guidance material and its glossary are available on the ICAO website at:
http://www.icao.int/icao/en/env/document.htm.
In addition, the ICAO website offers more general material on emissions trading at:
http://www.icao.int/icao/en/env/aee.htm.

Accountable Entities

Possible accountable parties discussed are: aircraft operators, fuel suppliers, air navigation service providers, airport operators, and aircraft manufacturers.

The guidance recommends that the aircraft operator should be selected as the entity that is accountable for emissions from international aviation.

Emission Sources and Inclusion Threshold

The guidance recommends that obligations under the scheme implemented should be applied on the basis of the total aggregated emissions from all applicable flights performed by each aircraft operator included in the scheme. To establish an adequate balance between emissions coverage and administrative burden regarding "small operators" the guidance recommends that States consider applying an inclusion threshold for aircraft operators based on aggregate air transport activity (e.g. CO_2 emissions) and/or aircraft weight.

Emissions Species Included

The guidance recommends that States start with an emissions trading scheme that includes CO_2 alone, while not precluding inclusion of other non-CO_2 aircraft emissions that contribute to climate change, as scientific understanding of their effects evolves.

International and Domestic Emissions

The guidance recommends that States use the IPCC (Intergovernmental Panel on Climate Change) definition of international and domestic emissions for the purposes of accounting greenhouse gas emissions as applied to civil aviation as States' reporting obligations in the UNFCCC process are based on the IPCC definition.

Geographic Scope

This was the most controversial issue. Based on advice from the Council, the guidance material outlines advantages and disadvantages regarding approaches for inclusion of foreign aircraft operators in the scheme. One approach is for inclusion through mutual agreement between the State or States responsible for administering the scheme. The other approach is that State(s) operating a scheme that would seek the inclusion of foreign aircraft operators without distinction as to nationality.

Also discussed in the document are different options for the architecture of geographic coverage based on routes, as well as on airspace.

Trading Units (Integration & Linking)

As international aviation emissions are not covered in national Kyoto Protocol inventories, options are discussed on how to integrate international aviation emissions in a scheme open to other sectors in consideration of the current Kyoto accounting system. The general assumption is that aviation is a net buyer of allowances. Several linking options are discussed: borrowing of AAU's (Kyoto allowances), no allocation of allowances, buying of allowances above non-tradable baseline or above tradable baseline. Gateway or clearing house mechanisms[2] can be considered if it is deemed necessary to prevent net selling of aviation allowances into the scheme. Whatever the choice, States are advised to put in place an accounting arrangement that ensures that emissions from international aviation are counted separately and not – whether deliberately or inadvertently – against the specific reduction targets that States may have under the Kyoto Protocol.

Types Of Trading Systems

This discussion includes different trading systems such as: cap and trade systems, credit systems, absolute and relative trading systems, and project-based mechanisms such as the clean development mechanism (CDM) and joint implementation (JI) under the Kyoto Protocol. Different approaches to generate a baseline or a cap for aviation are discussed as well.

Allowance Distribution Through Benchmarking

Aircraft operators may receive their allowances at the start of a trading period either from auctioning or through amounts distributed by the authority. Auctioning or grandfathering allowances based on historic emissions are not aviation-specific issues. The guidance therefore focuses on benchmarking as a distribution method applied to aviation under a benchmarking approach whereby allowances are distributed according to a specific formula based on a benchmark parameter that reflects the amount of emissions in relation to a level of activity representative of the sector.

A range of potential methodologies and parameters can be considered, including using revenue ton kilometers (RTK) or available ton kilometers (ATK).

Where States choose benchmarking over grandfathering or auctioning, the guidance recommends that a benchmark parameter be designed that: focuses on emissions performance of aircraft, rewards previous investments in new technology, provides incentives to operate the most emissions efficient aircraft in the most efficient way into the future, and avoids unintended distributional effects between different business models as much as possible.

Monitoring, Reporting, Verification, and Enforcement

Monitoring and reporting of emissions is an important element of any trading system and is indeed aviation specific. For monitoring and reporting the guidance recommends that, when possible the method with the highest accuracy should be applied. Calculations based on actual trip-fuel data relating to each individual flight is the preferred option and should perhaps be encouraged. Both the accuracy of the reported data as well as the environmental effectiveness of the emissions trading system would benefit from this approach.

If actual trip-fuel data cannot be easily obtained, emission modelling techniques can be used to calculate estimates. The level of detail for data can range from actual flight movement data with full flight trajectory information, to origin and destination data. For those trading entities that cannot meet high reporting standards, a minimum reporting standard based on emission modelling techniques that are consistent across the sector could be applied.

For verification of data and methods employed, the guidance suggests that it be carried out by an accredited organisation independent of the organisation whose data are being verified, with the aim of verifying the reliability, credibility and correctness of the data. An entity that meets the auditing criteria normally required by the State would be ideal to carry out a predefined verification procedure. ICAO is one of the organizations, along with State accredited verification entities, that could facilitate or assist such verification.

Finally, the guidance discusses enforcement and notes that various options are available for penalties that might be used. These include: different monetary penalties, restricting noncompliant participant's rights under the trading system, and reducing the number of allowances assigned for subsequent periods. States could consider penalty systems that may be in use for other sectors, and apply similar penalties to international aviation when it is feasible and practical.

Reference

1. This article is based largely on information developed by CAEP as contained in the CAEP/7 Report (Doc 9886) and on Andreas Hardeman and Kalle Keldusild 's presentation entitled, "Guidance on Emissions Trading for Aviation", ICAO Colloquium on Aviation Emissions, 14 – 16 May 2007.

[2] a clearing house mechanism would refer to a central point where aircraft operators would jointly settle their allowances to ensure that there would be no net flow of aviation allowances into the scheme.

Voluntary Emissions Trading for Aviation

By Andreas Hardeman
and Kalle Keldusild

Andreas Hardeman works for the International Air Transport Association (IATA) where he is responsible for advocacy of industry strategies and policies on airline environmental issues. He has been at the forefront of IATA's efforts to promote the role of air transport in sustainable development, building airline industry consensus on policies concerning climate change, local air quality, and noise. He holds degrees in International Air and Space Law (LLM) and International Economic Development (MA). In 2004, Andreas was appointed IATA's representative to ICAO's Committee on Aviation Environmental Protection (CAEP) where he also co-chaired the Emissions Trading Task Force from 2004 to 2007.

With a view to provide information on the various voluntary initiatives currently being undertaken, ICAO/CAEP developed a Report on Voluntary Emissions trading for aviation. That report describes the general nature and practical experiences of various types of voluntary emissions trading schemes. It also explores how voluntary trading schemes, based on current understanding and practical possibilities, could be considered and perhaps further developed for use by aviation. The full report is available on the ICAO website.[1] .

The following article summarizes the highlights of the report.

Discussion and understanding of voluntary trading systems requires addressing three important questions, as follow:

1. What exactly do we mean by voluntary trading?
2. How can voluntary trading be made to work?
3. What would be reasons for participating in voluntary trading?

To start with the first question, the report defines a voluntary trading scheme as any scheme in which participation by a State is not mandatory. Although, that may seem clearcut, one could legitimately ask the question, for example; Does the conclusion of a voluntary agreement still qualify as "voluntary", if the only alternative is exposure to strong regulatory action, such as taxes, for example?

Further, it is important to bear in mind that voluntary initiatives can range from unilateral actions at the company level to negotiated agreements between governments and sectors. Also, in practice, many voluntary agreements are in fact combined with some sort of incentive and/or disincentive measures. That is why schemes that involve some kind of government incentive for companies to participate also fall under the definition of "voluntary" used in the report.

Voluntary Trading Options for Aviation

The report describes four approaches for setting up Emission Trading Schemes (ETS) for voluntary trading in the aviation sector, focusing on aircraft operators as the main players. The report does not pass judgment as to the desirability or the merits of the different options.

1. Group of Airlines Decides To Create its Own ETS

For example, airline alliance partners might set up an ETS among themselves. This would be a sectoral trading system that could be designed in a way that would allow participants to purchase credits outside the scheme in order to meet their targets and minimize costs.

2. Airline Sector Creates a New ETS Together with Other Sectors

Under this approach, members of a national air transport association might get together, for instance, the national energy companies and the agricultural sector join foces to establish and participate in a national emissions trading scheme.

3. Airline or Group of Airlines Unilaterally Joins an Existing ETS

As part of national efforts to drive technology efficiency and reduce emissions, an airline or a group of airlines could choose to participate in an existing trading scheme administered by another group such as: its own government, a third party government, or a commercial entity such as an independent trading platform.

In addition to the above three options, more direct mechanisms may also be considered, for example:

4. Airline or Group of Airlines Compensates for its Carbon Emissions

Under this scenario, airline players could decide to compensate directly for their emissions through investments in carbon-offset projects that can play an important role in addressing climate change impacts from aviation. A carbon offset facility can either be run by the airline(s) itself (possibly as an option for passengers/customers) or by an independent service provider. In either case, money is paid into a fund that sponsors specific projects to reduce or avoid emissions from sources or remove emissions from the atmosphere through so-called sink projects.

[1] http://www.icao.int/icao/en/env/vets_report.pdf

Key Considerations when Developing a Voluntary ETS

The second important question to deal with when trying to understand voluntary trading systems is "How can it be made to work?". The report mentions a number of considerations that are key in designing a voluntary trading scheme that is both workable and credible. These include, for example, the following:

Environmental Results:
How stringent are the environmental targets? With what degree of certainty will these results be achieved? How likely are entities to participate and how broad is the emissions coverage under the agreement? and; What factors might undermine achieving the environmental results?

Overall Cost and Cost-Effectiveness:
Does the option have adverse effects on the cost-effectiveness of control (i.e. the cost per tonne of CO_2 reduced)? Or; Does it adversely affect overall control costs (i.e., the total costs of abatement plus purchase/sale of emission allowances and/or credits) for the aviation sector (domestic or international)?

Political Acceptability:
How will the trading scheme be viewed by the relevant stakeholders, including airlines and other industry parties that have an influence on aviation emissions but are not direct participants in the agreement (e.g. engine manufacturers, air traffic controllers, governmental and non-governmental bodies, etc.)?

Benefits of Voluntary Trading Schemes

The third question related to understanding voluntary trading schemes is; "What would be reasons for participating in voluntary trading?" To answer this question, the report advances a number of reasons why voluntary emissions trading schemes could be an attractive option for addressing aviation emissions:

Flexibility:
Voluntary trading schemes are not necessarily constrained by the framework of international agreements. This could allow early action under a voluntary framework while discussions on a possible mandatory approach are ongoing.

Cost Containment:
Successful voluntary measures can help minimize costs, compared with regulatory actions. Of course, as the report observes, the incentive to pursue voluntary trading diminishes as the cost of achieving a reduction target approaches that of potential regulations. Therefore, voluntary measures should be cost-effective and have low administrative and transaction costs.

Competitiveness:
Voluntary trading has potential to attract broad geographic participation by both States and airlines. Also, since operators would be unlikely to participate in voluntary trading if there's a risk of undermining their ability to compete, the competitive impacts of a voluntary scheme are likely to be small.

Learning by Doing:
A key benefit of voluntary trading might derive from "learning-by-doing", offering the important advantage of allowing participants to develop skills and learn trading strategies that may be useful as emissions trading schemes are developed in the future.

The CAEP report then goes on to describe key elements of various voluntary trading schemes, including: emissions trading schemes in Japan and the UK, Chicago Climate Exchange, Montreal Climate Exchange, European Climate Exchange, Asia Carbon Exchange, as well as airline carbon offset programs.

One aspect discussed in the report which is worth particular attention, especially in light of current developments, is the increasing interest among private and corporate airline customers who want to voluntarily offset their flight-related CO_2 emissions. For a number of years now, consumers have been able to do so through independent carbon offset providers who sponsor projects aimed at reducing carbon emissions. Initially many of these were through reforestation but they are increasingly related to renewable energy and energy conservation projects in non-Annex I countries. While the overall contribution of these schemes to global emissions reduction is still quite small at the moment, as the report notes there seems to be potential for this type of activity to multiply over time[2].

Kalle Keldusild, is a Senior Advisor at the Swedish CAA and he is also co-rapporteur of the ICAO Emissions Trading Task Force. Over the years Kalle's responsibilities have shifted from general air transport policy to environmental issues, particularly climate change and market-based measures. He served as Alternate Permanent Representative of Norway on the ICAO Council from 1998-2001 at which time he was also appointed to coordinate EU-related matters in ICAO. He has represented Sweden at five sessions of the ICAO Assembly. He is also co-rapporteur of the new Market-Based Measures Task Force. Kalle holds a Master of Political Science (economics, management and finance).

[2] Since CAEP/7 the number of airlines introducing carbon offset facilities has steadily increased. At the time of writing British Airways, SAS, Air France/KLM, Lufthansa, Cathay Pacific, Qantas, Air New Zealand, Air Canada, Delta Airlines, Continental, Virgin Blue, Flybe Please see article on carbon-off-set and the ICAO web site for information on the ICAO aviation methodology for calculating aviation carbon offset emissions

Getting Airlines Involved In Voluntary Trading

The last chapter of the report looks at a number of possible ways for airlines to become involved in some form of voluntary emissions trading. Four broad ways are considered in which this might be done.

Firstly, airlines might consider participation in an existing voluntary emissions trading scheme. However, the report finds that there would appear to be very little opportunity for this,either because these schemes are not open to new participants, or they are limited to certain countries, or they do not appear to be easily adaptable for participation by airlines.

Secondly, airlines might consider developing a carbon offset capability. This could either be done as a service offered to customers, or alternatively it could be funded directly by the operator itself. An important difference between these two options – besides the funding – is that in the first case, there is no predetermined amount of emissions reduction, while in the second case there would be.

Thirdly, airlines could consider the development of voluntary agreements as a precursor to an emissions trading system. Such agreements should then include an enforceable commitment to achieve emissions reductions below an appropriate baseline; for example, using a voluntary fuel efficiency target. To the extent that voluntary trading would be part of a voluntary agreement between government and industry partners, the ICAO Template for Voluntary Measures may be a useful reference document, although in that case the ICAO Template would have to be adapted for this specific purpose.

Finally, one could envision the establishment of an aviation-only voluntary emissions trading scheme. The report notes that given the greater worldwide focus by governments on solutions to climate change issues, the likelihood of government support for this type of solution would be expected to increase over time.

The Way Ahead

The final section of the CEAP report addresses future developments and describes some of the commonalities and differences between voluntary and mandatory trading schemes, making reference to the ICAO Guidance on Emissions Trading for Aviation addressed earlier in the previous article. It briefly discusses the role that ICAO could potentially play to encourage and support the development of voluntary schemes that interested Contracting States and international organizations might propose. While recognizing that ICAO may not wish to be directly involved in setting up voluntary emissions trading schemes, it is suggested it could play an important facilitator role, by:

- Providing a forum to develop and review voluntary emissions trading schemes;
- Encouraging the use and recognition of such schemes;
- Providing technical information to support such schemes;
- Encouraging consistency between such schemes;
- Facilitating or assisting in the verification of aviation emissions data.

Reference

1. This article is based largely on information developed by CAEP as contained in the CAEP/7 Report (Doc 9886).

A Proposed Emissions Trading Scheme For Aviation

By Niels Ladefoged

Niels Ladefoged is a policy officer in the Clean Air and Transport Unit of the European Commission's Directorate-General for the Environment. He has been working on environmental aspects of EU air transport policy since 2001 and has been responsible for developing the Commission's new strategy on aviation and climate change. Before joining the Commission, Mr. Ladefoged worked for the Danish Energy Administration on a number of issues ranging from energy demand forecasting to renewable electricity support schemes. Niels Ladefoged has a Master of Science in Mechanical Engineering with specialisation in energy conversion and emissions.

In December 2006 the European Commission proposed draft legislation to bring aviation CO_2 emissions within the European Union's Greenhouse Gas Emissions Trading scheme ("EU ETS"). The proposal aims at reconciling the aviation sector's future growth in Europe with the need for significant reductions in global greenhouse gas emissions from all sectors.

The Unique Status of International Aviation

International air transport is different from most other sectors in terms of how its greenhouse gas (GHG) emissions are accounted for under the 1992 United Nations Framework Convention on Climate Change (UNFCCC). Emissions from international flights are not included in the national GHG emission totals reported by Parties to the UNFCCC, and are therefore not subject to the quantified emissions limitations accepted by the developed countries which ratified the Kyoto Protocol (see article on 2006 IPCC Guidelines for National Greenhouse Gas Inventories, earlier in this chapter).

Instead, the parties negotiating the Kyoto Protocol agreed to include an explicit, collective obligation for developed countries (i.e. "Annex I countries") to pursue the limitation or reduction of emissions from aviation, working through the International Civil Aviation Organization (ICAO).

This means that the collective nature of the obligation on parties which is a key part of the legal and political pressure, and drives States to implement mitigation measures for other sectors, does not apply to international air transport.

Moreover, the fundamental role of the principle of "*common but differentiated responsibilities*" under the UNFCCC and the explicit distinction between Annex I countries and other countries in the Kyoto Protocol's provision on aviation emissions has made it difficult for ICAO Contracting States to agree on specific measures to be implemented uniformly by all nations. The reluctance of developing countries to commit themselves to more demanding policies, combined with the lack of leadership from industrialized countries has prevented this from happening.

ICAO Policy on Emissions Trading

However, at the 34th session of the Assembly in 2001, ICAO took an important decision by endorsing the idea of using "open" emissions trading for international aviation emissions[1]. Following three years of further studies on options for implementation, ICAO's Committee on Aviation Environmental Protection (CAEP) at its sixth meeting in 2004, concluded that a global, aviation-specific emissions trading system based on a new legal instrument under ICAO auspices "*…seemed sufficiently unattractive that it should not be pursued further*". This was a logical decision given that the institutional infrastructure required for open (cross-sector) trading by definition is not specific to aviation and to a large extent already exists or is being developed under the UNFCCC or by its parties.

ICAO instead decided to pursue implementation by developing guidance for Contracting States to facilitate the incorporation of international aviation into the State's existing emissions trading schemes. This approach is consistent with the principle of "*common but differentiated responsibilities*" as it enables States to decide individually whether or not to implement emissions trading in their country taking into account their level of development, and whether they have an emissions trading scheme in place. By definition, it requires an initiative from the State in question as only the States themselves can amend their own schemes to incorporate aviation. It is this approach which the European Commission has proposed for implementation in Europe.

[1] As opposed to a "closed" system, "open" emission trading refers to a system in which emissions rights can be traded across sectors and not just within a given sector. Open trading is generally considered more economically efficient.

In parallel with work on the proposal, the Commission and EU member States have actively participated in the development of ICAO guidance on emissions trading. The guidance material has benefited greatly from experiences with Europe's existing scheme, as well as findings from studies on aviation specific issues conducted by the Commission as part of developing its own strategy.

The EU Strategy - Emissions Trading as Part of a Comprehensive Approach

In September 2005, the European Commission issued a Communication on reducing the climate change impact of aviation[2]. The Communication recognized that the rapid growth in emissions in the aviation sector undermines progress to reduce emissions made in other sectors, and that a comprehensive approach with several elements is necessary. It stated that this approach must include: more research into cleaner technologies, further improvements in air traffic management, and continued development of ICAO technical standards. It also emphasized that the combined effect of these measures would not be sufficient to offset the growth in aviation emissions. It concluded that market-based measures should also be considered and that including aviation in the EU ETS would be the most cost-efficient and environmentally effective way forward. It therefore indicated that the Commission would put forward a proposal for European Union legislation by the end of 2006.

The Commission's strategy was widely welcomed by EU governments and other EU institutions. Several initiatives have been taken to implement the various elements, of which the proposed emissions trading scheme is just one. Other examples include the "Single European Sky" and "SESAR"[3] initiatives aimed at improving air traffic management and, more recently, the "Clean Sky" Joint Technology Initiative (JTI) presented in June 2007. The latter will set up a public-private-partnership, pooling aircraft industry and Commission resources into targeted large-scale research programmes dedicated to the objective of significant emissions reductions from future generations of aircraft and engine technologies. The EU's Seventh Research Framework Programme will contribute $ 800 million, a sum that will be matched by industry.

The EU Emissions Trading Scheme

The EU ETS is the cornerstone of the EU's market-based strategy to reduce greenhouse gas emissions as cost-effectively as possible. The EU ETS began operation on January 1, 2005 and sets a mandatory cap on the absolute emissions from around 10,600 large energy intensive installations across the EU. It covers around 2 billion tonnes of CO_2 or about half the EU's total CO_2 emissions.

Under the scheme, operators are allocated allowances, each giving them a right to emit one tonne of carbon dioxide per year. The total number of allowances allocated sets a limit on the overall emissions from the activities covered by the scheme. By April 30th each year, operators must surrender allowances to cover their actual emissions. Operators can trade allowances so that emissions reductions can be made where they are most cost-effective. In addition to allowances allocated under the scheme, operators can also use credits from emission-reduction projects under the Kyoto Protocol's Joint Implementation (JI) and Clean Development Mechanism (CDM) to cover their emissions. The EU ETS is already a major driver for the global carbon market and European demand for credits represents a large part of the investments generated in developing countries through the CDM (see Box 1).

Main Features of The Proposed Trading Scheme For Aviation

On December 20, 2006, the Commission adopted a legislative proposal to extend the EU ETS to aviation. The proposal is accompanied by a detailed impact assessment evaluating the pros and cons of various design options, and the magnitude of likely economic, social and environmental effects.

An important objective of the proposal is to provide a model for aviation emissions trading that can be a point of reference in the EU's contacts with key international partners and to promote the development of similar systems worldwide. The Commission also supports the objective of a global agreement aimed at effectively tackling aviation emissions as part of worldwide efforts to mitigate climate change.

[2]See http://ec.europa.eu/environment/climat/aviation_en.htm
[3] SESAR : Single European Sky ATM Research

Benefits Of Carbon Trading For Developing Countries

Just as measures to combat climate change will benefit Europe and other developed nations, they are also in the long-term interest of less wealthy countries. Since vulnerable populations are the first to suffer the impact of floods, storms, droughts and the other effects of climate change, developing countries have every interest in joining the global effort.

But also in a shorter timescale, the carbon market and not least the EU ETS create tangible benefits in terms of inward investments in countries all over the world through the Clean Development Mechanism (CDM) and Joint Implementation (JI) projects under the Kyoto Protocol. Examples of countries which already benefit substantially from such projects are:

- India - 459 projects in pipeline, amounting to 278 Mt[4] CO_2 eq.
- Brazil - 190 projects in pipeline, amounting to 148 Mt CO_2 eq.
- China - 177 projects in pipeline, amounting to 519 Mt CO_2 eq.
- Mexico - 132 projects in pipeline, amounting to 57 Mt CO_2 eq.
- Other countries – 316 projects

EU ETS is a key driver for these investments, and the expected market for JI and CDM in the EU ETS of up to 1.3 billion tonnes over 2008-12.

Source: New Carbon Finance

The key aspects of the proposal are as follows.

Scope

- At its start in 2011, only flights between EU airports would be included in the scheme. From 2012 this would be extended to all flights arriving at or departing from an EU airport;

- The scheme would not apply to flights arriving from any third country that puts in place equivalent measures to reduce the climate change impact of aviation;

- The scheme would only cover CO_2 emissions. The Commission will carry out a study and evaluation of the options to address nitrogen oxide (NO_x) emissions and put forward a further proposal, supported by an impact assessment, by the end of 2008.

Allocation

- In contrast to the existing EU scheme, the method of allocating allowances would be harmonized at EU and not at Member State level;

- The total number of allowances to be allocated to the aviation sector would be determined by reference to average emissions from aviation in the years 2004-2006;

- The majority of allowances would be allocated free of charge on the basis of a benchmark to aircraft operators which submit an application (the earliest application relating to 2008 data).

- In the first period, a small proportion of allowances (expected to be around 3%) would be auctioned. Thereafter, the percentage auctioned would be decided in the light of the results of the general review of the EU ETS due for completion later this year;

- Auctioning proceeds would be used to mitigate and adapt to the impacts of climate change and to cover administrative costs (see Box 2).

Access to Reduction Options in Other Sectors

- If necessary, aircraft operators would be able to buy allowances from other sectors in the scheme to cover increases in their emissions;

- Aircraft operators would also be able to use project credits – so-called Emission Reduction Units (ERUs) and Certified Emission Reductions (CERs) - from the Joint Implementation or Clean Development Mechanisms (JI/CDM) provided for in the Kyoto Protocol up to a harmonized limit equivalent to the average of the limits applied by EU Member States for other sectors in the EU ETS;

[4] Mt : Million Tonnes

Use Of Auctioning Revenues

The Commission has proposed that any proceeds from the auctioning of these allowances should be used to mitigate greenhouse gas emissions to: adapt to the impacts of climate change, fund research and development for mitigation and adaptation, and cover the costs of administering the scheme. The use of auctioning proceeds should in particular fund contributions to the Global Energy Efficiency and Renewable Energy Fund (GEEREF), and measures to avoid deforestation and facilitate adaptation in developing countries.

GEEREF is an innovative global risk capital fund set up by the European Commission in 2006 to mobilize private investment in energy efficiency and renewable energy projects in developing countries and economies in transition.

GEEREF will help to provide clean, secure and affordable energy supplies to some of the 1.6 billion people around the world who currently have no access to electricity. It will do so by accelerating the transfer, development and deployment of environmentally sound energy technologies. This will combat both climate change and air pollution, and will contribute to a more equitable distribution of Clean Development Mechanism projects in developing countries.

The Commission is investing $ 80 million into GEEREF over four years. Additional pledges, including those from Germany, Italy, and Norway, bring the total amount of investment so far to $ 122 million. This funding is expected to mobilize additional risk capital of between $ 300 million and $ 1 billion in the longer term. GEEREF should be operational and making initial investments before the end of 2007.

Administration

- Like other participants in the Community scheme, aircraft operators would have to monitor their emissions of carbon dioxide and report them to the competent authority. Member State by March 31st each year. The reports would be independently verified to make sure that they are accurate. The basic principles for monitoring, reporting and verifying of emissions set out in the proposal would be elaborated by guidelines;

- Aircraft operators would be the entities responsible for complying with the obligations imposed by the scheme;

- In order to avoid duplication and an excessive administrative burden on aircraft operators, each aircraft operator, including operators from third countries, would be administered by one Member State only;

The full proposal and supporting impact assessment can be accessed on the Commission's website at the following address:
http://ec.europa.eu/environment/climat/aviation_en.htm

Next Steps

It is emphasized that this is currently a *proposal* for legislation, and as such has no legal force. Before it can become European law it must be adopted by the Council of Ministers and the European Parliament. This process is known as the co-decision procedure and could take between one and three years. Once adopted there will be a further period for EU Member States to make the necessary legislative and administrative arrangements to implement the legislation.

The Commission presented its proposal after an open public consultation in 2005 accessible to all stakeholders via the Internet and after detailed discussions with any stakeholders expressing an interest. However, the Commission remains open to discuss any aspect of its proposal with stakeholders in and outside of Europe. As the proposal must be agreed by both the Council of Ministers and the European Parliament to become law, it is equally important to discuss potential concerns and possible remedies with the EU Member States (who together will define the position of the Council of Ministers), as well as members of the European Parliament.

Voluntary Emission Reduction Schemes and the Way Forward

By Katsuhiro Yamaguchi

Mr. Yamaguchi is a Professor at the Graduate School of Public Policy, University of Tokyo, where he is in charge of the International Transport Policy Research Unit. Before that he was Director of Planning and Research, Civil Aviation Bureau, Ministry of Land, Infrastructure and Transport, Government of Japan. There, he was responsible for a variety of aviation policy issues, ranging from airport construction, planning and financing, to global warming issues. He has been on leave from that department since 2005 when he assumed his current position. Mr. Yamaguchi holds a Bachelor of Law and a Master of Business Administration.

This article discusses voluntary emission reduction schemes in air transport and tries to find the path that could lead to sustainable growth. It is composed of three parts. First, it addresses basic issues by defining key concepts involved in voluntary emission reduction schemes. Second, as a case study, the unilateral commitment by Japanese airlines is described and analyzed, and an econometric analysis identifies the impacts of such an action. Finally, the paper concludes by highlighting key factors for identifying "The Way Forward."

Basic Issues and Definitions

Before discussing this subject in detail it is important to understand two basic concepts related to the reduction of emissions; the exact meaning and approaches to emission reductions, and the schemes that are used to achieve them.

Emission Reductions

The most orthodox definition of "emission reductions" is when the level of emission is projected into the future by the business as usual (BAU) case and then reduced by introducing new initiatives, such as installing new efficient aircraft and engines, improving operational efficiency, utilizing alternative fuel, etc.

The second approach is what is often referred to as an offset by which the end user pays money to mitigate what he/she has emitted. For example, approximately three tons of CO_2 emissions per passenger would be caused by a round trip journey between Tokyo and Montreal. Under the offset scheme, the carrier involved would provide money to an institution that would offset the environmental footprint of that flight by taking such actions as tree planting, carbon storage, etc. Some claim that this is not a true "reduction" since it may only serve as an excuse for pollution. However, it is believed that if the offset is executed properly, it would contribute to stabilize net emission levels. Today, there are numerous offset programs in operation throughout the world, although accreditation of programs and standardization of the method of calculating CO_2 emissions from specific trips, are both issues that need to be resolved. There is currently an initiative in ICAO to develop a standard methodology for the assessment of aviation emissions for offsets schemes (see article on the *Carbon Offset Project*).

The third way to look at emission reductions is in terms of units of reduction. Emissions are a product of CO_2 intensity and the level of output. Thus, reductions may be achieved through decreases in CO_2 intensity or in the absolute emission level. This difference is important because intensity targeting is more equitable when there is discrepancy in growth of output.

Voluntary Schemes

There are a number of issues that need to be addressed in explaining the meaning of voluntary emission reduction schemes and programs. First, it is important to define "who" is taking the voluntary action. Normally, we have the end users such as the airlines or passengers/shippers in mind when voluntary action is discussed. Other intermediate parties and stakeholders such as airports, aircraft/engine manufacturers, fuel suppliers, ATC providers, etc., are usually regarded as infrastructure rather than as end users. Measures taken by these groups are equally as important as steps taken by the end users, but the end users do not have direct control over the infrastructures. Thus, it should be noted that we are basically focusing in this article on actions taken by the end users when referring to voluntary actions.

There can also be various types of voluntary schemes, some of which are linked to other mechanisms, and others which are not. The unilateral commitment by airlines in Japan is an example of the latter. There are other schemes that have linkages to agreements among governments or that exist because of participation in an emission trading scheme. This leads to categorizing voluntary schemes in terms of whether incentives are provided or not. Unilateral commitments usually do not involve monetary incentives because social returns are what make them work. In many programs, some sort of reward is provided when a target is achieved and penalties are imposed when targets are missed. Voluntary Emissions Trading Systems (ETS) in UK and Japan offer tax-breaks and subsidies for participants that meet targets.

Finally, a clear distinction should be made between voluntary schemes and market-based options. Market-based options usually involve taxation, charges, or emission caps and are essentially a mechanism to offset social costs when the exact causes of emissions cannot be identified.

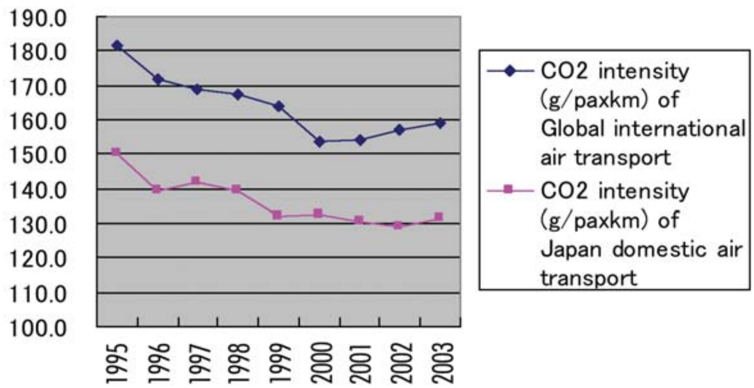
Air Transport in Japan: A Case of Voluntary Emission Reductions

The best way to understand how a voluntary emissions program works and to get a sense of its impact is to look at an actual case study such as the voluntary emission reduction scheme that was implemented for air transport in Japan.

CO_2 Emissions and Domestic Air Transport In Japan

The transport sector in Japan, is estimated to be responsible for 20% of total domestic green house gas (GHG) emissions, with air transport covering 4% of that, making it a relatively small sub-segment. Also, due to the utilization of modern aircraft and substantially larger fleet sizes, the CO_2 intensity of air transport in Japan has been approximately 20% below that of the average for global international air transport.

This 20% lower level of CO_2 in Japan shows how aircraft size can have a significant effect on CO_2 intensity. Average aircraft size in Japan is about 20-30% larger than the global average which accounts for about half of the intensity gap (elasticity is -0.5). Also, average aircraft age of the Japanese commercial fleet is about 20% younger than the global average, which is the other major factor that accounts for the difference. The following figure illustrates this difference caused by different fleet characteristics.



In Japan, as with most developed nations, the automobile makes up the major sub-segment of transport, accounting for two-thirds of total transport emissions. One characteristic that makes Japan's overall transport system relatively efficient is the extensive utilization of high-speed railways.

After Japan signed the Kyoto Protocol in 1997, the airline industry initiated a voluntary plan as part of multi-sectoral program implemented by Nippon Keidanren (Japanese Business Foundation). The target was set at 10% reduction in CO_2 intensity between 1990 and 2010. This voluntary plan was consolidated into the overall transport-sector program by the Ministry of Transport and then into the National Global Warming Prevention Package (NGWPP). Originally, intensity targeting was used for that target, but in 2002 the revised version of the NGWPP converted this target into absolute levels.

Table 1: Voluntary CO_2 Reduction Plan In Domestic Air Transport In Japan.

Year	Action Taken	Emission Reduction Targets	Related Events
1997	Airline voluntary plan initiated as part of multi-sectoral program by Nippon Keidanren (Japan Business Federation)	CO2/ASK -10% by 2010 (base year 1990)	COP3
1998	Airline voluntary plan consolidated into transport-sector program by Ministry of Transport		COP4
1999	Voluntary plan incorporated into the Global Warming Prevention Package	CO2/ASK -7% by 2010 (base year 1995)	COP5
2002	CO2 intensity target is converted into CO2 emission level in the Global Warming Prevention Package (version 2)	1.1 MT-CO2 reduction by 2010 Japan ratifies	COP3
2004	Airlines achieved 1.77 MT-CO2 reduction (CO2/RPK -14%)		COP10/MOP1
2005	Reduction target revised and incorporated into the legal framework of National COP3 Achievement Plan	1.9 MT-CO2 (CO2/RPK -15%) reduction by 2010	COP3 comes into effect

A follow-up was done in 2004 that revealed that the airline industry was doing very well and had in fact already accomplished the target. So, in response to a government request for a revised target, the airlines came up with the current target to reduce emissions to 1.9 CO_2-MT; which is equivalent to a 15% reduction in intensity from 2005 to 2010. Table 1 lists the calendar of events that led to this.

The performance of domestic air transport in Japan has been quite promising and we can see from Figure 1 that it has achieved sustainable growth when compared to the BAU case.

In 1985 CO_2 intensity for the air transport sector was 30% higher than for private automobiles but by 2005 the situation was reversed with the CO_2 intensity for the air transport at 25% below private automobiles. In fact, air transport is the only subsegment of the transport sector that has reduced CO_2 intensity.

Impact Of The Voluntary Plan

The logical question at this point was whether the emission reductions observed could be attributed directly to the implementation of the voluntary plan. To determine this, an econometric analysis was conducted to see exactly what was behind the change in CO_2 intensity. The equation that was used to estimate this scenario was as follows:

$$\ln(CO2/paxkm) = c + \alpha_1 t + \alpha_2 d + \alpha_3 \ln(dis) + \alpha_4 L/F + \alpha_5 \ln(capa) + \varepsilon$$

The dependent variable (*CO_2/paxkm*), is the amount of CO_2 emitted per revenue passenger-kilometer (RPK), and it is a function of five(5) variables as follows:

Natural log is taken for variables using "*ln*." Technological and operational improvements are captured by the time trend (*t*). A dummy variable for 1998 and onwards (*d*) is included to see if there is any systematic change after the voluntary plan. Constants are: average stage length (*dis*), load factor (*L/F*), and average aircraft size (*capa*). ε is the error term. The dependent variable is expressed in log form so that the time trend (*t*) could be seen as annual improvements, and the dummy variable (*d*) as a shift from the trend. The equation was estimated by autoregressive model (AR1) using 1985-2005 data.

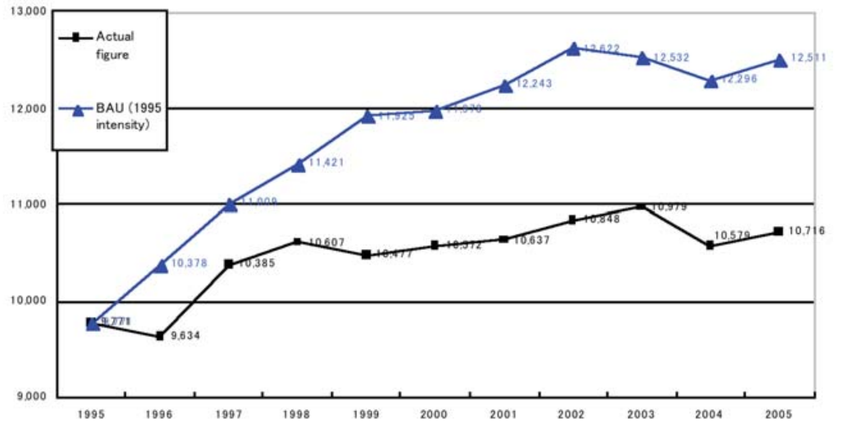


Figure 1 – CO_2 emissions from domestic air transport in Japan.

The result of the regression analysis is listed in Table 2. From 1985 to 2005, a 1.1% per annum efficiency gain is observed. In addition, there is a clear sign of a one-time efficiency gain of 3.6% after 1998. Other year dummies were tested and the best fit was 1998. To enhance robustness, a similar analysis of US domestic and global international air transport markets was conducted. There were no signs of systematic change after 1998 in these markets.

Table 2 – Results of the econometric analysis.

parameter	estimate	standard error	t-statistics
c	6.90	0.35	19.45**
t	-0.011	0.001	-11.44**
d	-0.036	0.008	-4.52**
ln(dis)	0.26	0.09	2.95**
L/F	-1.24	0.06	20.98**
ln(capa)	-0.49	0.07	-7.03**
rho	-0.37	0.20	-1.90

Dependent variable: ln(CO2/RPK)
**: Significance, $p<0.01$ Adjusted R2: 0.982

Based on this analysis, it appears that voluntary measures had a clear impact on CO_2 intensity improvements in Japan. This has a number of policy implications for international air transport. For example, would voluntary measures worldwide serve as a gateway to sustainable growth? Which is appropriate for targeting internationally; CO_2 intensity or absolute levels? What is unique about international air transport compared with domestic air services?

The Way Forward

Based on what we know to-date, it is difficult to draw conclusions about these questions. However, there are some implications that should be taken into account when we consider the next step.

The following two graphics put the current CO_2 emissions situation into perspective by depicting international aviation and marine CO_2 emissions from fuel consumption. Figure 2 shows total CO_2 emissions from air and marine transport fuel combustion in terms of tons, while Figure 3 shows those same emissions as a percetage of total global CO_2 emissions.

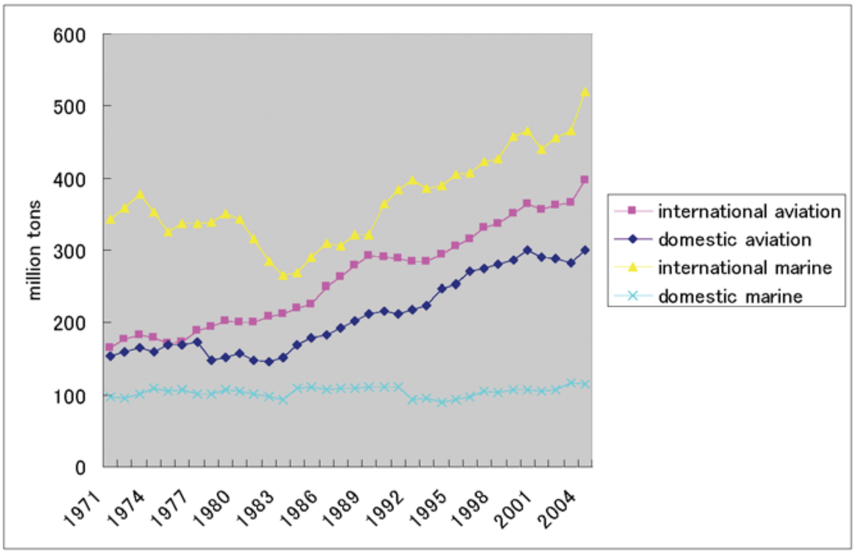


Figure 2 – CO_2 emissions from air and marine transport fuel combustion.
Note: international aviation and marine data are for "international bunker fuel."
Source: International Energy Agency.

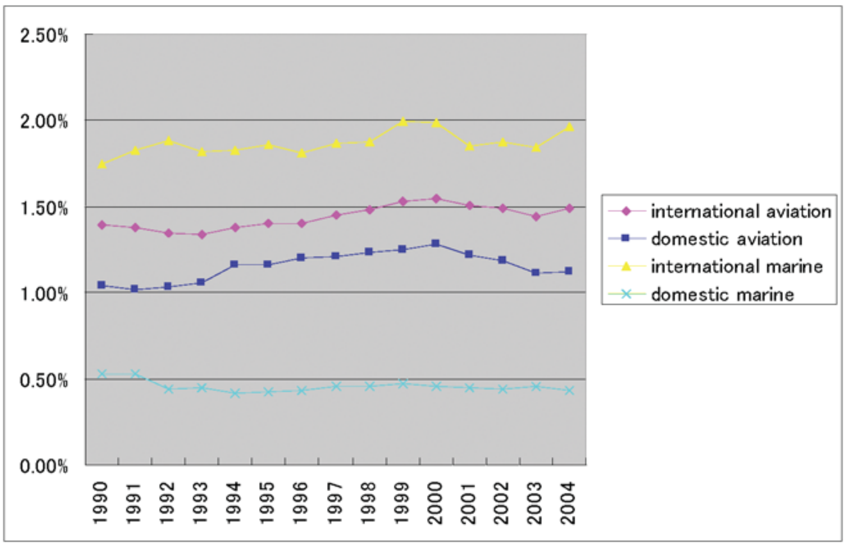


Figure 3 – CO_2 emissions from air and marine fuel combustion as a percentage of aggregate global CO_2 emissions.
Note: international aviation and marine data are for "international bunker fuel."
Source: International Energy Agency.

Past Trends and What Lies Ahead

From 1990 to 2004, global international air transport in RPK increased from 556 billion to 2,015 billion; a growth rate of approximately 6% per annum[1]. During the same period, total CO_2 emissions from global air transport increased from 290 million tons to 397 million tons; 2.2% growth per annum. The air sector's share of global CO_2 emission is relatively low and quite stable at 1.5%[2]. This performance is quite significant since the 3.8% difference between the 6% growth in output and the 2.2 % CO_2 emission increase represents an improvement in CO_2 intensity.

During the same period, global CO_2 emission per GDP fell by only 1.0% per year. ICAO/CAEP forecasts a 4.3 % annual growth in RPK for the period 2000 to 2020. The question then becomes; how much in CO_2 emission increases from this output growth could be offset by CO_2 intensity improvements, and is there a need for additional reductions?

Special Features of International Air Transport

The basic objective of overall GHG mitigation policy is to stabilize its concentration levels. There is no doubt that in order to stop the atmospheric concentration from rising, GHG production must be controlled. However, is it rational to apply the same framework to international air transport as to other sectors?

It is believed my many that there are important aspects of international air transport that deserve special attention such as:

- International air transport, together with international maritime transport, facilitates international trade and cross-border mutual understanding. This unique role needs to be taken into account.

- The global political economy is complex. Not only does international air transport involve 190 contracting states (both North and South), but in addition to governments, it consists of multiple stakeholders such as airlines, aircraft/engine manufactures, airports, ATC providers, fuel industry, etc.

[1] ICAO statistics compiled and calculated by the author. Two major factors are behind demand growth; economic growth and reduction in airfare. Between 1990 and 2004, global GDP grew by 2.6% per annum and average airfare declined by 3.4% per annum.
[2] IEA international bunker fuel data compiled and calculated by the author.

- The very fact that international air transport involves cross-border operations requires coordination among multiple nations. Thus, steps taken by individual states often have multiple extra-territorial effects.

Clearly, policy formulation needs to be based on international multi-agent collective goal-setting. There should be a clear distinction between general global warming prevention policies and schemes to mitigate CO_2 emissions in international air transport.

The Way Forward

Figure 5 depicts the governance structures for various reduction schemes. The left-hand side shows the regulatory and market-based measures; "hard governance." On the right-hand side, the "voluntary schemes" are listed. They are based on internal motivations. The obvious questions arise. Why are there differences in the governance structure? Which type should be chosen under what circumstances?

If we place emphasis on technology-driven dynamic sustainability it may be appropriate to start off with the soft governance and encourage stakeholders to take their own initiatives. The global political economy of international air transport is too complex to jump on the first solution that comes along. In the medium-term we may move on to something strict. As the expression goes, "More haste, less speed."

CO_2 emission targeting for aircraft manufacturers by independent experts initiated in ICAO/CAEP is a good starting point. CO_2 intensity targeting could also be effective and fair for the airlines, whether the scheme is voluntary or not. As we have demonstrated above with the Japanese experience, international air transport does have the capability of improving efficiency.

Thus, "the way forward" with respect to global aviation emissions depends on what consensus can be reached by the international air transport community in terms of what has to be done, who should be responsible for what; as well as timeframes to accomplish the goals set. The first step would be to reach consensus on the extent to which aviation contributes to global warming and then send out a credible and convincing message to that effect. Confrontation is counter-productive. In the international aviation community, we all need to move forward in the same direction. To this end, ICAO is expected to serve as a continuing forum for policy formation. The welfare of future generations rests on all of our shoulders.

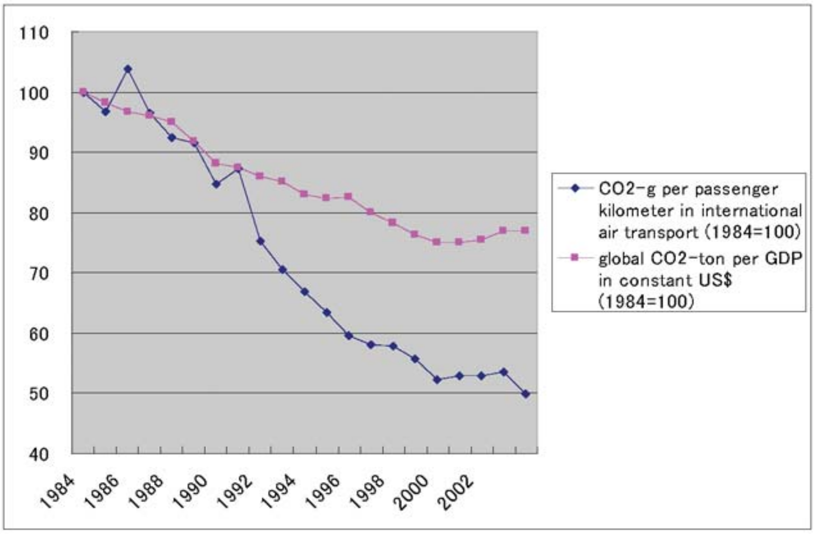


Figure 4 – Comparison of CO_2 intensity levels.
Note: CO2 per passenger kilometer in international air transport: (1)/(2) 1984=100.
Sources:
(1) CO_2 emission: CO_2 Emission from Fuel Combustion (International aviation bunker fuel[3]), International Energy Agency.
(2) International scheduled passenger kilometers performed: ICAO data.
Global CO_2-ton per GDP in constant US\$: (3)/(4) 1984=100.
(3) Global CO_2 emission: CO_2 emission from fuel combustion, International Energy Agency.
(4) GDP in constant US\$ (2000): World Economic Outlook Database, International Monetary Fund.

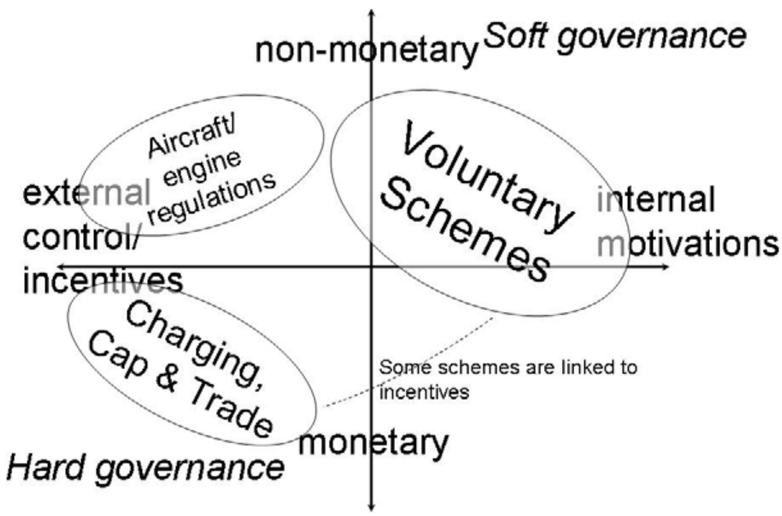


Figure 5 – Governance structures of various schemes and policy options.

[3] Appropriated by revenue share of international air passenger transport using ICAO data on international scheduled air transport passenger and cargo revenues.

Aviation Carbon Offsetting

By Peter Clarke and
Chris Caners

Mr. Clarke is a Project Manager with ICF International. His environmental background is augmented by experience in the petroleum, office furniture and energy industries on issues such as sustainable manufacturing, life cycle analysis and emissions management. He has significant experience in climate change based issues, including emission inventories, emission credit trading, risk mitigation strategies, and emission reduction initiatives.

The purpose of this article is to provide a description of carbon offsetting and an update of ICAO's efforts in this area. Specifically, the article explains the concept of carbon offsetting, discusses the factors involved in calculating per-passenger air travel emissions and describes some existing per-passenger aviation emissions methodologies. The article concludes with a summary of ICAO's ongoing work to evaluate per-passenger aviation emissions calculators outlines ICAO's efforts to develop a credible and transparent guideline for aviation carbon offsetting to be used by consumers and offset programme providers alike.

What is Carbon Offsetting?

Human activities, including aviation, release a number of greenhouse gases (GHG) such as carbon dioxide (CO_2), in the atmosphere and methane (CH_4) and nitrous oxide (N_2O). The impact of these gases on the climate is complex and is dependent on a host of variables (including atmospheric concentration and relative molecular impact).

Simple everyday actions such as turning on a light, driving to work or flying to a conference utilize fossil fuels. These actions, therefore, produce carbon emissions that contribute to climate change. It is therefore very important that those performing these actions become involved in a concerted and coordinated global effort to reduce the amount of energy they consume.

One way that an individual or organization can help with this effort is through voluntarily offsetting their carbon emissions. 'Carbon offsetting' is the action of compensating for (or 'offsetting') the GHG emissions associated with a given activity, by reducing emissions elsewhere. While offsetting lessens the impact of an individual's actions and raises awareness of his or her personal carbon footprint, it does not actually reduce the emissions contributing to climate change.[1]

Consumers can voluntarily purchase emission reduction credits (or 'offsets') that result from projects that have reduced carbon emissions in some way. Since climate change is a global issue, these carbon reducing projects may occur anywhere in the world.

Some examples of carbon offsetting projects that reduce greenhouse gas emissions are:

- forestation ;
- capture and destruction of greenhouse gases resulting from processes associated with landfill and wastewater treatment facilities;
- large or small scale renewable energy or energy efficiency projects;
- land-use improvement (such as agro-forestry, reforestation, soil conservation); and,
- reducing energy-related emissions through fuel-switching (such as replacing oil-fired burners with natural gas ones).

There are many retail companies that will sell carbon offsets to individuals or organizations interested in voluntarily compensating for the impact that their activities have on the climate, including air travel. Of course, in order to offset emissions from an activity, the quantity of greenhouse gases arising from that activity must be accurately calculated. Difficulties frequently occur, either when accounting for the effectiveness of a project to offset greenhouse gases, or when calculating the emissions to be offset, or both.

Approach to Calculation of Carbon Emissions

Numerous methodologies for calculating per-passenger emissions specific to the aviation industry have been proposed by a range of stakeholders (non-governmental organizations, airlines and for-profit companies). These existing methodologies are not harmonized and differ in terms of transparency, variables included, and formulas used to allocate emissions to the individual passenger.

Determining the per-passenger emissions from a given flight is a complex problem, with many factors that must be considered. The ability to extract and cross-reference vast amounts of difficult-to-access and current data is required, and as a result, primarily explicit assumptions are generally considered a necessity in addition to user inputs and information from existing databases.

[1] Consultation on establishing a voluntary Code of Best Practice for the provision of carbon offsetting to UK customers. Department for Environment, Food and Rural Affairs. January 2007.

The process of determining per-passenger has two stages, firstly calculating total flight emissions and then a per-passenger allocation. The former can be thought of as the total amount of carbon emissions associated with a specific flight, while the per-passenger allocation addresses the distribution of the total flight emissions on a passenger level.

Total Flight Emissions

The following is a non-exhaustive summary of the factors to be considered when calculating total flight emissions.

Gases and Particles that Impact Climate:

The combustion of jet fuel (kerosene) results in gases and particles that have an impact on the climate, including, carbon dioxide (CO_2), nitrogen Oxides (NO_x), and for example water vapour, unburned hydrocarbons and sulphate and soot particles.

For purposes of comparison and standardization, the common practice in climate science is to apply a multiplier called the 'global warming potential' (GWP), resulting in an equivalent amount of carbon dioxide (CO_2). For instance, the GWP of methane is 21; so every tonne of methane is equal to 21 tonnes of CO_2 in terms of its impact on the climate.

Another measure of GWP is known as the Radiative Forcing Index (RFI), which multiplies the amount of CO_2 actually emitted by a factor, accounting for the impact of the other emitted molecules and cloud formation. Although this issue was introduced by the IPCC in 1999, it, has since agreed that the RFI should not be used as an emissions metric since it does not account for the different residence times of different forcing agents.

Meteorological Conditions:

The weather conditions have a large impact on the amount and type of GHG gases (including some pollutants) associated with a flight for two reasons. First, engine performance varies significantly depending on the atmospheric operating conditions. Second, pollutants emitted from engines may react differently in the atmosphere depending on the weather conditions.

Due to the enormous volume of data required, most calculators do not include these effects or assume that they are negated on average. For instance, the increased fuel consumption due to a headwind will be negated by the decreased fuel consumption with a tailwind on the return journey.

Aircraft Type:

Emissions for a given flight are also heavily dependent on the combination of airframe, and engine and their configuration. Separate manufacturers may offer engines for use on a given airframe. Additionally, different configurations may be possible for a given airframe/engine configuration.

Apart from these differences, the age and maintenance history of a given aircraft will have an effect on the emissions. For instance, a recently overhauled engine will likely have better performance than an engine that is about to be overhauled.

Many calculators employ a 'representative' aircraft to address this issue, which generally involves determining an average, weighted or most common aircraft used on a given flight. However, total flight emissions are highly dependent upon the type of aircraft, and reductions in accuracy may occur due to these simplifications.

Flight Path and Cycle:

Of course, one of the main contributor to total flight emissions is the distance traveled. The shortest distance between two points on the globe is called the 'great circle distance'.

However, aircraft rarely, if ever, travel only the great-circle distance to their destination, as there are a number of flight phases, such as landing, take-off, approach and holding patterns that may be necessary due to air traffic movement and control requirements. In addition, in many instances, there may be intermediate stops that add significantly to the total distance traveled. For instance, a flight from Montréal to Prague may land in London.

Finally, during phases of flight such as run-up, taxiing, take-off, cruise, descent and landing, engine operations (and the resulting emissions rates) are radically different. For instance, the thrust setting for an engine during take-off is likely to be much higher than that for the cruise portion of the flight.

Mr. Caners obtained his Master of Science in Engineering from Queen's University. As an Associate at ICF International he works on multi-sector climate change policy analysis for Canadian and US jurisdictions. He has also performed extensive research in social marketing and energy efficiency, and has experience developing greenhouse gas inventories for large institutions.

Most calculators require that the user input origin and destination airports or cities; in some cases, the user is asked to supply a distance traveled, which very few travelers are likely to know..

When these factors are not averaged on the whole, various methods are employed to determine fuel consumption rate, thrust to fuel consumption ratings and averaged fuel consumption ratings. Typically, these are then correlated with factors representing the phases of flight for those engine settings.

Per-Passenger Allocation

Once the total emissions for a flight have been determined, those emissions must then be allocated to a passenger on that flight.

Aircraft Configuration:

Seating arrangements, even within a single airframe type, can vary significantly from aircraft to aircraft. For instance, one aircraft may be configured to carry a small number of dignitaries, while another may be configured to hold as many seats as possible. As the total emissions are not significantly effected by payload, the number of seats on a flight is an important factor.[2]

However, not all of the available seats on a given flight are necessarily filled. The ratio of the number of filled seat to the total number of seats is called the "load factor".

Many calculators assume an average aircraft configuration and load factor, over an origin/destination pair, region or airline. Few calculators allocate for increased carbon emissions to less dense seating arrangement.

Cargo:

Along with passengers and their luggage, aircraft normally carry a certain amount of other cargo, which is not associated with the passengers on the flight. A fraction of the emissions attribuable to the freight on a flight should therefore not be allocated to passengers.

Some calculators utilize an average freight loading factor, distributing the remaining emissions as discussed above to the passengers on-board.

The interaction of these and other factors not discussed here leads to a per-passenger emissions calculation. However, discrepancies between results are common, due to the range of available data and number of assumptions required.

Existing Per-Passenger Emissions Calculators

There is a range of online retail tools in existence for calculating the emissions associated with a given flight. Each of these calculators uses some combination of implicit or explicit assumptions, user inputs and information from databases. In the section above, the general steps required along with the current common practices (for those calculators where that information is publicly available) of per-passenger calculators were outlined.

Airlines frequently develop partnerships with these companies to assist their customers who wish to offset the carbon from their travel. However, some airlines have independently developed carbon calculators, taking advantage of available and more specific in-house data. Table 1 shows a listing of some common per-passenger emissions calculators and their basic methodologies:

Summary of ICAO's Carbon Offset Project

Aware of the potential environmental benefits as well as the high likelihood for consumer confusion surrounding the issue of carbon offsetting, ICAO has secured the services of experts from ICF to develop a Carbon Offset Project and publish a guideline methodology to calculate the per-passenger emissions of carbon dioxide associated with a given flight. The intention is to provide a reference tool based on this methodology for any user interested in an emissions estimate, using an open and transparent methodology. It also intends to promote the use of this methodology to entities interested in providing carbon offsets with a view to harmonizing the assessment of aviation emissions.

The project involves :

- identifying and reviewing existing methods and available data;
- developing an ICAO approved methodology;
- testing and validating the methodology;
- providing a web-based reference tool; and,
- disseminating the methodology through the ICAO website.

[2] DLR 2000: Databases with emissions profiles of civil jets. Research project 10506085 as commissioned by the German Federal Environmental Agency, TÜV-Rheinland, DIW, Wuppertal Institute for Environment, Climate and Energy.

Table 1: Comparison of existing carbon offset calculators.

Calculator	Basic User Inputs					Specific Variables			
	Flight Number	Seat Class	City Pair	By Airport	Round Trip or One Way Option	Specific Aircraft Type	Virtual or Average Aircraft	Freight Variable	Load Factor
1	N	N	Y	Y	Y	N	Y	N	N
2	N	N	Y	Y	Y	Y	Y	Y	Y
3	N	N	Y	Y	Y	N	Y	Y	Y
4	N	N	Y	Y	Y	N	NA	N	N
5	N	N	N	N	N	N	NA	N	N
6	N	N	Y	Y	Y	Y	N	N	Y
7	N	N	Y	Y	Y	N	NA	N	N
9	N	Y	Y	Y	Y	Y	Y	Y	Only for national airlines.

Source: ICF

ICAO Methodology

The aim of the methodology is to provide per-passenger CO_2 emission estimates that are based on industry averages in a reasonable and transparent manner, while accounting for all relevant factors. These relevant factors may include a passenger load factor and a freight factor based on recent historical route averages. The allocation between the passengers and the freight carried by the aircraft may be based on a mass basis to ensure that neither is allowed to "piggy-back" on the other.

In order to account for the differences in capacity the methodology will also provide cabin class factors based on the additional space required for premium seating arrangements. These factors may be based on industry averages as determined by ICAO.

The underlying dataset of the methodology may be that of the EMEP/CORINAIR Emissions Inventory Guidebook (EIG) which is the recommended dataset from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. This dataset includes similar aircraft types in representative aircraft groups. For each of the representative aircraft, discrete mission distances and accompanying fuel burn totals are reported. With the simplifying assumption that all fuel is burned to form carbon dioxide, it is possible to estimate the carbon dioxide emissions associated with any length of flight by interpolation.

The methodology will detail how the data of EIG is combined with the schedules databases maintained by ICAO in order to establish route specific average emission factors. The underlying factors supporting this tool can be updated annually by ICAO and provided in a common format to enable users to update their versions of the carbon dioxide calculator.

The reference tool will require only a minimum amount of information to be provided to it and will report the per-passenger emissions for a given city pair or a series of city pairs in tonnes of carbon dioxide per passenger.
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ICAO has endeavored to engage all interested industry stakeholders throughout the development process, and as a result, the methodology will reflect this consensus approach. The methodology is currently under development and will be evaluated by ICAO/CAEP.

This ICAO tool is part of ICAO's continuing commitment to support the UN's efforts to deal with climate change, and it will provide guidance to those participating in carbon offset programme.

Alternative Fuels

Potential Effects of Alternative Fuels on Local and Global Aviation Emissions

By ICAO Secretariat

Alternative fuels for aviation are not a new concept. Early jet engines were developed that used hydrogen, but, eventually, the realization that aircraft need a fuel that has high energy content per weight and volume led to the adoption of kerosene as the standard aviation fuel.

Since the energy crisis of the 1970's, almost all of the energy, aircraft, and engine companies have been investigating the practicality of using alternative fuels in near, mid, and long-term. Concerns about rising fuel costs, energy supply security and the environmental effects of aviation are providing a significant stimulus to take a fresh look at the use of alternative fuels for aviation. In the last two years, interest has increased dramatically.

This article looks at what is driving current research and development of alternative aviation fuels; it examines the possibilities being considered and how they compare with conventional fuels; it considers the reasons for optimism and caution and, finally, looks at future developments.

Issues Driving The Development Of Alternative Fuels

Environmental concerns are not the main motivation for developing alternative fuels for aviation. The dramatic rise in fuel prices we have experienced in recent years has caused intense concern in the aviation industry. The point is being reached where efficiency gains in other areas of the airline industry are being negated by increases in fuel costs. The possibility of switching to alternative fuels which may not be subject to the same factors which drive fossil fuel prices (i.e., availability of supplies; geopolitical events; extreme weather events, etc.), becomes increasingly attractive.

Discovery of new crude oil reserves has been falling while global demand has been rising. While demand for fuel in most sectors of the economy is either rising only slowly or is stable, demand in the transport sector continues to rise significantly. Some experts are concerned that future global fuel demands will outstrip supplies and that jet fuel prices could escalate significantly as a result.

Another major non-environmental driver of this search for alternative fuels is the concern over stability of supply, given current global political concerns and the fact that most states do not produce much or even any of their own crude oil.

Of course, the environmental concerns remain, and any fuel which could be used by aircraft which would produce lower emissions, such as particulate matter and carbon dioxide, would be of great interest to the industry.

Alternative Fuels For Aviation

Jet fuels that are currently used by both civil and military aviation are a blend of complex hydrocarbons, and the specific composition varies within broad performance specification limits. However, typically they comprise 60 percent paraffins, 20 percent naphthenes, and 20 percent aromatics. Also present may be sulphur; usually at less than 500 parts per million (ppm). The naphthenes and aromatics have a higher carbon to hydrogen ratio than the paraffins, which gives them greater volumetric efficiency, but they include compounds which are more likely to result in the release of particulate matter in the engine exhaust – which is becoming an area of increasing environmental concern. Table 1 shows the typical composition of aviation jet fuel.

Table 1 – Typical chemical composition of standard jet fuel.

Chemical Component	Amount
Paraffins	60%
Naphthenes	20%
Aromatics	20%
Sulfur	500 ppm

Alternative fuels for aviation may broadly be classified into two categories; drop-in fuels and non drop-in fuels.

Drop-In Fuels

Fuels referred to as "drop-in" fuels can be substituted directly for conventional fuels without any changes to aircraft or engines required. Currently, synthetic jet fuels are manufactured using a Fischer-Tropsch process, from coal, natural gas, oil shale or tar sands, or other hydrocarbon feed stocks (even biomass). The base feed stock is gasified to create a mixture of carbon monoxide and hydrogen. These particular gasses are then recombined to form a liquid hydrocarbon fuel.

Synthetic fuels are very similar in chemistry and performance to conventional jet fuel, but have almost zero sulfur and aromatics, and have a slightly higher hydrogen-to-carbon (H/C) ratio. This may result in lower particulate exhaust emissions, and slightly lower carbon dioxide (CO_2) emissions. In addition, synthetic fuels exhibit excellent low-temperature properties, maintaining a low viscosity at cold ambient temperatures. High temperature properties are also better, resulting in improved heat sink capabilities with less fuel system carbon deposits. Synthetic fuels have very good performance, and have already been in use for many years in the Johannesburg South Africa airport (Sasol fuel), hence it should be relatively easy to supplement current jet fuel supplies with synthetic derived fuel. If the additional CO_2 that is produced during the manufacturing process (1.8 times more than crude oil derived jet fuel) can be captured and permanently sequestered, synthetic fuel may be an acceptable near-term supplement. Some "drop in" fuels may be renewable (i.e., if produced from biomass).

Non Drop-In Fuels

The second category of alternate fuels is "non-drop-in" fuels[1]. Among other things, these fuels often provide less combustion energy per unit of volume, and consequently, aircraft using these fuels require larger fuel tanks. These fuels typically include cryogenic liquids such as liquid methane and liquid hydrogen. Cryogenic liquids have the added complication of being compressed and at very low temperature.

Renewable Fuels

Renewable fuels can fall under either category. Renewable fuels are typically made from biological sources, such as plants that can be grown year after year. The plant material — typically soy beans, canola, or palm — is generally made up of oils that are obtained from squeezing the plant's seeds. These lipids, or hydrocarbon containing organic compounds, contain long-chained carbon and hydrogen molecules. The properties of some renewable fuels fall outside conventional jet fuel specifications. Through additional processing, such as transesterification or hydrotreating, these molecules can be structured to be somewhat similar to diesel or jet fuels. Also, renewable fuels can be blended with other feedstocks to meet jet fuel specifications.

A drawback of renewable fuels is that, because of limited excess farmland, biofuels are currently not capable of supplying a large percentage of fuel without displacing food production. However, some believe that higher yielding future feed stocks, such as algae, may dramatically improve supply capability and eliminate the food versus fuel competition. The advantages of using biofuels would be their reduced overall life cycle (over fossil fuels), their lower CO_2 impact, and the potential to reduce engine emissions. If the performance and cost issues can be overcome, biofuels are envisioned to be blended with synthetic or conventional jet fuels, which could lead to a longer-term sustainable aviation fuel.

Comparing Alternative Fuels

Figure 1 shows relationships between the fuel, the tank needed, and the aircraft weight. The figure shows the correlation with the heavier weight of the fuel and the increase of the aircraft weight. Conventional jet fuels are optimum, as are synthetics. However, there are bio-diesel fuels which are very close.

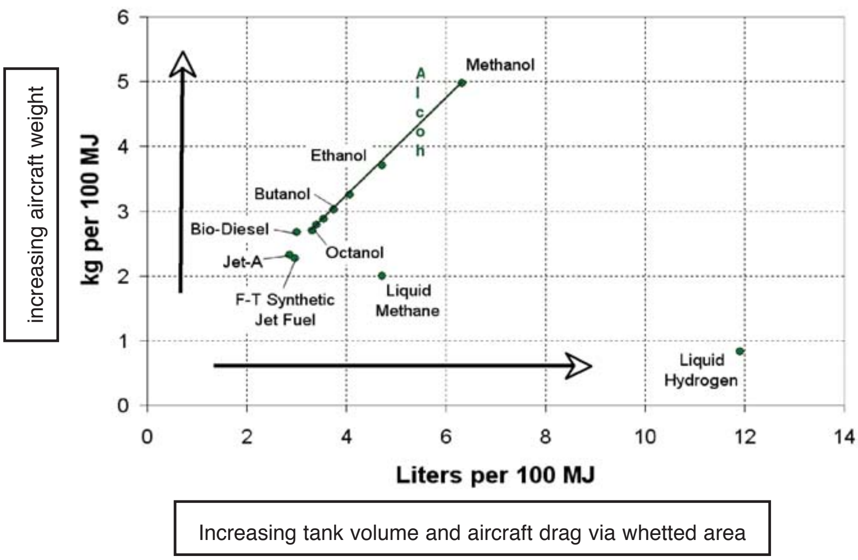

Figure 1 – Relationship between type of alternate fuel and the aircraft weight. From presentation by Lourdes Maurice - ICAO Colloquium on Aviation Emissions, 14 – 16 May 2007.

[1] Non Drop in Fuel means fuel which does not meet the specification to be a drop-in fuel.

An examination of the fuels other than the cryogenic liquids shows that as we move from conventional fuels through synthetic fuels and biodiesel to alcohols, the carbon fraction in the fuel decreases, leading to reduced carbon dioxide in the products of combustion for unit mass of fuel burned. The synthetic and biomass-derived fuels have the advantage that they contain no sulphur. Synthetic fuels also have no, or very little, aromatic compounds (as a result of blending), which greatly reduces the amount of particulate matter emitted. However, aromatic compounds are useful in engine operation as they help to preserve engine seals, and the sulphur compounds are good lubricants. It is therefore likely that synthetic fuels would not be used alone but would have to be mixed with conventional fuels or additives to provide for these otherwise lacking properties.

Some recent tests have shown that synthetic fuels (from coal or natural gas) can provide around 1.6% reduction in carbon dioxide emissions, 50 to 90% less particulate matter, 100% less sulphur dioxide, as well as possibly a 1% reduction in fuel consumption due to a greater gravimetric energy density. The reduction in particulate matter is seen as being especially helpful, since this material is believed to be significantly implicated in both global and local air quality issues.

Fischer-Tropsch Fuels Environmental Implications
Less Emissions

- ~ 1.6% less CO_2 created during fuel combustion
- 50% to 90% less particulate matter (PM) (measured)
- 100% reduction in SO_x
- ~ 1% less fuel burn (increased gravimetric energy density)

Development work is well advanced in the case of synthetic fuels derived from coal and natural gas. New initiatives have recently been announced in the area of biomass and other renewable fuels, although there remain concerns about the availability of feedstocks and the possible interruption of food production.

When considering the total impact of any type of aviation fuel it is important to examine the emissions arising from the production process in addition to the emissions arising from the actual burning of the fuel by aircraft. These production processes include the mining/drilling operations, the refining/gasification/liquidation processes and the transporting of the products both before and after processing. Initial studies of this area have been undertaken and show, for example, that synthetic fuel from coal, after burning in an aircraft engine and in the absence of carbon sequestration, would have produced 80% more carbon dioxide than similar fuels derived from crude oil. This type of study shows a significant advantage for biomass-derived fuels. There is clearly a need for more studies of this type before a commitment is made to any alternative fuel for aviation.

Figure 2 offers some insight into the relative CO_2 emissions for various alternative fuels. Standard Jet Fuel is considered the baseline. Clearly the Bio Jet Fuel is worth investigating further.

Reasons for Optimism and Caution

There are reasons for optimism about the future use of alternative fuels. The current high price of crude oil encourages the search for alternative aviation fuels. These fuels could have environmental benefits, especially in relation to particulate matter and sulphur compounds emissions. They may offer security and price stability in fuel supply, provided that the alternative sources themselves, e.g., coal, natural gas, biomass, etc. are available. Work on developing alternative fuels for aviation is already under way and aviation could well become a leader in the field.

However, there are also reasons for caution. Firstly we should not underestimate the technical difficulties we might encounter even with "drop-in" fuels and the constant need to ensure the safety of aviation operations. It may therefore be easier to make a transition to alternative fuels for ground use before using them in aviation. It has always been difficult to predict the crude oil market and, although it may seem unlikely at the present, a decrease in oil prices might remove one of the major incentives for the further development of alternative fuels. Finally the emissions of carbon dioxide during the production process may be a problem with some alternative fuels.

Future Developments

Before we embark on a transition plan towards the development of alternative fuels, it is important to establish whether we can and should develop alternate fuels. To do this it is necessary to establish the net environmental benefits of these fuels, taking fully into account the environmental costs of producing the fuels. It is also necessary to identify the framework and policies required to facilitate the introduction of alterna-

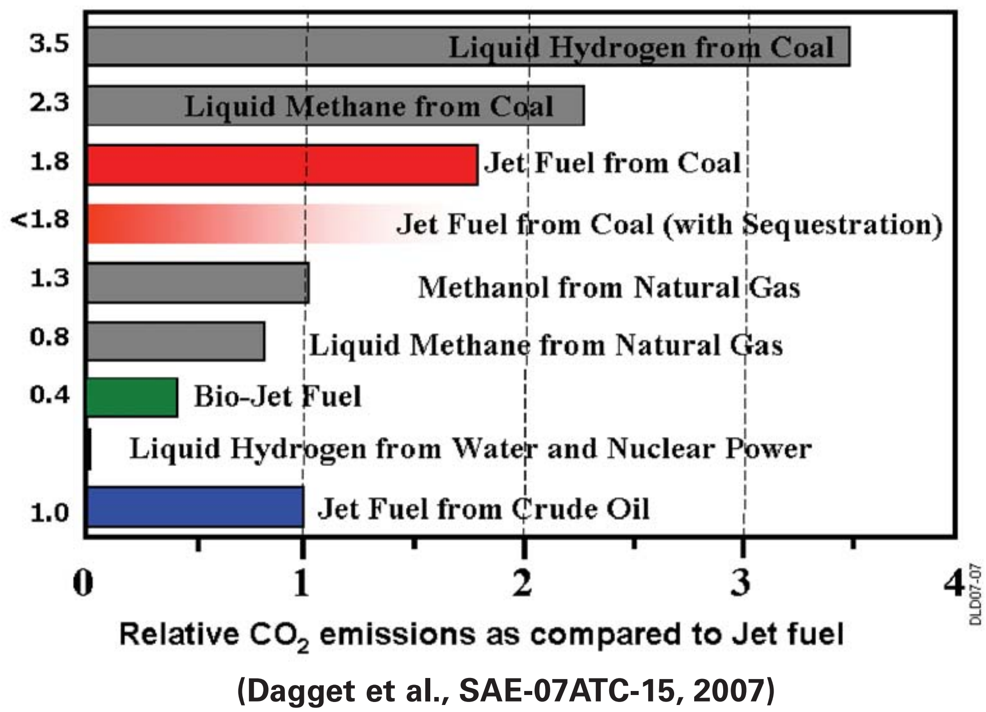

Figure 2 – CO_2 emissions from various fuels compared with Jet Fuel . From presentation by Lourdes Maurice; ICAO Colloquium on Aviation Emissions, 14 – 16 May 2007.

tive fuels. For example, in the United States all sectors of the aviation industry, including operators, manufacturers, and the government, have established the Commercial Aviation Alternate Fuels Initiative (CAAFI) to examine this subject and chart the way forward.

Conclusions

In summary, alternative fuels are not an abstract concept – they are already in use today. The aviation industry is interested in the possible savings and price stability offered by alternative fuels. The fuel industry is willing to start producing these fuels if given market guarantees (i.e., protection from drastically falling oil prices) to do so. Alternative fuels may provide environmental benefits and could become an element of the environmental strategy for sustainable future growth of aviation. We may be able to use alternative fuels to deal with some local air quality issues, allowing us to focus engine design on noise reduction and other environmental issues such as greenhouse gases. Alternative fuels efforts may offer future opportunities to ICAO's CAEP as it seeks balanced and robust strategies to mitigate aviation's environmental impact.

Drop-in fuels are quite feasible in the near term, but there is a need to consider the environmental impact of the whole chain of events, from mine or well to the aircraft's wake. Renewable fuels are a longer term prospect. Again, it must be stressed that the whole chain of events must be taken into account, not just the engine emissions. We must also understand that history has shown the difficulty of predicting energy markets and we must be cautious about pursuing alternative aviation fuels solely as a short-term response to high prices or an impending energy crisis. We must note that we have been down a similar road before in the late 1970s and early 1980s. Heavy investment in alternative fuel options was stranded by the oil glut of the mid 1980s. Ultimate success will require a long-term vision and the will of all stakeholders to see it through

References

All charts and Graphs were taken from the presentation of Ms. Lourdes Maurice, Chief Scientific and Technical Advisor for Environment, Federal Aviation Administration (FAA), U.S. Department of Transportation (DOT), in the ICAO Environmental Colloquium on Aviation Emissions held in Montreal in May 2007.
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Alternative Jet Fuels for Today's Airline Fleet[1]

By Gregory Hemighaus

Gregory Hemighaus is a Staff Scientist with Chevron Global Aviation, providing technical support to Chevron's refining, supply, trading and marketing activities for both jet fuel and aviation gasoline. He is a member of many aviation fuel technical groups including ASTM, Coordinating Research Council, Aviation Fuels Committee, IATA Technical Fuel Group and the International Society for Stability and Handling of Liquid Fuels. He is also the principal author of Chevron's Aviation Fuels Technical Review and Alternative Jet Fuels publications.

Petroleum products have always been the preferred aviation fuels because they offer the best combination of energy content, performance, availability, ease of handling, and price. However, concerns about energy security, climate change, the long-term availability of petroleum, and the recent increase in the price of oil have prompted the industry to search for alternatives.

Besides price, other factors must be taken into account when considering alternative aviation fuels. Of course, safe and reliable operation of the engine and aircraft must not be compromised in any way. The environmental effects of any alternative fuel must also be considered. This includes both emissions from the engine and also life-cycle effects associated with production and use of an alternative fuel.

When considering the possibility of alternative aviation fuels, the following questions arise; Are there viable alternatives to conventional jet fuel available today? What are some of the issues associated with alternatives to conventional jet fuel? This article will focus on potential "drop-in[2]" fuels for today's fleet, and discuss the successful use of an alternative jet fuel in South Africa.

Today's Jet Fuel

The kerosene-type jet fuel used in today's aircraft engines is a complex mixture of hundreds of different hydrocarbons. Hydrocarbons can be grouped into just a few classes, each of which has certain characteristic properties: paraffins, cycloparaffins, olefins, and aromatics. They differ in the geometry of the carbon backbone and the hydrogen/carbon ratio. The paraffin group is often subdivided into normal-paraffins (straight-chain) and iso-paraffins (branched-chains). The olefins are the most chemically reactive class of hydrocarbons and are effectively excluded from jet fuel by the demanding thermal stability requirement. Figure 1 shows the relationship between hydrocarbon class and some jet fuel properties.

Petroleum products are defined mainly by their density and boiling range distribution. Jet fuel boils over the temperature range of about 150^{O}C to 300^{O}C and includes hydrocarbons between about 8 and 16 carbon atoms as shown in Figure 2.

Petroleum-derived jet fuel will also has trace amounts of sulfur-containing compounds. The jet fuel specifications limit sulfur to a maximum of 3,000 ppm, although the average sulfur content of jet fuels is thought to be between 500 and 1,000 ppm.

This is the aviation fuel in use today. The fuel specification requirements reflect its properties. When we consider alternative fuels for *today's* aircraft engines, we are really limited to alternative sources of fuels that are very much like today's petroleum-derived kerosene-type jet fuel.

	Hydrocarbon Class			
Jet Fuel Property	**n-Paraffin**	**Isoparaffin**	**Cycloparaffin**	**Aromatic**
Energy Content				
Gravimetric	+	+	0	-
Volumetric	-	-	0	+
Combustion Quality	+	+	+	-
Low Temperature Fluidity	—	0/+	+	0/-

* "+" indicates a beneficial effect, "0" a neutral or minor effect, and "-" a detrimental effect.

Figure 1 – Potential contribution* of hydrocarbon classes to selected jet fuel properties.

[1] This article is based on the "Alternative Jets Fuels" publication by Chevron. It is available from the author or at http://www.chevronglobalaviation.com/docs/5719_Aviation_Addendum._webpdf.pdf

[2] "Drop-in" is a term used to describe fuels that fit today's fuel specifications and can be handled in the existing supply chain.

When we consider alternative fuels with properties that go beyond the bounds of the current fuel specifications, whether they are intended for current or future engine technology, we have to deal with such issues as: potential certification issues, compatibility with conventional jet fuel, and the fuel handling infrastructure. These are significant obstacles to the introduction of an alternative fuel.

Potential Sources of Alternative Fuels

The following paragraphs describe the primary fuel sources that are currently considered to be possible alternative fuels for aviation.

Fuels from Fossil Sources

Almost all jet fuel today is manufactured from petroleum (crude oil). A relatively small percentage is made from oil sands, mainly from Canada and Venezuela. There are also other fossil fuel sources that could potentially be used to manufacture jet fuel, namely: natural gas, shale oil, and coal. If practical and economical conversion processes can be developed, these reserves could provide alternate sources for jet fuel that would be essentially the same in composition as conventional, petroleum-derived jet fuel.

Fischer-Tropsch Synthetic Fuel

Fischer-Tropsch (FT) synthesis[3] converts a mixture of carbon monoxide and hydrogen, called synthesis gas, into higher molecular weight hydrocarbons. It can be thought of as a catalytic polymerization of carbon monoxide accompanied by reaction with hydrogen to make the CH_2 methylene units of paraffins.

$$CO + H_2 \text{ à } -(CH_2)_n- + H_2O$$

The process makes mainly straight chain hydrocarbons. The product composition will vary somewhat depending on the hydrogen to carbon monoxide ratio and the catalyst and process conditions. This raw product of FT synthesis must be further processed to make an acceptable fuel. This processing includes cracking the long chains into smaller units and rearranging some of the atoms (isomerizing) to provide the desired properties. This upgrading process produces a wide boiling range material encompassing naphtha (gasoline boiling range), kerosene, and diesel. This material is then distilled into final products.

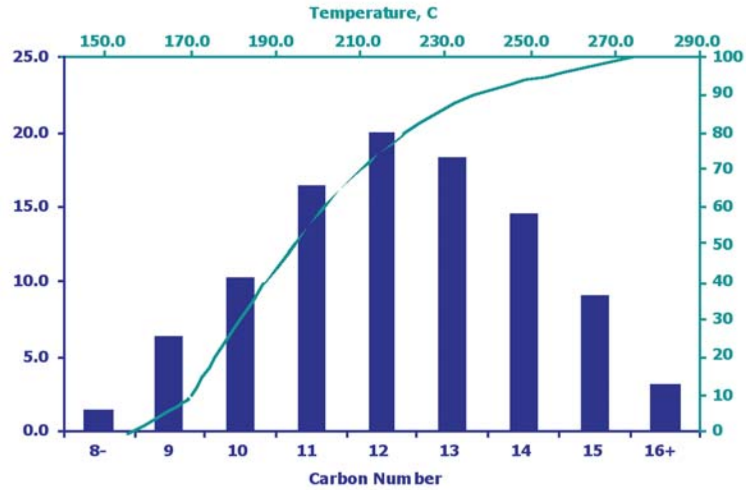

Figure 2 – Typical carbon number and boiling range distribution for jet fuel.

FT synthesis produces a product that is virtually free from the trace sulfur-containing compounds found in conventional jet fuel. The product is also free from aromatic compounds, but this property has both advantages and disadvantages. The main advantage of the aromatic-free fuel is that it is cleaner burning; FT fuel emits fewer particulates than conventional jet fuel[4], and, because it is sulfur-free, there are no sulfur dioxide (SO_2) or sulfuric acid (H_2SO_4) aerosol emissions.

However there are two disadvantages to not having aromatics in the fuel. First, FT kerosene that meets all other jet fuel specification properties will be below the minimum density requirement. Second, the aromatics in conventional fuel cause some types of elastomers (O-rings) used as seals in aircraft fuel systems to swell. There is concern in the industry that switching from conventional jet fuel to aromatic-free FT synthetic fuel will cause some of these elastomers to shrink, which may lead to fuel leaks. The effect of aromatics on elastomers is being actively researched in the industry. A possible solution may be to find an additive that would ensure elastomer-swell even in the absence of aromatics.

[3] "Fischer-Tropsch Technology", A.P. Steynberg and M.E. Dry eds. Elsevier, 2004.
[4] E. Corporan et. al. "Reduction of Turbine Engine Particulate Emissions using Synthetic Jet Fuel" American Chemical Society Division of Fuel Chemistry Preprints 2005, 50(1), p. 338. This work was done by the US Air Force on a military engine. Similar testing has not been done using a modern commercial engine.

These two disadvantages disappear when FT synfuel is blended with conventional jet fuel, although the advantage of lower emissions is reduced. The conventional jet provides the aromatics that cause elastomer swell and also increase the fuel density to meet the minimum requirement. The industry is using 8 percent aromatics content as a guiding minimum. This minimum is based mainly on experience and could be revised, up or down, in the future.

Since the FT synthesis starts with carbon monoxide, any source of carbon can potentially be used. The first plants used coal as the starting material, this conversion is called coal-to-liquids or CTL. The current generation of plants will use natural gas as the starting material (GTL). Biomass can also be used as the starting material going through a gasification step to produce carbon monoxide (BTL). In going through the gasification step, the connection to the starting material is lost, so FT liquids produced from any starting material will be essentially the same.

The FT industry appears to be on the verge of a period of expansion. Several major companies have announced plans to build large production plants. If completed, these projects could yield about 1 million barrels per day of total product by 2020, some of which could potentially be used as aviation fuel. These projections tend to be optimistic, so the industry may grow more slowly.

Jet fuel made from coal by the Fischer-Tropsch (FT) synthesis is currently being supplied to the Johannesburg South Africa airport. A blend of up to 50% FT synthetic fuel with conventional fuel was approved by specification authorities after an extensive review. This synthetic jet fuel was approved in 1999 by the UK Ministry of Defence in Defence Standard 91-91, the international Jet A-1 specification, and is being used by every commercial airplane that passes through that airport, although the fuel typically contains much less than 50% synthetic.

Blends of synthetic FT fuel with conventional jet fuel are probably the easiest technical solution to the alternative aviation fuels quest. A streamlined approval process is being developed to facilitate their use. The US Department of Defense is aggressively pursuing this type of fuel.

Bio-Derived Jet Fuels

Biomass[5] is being increasingly considered as an alternative source of transportation fuels. Ethanol and biodiesel have been used in recent years as blend components for gasoline and diesel fuel respectively, and this use is likely to continue to expand as a result of government mandates in many countries and a desire to diversify energy sources.

One thing that all biomass has in common is that it has a significant amount of oxygen incorporated into its molecular structure. This is a disadvantage when considering biomass as a source of fuel. The primary function of fuel is to provide a source of energy to propel the aircraft. The turbine engine converts the chemical energy stored in fuel into mechanical energy, providing the thrust that powers flight. The chemical energy in fuel is released by combustion, a rapid reaction with oxygen at high temperature. For hydrocarbon fuels, combustion is described by the following equation. The energy released during this reaction is called the *heat of combustion*.

$$C_xH_y + (x + y/4)\ O_2 \rightarrow x\ CO_2 + y/2\ H_2O + \text{heat}$$

Bio-derived fuels containing oxygen have lower energy content than hydrocarbons because the oxygen in the fuel molecule doesn't contribute any energy during combustion. Energy is released by breaking carbon-carbon and carbon-hydrogen bonds in hydrocarbons and converting them to carbon-oxygen and hydrogen-oxygen bonds; starting with carbon-oxygen bonds in the molecule doesn't gain anything. It's like carrying a little air in with the fuel; instead of all the oxygen needed for combustion coming from air, some of the oxygen is already in the fuel molecule. Oxygen in the fuel molecule is just dead weight in the fuel tank. As a result, these fuels have lower energy content than hydrocarbon fuels, which can lead to reduced flight range.

[5] The term biomass means any plant-derived organic matter. Biomass available for energy includes herbaceous and woody crops, agricultural crops, aquatic plants, and other wastes materials including come municipal wastes. Definition from National Renewable Energy laboratory, US Department of Energy.

Biodiesel Fuels

Biodiesel has been in the news in recent years as a possible alternative to conventional, petroleum derived diesel, and is being considered as an aviation fuel as well. In general usage, the term biodiesel covers a variety of materials made from vegetable oils or animal fats. Various crops are used in different parts of the world to make biodiesel. In the US, soybean oil is the largest source for biodiesel. In Europe, rapeseed oil is commonly used while in Asia, palm and coconut oil are used. Research is being conducted into using algae as a source of biodiesel. This is a promising option since algae can give much higher yields of feedstock oil per unit area cultivated and avoid the food vs. fuel tradeoffs associated with agricultural products.

Vegetable oils or animal fats themselves are not generally used as fuels. However, the oils and fats can be combined with methanol in a process known as transesterification to produce a material with better properties. The oils and fats are triglycerides of fatty acids. The process known as the transesterification reaction converts triglycerides into the fatty acid methyl esters (FAMEs).

These esters have chemical and physical properties that are similar to conventional diesel fuel, but not jet fuel. Biodiesel properties depend on the starting material. Triglycerides from different sources have different numbers of carbon atoms and varying degrees of unsaturation (number of carbon – carbon double bonds). These differences are reflected in the properties of the derived FAMEs. Some typical properties for biodiesel are compared to conventional jet fuel below.

The primary concern about using biodiesel is its low temperature properties. Biodiesels have freezing points near 0^{o}C, much higher than the maximum freezing point of jet fuel, -40^{o}C for Jet A and -47^{o}C for Jet A-1. This has definite safety implications since fuel is exposed to very low temperatures at cruise altitude, and it must remain fluid in order to be pumped to the engine. Even blends of biodiesel with jet fuel have much higher freezing points than jet fuel. Additives could potentially improve low temperature operability of biodiesel blends, but only by a few degrees C. Any new additive would have to go through an extensive approval process.

Another important jet fuel property is thermal stability. The thermal stability of FAMEs and blends of FAMEs with conventional jet fuel has not been reported, but is an area of concern. The higher carbon number and viscosity of FAMEs compared to jet fuel could affect atomization and vaporization in the combustion chamber. All of these issues would have to be studied thoroughly and all issues resolved before FAMEs could be used in aviation.

Triglycerides and the resulting FAMEs are the most fuel-like biological products. But even the FAMEs are not a good match for jet fuel properties. Another approach being used is to hydroprocess these materials using conventional refinery technology. This processing removes the oxygen from the molecule and saturates any double bonds. The resulting hydrocarbons, typically paraffins with 15 and 17 carbons, fall into the high end of the jet fuel range. A jet fuel can probably accommodate only small amounts of these compounds without exceeding the maximum freezing point.

Fuel Property	Biodiesel (typical)	Conventional Jet Fuel
Viscosity 40oC, Cst	4.7	1.2
Net Heat of Combustion, MJ/kg	36 – 39	43.2
Density, 15oC	0.87 – 0.89	0.80
Freezing Point, oC	~ 0	< -40
Approximate Carbon Number Range	16 – 22	8 – 16

Source: National Soy Diesel Development Board and National Biodiesel Board

Figure 3 – Properties of biodiesel and conventional jet fuel.

Another option is gasification, especially of waste biomass, followed by FT synthesis. It may also be possible to develop new processing technologies to achieve the molecular transformations required to convert biomass into kerosene. Significant molecular changes are required to transform triglycerides or any other biomass into "jet fuel molecules".

Environmental Considerations

Although today's interest in alternative fuels seems to be driven mainly by price and supply concerns, any environmental effects of an alternative fuel must also be considered. The industry and the general public will only accept improvements when it comes to environmental quality and stewardship.

Emissions testing has been conducted on FT synthetic fuel in combustor rigs. FT fuels emit much lower concentrations of particulates and because they are sulfur-free, they emit no sulfur oxides (SO_x) or sulfuric acid (H_2SO_4) aerosols. When blended with conventional fuels, the emissions benefit is roughly proportional to the synthetic fuel content.

There are no data available on emissions from biodiesel fueled turbine engines, but these are potentially a concern. FAMEs are more viscous than conventional jet fuel and have higher molecular weight. These properties could affect atomization and vaporization in the combustor and result in incomplete combustion and particulate emissions, especially at low engine power settings.

Emissions from the engine are not the only environmental concern. The whole life-cycle of fuel exploration, development and production must be studied. When considering bio fuels, issues such as land use, fertilizer and pesticide use, water for irrigation, waste products etc must be addressed. This type of analysis is called "cradle to grave" or "life cycle assessment" and has been conducted for several fuels.[6] [7]

Similarly, with use of coal or shale there are issues with mining, both deep-hole and strip mining, water use, run-off from mine sites, and waste material.

Also, any processing of raw material into finished fuel is energy intensive, resulting in emissions of carbon dioxide, a significant greenhouse gas. In contrast, growth of biomass removes carbon dioxide from the atmosphere so use of biomass-derived fuel in place of fossil-derived fuel can potentially result in a net decrease in carbon dioxide emissions.

Conclusions

There are no easy answers in the search for alternatives to conventional jet fuel. This is partly because safety and reliability cannot be compromised. Also, there are unique requirements for operation of the conventional turbine engine in commercial service that make a rigorous approval process necessary for any alternative fuel.

As mentioned above, bio-derived fuels for today's fleet face significant challenges because of the molecular transformations required to convert biomass into kerosene-type hydrocarbons. It will be easier to develop bio-derived fuels that can be used in blends with conventional jet fuel than to develop a stand-alone bio-jet fuel. From an environmental perspective, bio-derived fuel could help to reduce aviation's carbon footprint.

While there continues to be significant investment in the research and development of alternative jet fuels, the only alternative to conventional jet fuel on the near-term horizon is synthetic FT jet fuel used in a blend with conventional jet fuel.

[6] "Gas to Liquids Life Cycle Assessment Synthesis Report" Five Winds International, 2004. http://www.sasolchevron.com/pdf/publication/GTL_LCA_Synthesis_Report.pdf#search=%22life%20cycle%20assessment%20fuel%22.

[7] Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Argonne National Laboratory. http://www.transportation.anl.gov/software/GREET/index.html

Alternative Fuels for Commercial Transport Aircraft

By Oren Hadaller and Dave Daggett

Oren Hadaller is a senior fuel and propulsion engineer for Boeing Commercial Airplanes where he is the principal investigator for fuel research activities and a technical focal point on jet fuel and energy issues. He also provides technical support to Boeing's ICAO representatives. In 35 years with Boeing he has worked in: fuels research, manufacturing technology, preliminary design, central engineering, configurations, and competitor assessment. Since 1976, he has been conducting research on petroleum and alternative aircraft fuels and is a specialist in jet fuel properties, production, quality, and delivery. Mr. Hadaller holds degrees in Chemical Engineering, Chemistry and Math.

Alternative fuels, such as kerosene-type hydrocarbon jet fuels, have the potential to provide enhanced environmental performance over conventional jet fuels. This is possible due to the lower sulfur and aromatic content of alternate fuels. Depending on the hydrocarbon source for the alternate fuel, and the manner in which it is processed, life-cycle carbon dioxide emissions could dramatically increase or decrease. Other fuel performance characteristics, life cycle issues, and costs must be addressed before suitable candidates can be chosen. This article primarily addresses environmental issues associated with alternate fuels.

Background

Synthetic Fischer-Tropsch (FT) jet fuel or synthetic kerosene can be made from coal, natural gas, or other carbon-containing resources and can be produced by first turning the resource into gases, which are then processed to form desired hydrocarbon liquids. Synthetic kerosene can be tailored to have similar properties to petroleum jet fuel and can thus be thought of as a "drop-in" replacement fuel. Synthetic jet fuel derived from coal is currently used at one airport as a supplement to current petroleum supplied jet fuel. In the future, coal-based kerosene will be approved as a total replacement for petroleum jet fuel. Synthetic FT jet fuels are actively being tested and certified in actual aircraft used by the U.S. military (see article *U.S. Air Force Department of Defense "Assured Fuels" Program*).

Biofuels are combustible liquids that are manufactured from renewable resources such as plant crops or animal fats. Crops with high oil content such as soybeans, canola (rapeseed), sunflowers, and palm nuts are typically used as starting materials. Biofuels start with oil squeezed out of these crops/feedstocks and is then converted into biojet fuel through one of many different processing methods currently being developed by the fuel industry. Biojet fuel samples are being gathered by Boeing from suppliers and tested in collaboration with manufacturers, industry groups, and governments. Future high-yielding biofuel feedstocks, such as algae, are being investigated for their feasibility, sustainability, and cost.

Required Performance

The ideal fuel for commercial aviation is one that does not: become solid at very cold temperatures, break down under high temperature engine conditions, or evaporate easily As shown in Figure 1, other fundamental requirements for commercial jet fuel are that it: 1) has a low weight per unit heat of combustion to allow the transport of revenue-producing payload, and 2) occupies a small volume per unit heat of combustion to allow fuel storage without compromising aircraft size, weight or performance. Jet fuel and similar alternatives have the best performance in terms of requiring the least volume. Hydrogen is the best in terms of weight; however, hydrogen, along with methane, alcohols, and liquefied petroleum gases - all require new aircraft with new fuel delivery systems.

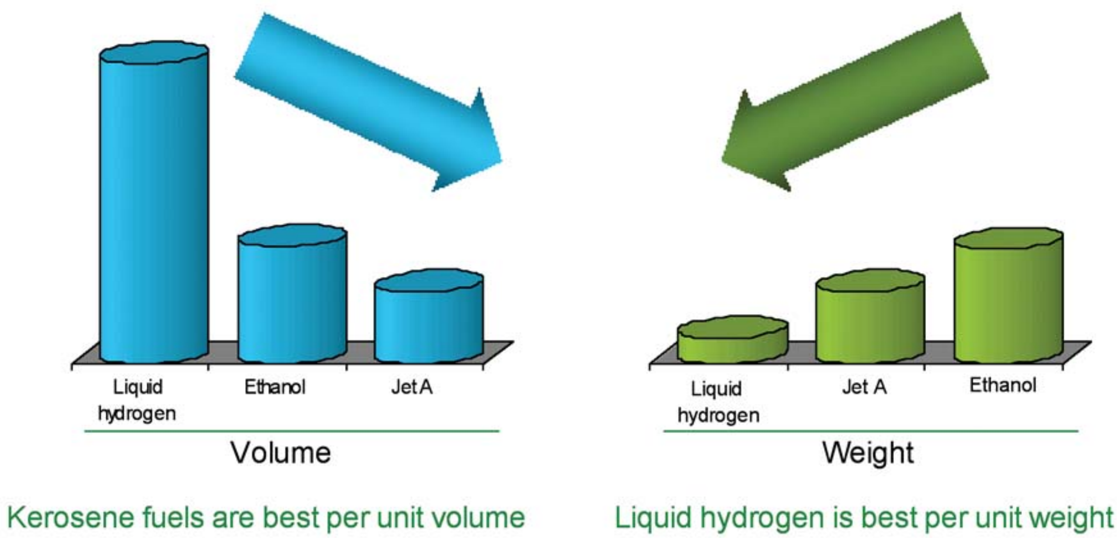

Figure 1 - Alternative fuel comparison for commercial transport aircraft.

Emissions Reduction Potential

Elimination of fuel-borne sulfur in alternate fuels would cut sulfur dioxide (SO_2) and other sulfur-based emissions.

There is the possibility that elimination and along with reductions in fuel aromatics, could possibly also offer reductions in soot emissions. Elimination of aromatics would significantly reduce Polycyclic Aromatic Hydrocarbon (PAH) emissions, which have been observed in diesel engines. These species contribute to the degradation of air quality. Reductions in fuel aromatics and naphthalene could also possibly reduce soot emissions. As aromatics and naphthalene decrease, fuel hydrogen content increases.

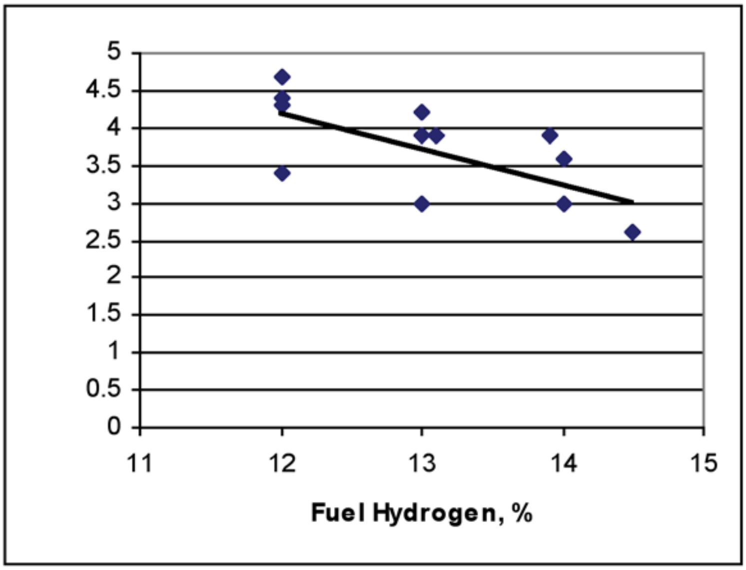

Figure 2 – Illustrates the impact of reduced aromatics and naphthalene, by way of hydrogen content, versus the smoke number for a modern CFM56 aircraft gas turbine engine.

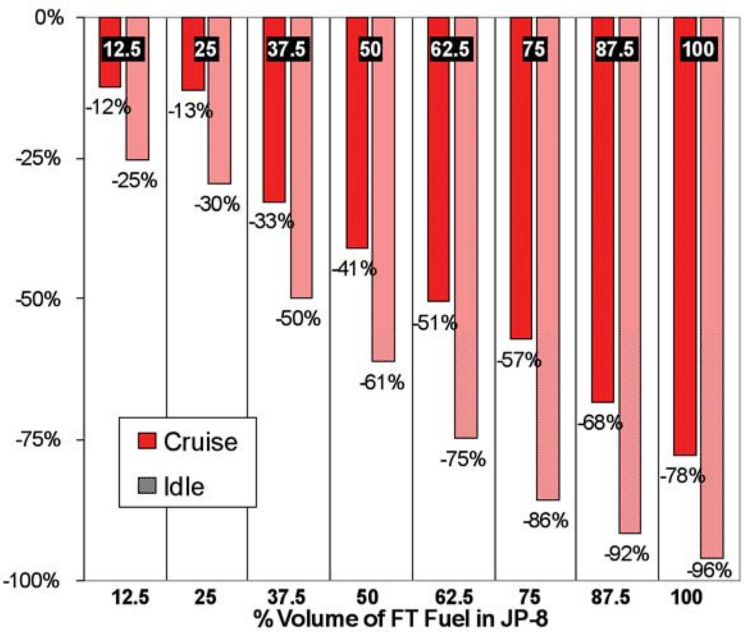

Figure 3 - Particulate emissions from helicopter engine compared to percentage of FT fuel blend (Chart compliments of Bill Harrison, AFRL, 2006.)

When biodiesel, which can have similar make-up to biojet fuel, is used in ground vehicles, a reduction in particulate, carbon monoxide (CO) and hydro carbon (HC) emissions has been observed. Nitrogen oxide (NO_x) emissions can increase in certain instances. Boeing plans to work with other stakeholders to quantify the emissions impact of biojet fuels when used in modern aircraft engines.

CO_2 Impact

The driving force for using biofuels in aviation is environmental. Finding an alternative drop-in fuel that can reduce the carbon footprint of aviation operations is very desirable.

Due to the carbon uptake during the growth cycle of biomass feedstock, biojet fuels are expected to be approximately carbon neutral over their life cycle, offsetting about the same amount of carbon as is produced when the fuel is burned in a jet engine. Depending on the feedstock, growing and harvesting practices, as well as fuel processing methodologies, the biojet fuel is anticipated to provide approximately a 60-80% reduction in the life cycle carbon dioxide (CO_2) emissions.

Figure 4 illustrates the life cycle CO_2 impact for the production through end use of various alternative fuels as compared to current jet fuel produced from crude oil. Synthetic FT fuel derived from coal is anticipated to result in an 80% increase in CO_2 emissions, while a similar process that captures and sequesters CO_2 will result in substantially less CO_2 emissions; about equal to the CO_2 emissions from jet fuel made from crude oil.

Life Cycle Issues

The environmental impact of alternate fuels must be evaluated over the entire life cycle of the fuel — a sort of "well to wake" evaluation.

For synthetic FT fuels, it was previously seen that CO_2 emissions generated during the manufacturing process can almost double the life cycle of CO_2 emissions. For FT fuels that are derived from coal, both the mining of the coal and the disposal of the coal cinders from the manufacturing process, can result in major environmental challenges. Large scale, permanent, environmentally benign CO_2 sequestration techniques for FT fuel

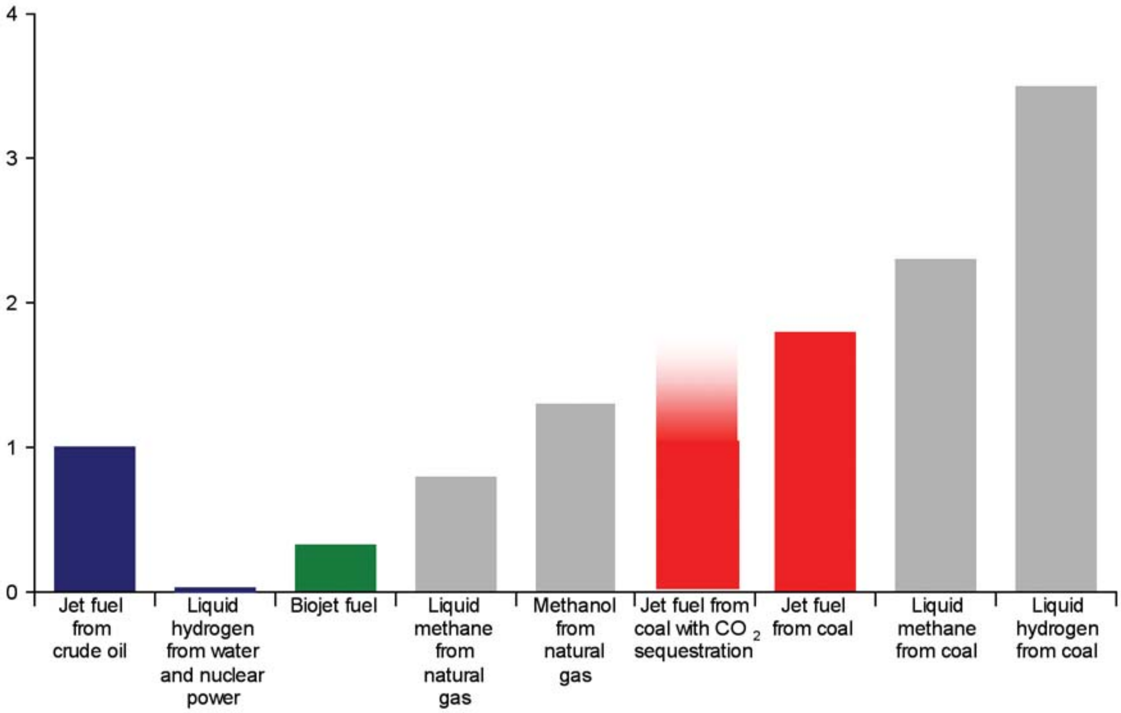

Figure 4 – Relative CO_2 emissions as compared to jet fuel - source through end use.

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He has over 30 years of experience in aerospace; first teaching aeronautics classes at San Jose State University, and then working for many years in the fuels and combustion group at Rolls-Royce. Dave is the chairman of SAE's environmental committee as well as the R&D leader of the Commercial Aviation Alternate Fuel Initiative (CAAFI) that is helping to commercialize alternative fuels. At Boeing, he is the project manager of the biojet fuel program. He also is responsible for researching other environmental technologies that will improve fuel efficiency or reduce emissions. His hobbies include making art glass and biodiesel (that he uses in his own cars.)

production are, as yet, a relatively unproven technology that in many instances could substantially boost the cost of the fuel.

For biofuels, a major area of concern is with the biomass feedstock. Presently, changes in land use (e.g. deforestation) are significant CO_2 contributors to global warming. Increasing the demand for traditional biomass, to produce biofuel, would likely result in the acceleration of deforestation (Figure 5.). These traditional feedstocks could also raise the "food vs. fuel" issue. Lastly, the growing of some crops, such as soybeans and canola, can produce nitrogen dioxide (N_2O) emissions, which is a shorter lived, but much more potent greenhouse gas than CO_2.

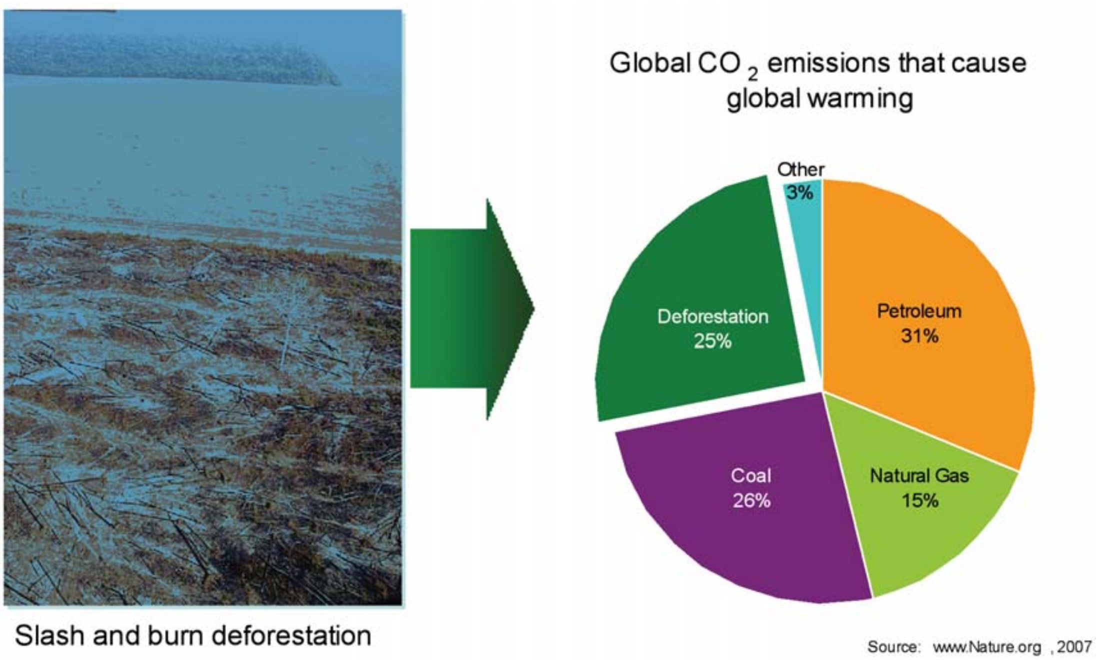

Figure 5 - Growing biofuels must not encourage deforestation or it will have a negative impact on global warming.

Solutions might be to develop alternate feedstocks, such as switchgrass and algae, both of which can be grown in areas generally not suitable for food crops. In the case of algae, it might one day be commercially grown with waste water effluent, thereby cleaning the water while lessening methane and CO_2 emissions from sewage plants. Through the use of specially developed enzymes, synthetic biology processing methods may one day commercially convert cellulose biowaste products, as well as switchgrass, into biojet fuel.

Sustainability

Specific regions of the world may hold specific solutions for providing the biomass feedstock for biojet fuel. For example we can look at Brazil where one sustainable solution might be to harvest nuts obtained from native Brazilian palm trees called "Babassu." The oil from these nuts might provide a sustainable source of oil for biojet fuel in Brazil. The production of palm nut oil in Brazil may be one way to encourage reforestation of devastated lands.

Future biofuels may involve other bio resources. One such promising feedstock is algae, which has been evaluated by the U.S. Department of Energy's National Renewable Energy Laboratory. Algae feedstocks are projected to theoretically produce up to 20,000 gallons/acre/year of bio-derived oil. With such a high production rate, algae could produce 150–300 times more oil than a crop of soybeans, as shown in Figure 6.

For example, with the potential for algae to provide 10,000 gal/acre/year, some 85 billion gallons of biojet fuel can be produced on a landmass equivalent to the size of the U.S. state of Maryland; enough to have met 100% of the fuel requirements for the global commercial aviation fleet in 2004.

Unlikely Alternative Aviation Fuels

In addition to the FT fuels and biofuels mentioned above, there are some other well known "fuel alternatives" that are often mentioned as possibilities as aviation fuel alternatives but which, after close examination, are less than ideal candidates for various reasons. All of these fuels are still under serious consideration as general alternative fuels but they do not meet the unique requirements for aviation fuels, as discussed below:

Hydrogen

This is publicized as the most environmentally benign alternative to petroleum, has its own drawbacks as an aircraft fuel. Hydrogen burns cleanly, but produces significantly more water vapour, so its effect on cloud formation and the atmosphere is uncertain. Hydrogen production needs an abundantly available source of energy, such as electrical power, produced from nuclear fusion or solar and a large source of clean water. Although the combustion of hydrogen emits no carbon dioxide emissions and is lightweight, its production, handling, infrastructure, and storage offer significant challenges. The volumetric heat of combustion for liquid hydrogen is so poor that it would force airplane design compromises and is only practical for longer range flights.

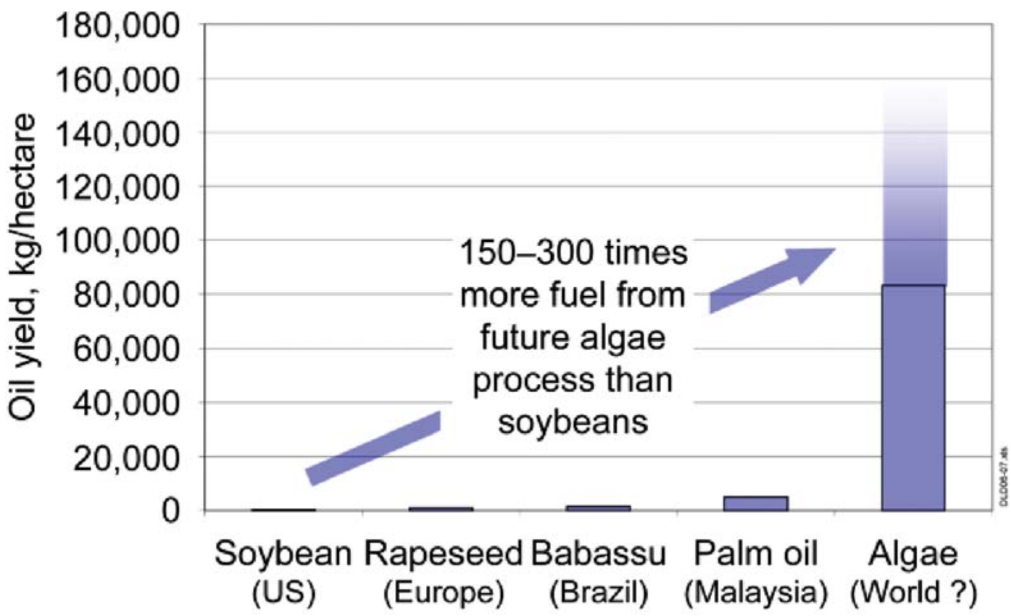

Figure 6 - Oil yield per hectare from selected bio sources.

Methane
Methane is the primary component of natural gas. Natural gas will needs to be stripped of its non-methane content to be suitable for aircraft. Both hydrogen and methane must be used in their liquid form, which are at extreme cold, cryogenic temperatures. Both liquid hydrogen and methane will require all new aircraft. In addition, the use of liquid hydrogen and methane will require entirely new and more complex ground transportation, storage, distribution and vent capture systems.

Liquefied petroleum gas
This gas is not a cryogen but has many of the same storage and transfer problems associated with a cryogen. In-depth studies of these fuels have not been conducted because the natural supply is not sufficient to support a worldwide aviation fleet and these fuels offer no availability, cost or environmental advantage as replacements for conventional jet fuel.

Alcohol
Fuels such as methanol, ethanol, and butanol have very poor mass and volumetric heats of combustion and are not satisfactory for use as a commercial aircraft fuel. Their low energy content results from the oxygen that is present in their molecular structure. Even though they are not useful for commercial aviation, their widespread production and use could influence the supply and cost of conventional jet fuel by freeing up additional petroleum resources for aircraft. Their production might have merit in that context.

Industry Research and Development
Developing alternative fuels for aviation is an industry-wide effort involving all sectors of the aviation industry: airlines (through the International Air Transport Association), aerospace manufacturers (through the International Aerospace Industries Association), safety, environmental, and regulations (the U.S.-Federal Aviation Administration), airport operators (Airports Council International-North America) and fuel suppliers; all working together. They have formed an organization called the Commercial Aviation Alternative Fuels Initiative (CAAFI) with the FAA as the lead organization.

Boeing is also working directly with biofuel suppliers, biojet producers, engine companies and airlines to conduct flight demonstrations using biojet fuels that are designed to create an "industry vision" and accelerate research and development.

Summary
Boeing is working internally, and with the industry group CAAFI, to investigate the use of synthetic Fisher-Tropsch (FT) and biojet fuels for use in commercial and military aviation applications.
FT fuels are able to satisfactorily match jet fuel's performance characteristics while a few biojet fuels presently appear to also be capable of meeting aviation industry performance requirements.

Elimination of fuel-borne sulfur in alternate fuels would offer reductions in sulfur oxide (SO_2) emissions and, along with reductions in fuel aromatics, could also possibly offer reductions in other emissions such as soot and other hazardous air pollutants. In the case of jet fuels derived from biological sources, there is also the opportunity to achieve substantially (i.e. 60-80%) lower life-cycle CO_2 emissions.

However, choosing the wrong alternative fuel could lead to an acceleration of deforestation and the production of more GHG emissions, thereby accelerating climate change. Fischer-Tropsch fuels may provide slightly lower CO_2 emissions in the engine exhaust. On the other hand, without the capture and sequestration of the CO_2 during the manufacturing process, the use of FT fuels would result in approximately a doubling of life cycle CO_2 emissions.

Environmental Recommendations

- Life cycle analysis should be performed on all alternate fuels.
- CO_2 capture and sequestration should be implemented with new Fischer-Tropsch fuel plants.
- Promising biojet fuels should be developed that would use sustainable feedstocks and also have low life-cycle CO_2, and environmental footprints.

Aviation Industry Commitment
The aviation industry is committed to reducing its environmental footprint and to working together with the energy producers and users and all stakeholders to supply a synergistic set of energy and environmental solutions. The Industry's vision is to eventually have jet fuels that are: affordable, derived from non-crude oil sources, and have minimal environmental impact.

U.S. Air Force/Department of Defense "Assured Fuels" Program

By Tim Edwards

Dr. Tim Edwards is a Senior Chemical Engineer in the Fuels Branch of the U.S. Air Force Research Laboratory's Propulsion Directorate/Turbine Engine Division. He has 23 years of experience in research in fuels and propellants, working at both of the Propulsion Directorate's sites at Edwards AFB and Wright-Patterson AFB. His interests include properties and applications of hydrocarbon fuels/propellants and endothermic fuels, in support of advanced propulsion programs for the Department of Defense.

The ongoing Air Force program in alternative (non-petroleum) fuels has two goals: 1) certification of all vehicles to use a 50/50 blend of conventional jet fuel and Fischer-Tropsch (FT) iso-paraffinic kerosene (from coal, biomass, or natural gas) by 2011, and 2) 50% of fuel purchased by 2016 will be an alternative, non-petroleum fuel or fuel blend produced in facilities that effectively manage (control) CO2 emissions.

The U.S. Air Force's current jet fuel usage is roughly 3 billion gallons per year, and is deliberately declining as a result of conservation efforts due to increasing fuel prices. The Air Force, and the Department of Defense in general, use essentially no gasoline and a relatively small amount of diesel fuel - the primary military fuel in the U.S. is jet fuel. Military jet fuel use is about 10% of U.S. jet fuel usage, with the Air Force consuming fuel at a rate similar to the largest U.S. airlines.

The Air Force is committed to completing its testing and certification of aircraft fleet for alternative fuels by 2011. Working with industry, we can accomplish this goal. Once accomplished, we look forward to buying domestically produced synfuel at competitive market prices from manufacturing facilities that engage in effective carbon dioxide capture and reuse.

Background

The Air Force's current alternative fuel program began in earnest in 2006 with a B-52 flight demonstration program, which culminated in December 2006 with thorough flight tests of a B-52 completely fueled by a 50/50 blend of JP-8 jet fuel and Fischer-Tropsch iso-paraffinic kerosene (IPK). The IPK was produced by Syntroleum Inc. in Tulsa OK from natural gas. While this blend is similar to the blend approved for use in South Africa (only) via the international specification, the flight demonstration was only a part of extensive ongoing testing and certification program aimed at certifying blends of any FT fuel with any petroleum jet fuel. This program is being closely coordinated with the commercial effort under CAAFI - the Commercial Alternative Aviation Fuel Initiative - sponsored by the FAA beginning in 2006. (See related articles in this Part of the report on Alternative Fuels for Commercial Transport).

There are two major differences between the current certification process and the certification of Sasol semi-synthetic jet fuel (SSJF) that occurred in 1999. First, the desire is to have approval for a generic Fischer-Tropsch blending component that is independent of feedstocks (coal, natural gas, biomass, petroleum coke, etc.) and independent of manufacturers. Second, the approval would be refinery/crude-source independent. The approval for Sasol SSJF [1], and the current effort to qualify Sasol Fully Synthetic Jet Fuel (FSJF) [2,3] apply only to synthetic fuels from the Sasol Secunda plant, mixed with petroleum Jet A-1 in South Africa. Note that the Sasol FSJF contains synthetic aromatics and is not 100% IPK.

Alternative Fuel Certification

The developing Air Force and commercial (ASTM) certification processes appear to be very similar and are consistent with the process used to qualify Sasol SSJF. Typically, the initial steps are measurements of the fuel specification properties (density, heat of combustion, boiling range, etc.). Next, fit-for-purpose properties are measured, as indicated by the specification test data. Fit-for-purpose properties are those properties that are important for jet fuel, but not specifically controlled in the specification (because the petroleum source typically produced fuels that had effective values of these properties). Examples include dielectric constant (for fuel gauging), materials compatibility, and lubricity. Depending on the results of these tests, component and engine tests may or may not be required.

Fischer-Tropsch kerosene fuels typically consist only of normal (straight chain) and iso-paraffins. The low freeze point of jet fuels (-40 C for Jet A and -47 C for Jet A-1 and JP-8) requires a relatively large portion of iso-paraffins. There are three major concerns with (pure) Fischer-Tropsch jet fuels: 1) lack of aromatics affects fuel system elastomer seal swell, 2) lack of heteroatomic species produces a low-lubricity fuel, and 3) the density of the iso-paraffinic kerosenes is typically below the 775 kg/m^3 limit in current jet fuel specifications. At this point (mid 2007), these concerns appear to be effectively mitigated by the limitation of the synthetic fuel content to 50%.

For the Air Force, the mandatory use of a corrosion inhibitor/lubricity improver additive mitigates any concern about lubricity. There is an issue with the proper lower limit on aromatic content. Current specifications have a 25 vol% upper limit on aromatics, but no lower limit. DEFSTAN 91-91 adds an 8% lower limit on aromatics for the Sasol SSJF blend. This 8% limit would prevent a significant fraction of U.S. jet fuels from being suitable for being mixed with 50% F-T IPK - and indeed many million gallons of petroleum jet fuel in the U.S. are burned yearly with less than 8% aromatics, with apparently no ill effects. So, this lower limit is still under investigation, primarily through extensive testing of nitrile elastomers with fuels of varying aromatic and F-T levels. The U. S. Army has also been actively studying elastomer compatibility [5]. Other fit-for-purpose properties are undergoing current testing or have completed testing with no adverse results. For example, extensive material compatibility tests (28-day soak) on 61 aircraft materials and dielectric constant/fuel gauging tests have indicated no issues for FT blends.

The main issue currently under study is the structure of the FT IPK specification - how tightly must it be written to ensure that IPK blend behavior in aircraft is consistent amongst manufacturers and feedstocks? Two IPK jet fuels have received extensive analysis and testing - the Sasol coal-derived IPK delivered in blends to aircraft at Johannesburg International Airport and the Syntroleum natural-gas derived IPK used in the blends in the B-52 flight demo (for which 100,000 gallons were purchased). A third IPK jet fuel is being purchased from Shell Inc. for testing in August 2007 (300,000 gallons).

Emissions Testing Issues

Extensive emissions testing has shown that the main influence on gas turbine engine emissions from the FT IPK fuels comes from the dramatic reductions in particulates due to the high H/C ratio of the FT fuel (~2.15 vs ~1.95 for petroleum-derived jet fuels). Particulates (soot) are typically reduced about 80% with pure IPK, with the reduction being linear with FT IPK addition [4]. Sulfur emissions are also decreased linearly with F-T addition, since the FT IPK is essentially sulfur-free. NO_x, unburned hydrocarbons, and CO are typically unchanged. The higher H/C ratio of the F-T fuels produces a small decrease in CO_2 emissions index (and a corresponding small increase in H_2O emissions index.)

The effect of Fischer-Tropsch fuel production on overall CO_2 emissions is a key issue. Tracking of CO_2 emissions from jet fuel production through to fuel combustion (i.e. a "well-to-wake" analysis)

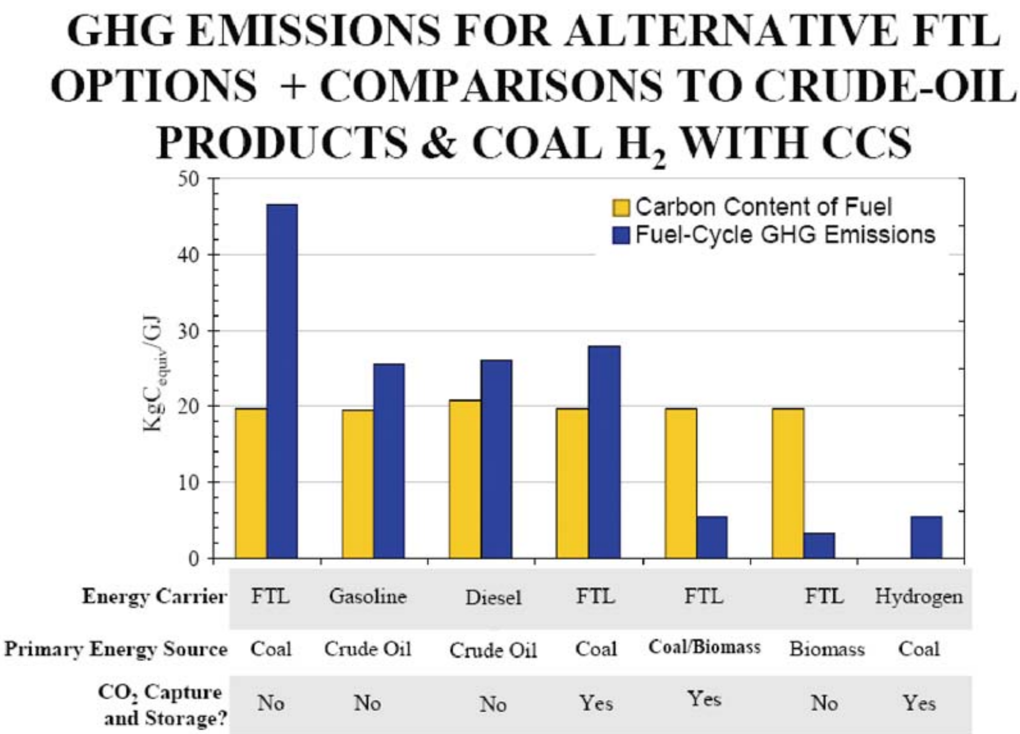

Figure 1 - Carbon emission rates (production + use) for various fuel options.
Figure from Robert Williams, Princeton [http://www.colorado.edu/law/eesi/EESI_Lecture_19_January_06.pdf].

typically shows that net CO_2 production per unit of energy release for coal-derived FT fuels are roughly twice that of baseline petroleum jet fuels (i.e. jet fuel made from a "Saudi-Arabian light" crude). It should be noted that oil produced from tar sands and heavy crudes (such as those from Venezuela) has a significantly larger CO_2 "footprint" than the baseline.

As stated in the quote at the beginning of this article, it is realized that deployment of Fischer-Tropsch technology on a large scale will require CO_2 mitigation strategies. The U.S Department of Energy is funding a significant amount of work on carbon capture and sequestration (CCS). One key observation is that, unlike coal-fired power plants, coal-fed Fischer-Tropsch plants produce a concentrated stream of CO_2, which has value as an aid in oil recovery and other applications. The use of biomass as a feedstock and CCS technologies can potentially produce a fuel with a lower CO_2 footprint than current fuels, as can be seen from Robert Williams' analysis in Figure 1.

Conclusions

The following points sum up where we are currently with respect to the investigation of alternative fuels as a means to reduce aviation emissions:

- It is recognized that fuels derived from biomass can have a significantly lower CO_2 footprint than fuels produced from coal. Combustion of biomass can be thought of as CO_2 recycling, rather than CO_2 production. Alternatively, biomass and coal can be gasified together to reduce the carbon emissions from an FT process.

- There are a number of ongoing studies (some with Air.Force co-funding) looking at the overall CO_2 impact of various fuel production approaches.

- There are a number of recently-initiated efforts to produce jet fuels from a variety of bio feedstocks. Notably, DARPA has initiated contracts with three companies to produce "biojet" fuels from seed oils, with delivery of 100 L each scheduled in 2008.

- Syntroleum Inc. has announced a joint venture with Tyson to produce fuels from animal fats, and has a contract with the Air Force to deliver 500 gallons of jet fuel in late 2007. The non-FT biofuels may be able to be used directly, rather than as blends.

- Air Force research continues to determine the feasibility of using pure FT IPKs as jet fuels, although the near-term focus remains a blend.

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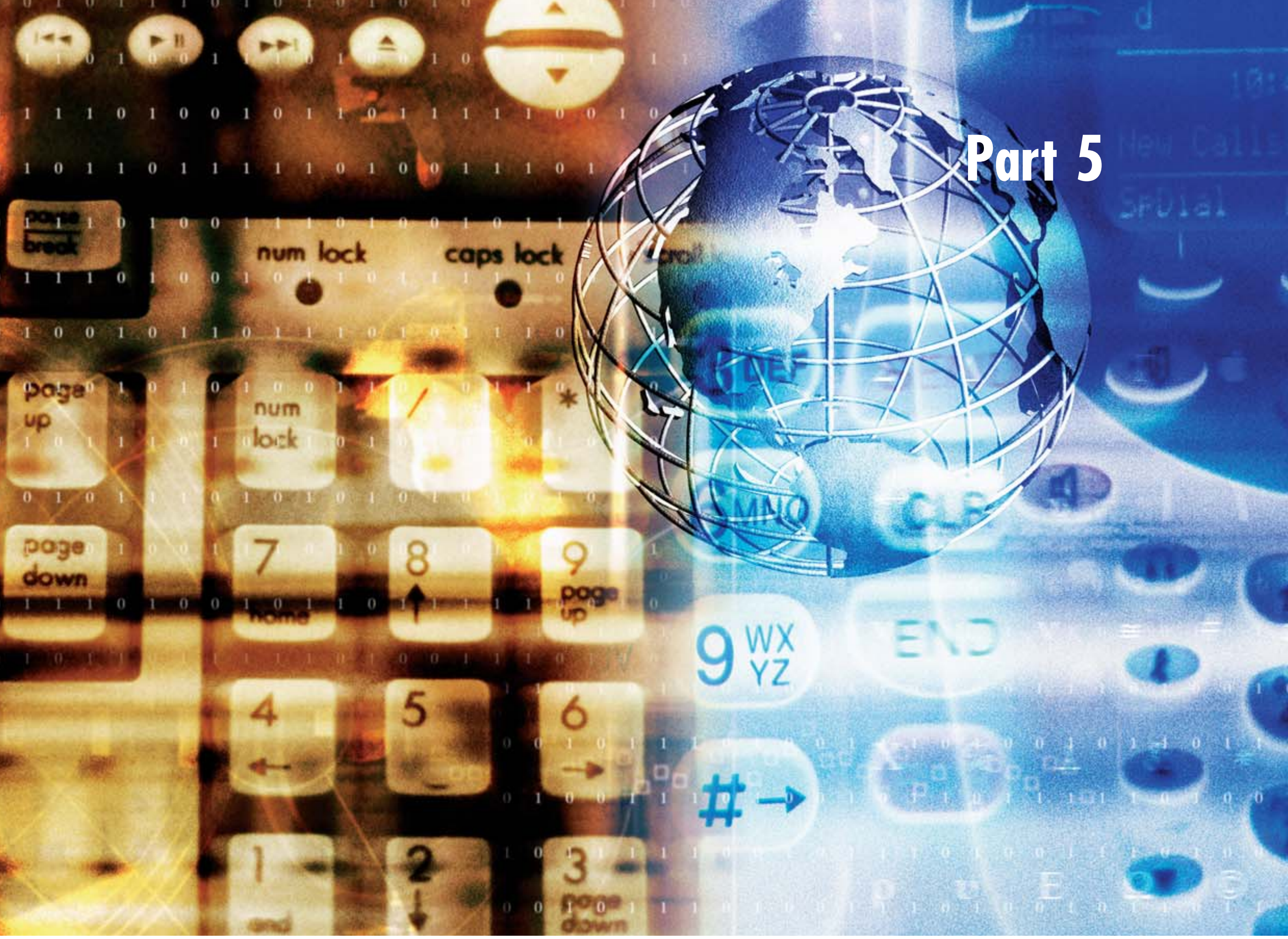

Part 5

Modelling and Databases

Modelling and Databases Overview

By ICAO Secretariat

One main role of ICAO's Committee on Aviation Environmental Protection (CAEP) is to identify and carry out analyses of the various options available to limit or reduce the impact of international civil aviation noise and emissions. The aim of these studies is to assess the technical feasibility, the economic reasonableness, and the environmental benefits of the options considered. In doing so, CAEP has relied on the use of a variety of computerised models and databases offered by contracting States and international organizations participating in CAEP.

Over the years, CAEP's analytical role has progressively expanded from basic assessment of standard-setting options to include analyses of policy measures such as the balanced approach to limit or reduce the impact of aircraft noise and market-based options (i.e. noise and emissions charges and emissions trading).

As the need for a better informed policy-making process grows, CAEP's modelling requirements in terms of coverage (i.e. noise, emissions, costs and benefits, etc.) and accuracy increase. In order to address these requirements, CAEP established, during its seventh meeting, a Modelling and Databases Task Force (MODTF) whose mandate includes the following tasks:

- Continue the candidate model evaluation process, which calls for sensitivity tests, comparisons with "gold standard data", and sample problems.
- Refine the process as appropriate on the basis of relevant criteria, to better inform CAEP which tools are sufficiently robust, rigorous and transparent, and appropriate for which analysis, and why there might be differences in modelling results.
- In support of the model evaluation process, conduct modelling sample problems to: identify gaps in existing tools, identify potential approaches for displaying interdependencies, and adapt models as necessary.
- Examine how CAEP will directly compare the results of the various modelling tools, including the direct comparison of all aviation environmental impacts, and costs versus benefits.

This part of report is dedicated to the description/presentation of the various modelling activities within CAEP.

CAEP was given the task of measuring aviations environmental performance through the ICAO environmental goals assessment exercise. The first article in this part presents example results of the CAEP/7 goals assessment work using some of the models described in the first article. The environmental goals are, in their current format, expressed in terms of "limit or reduce…" with no fixed numerical target attributed to them. The assessment was therefore conducted by exploring the trends of the number of people affected by noise and the quantities of pollutants emitted around the airports and in the atmosphere.

The second article in this part describes the existing models that either have been used in past CAEP work, and/or are undergoing an evaluation process to determine their suitability for future analyses. These models, which have various uses and levels of accuracy, are described under five categories: aircraft noise, local air quality, global emissions, interdependencies and economics.

While existing tools and models have been used effectively by CAEP in its analytical work and have been instrumental in shaping ICAO's environmental standards and policies, they need to evolve in order to respond to the changes in CAEP's assignments and the increasing requirements for a full evaluation of the potential impacts of aviation environmental policy options. To address these limitations, some member States and international organizations have launched new initiatives including the development of new tools, and pledged to offer them to support CAEP.

The third article in this part describes some of the research activities assisting CAEP work. It presents the Partnership for Air Transportation Noise and Emissions Reduction (PARTNER) Center of Excellence (COE) from the United States as well as a UK initiative named Opportunities for Meeting the Environmental Challenges of Growth in Aviation (OMEGA).

ICAO Environmental Goals Assessment

By ICAO Secretariat

ICAO has three goals related to aviation environmental protection: (a) to limit or reduce the number of people impacted by noise; (b) to limit or reduce the impact of aviation emissions on local air quality (LAQ); and (c) to limit or reduce the impact of aviation greenhouse gas (GHG) emissions on the global climate. In order to measure its performance in this field, ICAO needs to identify certain metrics, measure them over time in order to assess progress towards the achievement of the environmental goals. As the goals are, in their current format, expressed in terms of "limit or reduce…" and have no fixed numerical target attributed to them, the assessment can be conducted by exploring the trends of the corresponding metrics.

For noise, the reporting metric is people exposed to various day-night average sound levels (DNL). This is a well established metric used by ICAO's Committee on Aviation Environmental Protection (CAEP) and many Member States when conducting noise analyses. Unlike with noise, there is no accepted metric or modelling system for reporting the impact of local air quality[1] (LAQ) and greenhouse gas[2] (GHG) emissions. Work is in progress, within CAEP, to evaluate approaches for measuring impacts of LAQ and GHG emissions. For CAEP/7, the LAQ and GHG environmental goals assessment reported aircraft emissions burden in terms of mass of emissions.

This article presents example results of the CAEP/7 goals assessment.

Noise

In support of the CAEP/7 noise goals assessment, the AEDT[3]/MAGENTA[4] model was used to compute global noise exposure for the baseline years of 2000, 2001, 2002, 2003, 2004 and 2005, where for 2005 various sensitivity assessments were also conducted. (This model is a revised version of the legacy tool MAGENTA).

For consistency purposes, the fleet and operations module (FOM) for applying the FESG[5] forecast within AEDT was used to generate future operations data for 2010, 2015, 2020, and 2025. (This forecast was formerly accepted by CAEP as part of the MAGENTA development effort) This process assumed unconstrained growth; that is, infrastructure enhancements would keep pace with traffic growth. It utilized the 2002 FESG forecast, as well as the 2006 Version of the CAEP Best Practices (BP) database, thus implying that projections of future technology developments were not included in this assessment. These future operations files were then used to predict global noise exposure for the forecast years of 2010, 2015, 2020 and 2025.

The process for replacing retired aircraft in the future fleet was consistent for both noise and emissions scenarios, with the only difference being the use of the BP database for noise, as opposed to the 2006 Version of the CAEP In-Production database for emissions. To maintain consistency in the underlying operational data from noise to LAQ/GHG, these operational data were also used by three of the four LAQ/GHG modellers that participated in the CAEP/7 goals assessment.

As was done for CAEP/5 and CAEP/6, the Shell 1[6] airports[7] were run through AEDT/MAGENTA. Subsequently, a scaling factor of 1.25 was applied to the computed values for exempt regions[8] to account for contributions from Shell 2[9] airports.

Results were obtained for the population within the 55, 60 and 65 dB DNL contours. The global results in terms of population within the 65 dB DNL contour are presented in Figure 1.

Figure 1 shows that if no action is taken, the population highly annoyed by noise is increasing steadily, after a sharp decline due to the events of September 11, and will exceed the year 2000 population level by the year 2018.

[1] affected by emissions below 3000 feet above ground level
[2] emissions above 3000 feet above ground level
[3] Aviation Environmental Design Tool.
[4] Model for Assessing Global Exposure from Noise of Transport Airplanes.
[5] The Forecast and Economic Analyses Support Group of CAEP.

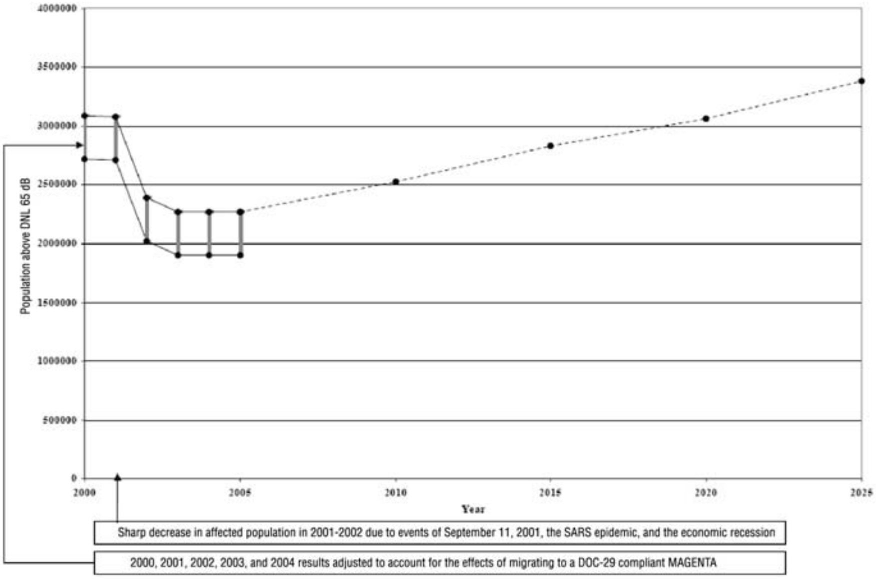

Figure 1 – Summary of CAEP/7 AEDT/MAGENTA Results for 65 dB DNL (Global).

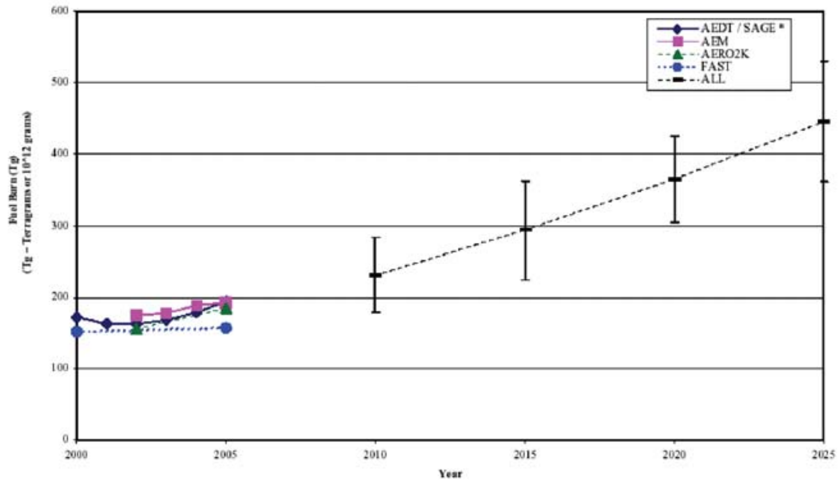

Figure 2 – Total aviation fuel burn model results (2000-2025).
Note: AEDT/SAGE (2000-2004) results have been adjusted down by 5% to account for the revised modelling assumptions resulting from migration from SAGE Version 1.5 to AEDT / SAGE in 2005.

LAQ and GHG Emissions

CAEP is currently in the process of evaluating computer-based models used to estimate aviation GHG and LAQ emissions for possible future CAEP use. Four GHG models have been offered for evaluation: AEDT/SAGE (US FAA), AEM (EUROCONTROL), AERO2k (UK/QinetiQ) and FAST (UK/MMU[10]).

The CAEP evaluation of these models was still ongoing when the goals assessments work was being carried out for CAEP/7. As an interim measure for CAEP/7, it was agreed to use existing GHG models, offered under the model evaluation process by CAEP member states. This would provide the information required for assessment of progress towards the two emissions environmental goals (LAQ and GHG). Consequently, results presented in this article have been produced using the four models.

In carrying out the modelling of emissions, the aircraft replacement data used for LAQ and GHG modelling were derived from a 2006 version of the CAEP In-Production database. Projections of future technology developments are not included in this assessment. Guidance for taking into account technology advances was not available in time for consideration for CAEP/7. Data presented here should be regarded as understating that which aviation might be expected to achieve through continued improvements in technology, operation and ATM. Figures 2, 3 and 4 present the total aviation fuel burn, the Greenhouse Gas NO_x emissions and the total CO_2 emissions.

Since the GHG models compute emissions and fuel burn from aircraft operating gate-to-gate, they effectively also provide LAQ data, in addition to data for the en-route portion of flight. Consequently, for the purposes of this initial LAQ/GHG analysis supporting CAEP/7, the results from the four models have been computed by flight regime[11], so as to preserve the output of interest (fuel burn or emissions) for LAQ, in this case computed as emissions below 3000 feet above ground level. As a result, there was no need to separately model the LAQ emissions using a model such as AEDT/EDMS[12].

6 Airports for which sufficient detail – both traffic and routes – is available for the calculation of complete noise exposure contours
7 Airports in regions that implement Noise Chapter 2 restrictions
8 Regions that do not implement Noise Chapter 2 restrictions
9 Airports described in terms of traffic only
10 Manchester Metropolitan University

Figure 2 presents the base-year (2000-2005) actual modelled fuel burn data, as well as the four-model, average fuel burn for each future year with an indication of the range of forecast results.

Figure 3 presents the base-year (2000-2005) actual modelled NO_x emissions (GHG) data, as well as the four-model, average fuel burn for each future year with an indication of the range of modelled results.

Figure 4 presents the base-year (2000-2005) actual modelled fuel burn data, as well as the four-model, average fuel burn for each future year with an indication of the range of forecast results.

Figure 5 presents the base-year (2000-2005) actual modelled NO_x emissions (local air quality) data, as well as the four-model, average fuel burn for each future year with an indication of the range of forecast results. Projections of future technology developments are not included in this assessment.

Summary and Conclusion

This article primarily summarizes the results obtained for the CAEP/7 environmental goals assessment.

However, it should be noted that data presented here may be understating that which aviation might be expected to achieve through continued improvements in technology, operations, and air traffic management. It should also be noted that as work continues on model evaluation and on the development of integrated aviation environmental analytical tools, it is expected that uncertainty in this type of analysis will decrease.

Reference
CAEP7/WP18: Environmental goals assessment (presented by WG2/TG2 Focal Point).

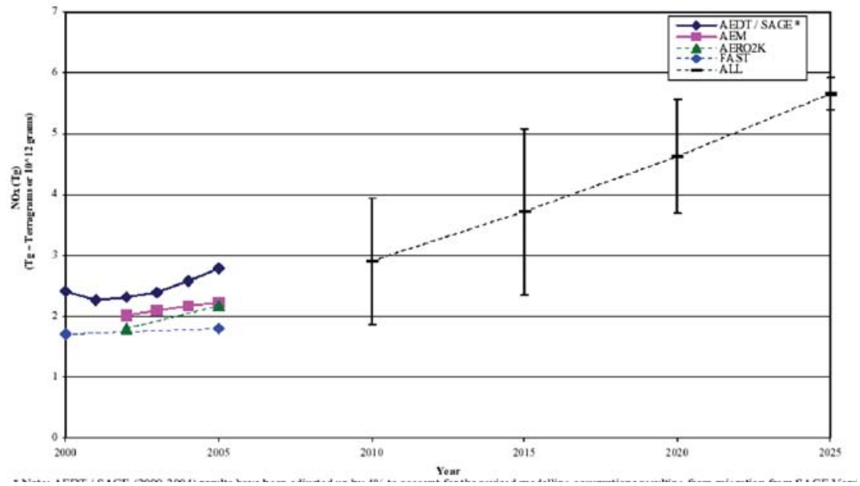

Figure 3 – Global aviation NO_x emissions > 3000 ft (Global Greenhouse Gases) model results (2000-2025).
Note: AEDT / SAGE (2000-2004) results have been adjusted up by 4% to account for the revised modelling assumtions resulting from migration from SAGE Version 1.5 to AEDT / SAGE in 2005. Projections of future technology developments are not included in this assessment.

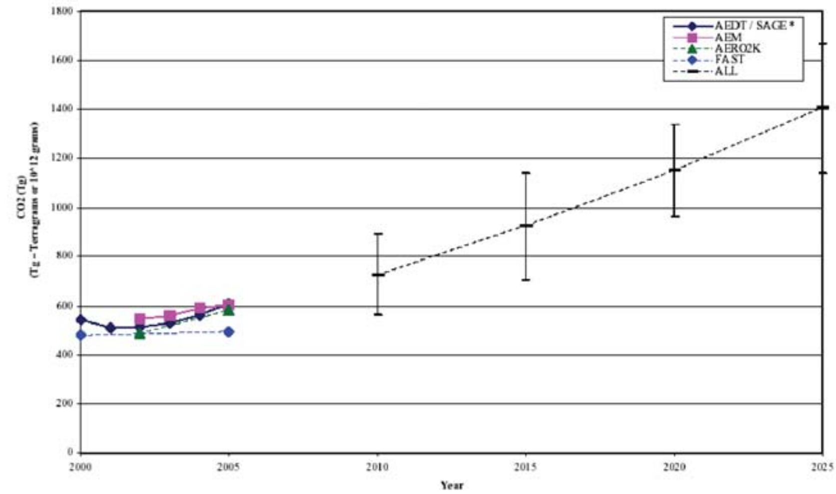

Figure 4 – Total aviation CO_2 emissions model results (2000-2025).
Note: AEDT / SAGE (2000-2004) results have been adjusted down by 5% to account for the revised modelling assumptions resultinbg from migration from SAGE Version 1.5 to AEDT / SAGE in 2005. Projections of future technology developments are not included in this assessment.

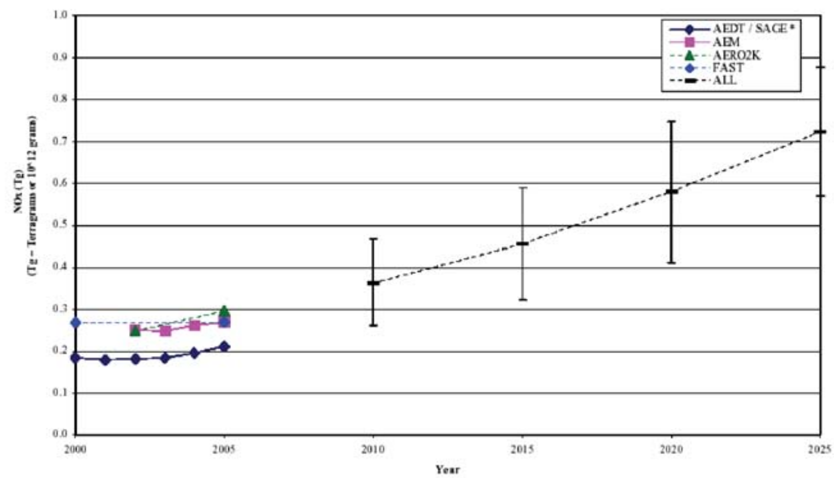

Figure 5 – Summary of CAEP/7 NO_x < 3000 ft (Local Air Quality).
Note: AEDT / SAGE (2000-2004) results have been adjusted down by 7% to account for the revised modelling assumptions resulting from migration from SAGE Version 1.5 to AEDT / SAGE in 2005. Projections of future technology developments are not included in this assessment.

[11] Take-off and climb out, cruise, approach and landing
[12] Emissions and Dispersion Modelling System

Overview of Analytical Capabilities for CAEP Work

By ICAO Secretariat

The main task of ICAO's Committee on Aviation Environmental Protection (CAEP), as stated in its terms of reference, is to undertake specific studies, as approved by the Council, related to the control of aircraft noise and gaseous emissions from aircraft engines. To perform this task, CAEP has made extensive use of various tools and models provided by member States. More tools and models have been offered to CAEP for its future work. The models described in this article have either already been used by CAEP, and/or are undergoing an evaluation process to determine their suitability for future analyses.

One recent development addresses the fact that existing analytical tools used by CAEP were not designed to assess interdependencies between noise and emissions, that is needed to properly analyze the costs and benefits of proposed mitigation measures. Accordingly, CAEP is developing a modelling system, comprising databases and compatible tools to enable such interdependency assessments to be carried out. Under the aegis of the CAEP Modelling and Databases Task Force, all of the tools described below are planned to form part of this compatible interdependency modelling system,wherever feasible. Those modelling capabilities made available to ICAO/CAEP are described below under five main fields of application: aircraft noise, local air quality, global emissions, interdependencies, and economics.

Aircraft Noise Models

Aviation Environmental Design Tools Integrated Noise Model (AEDT/INM)

As part of the U.S. Federal Aviation Administration's (U.S. FAA) [1] suite of environmental assessment tools, the AEDT/INM is a computer program developed by the US FAA to assess changes in noise impacts resulting from: (1) new or extended runways or runway configurations; (2) new traffic demand and fleet mix; (3) revised routings and airspace structures; (4) alternative flight profiles; and (5) modifications to other operational procedures. The US FAA has been using and revising the model since 1978 and Version 7.0 of the model was released in April 2007. AEDT/INM is used by more than 700 organizations in over 50 countries.

AEDT/INM is designed to estimate long-term average effects using average annual input conditions. Its core calculation module is based on standards documents produced by the Society of Automotive Engineers (SAE) Aviation Noise Committee (A-21). Members of this international committee represent: research institutions, engineering firms, aircraft and engine manufacturers, government regulatory agencies, and end-users of noise modelling tools.

AEDT/INM is based on the following three SAE standards documents:

1. SAE-AIR-1845 : "Procedure for the Calculation of Airplane Noise in the Vicinity of Airports".
2. SAE-AIR-1751: "Prediction Method for Lateral Attenuation of Airplane Noise During Takeoff and Landing".
3. SAE-ARP-866A: "Standard Values of Atmospheric Absorption as a Function of Temperature and Humidity".

In particular, AEDT/INM aircraft flight profile and noise calculation algorithms are based on the methodology presented in the SAE-AIR-1845 report.

Aviation Environmental Design Tools Model for Assessing Global Exposure to the Noise of Transport Aircraft (AEDT/MAGENTA)

As part of the U.S. FAA's suite of environmental assessment tools, AEDT/MAGENTA is a model developed, within the ICAO/CAEP framework, to estimate global noise exposure caused by civil aircraft operations. The model computes, under any specified noise certification and transition scenario, the noise exposure contours around a large number of civil airports and counts the number of people affected. Input data includes aircraft noise and performance characteristics and aircraft traffic forecasts. Outputs include noise-exposed population numbers together with regional breakdowns.

[1] This reference also includes the Office of Aviation Energy and Environment (AEE) within US FAA.

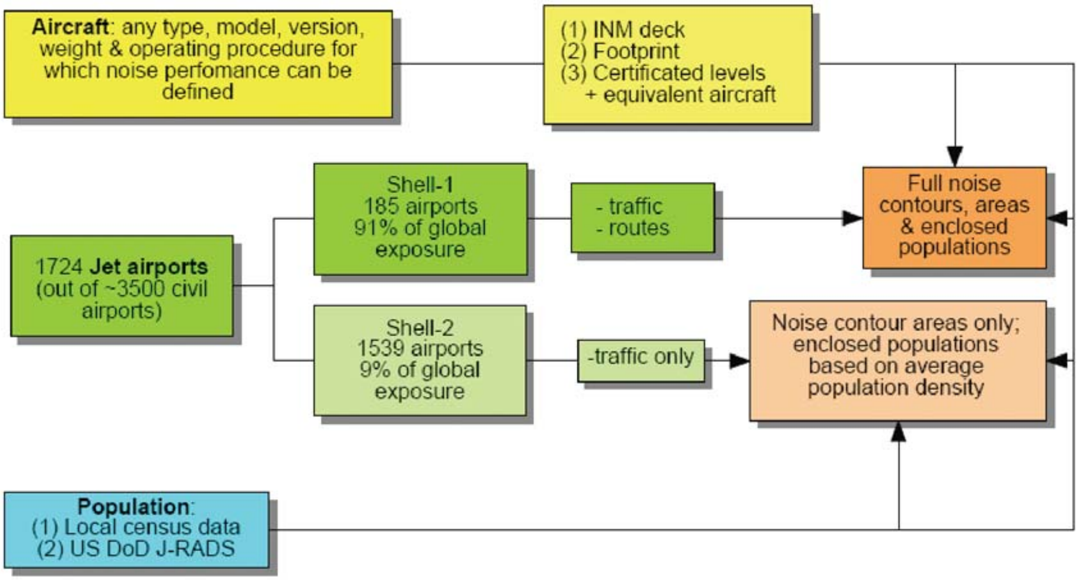

Figure 1 – AEDT/MAGENTA model structure.

The development of AEDT/MAGENTA was led by a team from various member countries: the U.K. led design and development and the U.S. FAA provided direct funding support. Recent work on the AEDT/MAGENTA led to an updated version that is DOC 29[2] compliant. Figure 1 illustrates the structure of the model.

The basic features of the AEDT/MAGENTA model are as follows:

Airport Noise and Operations Data

The AEDT/MAGENTA airports database includes information on more than 1,700 civil airports that handle jet traffic, which are divided into two computational categories known as Shell-1 and Shell-2. Shell-1 airports are described in sufficient detail – both traffic and routes - to allow the calculation of complete noise exposure contours using the "engine" of the AEDT/INM model. These contours are then overlaid on population maps. Although a small proportion of the global total (11%), the Shell-1 airports account for an estimated 91% of total global noise exposure. Shell-2 covers the remainder, a much larger number of airports described in terms of traffic only. For these, noise impact is estimated by a relatively simple regression model which calculates noise-exposed populations for contour areas only, based on average population densities.

Noise Engine

After reviewing international noise modelling practices, CAEP has accepted that, in general, AEDT/MAGENTA should have the flexibility to incorporate any practice that ICAO might recommend in the future. For the present, it was agreed to use the engine[3] of the U.S. FAA's AEDT/INM, since this model is readily available and widely used, either on its own, or in conjunction with other noise models; the same reasons that AEDT/INM was recommended for the CAEP/3 assessments.

Equivalency Method Used

Most airports in Shell-1 have high traffic levels, often comprising many different aircraft types, so that conventional AEDT/INM computations would be unacceptably long, often involving hundreds of computer hours. The process has been speeded up by using "surrogate aircraft fleets" to create an "equivalent" scenario. Under this method, each specific "target" aircraft (a 'real' aircraft type/variant operated in a particular way) is simulated by a weighted average of just four surrogate aircraft which together generate a matching noise footprint. Thus, the traffic at each and every airport is modelled using movements of these four surrogates only, each one being a particular AEDT/INM type, at a particular weight, using a particular operating procedure. The surrogates are chosen to span different climb profiles of 2, 3 and

[2] European Civil Aviation Conference, DOC29: Report on Standard Method of Computing Noise Contours around Civil Airports 3rd Edition, 07/12/2005.
[3] The 'engine' is the core programme which calculates the noise footprints of individual aircraft operations.

4-engine aircraft operating at a variety of take-off weights and mission lengths, under different operating procedures, thus resulting in different footprint shapes.

Despite this simplification method, tests have shown that there is close agreement between "complete" and "surrogate" contours produced, even at the individual airport level. This significant reduction in the number of aircraft types and operations reduces AEDT/INM computer run times by around 99%; thus allowing the completion of a "global" (Shell-1) analysis in about 8 hours (excluding data preparation).

Main Assumptions

Assumptions about airport capacity constraints have a profound effect on the calculated change of population noise exposure over time. Namely, the rate at which large, older airports situated close to cities are replaced by new ones farther away can be more critical than the reductions in aircraft noise emissions. As this is very difficult to predict, a range of upper and lower estimates are produced by assuming: (a) no capacity constraints and, (b) maximum constraints. It is stressed that "constraint" in this context relates only to airport capacity, and not to total traffic; it is assumed simply that traffic not accommodated at existing airports in the AEDT/MAGENTA database is transferred to as yet unidentified non-noise sensitive airports.

Population noise exposures are expressed in terms of numbers of people living above specified DNL[4]s. Typically, two thresholds are identified: DNL55 for "significant" noise impact, and DNL65 for "high" impact. Population distributions around the airports studied are assumed constant over the study period.

The AEDT/MAGENTA model had been used to study a number of scenarios specified by CAEP in conjunction with some possible aircraft type phase-out options.

The Civil Aircraft Noise Contour Model (ANCON 2)

ANCON is the model used to produce the annual aircraft noise exposure contours published by the UK Department for Transport. It is also used to produce noise exposure forecasts for use in airport planning studies. Similar aircraft noise models are used in many other countries.

In general, such models may be described as being either empirical or deterministic. Empirical models are those which mainly rely on aircraft noise and flight path measurements made around the airports of interest. Deterministic models synthesize aircraft flight paths and noise emissions, making use of aircraft noise and performance data (usually provided by aircraft manufacturers). To calculate noise exposure patterns, both types of models define ground tracks of arriving and departing aircraft along with their "flight profiles"; the variations of height and speed along the flight tracks, which are then related to noise emissions.

ANCON calculates Leq[5] at a point on the ground by summing the SELs[6] caused by all passing aircraft. The SEL caused by one aircraft depends upon its flight path (in three dimensions), the amount of noise it emits along that path, and the way the sound propagates from the aircraft to the ground. A crucial factor governing SEL is that, for each aircraft, the flight path and the noise emission are linked: both depend upon the way the aircraft is flown, i.e. upon the operating procedure; particularly the way in which engine power is varied. For this and other reasons, noise event levels caused by different movements of the same or similar aircraft type can vary markedly.

ANCON Version 1, known simply as ANCON-1, was empirical. It used "Reference Noise Levels" (RNLs) to define aircraft noise emission levels for each different aircraft type at various points along its average flight profile. These were expressed as maximum levels (Lmax) in dB(A), at a standard reference distance of 500 ft (152 m) from the aircraft. RNLs were average values, determined from large numbers of noise and radar flight path measurements made regularly at the London airports. Noise contours were then calculated taking into account the average flight tracks and their associated lateral dispersions which were also determined from the radar measurements.

Although this approach produced reliable "historical" contours (the principal purpose for which the model and its predecessors were developed), a disadvantage was that ANCON-1 could not readily be adapted for forecasting the noise consequences of possible future changes to the aircraft types and/or their operating procedures, both of which alter flight profiles and noise emissions. This was because RNLs and the associated flight

[4] DNL: Annual Day-Night average sound Level: 365-day average, in decibels, day-night average sound level.
[5] Leq: Equivalent Sound Level of aircraft noise in dB(A): the sound level averaged over a specific period of time, e.g. 16 hours, 24 hours etc.
[6] SEL: Sound Exposure Level: a measure of the noise event generated by a single aircraft fly-by, in dB(A).

paths were linked; that is, they reflected average day-to-day operations of existing aircraft. Certain comparative studies could be performed independently using other (deterministic) models, but the results might not be fully consistent with existing noise exposures that had been determined empirically.

Accordingly, to produce historical contours and forecast future trends in a fully consistent manner, the model has been modified, and the product is ANCON Version 2. This tool combines the strengths of both empirical and deterministic noise modelling. In most respects ANCON-2 is unchanged from ANCON-1. The key improvement is that noise emissions, previously defined purely empirically via RNL, are now linked to engine power via so-called noise-power-distance (NPD) relationships. Engine "power" is a broad generic expression that may refer to "thrust" for jet engines, or "shaft power" for turboprops.

For the purposes of modelling the "historical" annual contours (a form of noise monitoring), average flight profiles are determined from operational radar data. From these, the corresponding engine thrust levels, and hence noise emissions, are then calculated using information or inferences about the flight configuration, especially the aircraft weight and flap settings, and aircraft performance characteristics. For forecasting, the sequence is usually reversed; first the aircraft weights and operating procedures are defined, the latter in terms of the management of flap and engine thrust schedules; then the resulting flight profiles are calculated using appropriate aircraft and atmospheric data.

The ANCON-2 model is subject to continuing development.

The European Harmonised Aircraft Noise-Contour Modelling Environment (ENHANCE)

The ENHANCE model aims at improving the quality of noise contours produced by noise models like the U.S. FAA's AEDT/INM, mainly by improving the quality of the input data used by these models. An interface/pre-processor combination is used to enable full 4-D trajectories, taken from either smoothed radar data, or from an ATC simulator, to be used for noise calculations. Thrust profiles, which are generally missing in the input data, are calculated by the pre-processor from these trajectories. Now in its second version, ENHANCE is rapidly becoming the de facto standard in noise contour modelling for the European 5th and 6th Framework projects.

This use of 4-D trajectories enables ENHANCE to be used as a validation platform for noise models. Several data collection campaigns have been undertaken at different European airports, providing Radar and Noise Monitor (NM) data for single flights, in order to validate calculated noise levels against measured ones.

JCAB Aircraft Noise Prediction Model

The Civil Aviation Bureau of the Ministry of Transport of Japan (JCAB) first developed its own aircraft noise prediction program in 1978. The development of the first edition of JCAB Model was based on the first version of the U.S. FAA's INM. The JCAB model uses several basic data inputs including: (1) Noise-Distance Data, which determine relationship of LAmax[7] to source-receiver distance according to engine thrust values for various aircraft types, (2) Altitude Profiles showing the transition of flight altitude and engine thrust, and (3) Flight Tracks which are flight paths projected onto the ground. This model usually calculates noise predictions in a simplified form of WECPNL[8] ($WECPNL_j$) on the basis of information on airport and flight operations, and the depicts noise contours. In the calculation, it first determines a flight altitude and an engine thrust value at minimum distance on the flight route from an observation point. Next, it calculates noise exposure due to the flight using Noise-Distance Data. The model corrects for distortion due to excess ground attenuation, based on elevation angle looking up at the aircraft. It also takes flight route dispersion into account. $WECPNL_j$ is calculated by adding up all energy contribution of noise exposure calculated for all types of aircraft and flight operations with the corrections.

SONDEO

The SONDEO model can predict, to a relatively high degree of accuracy, noise contours surrounding an airport, as well as the number of people affected. It was developed by Anotec Consulting.

The noise contour module (NCM) calculates noise contours of Lden[9] and Lnight according to ECAC Doc 29 (Edition 3). The noise and performance databases used are those provided by INM (Version 6.1).

[7] LAmax: Maximum A-weighted noise level recorded at a field point during an aircraft fly-by.
[8] WECPNL: Weighted Equivalent Continuous Perceived Noise Level: the basic noise index for the evaluation of environmental noise effects due to aircraft noise around airports.
[9] Lden: the 24-hr Leq calculated for an annual period, but with a 5 dB weighting for evening and a 10 dB weighting for night.

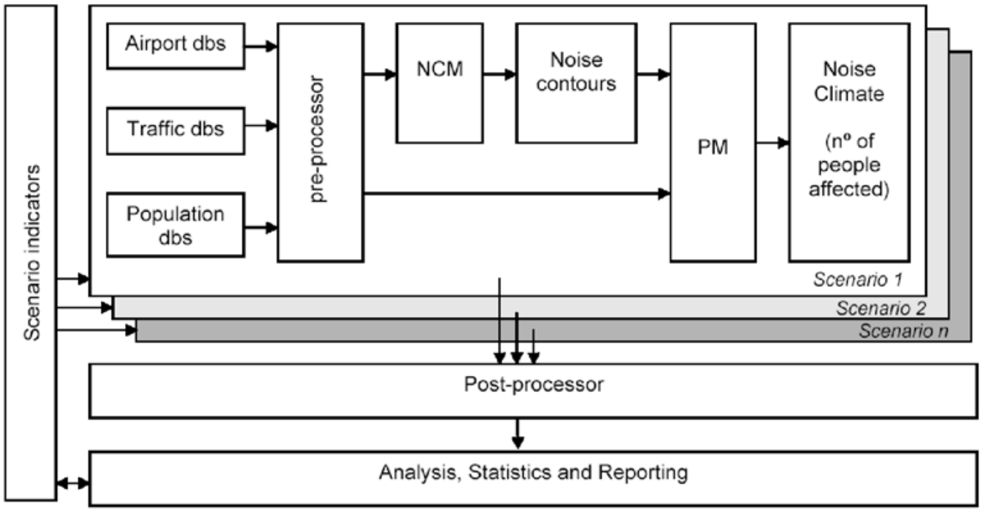

Figure 2 - Overview of SONDEO modules.

The population module (PM) is capable of overlaying the noise contours from NCM on population maps, so as to determine the number of people affected by noise. From the total number of people affected, the percentage of highly annoyed people will be derived. A schematic overview of the software is given in the Figure 2:

Local Air Quality Models

Atmospheric Dispersion Modelling System (ADMS) -Airport

Emissions

EMIT (EMissions Inventory Toolkit) provides a complete system for the management and manipulation of emissions inventories, allowing a comprehensive review of the impacts of aircraft, traffic (road and rail), industrial, commercial, and domestic sources. Emissions can be aggregated onto grid squares, and can be exported from EMIT into the ADMS-Airport air quality model.

The important features of EMIT are:

- **Source types**: Major road, rail, industrial point and area sources can all be stored explicitly in EMIT. Minor roads, commercial and domestic sources and other small or poorly defined sources are stored as emissions aggregated on a 1km square grid.

- **Data import**: Emissions inventory data can be imported, for instance aircraft emissions calculated from the ADMS-Airport flight performance pre-processor. Data can be imported from ArcView (.shp), MapInfo (.mif) or comma separated variable (.csv) file formats using an Import Wizard, or entered directly in the user interface

- **Emission factors**: The very latest available emission factor datasets are included in EMIT for the full range of source types.

- **Data export**: EMIT exports emission source data in ADMS-Airport format, so that the data can be directly imported to the air quality model. It also exports source data and inventory totals as ArcView shp files.

- **Links to GIS and Mapper**: EMIT has a link to ArcView GIS with tools provided for manipulation of EMIT data and viewing of total emissions, and

- **Pollutants**: EMIT calculates emissions of toxic air pollutants and greenhouse gases including NO, NO_2, CO, PM_{10}, $PM_{2.5}$, SO_2, VOCs and CO_2.

Calculating Aircraft Emissions

Flight Performance

ADMS-Airport has a flight performance pre-processing tool for calculating aircraft emissions. It determines aircraft emissions based on aircraft performance according to aircraft type, weight and airport elevation and aircraft engine.

The ADMS-Airport pre-processor uses the European Civil Aviation Conference (ECAC) Document 29 Edition 3 and the Eurocontrol Aircraft Noise and Performance Database (ANP) aircraft performance characteristics to generate departure and arrival trajectories. The Boeing Method 2 Fuel Flow Methodology (BM2FFM), Eurocontrol Base of Aircraft Data (BADA) and ICAO engine emissions databank are used to calculate fuel flow and gaseous emissions. The first order approximation (FOA) 3.0 is used to calculate PM emissions.

The ADMS-Airport pre-processor evaluates emissions quantities and location of emissions of NO_X, PM, HC, CO, CO_2, SOx and H_2O to create an aircraft emissions inventory that can be compiled with other emissions data in EMIT and/or input to the ADMS-Airport air quality model.

ICAO (Issue 13) 2005 Emission Factors

If users do not have detailed flight information, EMIT contains the ICAO emissions factors for engines that have entered production. Using times in mode for taxiing and hold, take-off roll, climb and approach and fleet information, aircraft emissions can rapidly be calculated. The pollutants calculated are: CO, NO_2, NO_X, VOC.

Other Airport Emission Factors

The APU 2004 dataset includes emission factors of CO, NO_2, NO_x and VOC for 29 different types of Auxiliary Power Units.

The IPCC96 Air (average fleet) and IPCC96 Air (old fleet) datasets have been compiled using data from Table 1-52 in Section 1.5 of Volume 3 of the IPCC manual (IPCC, 1996). Emission factors of CO, CO_2, CH_4, N_2O, NO_2, NO_X, SO_2 and VOC are given for the Landing/Take-Off (LTO) cycle, and for cruise.

Air Pollutant Concentrations

The air pollutant concentration modules of ADMS-Airport have been developed by CERC[10] and comprise an extension of the ADMS-Urban system for urban air quality (Carruthers et al 2000) which models the impact of the complex mix of sources typical of an urban area including: road, industrial, commercial, and domestic sources, as well as other diffuse or small sources – all aggregated onto a grid. ADMS-Urban is a spin-off of the widely used Atmospheric Dispersion Modelling System (ADMS 4) (Carruthers et al 1994) developed by CERC in collaboration with the UK Meteorological Office and UK power companies. Each of these models run on PCs with user-friendly Windows-based interfaces, and links to GIS for input and output/presentation of results.

The basic approach used in ADMS-Airport is to calculate pollutant concentrations for each hour using as input hourly varying meteorological data, emissions data and background pollutant data. The meteorological input data are derived from standard meteorological measurements from one met site – typically Julian day number and hour (which determine solar elevation), wind speed and direction, cloud cover and temperature for each hour are used to calculate the friction and convective velocity scales, Monin-Obukhov length and boundary layer height. These quantities are then used to derive vertical profiles of mean velocity, turbulence, temperature, etc. for use in the dispersion algorithm. The emissions data may be based on hourly activity data, or it can be actual estimated/measured emissions for each hour, or it can use typical diurnal profiles. Sources are generally represented explicitly within the output domain but aggregated onto a grid outside the output domain. The background data of pollutant concentrations are either taken from rural monitors outside the emissions domain with the background value for each hour being that measurement most closely aligned with the upwind direction, or from regional scale air quality models. ADMS-Airport calculates concentrations of all common pollutants including NO_x (NO_2 and NO), PM_{10}, $PM_{2.5}$, O_3, SO_2, CO and VOCs.

The additional features of ADMS-Airport when compared with ADMS-Urban relate to its treatment of aircraft sources. The approach is to use the ADMS 4 jet model (CERC 2007) to represent emissions from the jet engines modified to take into account the velocity of the jets. The impact of wake vortices on plume dispersion is taken into account by using a vertical displacement for airborne aircraft, but it is neglected for the take-off roll, for which emission concentrations are very small.

Other aspects of ADMS-Airport include treatment of road sources and chemistry. Roads are treated as line sources with width equivalent to the road width and initial mixing depth representing the vertical mixing very close to the exhaust. Additionally, allowance is made for traffic-induced turbulence and the effect of both canyons and noise barriers can be accounted for if necessary. The chemical reaction uses explicit reactions for the NO, NO2, O3 interactions, but a limited set of surrogate reactions for the impact of VOCs.

Scenario Modelling

"What If?" and various future scenarios can be modelled in two stages, firstly, assessing the effect on emissions using EMIT and secondly, assessing the impact on air quality of the scenario using ADMS-Airport.

[10] UK Cambridge Environmental Research Consultant

Once the baseline inventory data are entered into EMIT, a number of functions are provided for manipulating that data in order to take into account changes in the transport system. This may include:

- Rerunning the ADMS-Airport flight performance pre-processor using new information on fleet and/or operation.

- Applying changes in the aircraft or road traffic fleet to recalculate emissions using the emissions factors datasets e.g. ICAO.

- The use of emission factors for future years.

- Changes in traffic numbers and distribution e.g. due to changes in passenger movements, modal shift

- Addition of new sources or the removal of obsolete sources.

EMIT and ADMS-Airport can also be used in source-apportionment studies to determine the contribution of a source or group of sources to emissions and air quality.

Aviation Environmental Design Tool's Emissions and Dispersion Modelling System (AEDT/EDMS)

As part of the U.S. FAA's suite of environmental assessment tools, AEDT/EDMS is a combined emissions and dispersion model for assessing air quality at civilian airports and military air bases. The model was developed by the U.S. FAA in cooperation with the United States Air Force. The model is used to produce an inventory of emissions generated by sources on and around the airport or air base, and to calculate pollutant concentrations in these environments. The original model, labelled Complex Source Microcomputer Model, was developed in 1985. The latest version of the model, AEDT/EDMS 5.0, was released in 2007.

AEDT/EDMS 5.0 has been given a new architecture and includes over 150,000 new lines of code to support additional enhancements to its capabilities. A study can now contain multiple scenarios and airports, and can span multiple years, with emissions or dispersions being run for all variables at once. The First Order Approximation version 3.0 has been incorporated for estimating PM[11] emissions from jet aircraft. Aircraft fleet data have been harmonized with AEDT/INM, and a common dynamic flight performance module exists in both tools that accounts for aircraft weight and meteorological conditions. AEDT/EDMS 5.0 represents the state of the art for airport emissions modelling and an important step toward the development of AEDT.

Components and Modules

In offering functionality for performing both an emissions inventory and dispersion modelling, AEDT/EDMS consists of several layers of interaction as depicted in Figure 3. This figure is a high level representation of the interaction between different components within the framework of a single integrated environment.

This architecture is typical of current-day multi-tiered applications and allows for modularity of components by separating the database-related functions from the core business logic from the graphical user interface (GUI).

In Figure 3, external interfaces to AEDT/EDMS are shown with a dashed border. These programs include: AERMAP (v.06341), AERMET (v.06341), AERMOD (v.07026), and MOBILE (v.6.2), all of which are maintained by the U.S. EPA (Environmental Protection Agency). For all of these programs, inputs are collected through the GUI, passed to the business layer, and sent to the external program for processing. Once the run is complete, the results and associated messages are interpreted by AEDT/EDMS and displayed to the user.

AEDT/EDMS 5.0 uses the EUROCONTROL Base of Aircraft Data ("BADA") for aircraft performance modelling.

The back-end for both the emissions inventory and dispersion modelling is the database comprising tables for system data and user-created sources. The front-end is the graphical user interface through which the user interacts with the model and the database. At the GUI level, the user performs data entry (with parameter validation), executes commands, and receives visual feedback of both the data entered and the results generated. The middle portion between the GUI and the data tables is the core of the AEDT/EDMS application, and contains the set of classes and functions that represent each emissions source and dispersion object and its associated properties. This middle layer allows for study and system data to be retrieved from disk and stored in memory while allowing the user to make changes without those changes immediately altering the original study on disk.

[11] PM: Particulate matter.

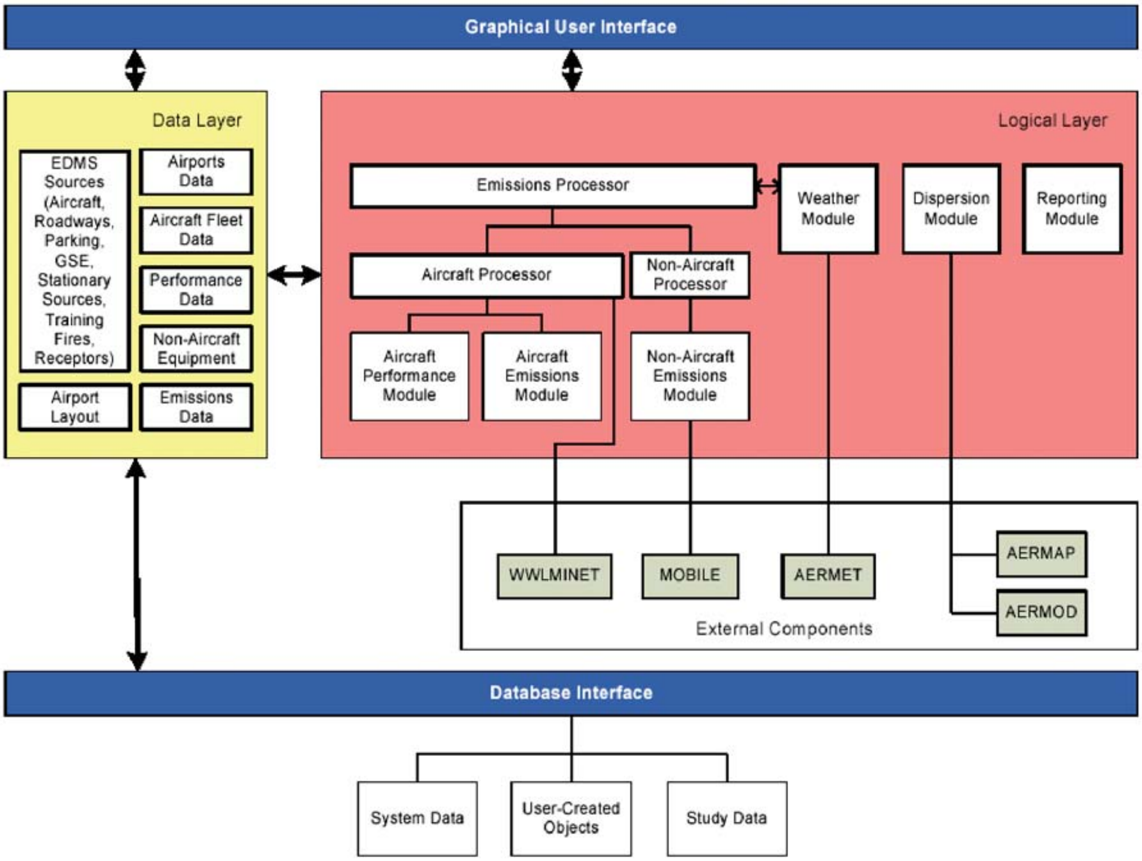

Figure 3 - AEDT/EDMS System Architecture.

In addition, AEDT/EDMS contains an Aircraft Performance Module and Aircraft Emissions Module that are common to components in AEDT.

The emissions processor uses a combination of EPA models and best available models from other sources such as CAEP for calculating aircraft emissions, on-road and off-road vehicles emissions, and stationary source emissions. On-road vehicle emissions are calculated by the version of EPA's MOBILE model selected. The dispersion-modelling module generates input for the EPA-developed dispersion model, AERMOD. The AEDT/EDMS model offers the flexibility of allowing users to perform an emissions inventory only, or they can also perform dispersion modelling.

The view modules permit the user to view output, receptor concentrations and system data stored in the database. They also allow the user to view a graphical representation of the various sources in the database. AEDT/EDMS contains a reporting component for generating emissions inventory results formatted for the printer. Dispersion results and reports are generated by AERMOD.

An emissions inventory is a summary of the total annual pollutant emissions for the sources defined in a study. Depending on the purpose of the study, the emissions inventory may be an end in itself or an intermediate step towards performing a dispersion analysis.

AEDT/EDMS calculates emissions for eight pollutants:

1. CO (carbon monoxide);
2. THC (total hydrocarbons);
3. NMHC (non-methane hydrocarbons);
4. VOC (volatile organic compounds);
5. NO_X (nitrogen oxides);
6. SOx (sulfur oxides);
7. PM-10 (particulate matter, 10 microns);
8. PM-2.5 (particulate matter, 2.5 microns).

AEDT/EDMS generates input files for use with EPA's AERMOD dispersion model, its meteorological preprocessor, AERMET, and its terrain preprocessor, AERMAP. The AERMOD software is a steady-state plume model that assumes a Gaussian concentration distribution in both the horizontal and vertical directions in the stable boundary layer. In the convective boundary layer, dispersion is Gaussian in the horizontal direction, with the vertical direction being modelled by a bi-Gaussian probability density function.

Airport Local Air Quality Studies (ALAQS-AV)

ALAQS-AV is an airport air quality toolset based on a Geographical Information System (GIS) that includes emissions inventory tool. ALAQS-AV was developed by EUROCONTROL as a test bench tool which can be used to evaluate the impact of various emission inventory and dispersion calculation methods and parameters.

The toolset is an integral part of the EUROCONTROL Airport Local Air Quality Studies (ALAQS) project, launched in 2002 and which aims to promote best practice in the field of airport emission inventories and air quality modelling.

ALAQS-AV considers four categories of airport emission sources: aircraft, Ground Support Equipment used for aircraft handling, stationary sources (i.e. power / heating plants, fuel farms, etc) and road traffic (airside and landside). Each source can be represented as a point, a line, or an area. For each source category, various emission calculation methods can be applied, making it possible to compare different methods using the same input data.

ALAQS-AV is implemented using the ARCVIEW GIS (Geographical Information System). The choice of a GIS platform allows other geo-spatial data to be presented on the same map as the emissions and airport data. ALAQS-AV is implemented in such a way that it is easy to implement new emissions methods for the relevant emission sources at an airport.

The ARCVIEW GIS allows for the three dimensional modelling of the airport and its features in a very detailed way. This is useful for analysing dispersion results, as population density and other sensitive areas such as schools and hospitals. Similarly the airports emissions may be shown integrated to the wider regional or national scale.

The output of ALAQS-AV emission inventory can be used to run a dispersion study with the LASAT tool (Lagrangian dispersion model) using the transformation tool ALAQS-TRANS. In the near future, it is expected that ALAQS-AV will be fully compatible with at least one Gaussian dispersion model and possibly an Eulerian model, facilitating thereby the comparison of dispersion models using exactly the same set of input data.

Lagrangian Simulation of Aerosol Transport for Airports (LASPORT)

LASPORT is a program system for the calculation of airport-induced pollutant emissions and concentrations in the atmosphere. It utilizes the Lagrangian particle model LASAT.

Based on experiences with applications of LASAT at airports in Germany and Switzerland, LASPORT was developed in 2002 on behalf of the Federal German Airports Association (ADV) as a standard tool for dispersion calculations. It has been steadily adapted to the requirements of practical demands, among other in cooperation with EUROCONTROL.

The following source groups are accounted for explicitly:

- Aircraft traffic (complete LTO cycle);
- Auxiliary power units (APU) and ground power units (GPU);
- Ground support equipment (GSE) and handling;
- Motor traffic (airside and landside).

Other sources can be defined in form of point, line, and volume sources with individual emission strengths. From these specifications, LASPORT creates the individual, time- dependent source elements.

Aircraft traffic can be handled either on the basis of generalized traffic information (scenario calculation) or based on a movement journal with individual aircraft movements (monitor calculation). Monitor calculations are a tool for detailed studies of actual traffic movements. In contrast, scenario calculations are particularly suited for prognosis calculations as they require only general information about the aircraft traffic and less computation time.

The overall emissions of the various source groups can be calculated separate from a dispersion calculation. The dispersion calculation is carried out based on a meteorological time series to account for correlations between emissions and meteorology. Exit dynamics of the engine exhaust gas, thermal plume rise, and chemical conversion of NO to NO_2 are accounted for.

An integrated diagnostic wind field model allows it to carry out dispersion calculations in complex terrain and in the presence of buildings. Alternatively, three-dimensional wind fields from other meteorological models can be applied. The dispersion calculation is carried out on the basis of a meteorological time series with hourly means of wind velocity, wind direction and a measure of the atmospheric stability (e.g. Monin-Obukhov length). The result of the dispersion calculation is the three-dimensional concentration field of each trace substance averaged over successive time intervals of one hour.

From these time series, long-time means and short-time values are derived according to EU directives. The overall emissions that are taken into account in the dispersion calculation are listed for each source group and trace substance. In addition, the user can perform separate emission calculations. For aircraft traffic, the actual LTO times can be used in the dispersion calculation, or user-defined LTO times such as standard times according to ICAO, or a mixture of both can be applied.

The dispersion calculation is carried out with programs of the software package LASAT which are integrated in the program system LASPORT.

The dispersion model LASAT (Lagrangian Simulation of Aerosol Transport) computes the transport of passive trace substances in the lower atmosphere (up to heights of about 2000 m) on a local and regional scale (up to distances of about 150 km). The dispersion of trace substances in the atmosphere is simulated utilizing a random walk process on a computer for a group of representative simulation particles.

These processes are summarised in the flow chart in Figure 4.

LASAT is based on a research model which was developed in 1980 and tested in various research projects. Since 1990 LASAT is used by national and local authorities, consulting bureaus, and industrial companies in Germany and neighbouring countries.

Global Emissions Models

Advanced Emission Model (AEM)

The Advanced Emission Model (AEM) is a stand-alone system used to estimate aviation emissions (CO_2, H_2O, SO_x, NO_X, HC, CO, Benzene, VOC, TOG) and fuel burn. It is able to analyse flight profile data, on a flight-by-flight basis, for air traffic scenarios of almost any scope (from local studies around airports to global emissions from air traffic).

AEM was developed in the late 1990's by EUROCONTROL originally to support CAEP, in a cooperative effort with the US FAA, in the assessment of the environmental benefits arising from CNS/ATM initiatives.

AEM 3 uses several underlying system databases (i.e. aircraft, aircraft engines, fuel burn rates and emission indices) provided by several external data sources. All of those data sources are well recognized dependable data providers that are widely known for their data accuracy and validation tests. This assures the quality of the information used by AEM3. This system information is combined with dynamic input data, represented by the air traffic flight profiles.

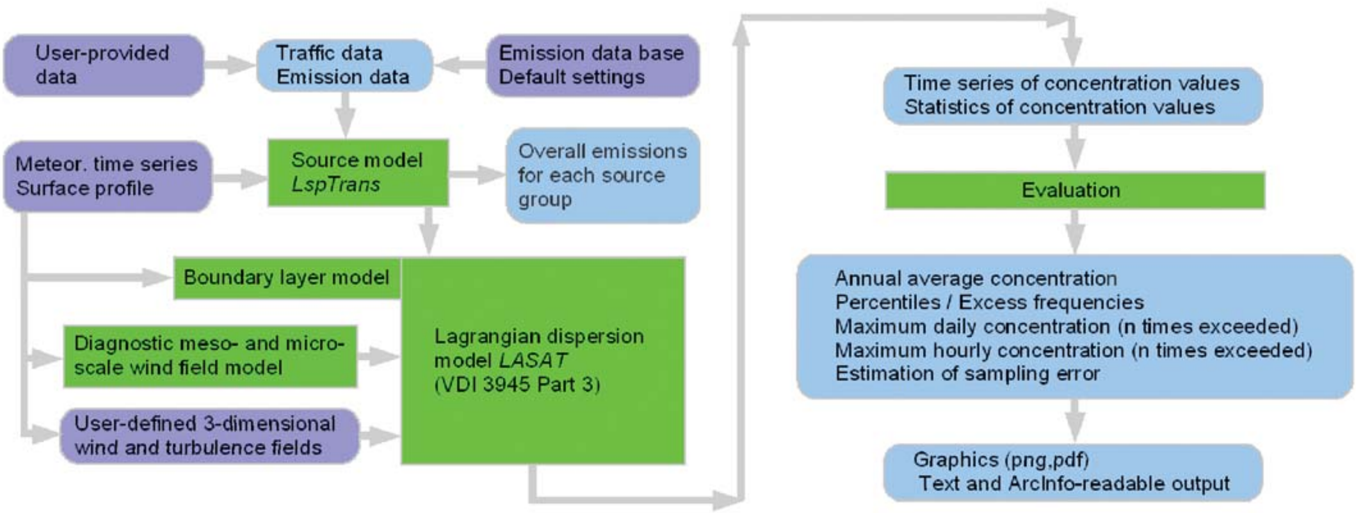

Figure 4 - LASPORT system architecture.

Fuel Burn Calculations

Below 3000 ft, the fuel burn calculation is based on the Landing and Take-Off Cycle (LTO) defined by the ICAO Engine Certification specifications. ICAO LTO covers four engine operation modes which are used for modelling: Taxi-Out, Take-Off, Climb-Out, Approach, Landing, and Taxi-In aircraft operations. The ICAO Engine Exhaust Emissions Data Bank includes emission indices and fuel flow for a very large number of aircraft engines.

AEM 3 links each aircraft appearing in the input traffic sample to one of the engines in the ICAO Engine Exhaust Emissions Data Bank.

Above 3,000 ft, the fuel burn calculation is based on the “Base of Aircraft Data” (BADA). This database provides altitude and attitude dependent performance and fuel burn data for more than 150 aircraft types, and the most recent version (3.5) includes nearly 90 % of the aircraft types operating in European airspace. The BADA is developed and maintained by the EUROCONTROL Experimental Centre.

Figure 5 presents a simplified view of the different approaches followed by AEM 3 to obtain most realistic fuel burn estimations for all phases of the flight profile.

The LTO cycle can be added to all input flight profiles, even than when data for those operations is available. The application of the ICAO LTO cycle is common practice in aviation emission estimation and assures complete information for all profiles during those phases of flight. Nevertheless, AEM3 offers the user the option to perform the calculation only on the initial portion of each flight (i.e. without completing the missing portions of the flights). In this case, BADA is used to estimate fuel burn for the entire flight profile, including low flight levels.

Emission Calculations

Below 3,000 ft, the emission calculation is based on the ICAO Engine Exhaust Emissions Data Bank.

Above 3,000 ft, the emission calculation also based on the ICAO Engine Exhaust Emissions Data Bank, but emission factors and fuel flow is adapted to altitude using a method developed by the Boeing Company. The “Boeing Method 2 – EUROCONTROL modified” approach uses an improved formula for the humidity correction factor to give more accurate results. The differences in results between the two methods, however, is negligible in the context of the methodology as a whole.

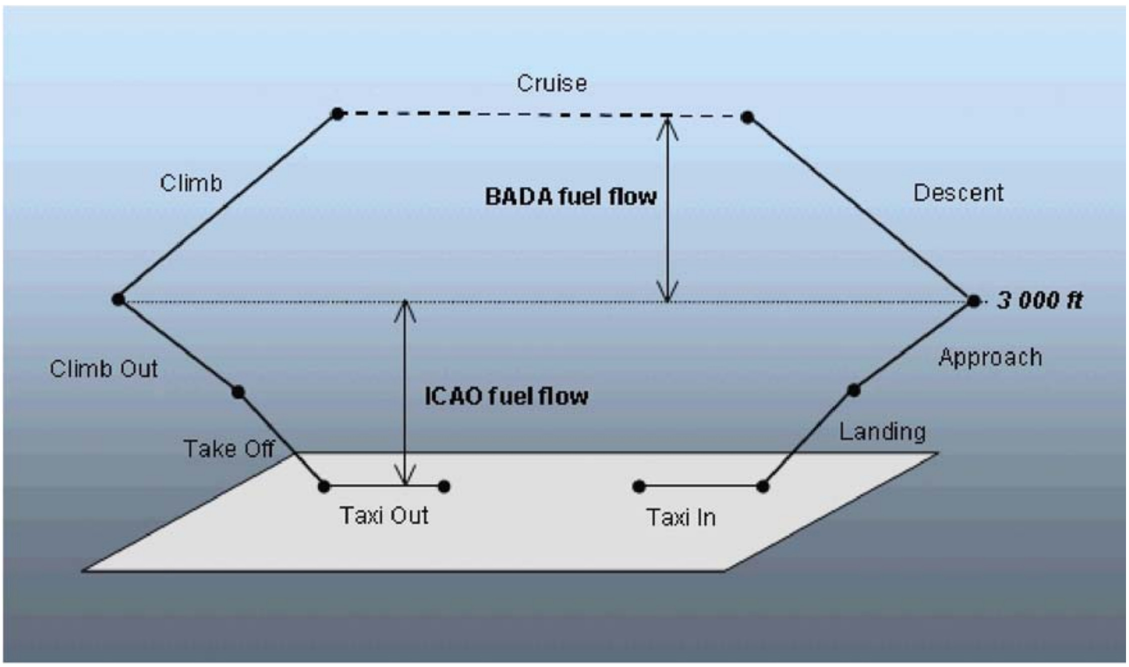

Figure 5 - The AEM 3 fuel calculation cycle.

In this way, emissions for the pollutants NO_X, HC, CO can be estimated. The emissions for the pollutants H_2O and CO_2 are direct results of the oxidation process of carbon and the hydrogen contained in the fuel with the oxygen contained in the atmosphere. The SO_2 emissions depend on the sulphur content of the fuel used. All three are emitted in direct proportion to the fuel burn.

Volatile Organic Compounds (VOC) and Total Organic Gases (TOG) results are proportional to the HC emissions and are estimated by using a method published by the U.S. EPA. The following table summarizes the underlying approach within AEM 3 used to estimate fuel burn and emissions.

An understanding of fuel composition is vital for determining the proportional coefficients between fuel burn and emissions.

AERO2K

The European Commission 5th Framework Programme project "AERO2k" has developed a global inventory of aviation fuel usage and emissions, building on previous inventories. Additional parameters (e.g. particle emissions and km travelled/grid cell) are now needed for the climate modelling community, in addition to the previously provided gas phase species of carbon dioxide (CO_2), carbon monoxide (CO), hydrocarbons (HCs) and NO_X.

To provide new aviation emissions data on a global-gridded basis, AERO2k has taken the available civil and military flight information for the year 2002. For civil aviation, this includes radar tracked and flight plan data from North America and Europe showing actual latitude, longitude and altitude along the flight path. Routing information is used to place scheduled flights from the rest of the world onto a global grid. Using 40 representative aircraft, fuel used for each flight is calculated using performance data from the PIANO aircraft performance model. Using the latest publicly available information on emissions factors, emissions are calculated based on aircraft height, weight and speed, throughout the flight. New information on particulate emissions (soot) has been added to provide a first gridded estimate of these emissions from civil aviation. Calculated emissions from all flights are then allocated into one of 6.5 million individual cells on a global 3D grid, representing the latitude, longitude and altitude of the flight segment. To assist with contrail and cirrus impact assessment, the distance flown in each cell is also recorded.

In addition to these 2002 data, a forecast has been generated for 2025. Aviation traffic growth, fleet rollover and technology improvement factors, estimated by the UK DTI and Airbus, has been applied to the 2002 results to provide the forecast emissions for 2025. These 2025 results are presented in gridded form in a similar manner to the 2002 results.

The output from AERO2k comprises an aviation emissions inventory for 2002 and an emissions forecast for 2025. The output that takes the form of global gridded data (1 deg x 1 deg x 500ft cells) of fuel used, emissions and distance flown in each cell.

For CAEP work, the AERO2k tool uses CAEP standard format input data in order to calculate global emissions for current years and for future policy scenarios. Gridded AERO2k output can be used as input to climate impact models when required.

Future Aviation Scenario Tool (FAST)

The FAST model was originally developed for the UK Department of Trade and Industry (DTI) and was subsequently used in the European Fifth Framework Project, TRADEOFF. The FAST model was used in TRADEOFF to calculate global civil aviation emissions for 1992, and projections for 2000 (based on 1992 traffic) so that the data could be used to evaluate the impacts of aviation NO_X emissions on O3 and CH4, contrails, and cirrus cloud enhancement.

	Fuel burn	**NO_X, HC, CO**	**CO_2, H_2O, SO_X**	**VOC, TOG**
Below 3000 ft LTO flight phases	ICAO Engine Exhaust Emissions Data Bank		Proportional to fuel burn	Proportional to HC emissions (US EPA method)
Above 3000 ft Non-LTO phases	Eurocontrol BADA data	Boeing Method 2		

The basic FAST model was designed around the methodology employed for the ANCAT/EC1&26 inventories of aviation emissions, the results of which were examined and compared with other data in some detail by the IPCC.

The FAST modelling system is based on a dataset of aircraft movements for year “x” which indicates the frequency of flights of specific aircraft types between city pairs. From this database, the aircraft types are grouped, with representative aircraft types assigned. A separate aircraft performance model (the PIANO model), provides data on fuel flow for specific aircraft/mission combinations using standard assumptions of load factor and fuel reserves etc. Fuel flow data are then used as the basis of calculating NO_X emissions, based upon an algorithm that relates sea-level NO_X emissions from Certification data to altitude. Fuel consumption over a specific mission is calculated between a departure and arrival location, linked by the great circle distance. The emissions are then allocated onto a 3D grid of variable resolution (in latitude, longitude and height). The distances travelled over the grids are calculated accurately, via trigonometric functions, and not averaged in any way. These data provide the basis of input to other impact assessment models such as GCMs and CTMs (Chemical Transport Models) for calculation of e.g. tropospheric O3 enhancement, contrail coverage, and consequential radiative forcing.

While the primary purpose for the FAST model development was to enable impact assessment, the results of the emissions modelling are of direct interest in and of themselves, and the FAST model utilizes an underlying country database in order to apportion emissions.

The original FAST model (v1_1) was significantly developed and upgraded to two model versions ‘FAST-2000 (v1.0)’ and ‘FAST-1990 (v1.0)’, representing the different traffic years.

Aviation Environmental Design Tools System for Assessing Aviation’s Global Emissions (AEDT/SAGE)

As part of its suite of environmental assessment tools, the U.S. FAA has developed the Aviation Environmental Design Tools System for assessing Aviation Global Emissions (AEDT/SAGE) with support from other organizations. Currently at Version 1.5, AEDT/SAGE is a computer model used to predict aircraft fuel burn and emissions for all commercial (civil) flights globally in a given year. The model is capable of analyzing scenarios from a single flight, up to airport, country, regional, and global levels. AEDTA/SAGE is able to dynamically model aircraft performance, fuel burn and emissions, capacity and delay at airports, and forecasts of future scenarios.

Objective and Scope

The objective for AEDT/SAGE is to be an internationally accepted computer model that is based on the best publicly available data and methodologies, and that can be used to estimate the effects on global aircraft fuel burn and emissions from various policy, technology, and operational scenarios. With regard to scope, the model is capable of analyses from a single flight, up to airport, regional, and global levels of commercial (civil) flights on a worldwide basis.

Modelling Capabilities

AEDT/SAGE can generate inventories of fuel burn and emissions of carbon monoxide (CO), unburned hydrocarbons (HC), nitrogen oxides (NO_X), carbon dioxide (CO_2), water (H_2O), and sulfur oxides (SO_X calculated as sulfur dioxide, SO_2). The three basic inventories generated by AEDT/SAGE are: (1) four dimensional (4D) variable world grids currently generated in a standardized 1^o latitude by 1^o longitude by 1 km altitude format; (2) modal results of each individual flight worldwide; and, (3) individual chorded (flight segment) results for each flight worldwide. These outputs and the dynamic modelling environment allow for a comprehensive set of analyses that can be conducted using AEDT/SAGE.

With the computation modules and the supporting data integrated in a dynamic modelling environment, AEDT/SAGE provides the capability to model changes to various parameters including those associated with flight schedules, trajectories, aircraft performance, airport capacities and delays, etc. This results in the ability to use AEDT/SAGE for applications such as quantification of the effects of such activities as: Communication, Navigation, and Surveillance operations (CNS) and Air Traffic Management (ATM) initiatives, determining the benefits of Reduced Vertical Separation Minimum (RVSM), investigation of trajectory optimizations, and computing potential emissions benefits from the use of a Continuous Descent Approach (CDA).

Interdependencies

Existing aircraft noise and emissions analytical tools used by CAEP were not designed to assess interdependencies between noise and emissions, or analyze the costs-benefits of proposed actions. Accordingly, CAEP is developing a modelling system, comprising databases and compatible tools to enable such interdependency assessments to be carried out. Under the aegis of the CAEP Modelling and Databases Task force, all the tools described here are planned, where feasible, to form part of this compatible interdependency modelling system.

In this section, the comprehensive suite of software tools that will allow for thorough assessment of the environmental effects of aviation which is being developed by the U.S. FAA is described. This suite of tools not only involves the AEDT noise and emissions components, AEDT/INM, AEDT/MAGENTA, AEDT/EDMS, and AEDT/SAGE discussed above, it also involves the Environmental Design Space (EDS) and the Aviation environmental Portfolio Management Tool (APMT).

The components of this suite of software tools that integrates existing noise and emissions models is highlighted in Figure 6.

The existing AERO-MS tool that was developed in the Netherlands, which also provides interdependency assessment, is also described.

Environmental Design Space (EDS)

Environmental Design Space (EDS) provides integrated analysis of noise, emissions and performance at the aircraft level (see CAEP/7 Environmental Design Space information paper).

Aviation Environmental Portfolio Management Tool (APMT)

Aviation environmental Portfolio Management Tool (APMT) interacts with AEDT, EDS, and economic modules to provide the common, transparent cost/benefit methodology needed to optimize aviation policy in harmony with environmental policy. (See CAEP/7 Aviation environmental Portfolio Management Tool information paper.) In Figure 6, APMT is represented in terms of its primary components: "Benefits Valuation," "Partial Equilibrium," and "Costs and Benefits."

Aviation Environmental Design Tool (AEDT)

AEDT comprises the integration of existing or new aviation noise and emissions analytical modules to provide an integrated capability for assessing interrelationships between noise and emissions. For emissions, this can be done at the local and global levels.

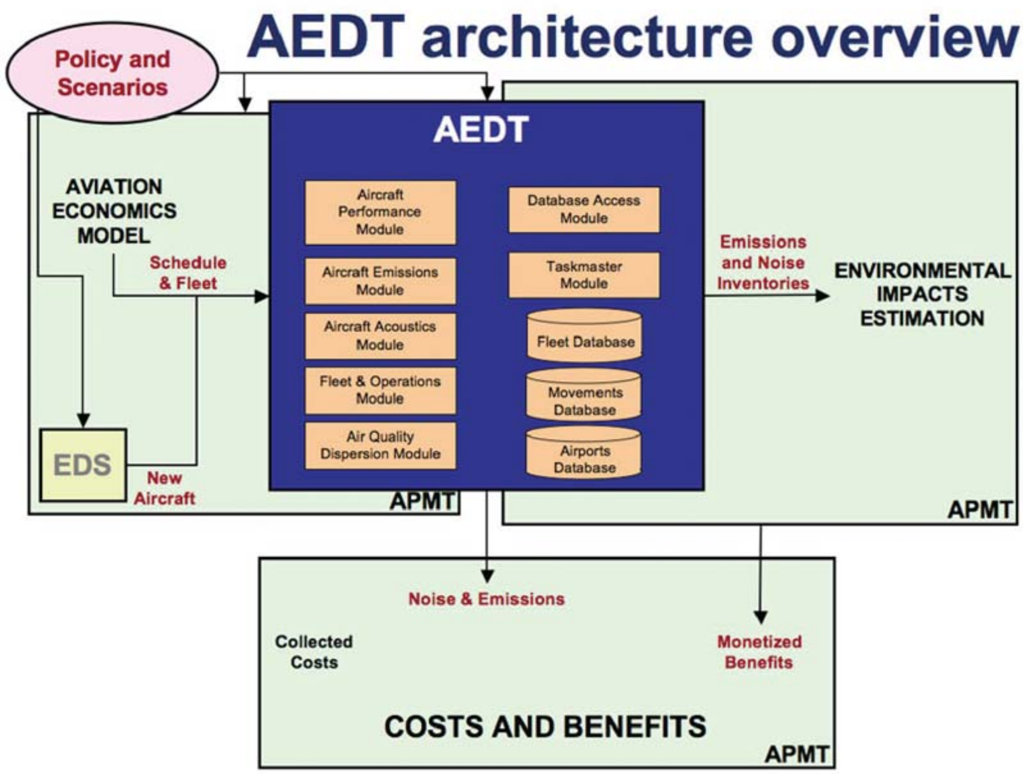

Figure 6 - Components of the New Aviation Environmental Tool Suite (AEDT).

Economics

Aviation environmental Portfolio Management Tool (APMT)

In addition to providing tools to assess the emissions and noise from aircraft, the U.S. FAA, in collaboration with Transport Canada, is developing a comprehensive suite of software tools that will allow for thorough assessment of the environmental effects of aviation. The main goal of the effort is to develop a new, critically needed capability to assess the interdependencies among aviation-related noise and emissions, impacts on health and welfare, and industry and consumer costs, under different policy, technology, operations and market scenarios.

The impact and economic analysis function of this suite of software tools has been given the rubric Aviation Environmental Portfolio Management Tool (APMT). The detailed structure of APMT is comprised of building blocks, as depicted in Figure 7:

(a) The Aviation Economic Module /Partial Equilibrium Block – simulates economic flows in the aviation market.

(b) The Environmental Design Space (EDS) – provides vehicle noise, emissions, flight performance, and economic characteristics to AEDT to simulate technology trade-offs for potential future vehicles when this option is desired (these trade-offs can be based on either existing technological capability or future technological capability).

(c) The Aviation Environmental Design Tool Block (AEDT) – converts aviation activity into quantities of emission and noise distributed in space.

(d) The Environmental Impacts Estimation Block – converts the quantities of emissions and noise into health and welfare impacts, including broad socioeconomic and ecological effects.

(e) The Costs and Benefits Block – integrates collected costs, environmental inventories and monetized benefits, allows graphical analysis, and qualitatively estimates uncertainties.

A schematic of APMT is shown in Figure 7; also showing its relationship to other FAA tools, the Environmental Design Space (EDS) and the Aviation Environmental Design Tool (AEDT).

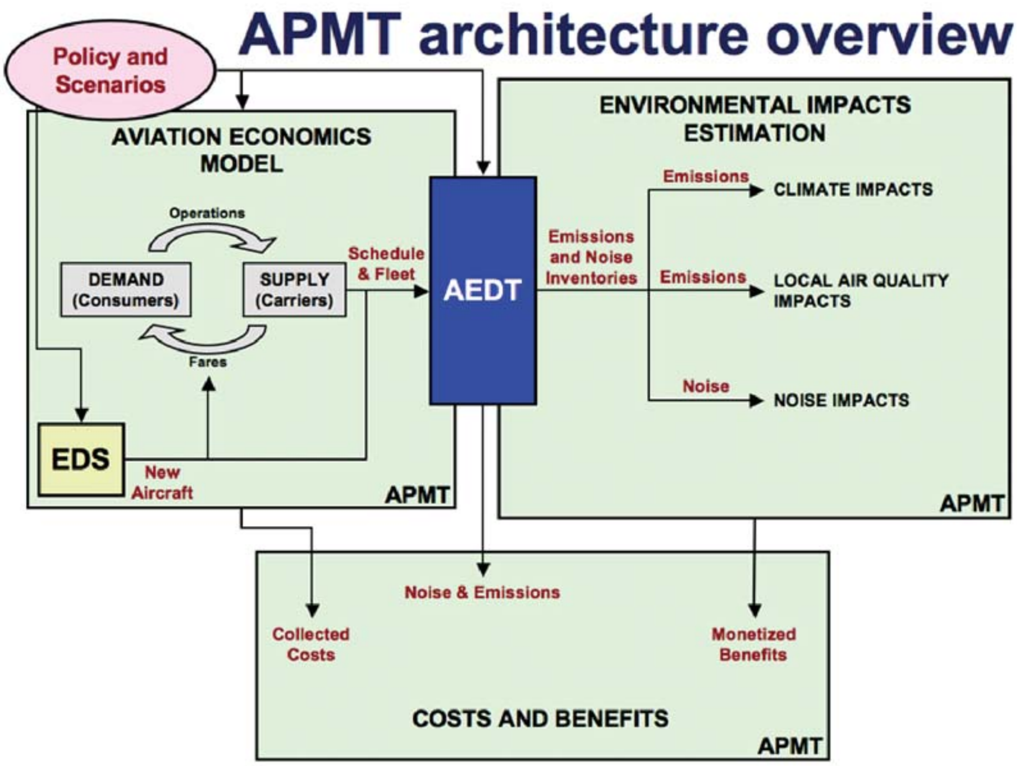

Figure 7 - Components of the New Aviation Environmental Tool Suite (APMT).

APMT Development

Since 2004, information and plans for APMT have been submitted to CAEP and government, industry, and community stakeholders. In response to CAEP-Memo/65, information regarding APMT was submitted to Working Group 2 – Task Group 2 for its consideration as a candidate economic model and tool for future CAEP use. In February 2006, FESG was briefed on the completion of the APMT requirements and architecture studies, and the initiation of a prototyping effort for APMT. In August 2006, the APMT development team met with the CAEP-WG2/TG2-FESG Ad Hoc Group to learn more about APMT and to begin the process of assessing APMT for CAEP acceptance. In December 2006, a detailed set of briefings on APMT activities was presented at the US National Research Council, Transportation Research Board AEDT/APMT Workshop in Washington DC. Several CAEP participants attended this meeting.

As reported previously, research on the design requirements for APMT builds on the efforts of previous CAEP economic analysis tools, as well as future analysis needs and best practice guidance. The resulting architecture of APMT takes aviation demand and policy scenarios as inputs and simulates the behavior of aviation producers and consumers to evaluate policy costs. Detailed operational modeling of the air transportation system within AEDT provides estimates of the emissions and noise outputs. Then, a benefits valuation module is used to estimate the health and welfare impacts of aviation noise, local air quality and climate effects, using a variety of metrics. These metrics include, but are not limited to, monetized estimates of value for these changes in environmental quality. These modules jointly enable both cost-effectiveness and cost-benefit analyses of policy alternatives, as depicted in the Figure 8 overview.

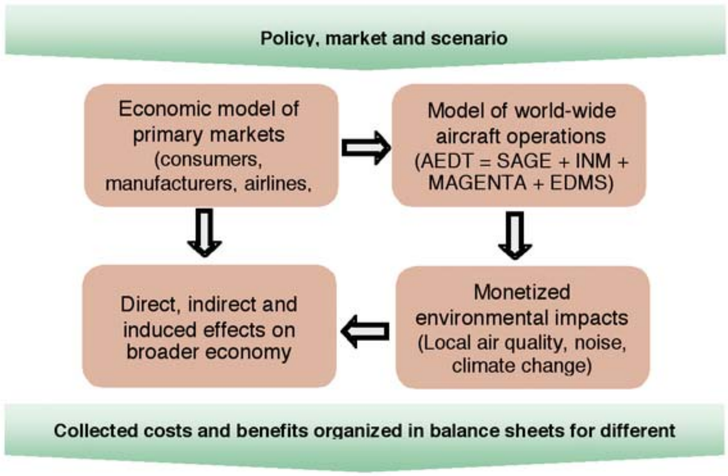

Figure 8 – APMT Architecture Overview.

Aviation Emissions and Evaluation of Reduction Options Modelling System (AERO-MS)

AERO-MS is a comprehensive tool for analyzing the complex environmental and economic effects of policy measures to reduce aircraft engine emissions at the local, regional and/or global levels under different scenarios. It was developed by the Dutch Civil Aviation Authority.

The AERO-MS was specifically designed to consider the environmental impacts of global aircraft engine emissions at cruise level. While focusing on the global perspective, in view of the spatial detail considered, the modelling system is also able to assess the impacts of emissions on a regional and local scale. Moreover, since the modelling system includes a detailed description of the technical and economic features of air transport demand and supply, it potentially provides an important basis for assessing other environmental impacts. Nevertheless, the present applications of the AERO-MS are focused on global aircraft engine emissions and their related problems.

The AERO-MS covers a sequence of steps: description and generation of air transport demand, assessment of the environmental and economic impacts of aircraft engine emissions, and provision of a comprehensive integration of the relevant economic, commercial, technological and environmental forces. In essence, the AERO-MS is a policy-testing tool to evaluate the environmental and economic consequences of responses to emission-related measures within the context of relevant future developments in the air transport sector.

Potentially, a great many possible measures and different future developments are possible. Consequently, the AERO-MS had to be capable of analysing a wide range of measures (e.g. economic, regulatory, technical and operational measures) within a variety of autonomous developments (economic and technological). The AERO-MS was therefore designed to meet the following analysis requirements:

- to provide an adequate description of the economic and environmental aspects of the air transport system (in particular the extent and effects of aircraft engine emissions);

- to adequately reflect the economic and technological developments in air transport;

- to assess the effects of a range of possible measures to reduce the environmental impact of air transport, taking into account the responses of the major actors (i.e. airlines, consumers, manufacturers) to such measures.

The design philosophy and architecture underlying the AERO-MS allow the user a large degree of flexibility in analysing the effects of specific developments and measures in a "what-if" fashion. This was implemented by creating a great many user options to change key assumptions, schematization aspects, scenario developments, and possible measures (policy options).

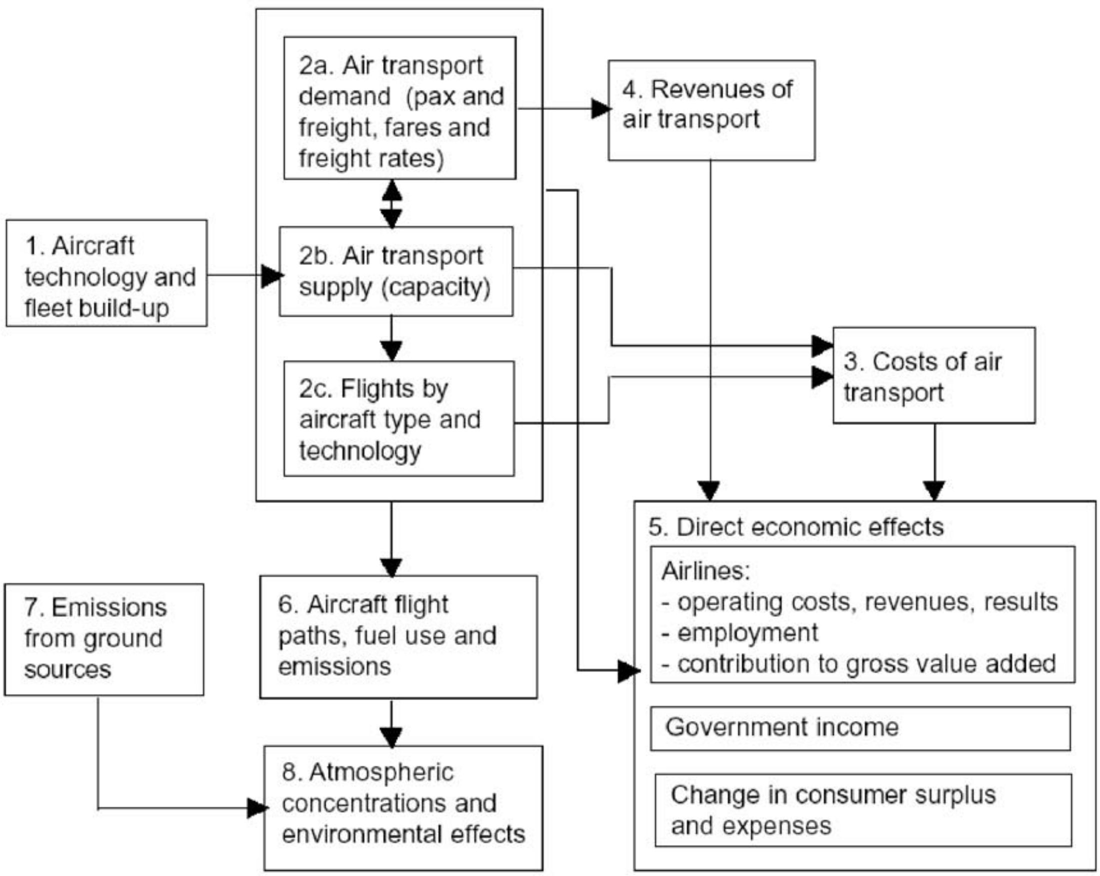

Figure 9 – Overview of computational steps in the AERO Modelling System.

Computational Steps

The AERO-MS includes a sequence of logical steps from the description and generation of air transport demand to the assessment of the environmental and economic impacts of aircraft engine emissions. These steps cover the following computations:

1. Aircraft technology and fleet build-up;
2. Air transport demand (passengers and freight), supply (capacity offered) and aircraft;
3. Costs of air transport;
4. Revenues from air transport;
5. Direct economic effects of air transport;
6. Aircraft flight paths, fuel-use, and emissions;
7. Atmospheric emissions from ground surface sources;
8. Atmospheric concentrations of key substances and related environmental effects.

The result from the computation of one step feeds into another and this logical sequence defines the relationships between them. A graphical overview of these steps is provided in Figure 9.

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Research Activities Assisting CAEP Work

By ICAO Secretariat

The role of ICAO's Committee on Aviation Environmental Protection (CAEP) has progressively expanded from one of basic standards-setting, to the development of broad policy measures such as the balanced approach to limit or reduce the impact of aircraft noise, and the creation of market-based measures to handle noise and emissions charges and emissions trading. This broader role highlights the need for a better informed policy-making process that benefits from the best available scientific and technical knowledge, techniques, and tools.

Background

The environmental challenges that CAEP addresses are a reflection of issues and concerns being tackled by ICAO Contracting States as well as observer organisations. Substantial research programmes are underway and tools and capabilities are being developed across the world to advance both domestic agendas and international issues. Significant amounts of that work are brought to the CAEP policy debate to inform decision-making. Some programmes and projects are directly focused on supporting CAEP endeavors, while others form part a wider body of knowledge.

Clearly there is a need for much supporting research work to enhance the efficiency and capacity of products under development, as well as to minimize their environmental impacts. At the industrial level, the manufacturing industry commits extensive resources to understanding the relationship between technology and environmental performance that directly benefits CAEP work on setting standards and goals and assessing trade-offs. Similarly, the Air Traffic Management (ATM) community also invests to improve its knowledge of the environmental implications of enhanced ATM technologies that could be embraced by the international community through ICAO. At the fundamental science level, there is a massive effort dedicated by States and international organisations that is focused on better understanding of the impacts of aviation. The core of this work relates to upper atmospheric climate related impacts, and local air quality and noise impacts in the vicinity of airports.

As environmental pressures increase, there has been a specific response from States and Observers by committing resources to what might be termed 'policy-relevant' research and study. More of this work will be directed at international as well as domestic policy debates such as: improving understanding of particulate emissions, building tools to support options and trade-off analysis, evaluating ATM efficiency strategies, and examining the efficacy of market instruments. Work programmes and projects are underway in many ICAO States, as well as in organizations such as ICCAIA, IATA, the EC, EUROCONTROL, and ICSA, to name just a few.

This article provides an overview of two specific programmes that were presented to ICAO at the CAEP/7 meeting. One of these in particular, the Partnership for Air Transportation Noise and Emissions Reduction (PARTNER) Center of Excellence, has provided significant analytical capability to support CAEP activities. However, these programmes must be viewed as illustrative of a wider body of work that is being conducted elsewhere and also results in major contributions to the work of CAEP. ICAO is very open to hearing about programmes being conducted by other ICAO States and how these might add value to the international work to address the aviation environmental challenge. The two programmes presented here are the work of PARTNER with the support of the US Federal Aviation Administration and Transport Canada, as well as a UK-based research initiative named Opportunities for Meeting the Environmental Challenges of Growth in Aviation (Omega). Work under these two major initiatives is currently being offered to support CAEP in its ongoing work programme.

1. Partnership for Air Transportation Noise and Emissions Reduction (PARTNER)

In December 2003, the United States established the Partnership for Air Transportation Noise and Emissions Reduction (PARTNER) Center of Excellence. In the spring of 2004, Transport Canada joined the U.S. Federal Aviation Administration (FAA) and the U.S. National Aeronautics and Space Administration (NASA) as a sponsor. PARTNER is a long-term partnership of academia, industry, and government established to create a world-class consortium, closely aligned with national and international needs to foster breakthrough technological, operational, policy, and workforce advances for the betterment of mobility, the economy, and the environment. The PARTNER group conducts basic research and engineering development to reduce uncertainties associated with aviation's environmental impact and prototype solutions to mitigate these impacts. The knowledge and capabilities gained from this research will provide critical information to government, industry, and community decision-makers to tackle environmental impacts, which may represent the single greatest challenge to the continued growth and prosperity of civil aviation. With respect to aviation and the environment, PARTNER is conducting aviation environmental research activities that include, among other things, support of ICAO's CAEP work programme.

Some of PARTNER's efforts are a major response to an increasing need by CAEP for improved modelling capabilities in terms of coverage (i.e. noise, emissions, trade-offs, costs and benefits, etc.), and in terms of accuracy. The existing models have several limitations and do not allow CAEP to evaluate the potential impacts of all aviation environmental policy options. In particular, existing models do not allow the assessment of trade-offs between the effects of noise and engine emissions and among those emissions nor allow for monetizing the potential environmental benefit gains of aviation mitigation actions by ICAO. All of these issues are addressed through the comprehensive model toolset being developed through PARTNER. The tools being developed are in themselves a subset of a much broader capability being developed by a host of U.S. and European entities under FAA sponsorship. In addition to the development of tools, research is being done to develop metrics for the quantification of impacts; such methodologies and measurement approaches to characterize noise and emissions are critical elements of developing a robust capability to assess trade-offs.

The broader aviation community benefits from enhanced research collaboration between PARTNER and international research establishments. To provide the best scientific and technical input and foster consensus to inform policy decisions, PARTNER and its sponsors have adopted a vision of commonality and interconnectivity in research plans, which would be separately funded by home agencies. One of PARTNER's key strategic goals is continued expansion of its international activities. Companies such as SNECMA, Airbus, Bombardier, and Rolls-Royce are among PARTNER international industrial affiliates. PARTNER has research relationships with the Environmentally Compatible Air Transport System (ECATS) Network of Excellence, EUROCONTROL, and OMEGA Singapore. PARTNER is also exploring collaborations with entities in China and Japan and has expanded its student paper competition to participants of all nationalities.

PARTNER Research Results and Collaborative Activities

PARTNER's research portfolio involves three detailed research plans, each with a specific mission, as follows:

Noise: Provide quantitative predictions and qualitative assessments of aviation noise and its impacts, and contribute to mitigation strategies considering all interrelationships.

Emissions: Provide quantitative predictions of aviation emissions and their impacts that contribute to mitigation strategies considering all inter-relationships.

Interdependencies: Enable better communication and decision-making in addressing the interdependent environmental effects of aviation through the ability to fully assess the benefits and costs of interdependent policies, technologies, operational procedures, and market conditions.

The tangible outcomes of PARTNER research are growing. These include the public release of the *Report to Congress: Aviation and the Environment*, and the first PARTNER reports: *Development, Design, and Flight Test Evaluation of a Continuous Descent Approach Procedure for Night-time Operation at Louisville International Airport; Assessment of the Effects of Operational Procedures and Derated Thrust on American Airlines B777 Emissions From London's Heathrow and Gatwick Airports; Advancing the Understanding of Aviation's Global Impact; Workshop on the Impacts of Aviation on Climate Change: A report on findings and recommendations, June 7-9, 2006, Cambridge, MA.; Requirements Document for the Aviation Environmental Portfolio Management Tool; Architecture Study for the Aviation Environmental Portfolio Management Tool Architecture Study for the Aviation Environmental Portfolio Management Tool; Prototype Work Plan for the Aviation Environmental Portfolio Management Tool*; and several papers and theses, which are, or will shortly be, available at PARTNER's website, http://partner.aero. Perhaps most importantly, the first PARTNER students are graduating and entering the workforce.

The following paragraphs summarize some of the highlights of recent PARTNER research activities:

Low Frequency Noise

PARTNER is nearing completion of a substantial effort to study low frequency noise. The final report will be published late 2007. This research may have implications on airport operations and future regulations. It may eventually result in a set of recommended acceptance metrics for low frequency noise. The findings could inform regulatory action and technology development to mitigate the impacts of low frequency noise. PARTNER is now turning its attention to examining other noise metrics and health impacts.

Aviation Emissions Measurement

PARTNER conducted its third aviation emissions measurement campaign, which took place at Cleveland Hopkins International Airport in November 2005. Researchers continue to reduce the extensive data sets collected during this exercise, along with data gathered at two other aviation emissions measurement campaigns at two North American Airports (September 2004 and August 2005). Results have helped refine the First Order Approximation (FOA), an ICAO-endorsed methodology developed to correlate the smoke number reported in the certification process with mass emission rates of non-volatile particulate matter (PM) emissions to also quantify the volatile fraction of PM. The results have also supported similar measurement campaigns in the UK. Research efforts will continue to gain understanding of particle formation, composition, and growth and transport mechanisms for assessing aviation's particulate emissions, and understanding their impact on human health and the environment. Researchers are also starting to tackle the impact of hazardous air pollutants (HAPs), commonly referred to as "air toxics."

Continuous Descent Arrival Procedures

PARTNER research led to the development of continuous descent arrival procedures or CDAs. CDAs are proving to be a highly effective and efficient way to reduce emissions, and to mitigate aviation noise effects on local communities. Both the economic and environmental advantages of CDA offer it as a way forward in sustainable aviation. These procedures are being implemented at select airports in low traffic density scenarios. PARTNER research is currently focused on research to enable CDAs, or other procedures, in higher density traffic. PARTNER has also started research efforts to optimize en route operations to minimize fuel burn and to modify ground procedures to reduce local emissions and fuel burn.

Development of Analytical Tools

In the past year, PARTNER's most significant area of growth has been in developing analytical tools that provide rigorous guidance to policy-makers who must decide among alternatives for addressing the environmental impacts of aviation. PARTNER is collaborating with an international team to develop aircraft-level and aviation system-level tools to assess the costs and benefits of different policies and R&D investment strategies. A critical area of research is an effort to monetize the health and welfare impacts of aviation noise, local air quality, and climate effects to enable a robust cost-benefit analysis of policy alternatives.

Alternative Aviation Fuels
PARTNER is also at the forefront of increased efforts to advance the development of alternative aviation fuels, as discussed elsewhere in this report. PARTNER is conducting a major study to assess feasibility, production, and the environmental footprint of aviation fuels; from "well to wake" PARTNER is also involved in an upcoming measurement campaign to assess emissions characteristics of commercial engines fuelled by synthetic and bio-derived jet fuels.

Decision-Making Support
PARTNER's sponsors are increasingly relying on its expertise to advise them on key decisions. The FAA has identified seven PARTNER research efforts as "highly influential," a moniker that is applied to research whose dissemination could have a potential impact of more than 500 million U.S. dollars in any one year on either the public or private sector, or if the work is deemed novel, controversial, or precedent setting. This means that after a formal peer review process, the research will be used to help inform U.S. policy decisions. However, an international approach in formulating the regulatory framework on aircraft noise and emissions issues encourages harmony in rulemaking. An international approach is also critical to reducing scientific uncertainties to levels that enable appropriate actions to be undertaken. The Canada-United States collaboration in PARTNER has served to enrich perspectives and better focus research on issues that impact all global stakeholders. A major focus for PARTNER during the past year has been on expanding its international activities.

Cooperation With ECATS
The collaboration with the Environmentally Compatible Air Transport System (ECATS), http://www.pa.op.dlr.de/ecats, Network of Excellence established by the European Commission has rapidly and significantly matured. Tasks being pursued are (1) quantifying socio-economic effects of aviation emissions; (2) assessment of technological and operational options for reducing impacts; (3) characterizing global and local atmospheric impacts of aviation emissions; and (4) educating practitioners and the public on aviation emission issues. The agreement was formally signed at the Transport, Atmosphere, and Climate Conference in Oxford, England, June 26-29, 2006, and collaborations are ongoing. Several PARTNER universities are also collaborating with Manchester Metropolitan University and other UK institutions on the recently awarded Opportunities for Meeting the Environmental challenge of Growth in Aviation – OMEGA project. This collaboration is an outgrowth of the ECATS-PARTNER relationship and one of its first efforts focuses on alternative aviation fuels.

International Research Cooperation
PARTNER also seeks to expand collaborative activities in the noise and interdependencies elements of its research portfolio. The team of PARTNER researchers and sponsors charged with expanding and formalizing collaborative research with European partners also met with representatives from EUROCONTROL and defined specific areas for collaboration. Collaboration between PARTNER and EUROCONTROL is included in the research work program between the FAA and EUROCONTROL.

PARTNER is also contributing to the fostering the next generation of scientists who will tackle aviation environmental effects. The PARTNER Joseph A. Hartman Student Paper Competition is a prime example. This competition seeks to reward captures best technical solutions, economic analyses, methodologies, and processes that work towards reducing aviation noise and emissions exposure through source reduction technologies, noise abatement operating procedures, compatible land use management, and airport operational control measures.

2. Opportunities for Meeting the Environmental Challenges of Growth in Aviation (OMEGA)

OMEGA is a multi-disciplinary alliance of academics from nine UK universities which is supported by the UK Government. The partnership has been established to study scientific, technological, operational and market aspects of the environmental impact of aviation and to develop strategies to reduce that impact and related business risks. In addition to its university partners, OMEGA has many stakeholders in government, industry and the NGOs (non government agencies), and it cooperates with the PARTNER network in the US and ECATS[1] in Europe.

The main aim of OMEGA is to strengthen the knowledge base that will be applied to reduce aviation's environmental impacts and enhance its sustainability; a clear synergy with the goals and programme of ICAO and its technical work through CAEP.

[1] Environmental Compatible Air Transport System – Network of Excellence.

OMEGA Environmental Projects and Areas of Research

OMEGA's knowledge transfer (KT) studies and forum for discussion will assist ICAO's extensive environmental work programme. OMEGA is currently working on projects in a wide range of topic areas that will provide information to support CAEP deliberations, the highlights of which are summarized in the following paragraphs.

Air Quality

OMEGA has commissioned a number of KT studies into the various aspects of the airport air quality debate, examining issues such as:

- near-surface aircraft particulate emissions;
- aviation emissions and their impact on air quality;
- aircraft plume analysis;
- understanding initial dispersion of engine emissions: the mixing of engine exhaust gases, jet vortex interaction, and modelling aircraft engine efflux in a wind tunnel.

The information produced by these studies will be offered as input to the CAEP discussions towards developing the modelling Chapter of the Airport Air Quality Assessment Manual. Air quality is an area where OMEGA and PARTNER are working in close collaboration, given their corresponding aims to tackle this significant widespread local issue.

Sustainable Fuels

There is increasing interest in looking at the potential of alternative or bio-fuels and their environmental performance. PARTNER in the US has been active in this area with a wide range of projects looking at life-cycle issues and the full range of impacts. In the UK, OMEGA is conducting a study into sustainable fuels for aviation that has a narrower focus with much of the effort dedicated to looking at the specific emissions characteristics of a range of potential alternative fuels such as kerosene reformulations, synthetic liquid fuels manufactured from coal, biomass or natural gas, and bio-fuels made from agricultural crops. The project team will assess the noise, emission and engine performance of each sustainable fuel and will develop fundamental data on the properties and combustion characteristics of both sustainable fuels and fuel blends, as well as develop sustainable aviation fuel reaction models. OMEGA and PARTNER will collaborate to share information and results as these studies mature, and the outputs will be provided to CAEP for its analysis of the potential for alternative fuels to mitigate some of the environmental effects of aviation.

Emissions Trading Schemes and Carbon Offsetting

OMEGA is currently undertaking studies on the possible impacts on the aviation industry, and on economic activity in general; of including the aviation sector in the European Union (EU) Emissions Trading Scheme (ETS). A wide range of scenarios are being studied in order to determine the conditions under which the inclusion of aviation in the EU ETS might lead to technological change in the aviation industry that will result in improved energy and emissions efficiencies. The project will provide policy-relevant information for both governments and industry.

Attention is increasingly being paid to the role of carbon-offsetting schemes as a means of reducing the net climate effect of aviation activity. OMEGA is looking at the efficacy of different scheme approaches and the concomitant public perceptions and sensitivities to paying an offset charge for the carbon produced by the public's air travel. The study focuses on the respective merits of voluntary versus mandatory schemes and the potential for greater adoption if offset schemes offer more immediate local environmental and social benefits.

Contrails and Aviation-Induced Cirrus Cloud

The work of CAEP has demonstrated a generally robust correlation between emission outputs at ground level and cruise altitudes for the regulated emission species using current technologies. A significant uncertainty remains among members of the scientific community in relation to the effects of contrails and aviation-induced cirrus clouds. This uncertainty raises questions for CAEP to consider from the technical emissions perspective. For example, what is the role of particulate matter emitted from engines as ice nuclei precursors for cirrus; and what is the operational scope to alter flight patterns to avoid seeding contrails? Developments in both of these areas are influenced by the scientific understanding of contrail and cirrus formation and their relative importance in climate terms.

OMEGA is adding to knowledge in this area by incorporating contrails and greenhouse gas emissions into one of the world's foremost climate models – that of the Hadley Centre, part of the UK Meteorological Office. This work will enable scientists to examine climate impacts of aircraft in depth, giving first insights into daytime temperature range effects and regional climate responses. The resulting model will serve as a valuable, policy-relevant tool, ideal for potential mitigation studies. The model will provide a unique resource for scientists and governments, and is a significant step forward in the UK's capacity to analyze the climate impacts of aviation and to offer information and data as input to the CAEP discussions.

Linked studies are being conducted into the characterisation of particulate matter[2] (PM) that will support CAEP's development of a measurement procedure and acquisition of PM data for new engines over time. A study is also underway in relation to combining models of jet engine exhaust and the impact on climate in order to quantify the trade-offs between changes in engine design and aircraft operation.

Noise Issues

One of the OMEGA studies aims to better understand how people regard and cope with noise. A KT study entitled *Understanding Community Responses to Aircraft Noise Exposure* examines airport-to-community communication and tests the viability of introducing new noise exposure measures which are designed to address these issues. New noise indicators allow users to 'see inside' and thus better understand aircraft noise contours, and learn about the location of flight tracks. They may also provide a clearer understanding of the impact of aircraft noise on people's lives and the factors that affect the tolerance of aircraft noise.

If the new measures are found to be successful they will improve communication between airports and neighbouring communities on aircraft noise disturbance issues. They will also lead to the implementation of improved noise control measures that will enhance the potential for airport growth so that the social and economic benefits of air transport may continue.

Another aspect of the noise issue is being addressed by OMEGA in a study that looks at the possibility of reducing the noise associated with open rotor engines, for everyday operation. This technology is attractive because of the significantly greater fuel efficiency that derives from much higher engine by-pass ratios (i.e. increasing the mass flow of propulsive air from the engine). This study connects in particular with ICAO's work on long-term goals around technology and noise performance.

The advanced open rotor concept is one of the few propulsion technologies that has the potential to make significant reductions in aviation emissions, but with significant noise impacts. For example, by using open rotor aircraft as shown in Figure 1 instead of fixed-wing aircraft for short-haul flights, it may be possible to reduce the average trip fuel burn by as much as 30%. However, open rotor technology faces major noise and safety problems that must be overcome if advantages are to be achieved. This led to the rejection of the concept when it was last seriously considered in the 1980s.

Figure 1 – Example of an open rotor engine.

The OMEGA study is driven by real industrial imperatives and shaped by what is technically and commercially feasible. It aims to guide the formulation of policy that will give priority to the introduction of new technologies. It is expected that industry and government will be able to apply the results of this project to evaluate the viability of future aircraft operations from a noise perspective.

2 Particulate Matter is tiny particles of solid or liquid suspended in a gas.

Trade-Offs

The open rotor study is a good example of a case in which technologists have to weigh the relative trade-offs as well as the merits and disadvantages of alternative and new technologies. The key question here is whether researchers can deliver open rotor aircraft at acceptable noise levels in order to maximize fuel efficiency savings.

Trade-offs come into play across many of the OMEGA KT studies. The relationship between technological developments and environmental performance is a delicate, evolving one. Noise and emissions technological advances tend to be incremental and hard won, and may sometimes come at the expense of other environmental parameters. PARTNER has expended much effort to develop tools that can characterise these trade-offs. OMEGA has not sought to do this but is taking a parametric approach to assessing the broad trade-off implications among the various technological, operational and market issues that it is addressing.

The OMEGA KT study (JETCLIM), specifically quantifies the trade-offs between changes in engine design and aircraft operation; combining models of jet engine exhaust and climate impact. The project examines the trade-offs among: climate impacts of contrails, CO_2 emissions and ozone, and methane changes that result from NO_X emissions. It will take output from an existing thermodynamic model of an aircraft and engine to estimate the effect of engine design and aircraft operation on the formation and climate impact of contrails; particularly persistent contrails. The study has the potential to provide a practical guide to engine manufacturers, aircraft manufacturers and airlines on how to minimise aircraft impact on climate, both for current and future fleets.

More about the work of OMEGA can be found on its website at http://www.omega.mmu.ac.uk.

Conclusion

Significant work is already being done by the PARTNER and OMEGA programmes and there is much more yet to do in those two initiatives.

In order to meet its many work programme challenges, ICAO's CAEP is keen to draw in and use of emerging research done by contracting States and Observers. This will allow CAEP to make more informed decisions on how best to achieve its environmental goal of reducing or limiting the effects of aircraft noise and engine emissions (local and global) in ways that are technologically feasible, economically reasonable, and environmentally friendly.

References

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CAEP7 / IP 23: Environmental Design Space (EDS) Progress - (Information paper presented by the members from the United States and Canada).

CAEP7 / IP 25: Aviation Environmental Portfolio Management Tool (APMT) Progress - (Information paper presented by the members from the United States and Canada).

CAEP/7 /26: Workshop on the Impacts of aviation on climate change (Information paper presented by the members from the United States and Canada).

CAEP 7 / IP 33. OMEGA – A new UK Knowledge Transfer Network (Information paper presented by the member from the United Kingdom).

International Cooperation

Overview

By ICAO Secretariat

Harmonization at the international level is only possible through global cooperation, dialogue, and partnership. Since its creation in 1944, ICAO has worked in that spirit enhancing its ability to fulfil its mandate as the global authority for civil aviation.

On environmental matters, ICAO works in close collaboration with other specialized agencies of the United Nations as well as international organizations representing airlines, airports, airframe and engine manufacturers, pilots, and environmental Non-Governmental Organizations, mainly through its Committee on Aviation Environmental Protection (CAEP).

This Part of the report describes the work of CAEP, and ICAO's activities in cooperation with other UN bodies and key partners. A short description of their activities and views on the important collaboration with ICAO on the environmental front is provided.

Committee on Aviation Environmental Protection (CAEP)

ICAO's environmental activities are largely undertaken by its Committee on Aviation Environmental Protection (CAEP). CAEP is the only ICAO technical committee that reports directly to the ICAO Council, although the ICAO Air Navigation Commission (ANC) and Air Transport Committee (ATC) usually review CAEP recommendations.

Currently, CAEP consists of 22 Members, and 12 Observers who are experts representing States from all ICAO Regions and international stakeholders representing major aviation interested parties.

CAEP Members

Argentina, Australia, Brazil, Canada, China, Egypt, France, Germany, India, Italy, Japan, Netherlands, Poland, Russian Federation, Singapore, South Africa, Spain, Sweden, Switzerland, Tunisia, United Kingdom and United States.

CAEP Observers

Greece, Norway, Airports Council International – ACI, Arab Civil Aviation Commission – ACAC, European Commission – EC, International Coalition for Sustainable Aviation – ICSA, International Air Transport Association – IATA, International Business Aviation Council – IBAC, International Co-ordinating Council of Aerospace Industries, Associations – ICCAIA, International Federation of Air Line Pilots' Associations – IFALPA, United Nations Framework Convention on Climate Change (UNFCCC) Secretariat, and World Meteorological Organization – WMO.

Figure 1 – CAEP Members and Observers - CAEP/7 meeting, Montreal, February 2007.

CAEP is responsible for conducting studies and recommending measures to minimize and reduce aviation's impact on the environment, and for maintaining certification standards for aircraft noise and aircraft engine emissions up to date for inclusion in ICAO's Annex 16. CAEP recommendations, in particular standard setting activities, are developed with consideration to four criteria as follows: whether the proposal is ***technically feasible***, ***economically reasonable***, and provides an ***environmental benefit***, while taking into account the potential ***interdependence*** of other measures taken to control noise and engine emissions.

CAEP usually meets once every three years, in the months preceding the ICAO Assembly, and once a year as a Steering Group to review and provide guidance on the progress of the activities of the working groups. In turn, its working groups study and evaluate aviation related environmental matters referred to them by CAEP and develop specific recommendations for the consideration of CAEP.

The structure of CAEP leading to CAEP/8 is illustrated in Figure 2; it has three Working groups, two task forces, and one support group. At each CAEP meeting, the overall structure and the work programme of each group are reviewed and updated as necessary. The working groups are composed of subject area experts from certificating authorities, manufacturers, airlines, and airport operators who have been nominated by their respective CAEP members or observers. More details on each of the groups is provided in the figure and in the following paragraphs.

Working Group 1 - Aircraft Noise Technical Issues

The main aim of WG1 is to keep ICAO noise certification Standards (Annex 16, Volume I) up to date and effective, while ensuring that the certification procedures are as simple and inexpensive as possible. WG1 has two sub groups: TTG dealing with Technology and SSTTG for supersonic aircraft noise.

Working Group 2 - Operations

WG2 has historically addressed aircraft noise issues linked to airports and operations. Its mandate was subsequently expanded to include other emerging issues related to aviation emissions. Currently WG2 is organized into four task groups: Task Group 1 – Airport and Land Use Planning and Management, Task Group 2 – Air Traffic Management, Task Group 3 – Operational Measures, and Task Group 4 – Local Air Quality.

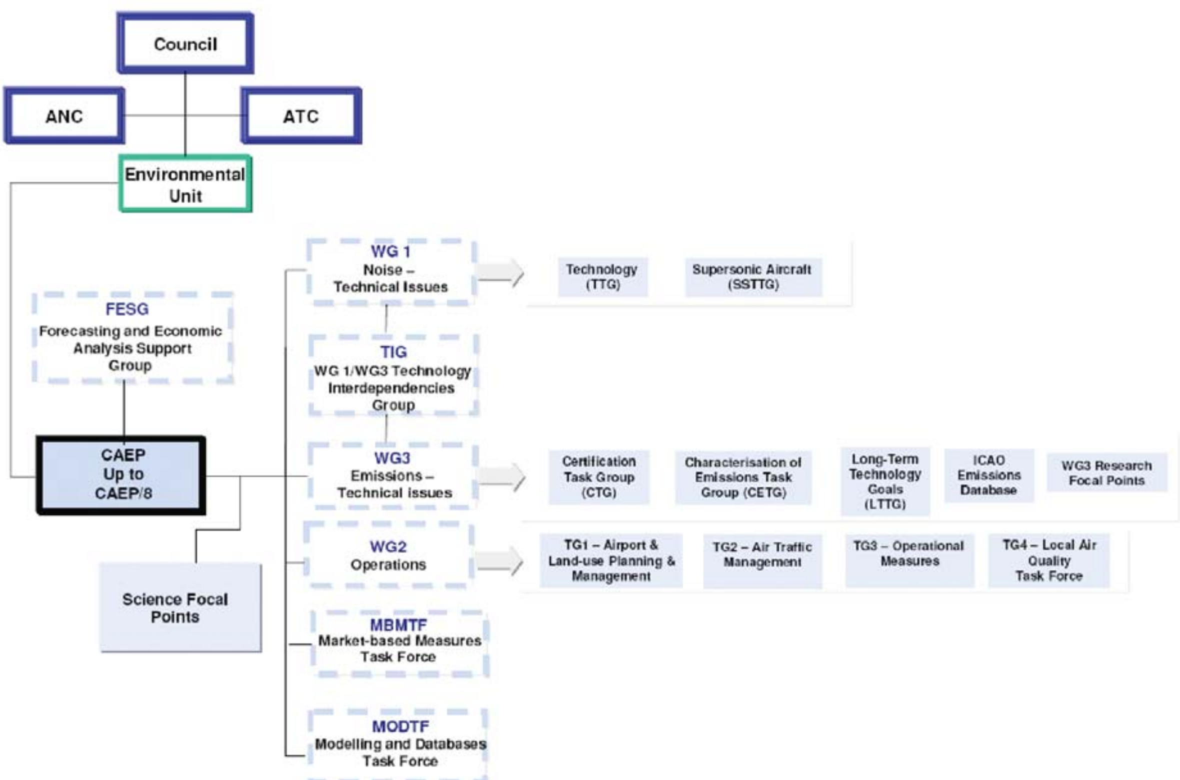

Figure 2 – CAEP working groups structure leading to CAEP/8 (2010).

Working Group 3 - Emissions Technical Issues

WG3 deals with aircraft emission technical matters, including the updating of Annex 16 - Volume II. WG3 is structured into three sub-groups, namely the Certification Task Group (CTG), the Characterisation of Emissions Task Group (CETG), and the Long-Term Technology Goals Task Group (LTTG). In addition, it includes focal points to maintain the ICAO emissions database and provide specific scientific input on research developments.

Market-Based Measures Task Force (MBMTF)

MBMTF was established at the CAEP/7 meeting in 2007, to carry out several tasks including updates of the Report on Voluntary Emissions Trading for Aviation and the Voluntary Emissions Trading Report. MBMTF has also been asked to conduct a study of issues related to linking open emission trading systems involving international aviation, and to examine the potential for emissions-offset measures as a further means of mitigating the effects of aviation emissions on local air quality and global climate change.

Modelling and Databases Task Force (MODTF)

MODTF was also established during the CAEP/7 meeting. This task force carries out modelling efforts in support of the activities of the other CAEP groups. It provides information for the assessment of ICAO environmental goals for noise, local emissions and global emissions. In addition, this group maintains various databases such as the aircraft movements, fleet, and population databases.

Forecasting and Economic Analysis Task Force (FESG)

FESG cooperates with and supports all of the technical groups. The main role of the FESG is to develop and maintain databases necessary to provide the framework for performing economic analysis and forecasting fleet growth. It provides support to the other working groups within CAEP and works with them on data issues that concern more than one working group.

To support inter-group coordination, CAEP has also established the Technology Interdependencies group (TIG) to ensure effective relations between the WG1 and WG3 activities.

Figure 3 – Photo of the CAEP/7 meeting – February 2007.

In addition to experts participating in CAEP's working groups and task forces, the Committee has the cooperation of four scientists that serve as focal points.

CAEP supports ICAO in the organisation of periodic workshops, colloquia, and symposia on the various environmental aspects of aviation. Examples of such events are: Colloquium on Aviation Emissions, Montreal, 2007, Noise Certification Workshop, Bangkok, 2006, and the ICAO/Transport Canada Workshop On Aviation Operational Measures For Fuel and Emissions Reductions, Montreal, 2006.

The work described above results in several ICAO environmental documents being published as reports, guidance material, and/or specific studies. The proceding of CAEP meetings are published as "CAEP Reports", the most recent being the "*Report of the Committee on Aviation Environmental Protection, Seventh Meeting, Montréal, 5 – 16 February 2007 (Doc 9886, CAEP/7*)".

UN Bodies - Delivering As One

Environmental protection is one of the primary areas of work of the United Nations. In September 2000, at the United Nations Millennium Summit, world leaders gathered and reinforced the strong need for global efforts to combat environmental degradation. They agreed to a set of time-bound and measurable goals for the UN. One of the UN Millennium Goals is to ensure environmental sustainability by integrating the principles of sustainable development into country policies and programmes; and to reverse loss of environmental resources.

The UN Secretary-General Ban Ki-Moon, in his inaugural speech, re-affirmed the role of the United Nations in tackling problems in a coordinated, comprehensive and consistent way. Furthermore, in the Report of the Secretary-General's High-Level Panel[1] in 2006, he described the UN system as an indispensable instrument in an age of growing interconnection between peace and security, sustainable development, and human rights. The report says that to achieve these goals the UN needs to overcome its fragmentation and "deliver as one" through a stronger commitment to working together on the implementation of a single strategy.

In this context, ICAO as the UN agency responsible for international civil aviation, is collaborating with its UN sister organizations in the global effort to limit or reduce emissions from international civil aviation and to reduce the impact of aircraft noise on exposed populations. Over the years, ICAO has participated in various high-level environmental events on climate change and provided advice to technical panels, particularly the UN Framework Convention on Climate Change (UNFCCC) and the Intergovernmental Panel on Climate Change (IPCC).

Liaison on environmental matters also takes place with a number of other UN bodies including: the United Nations Environment Programme (UNEP), the Montreal Protocol on Substances that Deplete the Ozone Layer, the UN Commission on Sustainable Development (CSD), the UN ECE Convention on Long-range Transboundary Air Pollution, the World Health Organization (WHO), the International Maritime Organization (IMO), the World Meteorological Organization (WMO), and most recently, the UN World Tourism Organization (UNWTO).

Another point to note was ICAO's cooperation with IPCC on the development of an aviation sector-specific report in 1999 (Special Report on Aviation and the Global Atmosphere) and the participation of ICAO's experts as lead authors or contributors to various IPCC reports.

A Climate-Neutral UN

One of the United Nations Secretary-General's high priorities for his mandate is to adress climate change. He has stated that climate change is a major global challenge and that he intends to take a leadership role in helping the international community address the problem. As a starting point, he has initiated a project to make UN practices more climate-neutral and environmentally sustainable.

As part of the UN system, ICAO supports this initiative and will cooperate with UNEP as it coordinates the "Greening of the UN Proposal"; first by providing technical support and methodologies to calculate aviation emissions related to air travel, and also by identifying means of greening ICAO's own activities.

[1] http://www.un.org/events/panel/resources/pdfs/HLP-SWC-FinalReport.pdf

Robert J. Aaronson
Director General

ACI – Airports Council International

www.aci.aero

"ACI advocates an industry-wide approach to reduce aviation's environmental impact, working with industry partners under ICAO leadership to agree on meaningful targets while ensuring the economic and social benefits of aviation."

Airports Council International (ACI) is the world-wide association of airports representing the common interests of airport operators and has 573 members operating over 1640 airports in 178 countries and territories.

As an observer to CAEP, ACI ensures that the views of the airport community are reflected in the formulation of global environmental polices and regulations. In addition to influencing international standards, ACI brings awareness of local environmental issues to CAEP, an invaluable contribution to the work of the committee. ACI supports the ICAO initiative of a Balanced Approach for addressing aircraft noise at airports.

Jane Hupe
CAEP Secretary

CAEP – Committee on Aviation Environmental Protection

http://www.icao.int/icao/en/env/caep.htm

"The value and relevance of CAEP's work is the result of a highly-specialized unique group of experts cooperating in a consensus building process, based on sound data and knowledge and a profound respect for different views and needs, to achieve globally-accepted solutions to the aviation environmental challenge."

The Committee on Aviation Environmental Protection (CAEP) , is a Technical committee of the ICAO Council and undertakes most of the organization's work in this area. It is composed of 22 Members, 12 Observers, and approximately 400 experts that are involved in its overall activities. It is the international expertise forum for the study and development of proposals to minimize aviations effects on the environment. Every proposal from the CAEP is analysed on four merits: technical feasibility; environmental benefit; economic reasonableness and in terms of its interrelationships – how they influence other measures (a classical example is if measures to minimize noise increase emissions).

The ICAO Council reviews and adopts the CAEP recommendations including Annex 16 Standards and Recommended Practices and in turn reports to the ICAO Assembly (190 States plus international organizations), where the main policies on environmental protection will be defined and issued as the "Consolidated Statement of Continuing ICAO Policies Related to Environmental Protection".

Alexander ter Kuile
Secretary General

CANSO – Civil Air Navigation Services Organisation

www.canso.org

"CANSO Members are committed to contributing to the mitigation of the environmental impact of aviation. Supporting ICAO in reaching global agreement is an essential element of our contribution."

The Civil Air Navigation Services Organisation (CANSO) was established in 1998 to represent the interests of Air Navigation Service Providers (ANSPs) worldwide. CANSO creates an international forum for discussion on air traffic management related issues, where stakeholders unite to develop and exchange ideas in support of global air navigation services. CANSO sets itself the following objectives:

- to be the voice of Air Navigation Service Providers - ANSPs
- to support the improvement of global Air Navigation Services (ANS) performance
- to optimize the effectiveness of the organization

Overall CANSO develops an international communications network for ANS experts to facilitate information exchange between specific ANSP departments for the promotion of best practices in Air Traffic Management. This includes an ATM Environmental Workgroup committed to ensuring that expert ATM operational input is included in the global decions-making process on environmental issues.

Daniel Calleja
Director
for Air Transport
European
Commission

EC – European Commission

www.ec.europa.eu

"The European Community and its 27 Member States have been working with ICAO to address the impact of aviation on climate change since the Kyoto Protocol to the UN Framework Convention on Climate Change was agreed in 1997. Climate change is a global problem and the civil aviation sector must make a fair contribution to the response.

We believe in a comprehensive approach encompassing the development of the most environmentally friendly technology possible, the modernisation of air traffic management to reduce unnecessary emissions, more stringent technical design standards to limit emissions at source, and market-based measures which give an incentive to the sector to take further action

The European Commission looks forward to continuing to work with ICAO in order to further develop the civil aviation sector's response to this huge challenge."

The European Commission is the executive branch of the European Union (EU). It represents the common interest of EU Member States. Composed of 27 Commissioners, it is responsible for implementing common policies, proposing legislation, administering the budget and managing the programmes of the Union.

The Commission works for the good of the EU as a whole and not for the benefit of any one Member State or interest group. It consults extensively so that the parties concerned by the legislation it proposes have a say in its preparation. An assessment of the economic, environmental and social impacts of the proposed legislative initiative is often drawn up and made publicly available together with the proposal. As an observer to CAEP, the Commission ensures that the environmental interests and concerns of its Member States are well represented.

Victor Aguado
Director General

EUROCONTROL – European Organisation for the Safety of Air Navigation

www.eurocontrol.int

"The importance of ATM's role in making air mobility more sustainable is now high on the political agenda. EUROCONTROL is working closely with ICAO to develop globally endorsed environmental assessment resources and environmental operational improvements such as Continuous Descent Approach."

EUROCONTROL is the European Organisation for the Safety of Air Navigation. Its primary objective is the development of a seamless, pan-European Air Traffic Management (ATM) system. EUROCONTROL develops, coordinates and plans for implementation of short-, medium- and long-term pan-European air traffic management strategies and their associated action plans in a collective effort involving national authorities, air navigation service providers, civil and military airspace users, airports, industry, professional organisations and relevant European institutions. EUROCONTROL examines closely how air traffic management can reduce aviation's environmental impact and its potential effect on climate change by allowing air traffic to fly more direct and at more fuel efficient flight levels, which will reduce fuel consumption and thus aviation emissions. It provides valuable input to the work of ICAO/CAEP.

Giovanni Bisignani
Director General
& CEO

IATA – International Air Transport Association

www.iata.org

" The environment is a global issue facing our industry. IATA's vision is for a carbon neutral and eventually carbon-free industry. Cooperation between global institutions – including ICAO and IATA – is key to delivering the global solutions needed to turn the vision into reality."

The International Air Transport Association (IATA) is the worldwide association of airlines. It consists of some 240 airlines comprising 94 per cent of scheduled international air traffic. IATA supports the work of ICAO in developing global solutions and harmonized standards. Through its involvement with CAEP as an observer, IATA ensures that the views of airlines are considered at meetings of the committee.

IATA's has an Environment Committee (ENCOM) which replaced the former Environment Task Force (ENTAF) in June 2005, responsible for monitoring, assessing and responding to environmental developments, policies and regulations of concern to IATA member airlines, for developing and recommending common industry positions on environmental issues and for advising and implementing strategies to promote IATA positions, amongst regulatory bodies and stakeholders. As the focal point on environmental issues, ENCOM advises the Board of Governors, the Director General and other relevant IATA bodies on all environmental matters.

Rich Gage
President and CEO,
Canadian Business
Aviation Association
(CBAA).

IBAC – International Business Aviation Council

www.ibac.org

"There is absolutely no doubt that managing and reducing GHG emissions is one of the key current issues which presents significant challenges and opportunities for the continued growth and prosperity of business aviation."

The International Business Aviation Council (IBAC) is the international representative body for the business aviation community, representing approximately 14,000 operators worldwide. Business aviation coordinates environmental positions and activities through an Environmental Issues Working Group (EIWG) consisting of IBAC members from North and South America and Europe. The group receives technical expertise from operators and a number of business and aircraft and engine manufacturers. The Chairman of the EIWG also serves as the IBAC representative at CAEP. IBAC has been represented as an Observer in CAEP since the fifth meeting of the committee (CAEP/5).

Howard Aylesworth
Director,
Air Traffic Systems
& Aircraft Noise
& Emissions

ICCAIA – International Coordinating Council of Aerospace Industries Associations

www.iccaia.org

"Aviation is a global enterprise. ICAO's leadership is essential. Manufacturers will continue to agressively improve the environmental performance of aircraft. This is fundamental. Today's imperative is eliminating airport congestion and air traffic delay. This is indispensable."

The International Coordinating Council of Aerospace Industries Associations (ICCAIA) was established to provide the civil aviation industry observer status in the deliberations of ICAO.

ICCAIA is constituted by the Aerospace Industries Association of America (AIA), the AeroSpace and Defense Industries Association of Europe (ASD). the Aerospace Industries Association of Canada (AIAC), the Society of Japanese Aerospace Companies (SJAC) and the Aerospace Industries Association of Brazil (AIAB) having over 500 Members.

Through ICCAIA, the world's aircraft, rotorcraft, engine and air traffic systems manufacturers offer their industry expertise to ICAO in the development of international standards. ICCAIA's committee on Aircraft Noise and Engine Emissions (ANEEC) provides CAEP with valuable input as to how to measure the effects of noise, emissions (NOx, HC, CO and smoke) and fuel burn (CO2) and how to control them, the technology available for such control, as well as trade-offs that may occur when trying to reduce their impact on the environment.

Tim Johnson
Director, Aviation
Environment
Federation For ICSA

ICSA – International Coalition for Sustainable Aviation

www.aef.org

"Participation provides an opportunity to share environmental NGO perspectives and expertise with the aim of contributing to the development of global solutions that will demonstrate leadership on tackling aircraft emissions and noise."

The International Coalition for Sustainable Aviation (ICSA) is the environmental NGO observer to CAEP. ICSA represents an international network of environmental NGOs all sharing a common concern for aviation's environmental impacts in relation to climate change, noise and air quality. ICSA is committed to contributing technical expertise to the work of ICAO vis-à-vis its presence on various CAEP working groups.

Capt. Robert Brons
Captain with KLM
Member of IFALPS's
Aircraft Design
and Operation
Committee and
represents IFALPA
at CAEP

IFALPA – International Federation of Air Line Pilots' Associations

www.ifalpa.org

"IFALPA believes that the only way forward in the quest to develop an environmentally sustainable future for aviation is for all stakeholders to collaborate in the development of operational measures and technical solutions that can deliver the level of ecological performance and safety that will be demanded of the industry in the coming years."

The International Federation of Air Line Pilots' Associations (IFALPA) represents more than 100,000 airline pilots worldwide through its more than 90 member associations and serves as the global voice of airline pilots. The federation was created to provide a formal means for airline pilots of the world to interact with ICAO, stemming from the belief that the unique experience of line pilots is critical to the formulation and revision of ICAO Standards and Recommended Practices (SARPs), particularly those pertaining to aviation safety. IFALPA maintains observer status on ICAO's Air Navigation Commission (ANC), the technical body responsible for developing and revising SARPs and is also an observer to CAEP.

Efthimios E. Mitropoulos
Secretary General

IMO – International Maritime Organization

www.imo.org

"In the common quest to regulate the carriage of people and shipping of goods all over the world in a safe, secure, efficient and, crucially, an environmentally-friendly manner, ICAO and IMO together strive to minimize the effects of engine exhaust and greenhouse gas emissions into the atmosphere."

The International Maritime Organization (IMO) is a specialized agency of the United Nations responsible for improving the safety and security of international shipping and preventing marine pollution from ships. With 167 Member States, IMO's primary task has been to develop and maintain a comprehensive regulatory framework for the shipping industry. The technical work of the organizations is carried out by the Maritime Safety, Marine Environmental Protection, Legal, Technical Co-operation and Facilitation Committees.

Dr. Renate Christ
Secretary of the IPCC

IPCC – The Intergovernmental Panel on Climate Change

www.ipcc.ch

"I value ICAO, an important partner of the IPCC for its assessment of global climate change in providing relevant information to policymakers on emissions and mitigation options in the aviation sector. "

Recognizing the problem of potential global climate change, the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) established the Intergovernmental Panel on Climate Change (IPCC) in 1988.

The role of the IPCC is to assess on a comprehensive, objective, open and transparent basis the scientific, technical and socio-economic information relevant to understanding the scientific basis of risk of human-induced climate change, its potential impacts and options for adaptation and mitigation. The IPCC does not carry out research nor does it monitor climate related data or other relevant parameters. It bases its assessment mainly on peer reviewed and published scientific/technical literature.

Most of the ICAO cooperation activities with the IPCC are of mutual technical support. In 1999 ICAO requested the IPCC to produce a Special Report on Aviation and Global Atmosphere, and has in 2005 requested its update in the "Climate Change – 2007" - Fourth Assessment Report (AR4). In parallel ICAO CAEP experts participated as lead authors and contributors to several aviation related reports produced by the IPCC.

Frank Bokulich
Aerospace Standards Engineer
SAE International

SAE – Society of Automotive Engineers

www.sae.org
http://aerospace.sae.org/

"The collaborative efforts between the SAE International A-21 Aircraft Noise committee and ICAO have enabled the industry to better share knowledge and expertise with international authorities. The result is lessened impact of aircraft operations on the environment."

SAE International, through the voluntary work of more than 7,000 committee members and participants, maintains over 8,300 technical standards and related documents. Aerospace Standards from SAE International were developed to ensure the global design, build, and support of the newest products, technologies, and applications.

Martina Otto
Head of the Energy & Transport Policy Unit

UNEP – United Nations Environment Programme

www.unep.org

"Climate chage will cause more extreme weather events with possible impacts on travel destinations, spur the development of carbon markets, and influence public perceptions about travel, all of which will affect the aviation industry. High oil dependence makes the sector vulnerable, and reducing or offsetting GHG emissions will increasingly become an economic necessity. UNEP looks forward to increased cooperation with ICAO and the aviation industry in shaping the framework for aviation in a carbon constrained world."

The United Nations Environment Programme (UNEP) is the specialized agency of the United Nations responsible for coordinating environmental acitivities and policy at the global and regional level. UNEP encourages sustainable development through sound environmental practices and provides assistance to developing countries in implementing sound policies. It works with many partners including other United Nations entities, international organizations, national governments, non-governmental organizations, industry and others. The work of UNEP involves assessing global, regional and national environmental conditions and trends, developing international agreements and national environmental instruments, integrating economic development and environmental protection, and facilitating the transfer of knowledge and technology for sustainable development.

Mr Yvo de Boer
Executive Secretary of the UNFCCC

UNFCCC – United Nations Framework Convention on Climate Change

http:///www.unfccc.int

"The international community must identify ways and means to significantly reduce rising GHG emissions from aircraft as part of a concerted, long-term, global response to climate change that contributes to sustainable development paths."

Over a decade ago, most countries joined an international treaty — the United Nations Framework Convention on Climate Change (UNFCCC) — to consider ways and means of reducing greenhouse gas emissions from human activities that cause climate change, as well as how to cope with the effects of climate change, such as the increased frequency and severity of extreme weather events. To date, 191 countries have ratified the Convention, making it a near universal instrument.

The Kyoto Protocol shares the Convention's objective, principles and institutions and constitutes a first step under the UNFCCC to set greenhouse gas emission reduction targets. With the Protocol's entry into force and its first commitment period about to begin, 35 industrialized countries and the EEC are now bound by concrete emission reduction targets for the period 2008-2012. The Kyoto Protocol's international cap-and-trade system and carbon market allows for cost-effective emission reductions for industrialized countries, therefore lowering the cost of compliance, while greening investment and generating funding for mitigation and adaptation in developing countries.

International aviation emissions are currently excluded from the Kyoto Protocol National targets, being covered instead by Article 2, paragraph 2, which states that developed countries (Annex I Parties) shall pursue limitation and reduction of greenhouse gas emissions from aviation bunker fuels working through ICAO.

The UNFCCC secretariat is a CAEP Observer. During CAEP/7, it provided technical assistance in the development of ICAO's new Guidance on Emissions Trading for Aviation, particularly in the areas of emissions inventory and geographic scope and more recently on the issue of clean development mechanism. It also regularly cooperates with the ICAO secretariat on methodological and technical issues regarding the estimation and reporting of emissions from international aviation.

Chris Lyle
UNWTO
Representative
to ICAO

UNWTO – United Nations World Tourism Organization

www.world-tourism.org

"Sustainable development is a keystone of the World Tourism Organization. Aviation and tourism are integral and hence the prodigious work of ICAO and our mutual cooperation are greatly valued."

The World Tourism Organization (UNWTO/OMT) is a specialized agency of the United ?Nations and the leading international organization in the field of tourism. It serves as a ?global forum for tourism policy issues and a practical source of tourism know-how. Its membership includes 157 countries and territories and more than 300 Affiliate ?Members representing the private sector, educational institutions, tourism associations ?and local tourism authorities.?

UNWTO is committed to the United Nations Millennium Development Goals, geared ?toward reducing poverty and fostering sustainable development, specially in what regards climate change. Cooperation with ICAO is of special relevance on climate change issues.

Dr. Herbert Puempel
Chief, Aeronautica
Meteorology Unit

WMO – World Meteorological Organization

www.wmo.ch

"The World Meteorological Organization (WMO) - the world's authoritative voice on weather, water and climate – assesses the impact of aviation on our climate. Increasingly accurate weather forecasts provided by the National Meteorological and Hydrological Services of its 188 Members are vital for safe and efficient air navigation. They are essential for minimizing flight times, fuel consumption and greenhouse gas emissions, and thus help combat climate change."

The World Meteorological Organization (WMO) is the United Nations' organization responsible for monitoring the state and behaviour of the Earth's atmosphere, including its interaction with the oceans, the climate and water resources. WMO has a membership of 188 Member States and Territories playing a leading role in international efforts to monitor and protect the environment through its many programmes and is an observer to ICAO/CAEP. In collaboration with other UN agencies and the National Meteorological and Hydrological Services, WMO supports the implementation of a number of environmental conventions and is instrumental in providing advice and assessments to governments on related matters, thereby contributing towards the sustainable development of nations.

Closing Message

Secretary General
of the International Civil Aviation Organization (ICAO),
Dr. Taïeb Chérif

ICAO is resolutely pursuing its global leadership role with the international aviation community to minimize the adverse effects of civil aviation on the environment, with regards to noise and aircraft engine emissions. Environmental protection is one of the strategic objectives of the Organization.

The goal is to ensure that these effects are properly identified, reasonably quantified and that appropriate measures are developed using a proactive, result-based approach.

This includes promoting a better understanding of the environmental effects of aviation by encouraging research on aviation's impact on the environment in scientific areas where knowledge is still limited. ICAO contributes to this endeavour through the collection, generation, analysis, harmonization, exchange and dissemination of the aviation-related environmental data required as the basis for the research.

We shall do so in close cooperation with all organizations concerned with environmental issues relating to aviation, ensuring accurate comprehension of the unique nature of aviation, its capabilities and limitations, the role it plays in the global economy and the leadership mandate of ICAO in this regard.

In the area of noise in the vicinity of airports, ICAO has been successful over the years in developing ever stringent standards for aircraft and in gaining consensus around the "Balanced approach" policy - an internationally agreed approach to addressing aircraft noise problems where they occur (at individual airports) in an environmentally responsive and economically responsible way. ICAO has also been actively engaged on measures to reduce aircraft engine emissions with an impact on local air quality and global climate change.

The 35th Session of the ICAO Assembly in 2004 requested that the Organization pursue concrete measures to address emissions, emphasizing technological and operational measures which remain the primary means of mitigating international aviation emissions.

ICAO continues to work on developing Standards and guidance to limit or reduce aircraft emissions. We also must continue to encourage progress, for example by setting long-term goals similar to those established early in 2007 for Nitrogen Oxides (NOx), and we should strive for similar targets for fuel burn. Eventually, I envisage ICAO regulating new engines using alternative fuel sources.

Operational measures are equally important to reaching our objectives. ICAO must take the lead in encouraging the implementation of the new Communications, Navigation, Surveillance and Air Traffic Management (CSN/ATM) systems at the global and regional levels so that their environmental benefit can be realized, while developing and promoting other improved operational practices. Advancements in this area are already being made, but they must be better structured to include specific environmental goals and timelines.

In addition to the technological and operational measures, ICAO has been exploring market-based measures. In 2004, the Organization developed a template agreement for voluntary measures to reduce aviation emissions; it was adopted by several Member States as a model for their policy on emissions.

ICAO is currently considering integrating international civil aviation emissions into existing carbon trading schemes and draft guidelines have been developed. In addition, ICAO is exploring the use of other flexible mechanisms.

The Organization places particular emphasis on providing updated information about ICAO activities and relevant aviation data to relevant United Nations fora and, in particular to the United Nations Framework Convention Climate Change (UNFCCC) process and the Intergovernmental Panel on Climate Change (IPCC).

Facilitating dialogue and collaboration within the aviation community on measures to address aviation's impact on climate change is essential for developing appropriate standards, guidance and policy recommendations.

In short, our focus over the next three years will be to continue fostering cooperation among all stakeholders, provide the required assistance, create standards, develop supporting guidance and facilitate the overall regulatory process. All of this is essential but it is only the baseline for a longer-term action.

Ultimately, to reach our goals, we must continue to explore all measures that can help mitigate the effect of aviation on local air quality and global climate. Such measures must come under an agreed framework, that provides the flexibility required for States to address the issue of international aviation emissions.

Global cooperation is key to sustained and long-lasting progress. Only by working together, through ICAO, can we attain the results we strive for.

I trust that this triennial Environment Report, to be published in conjunction with ICAO Assemblies, will come to be considered as a definitive information resource in addressing one of the most pressing societal challenges of this early part of the 21st century.

Dr. Taïbeb Chérif

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This report was coordinated and prepared by the Environmental Unit with contributions from many experts within ICAO, CAEP and others organizations.

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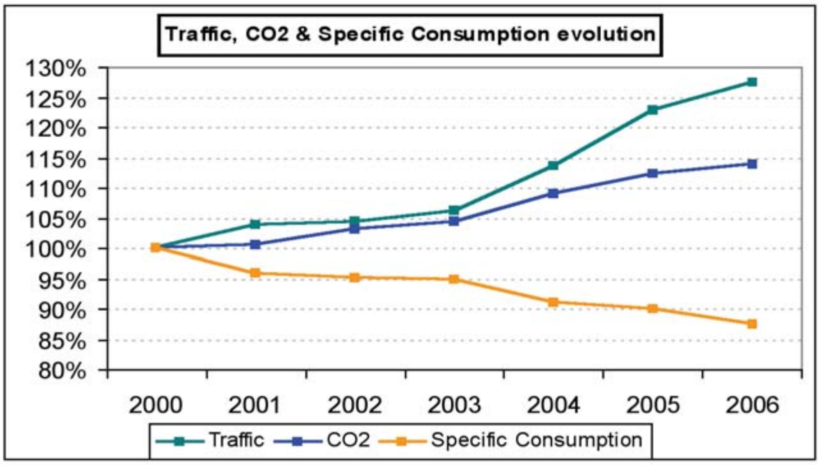
Climate change

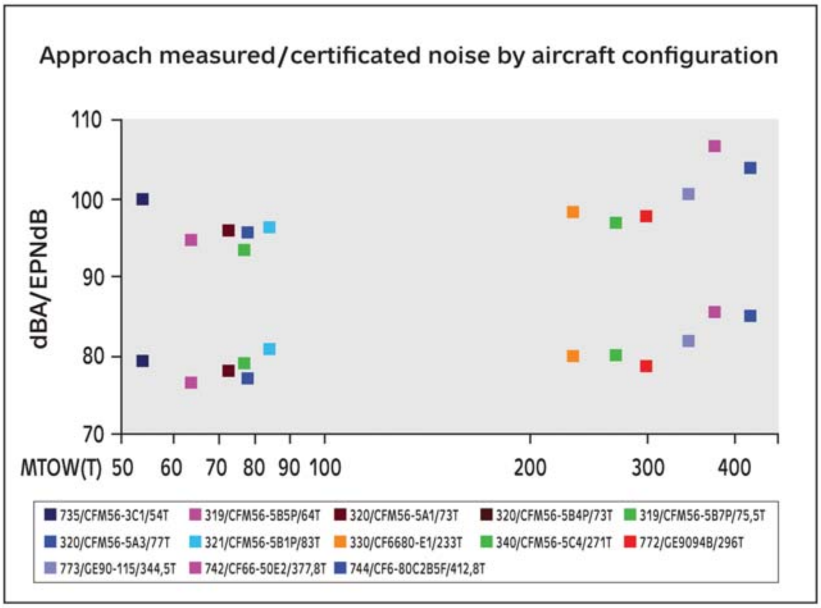
The growth in CO_2 emissions of Air France-KLM Group aircraft has been under control for several years: indeed it represents only half of the increase in traffic (in RPKs or equivalent RPKs for freight), thanks primarily to the renewal of its fleet, its hub-based operating model and the ongoing optimization of procedures.

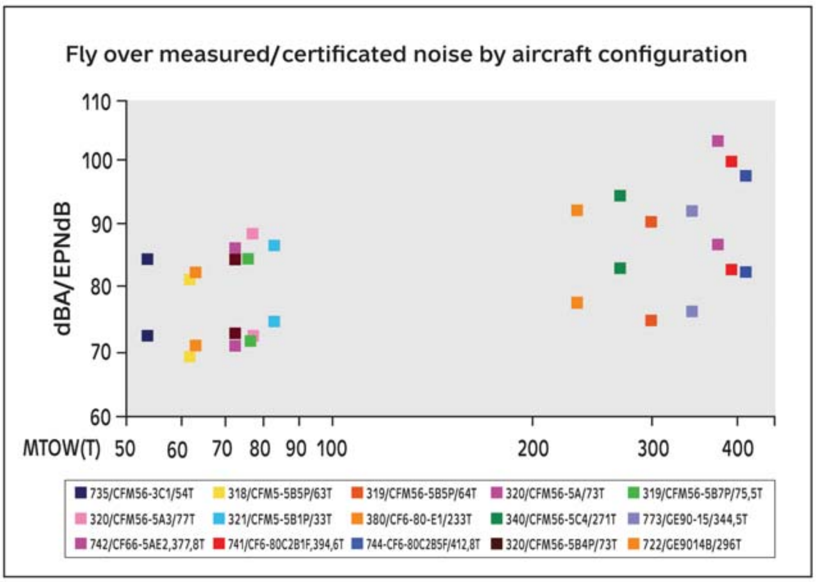


Because air traffic management today leaves a lot to be desire, for every short or long-haul flight, aircraft fly 200 km more than the orthodromic distance they should fly. The increased flight time can be reduced by optimized air traffic management, with a positive impact on aircraft emissions as is the case with fleet renewal and the optimization of the network. We believe that improved air traffic management combined with fleet renewal would enable to offset the effects of the increase in traffic on emissions for several years.

The Air France–KLM Group therefore believes that ICAO absolutely must consider the improvement of air traffic management in all countries as their biggest priority in order to fight against the contribution of aviation to global warming.

Furthermore, as long as the new technologies for future aircraft, including CO_2 storage, do not really provide an innovative outlook, the contribution of the air transport sector to the fight against global warming must necessarily require the participation to other sectors' efforts for the overall control of CO_2 emissions.





The best way for aviation to contribute effectively to the fight against global warming is to participate in states' Emissions Trading Schemes, with wide access to the Kyoto mechanisms of flexibility (Clean Development Mechanisms and Joint Implementation).

The Air France–KLM Group strongly supports the inclusion of aviation in the States' open ETS and considers that its success and efficiency would depend on certain prerequisites in order to :

- Favor the use of the best available technology and consider all products equitably,
- Not to create the risk of diverting traffic to airports outside the concerned perimeter,
- Treat air transport in a non- discriminatory way compared with other sectors,
- Gradually move to a worldwide coverage with no loopholes nor duplications.

The ICAO therefore has to pursue its work initiated by the preparation of recommendations for the inclusion of international aviation in an open ETS. Air France participates in this work and strongly backs proposals for the improvement of European project.

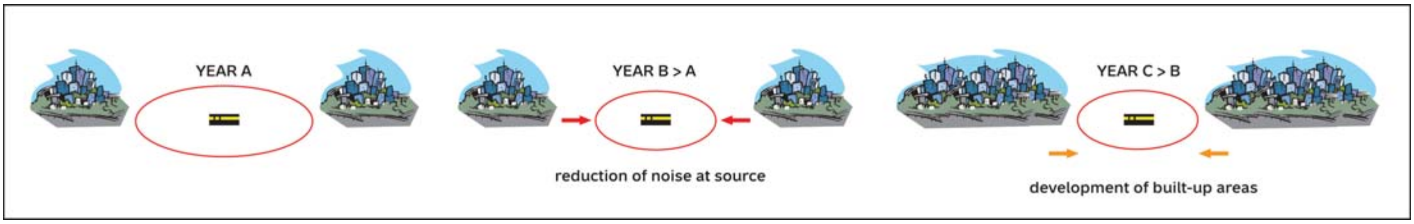
Noise pollution around airports

ICAO Working Group 1 (noise certification) in the framework of the CAEP7 work cycle concluded that the diagram of the acoustic certification of aircraft is not to be amended because the correlation between the certified levels of noise and the levels of noise measured in operations is satisfactorily accurate..

For example, around PARIS-CDG:
The average noise levels measured annually in dBA 5000 meters after the end of the runway (for every type of Air France aircraft) is about 13dB lower than the certified fly-over level measured in EPNdB
The average of noise levels measured annually in dBA 5000 metres before the runway threshold (for every type of aircraft) is about 19dB lower than the certified approach level measured in EPNdB.

Globally, the noise pollution level has decreased : all Air France-KLM Group movements throughout the world produce a sound energy around airports that has decreased by 21 % in 5 years, even when the number of movements has increased by 19 % (see graphic next page).

This improvement is due to the fleet renewal effort and to the use of regularly optimized procedures.

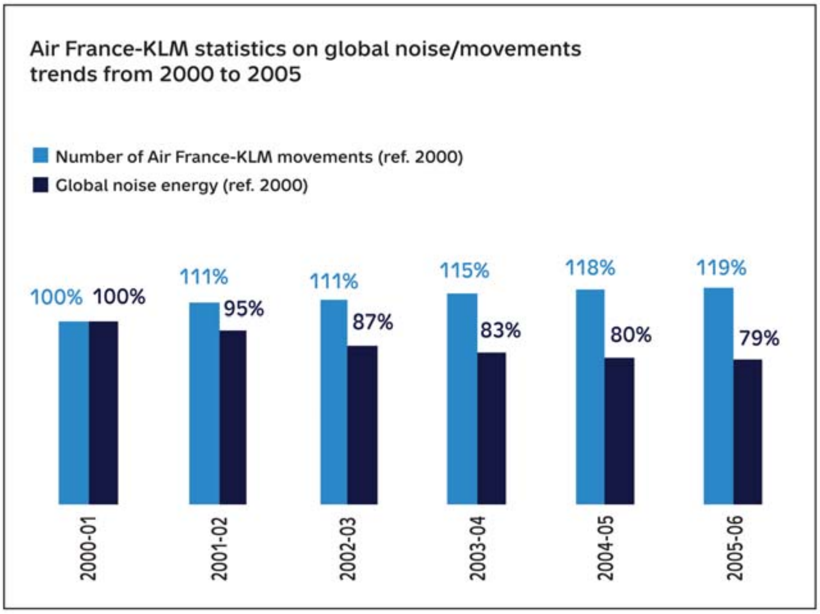


Even though the reduction in noise exposure despite increasing traffic has been observed for some time now, generally speaking, it has not contributed to improving noise levels around airports : it has been accompanied by a trend of constructing housing closer to the runways, increasing population density and increasing the value of grounds around airports.

That is why Air France has been working with the IATA to prepare ICAO's definition of the "Balanced Approach": controlling the use of grounds around an airport and building and construction on these grounds is vital if we are to improve noise exposure around airports , as well as fleet modernization, implementing operational restrictions or enhanced operational procedures.

Air Quality around airports

In the absence of precise data on particulates emissions from aircraft engines, air quality around airports is mainly defined by the level of nitrogen oxides emissions at low-altitude (under 3000 ft) : in the Paris region, the contribution of aircraft activity, essentially during takeoff and over a distance of approximately 20 kilometers after take-off, to the global NO_x concentration is only 6 %, with the remaining caused by the emissions from road traffic and the ground facilities pertaining to other industries.



2/3 of the Air France NO_x emissions are produced by the planes, the other contributor being the road transport means passengers and agents use to get from the city to airport and, to a lesser extent, the equipment and vehicles used to service aircraft in airports.

The emissions of NO_x in turbojet engines have to satisfy the standard promulgated by the ICAO , the severity of which was already revised three times; Working Group 2 plans to reexamine a more severe standard during the work cycle CAEP 8.

Over time, the evolution of technology has allowed to reduce noise and carbon dioxide emissions but it has led to an increase in Nox emissions, as quantified by the low-altitude cycle of the international standard (LTO).

It is necessary to put this evolution into perspective because the improved aircraft performance indeed limits the increased NO_x per transported passenger. Furthermore, the superior ascent rates of twin-engined planes (whose proportion is rapidly progressing in the long-haul fleet) with regard to four-engined planes also helps to moderate the situation because they reduce the low-altitude emission time (below 3000ft). Nevertheless the quantity of NO_x around airports has globally increased with traffic.

Research programs and manufacturers believe that by 2020 the NO_x emissions of new engines will be reduced by 80% compared with their level in 2000.The CAEP7 recorded the analysis of independent experts who also foresee significant improvements on an average and long term basis.

The Air France–KLM Group thus hopes that the analysis of CAEP8 will effectively lead to reinforced stringency of the NO_x standard , thus promoting the potential for improving engines in the medium-term, by eliminating recourse to other policies considered by the Group as ineffective.

CANSO ANSPs take concerted action on the environment

In northern Europe the issue of aviation's responsibility for greenhouse gas emissions is becoming one of the hottest political issues of the summer. Pressure is growing on the European Commission to speed up the Single European Sky (SES) implementation process on the basis of the environmental benefits the SES could bring to European citizens. Pressure is growing, too, from airlines who see ATM efficiency improvements – especially shortened routes - as one of the most important short-term gains they can make to their fuel burn and emission performance. Environmental campaigning organisations have started to argue for ANSPs to treat environmental protection at the same level as aircraft safety. At the upcoming ICAO Assembly, States will be under increased pressure to agree on clear action and guidance on environmental mitigation measures, such as an emissions trading scheme.

© Image courtesy of Belgocontrol

ANSPs realise they have an important role to play. Many have already taken widespread action at a national level to tackle key environmental challenges. In the last few years they have delivered substantial, quantifiable reductions in aircraft pollution levels through pioneering work to shorten routes, reduce delays, provide continuous descent approaches into airports and optimise aircraft efficiencies.

Individually their environmental programmes have provided major short-term gains in lowering fuel burn and decreasing emissions of greenhouse gases. Here are just some examples.

• Airservices Australia's "flextracks" programme enables aircraft to use the prevailing jet-stream conditions to fly more efficient routes; one airline calculated it had saved 8408kg of fuel and 43 minutes of flying time on a single service between the Middle East and Australia by diverting from the straight path to hitch a ride on the high-speed jet-streams.

• The use of continuous descent approaches (CDAs) – allowing the pilot to set the aircraft's engines to "idle" when approaching the runway - can save between 100 and 300 kilos of fuel per flight, according to Sweden's LFV, and they have been operationally in use at Stockholm/Arlanda since March 2006.

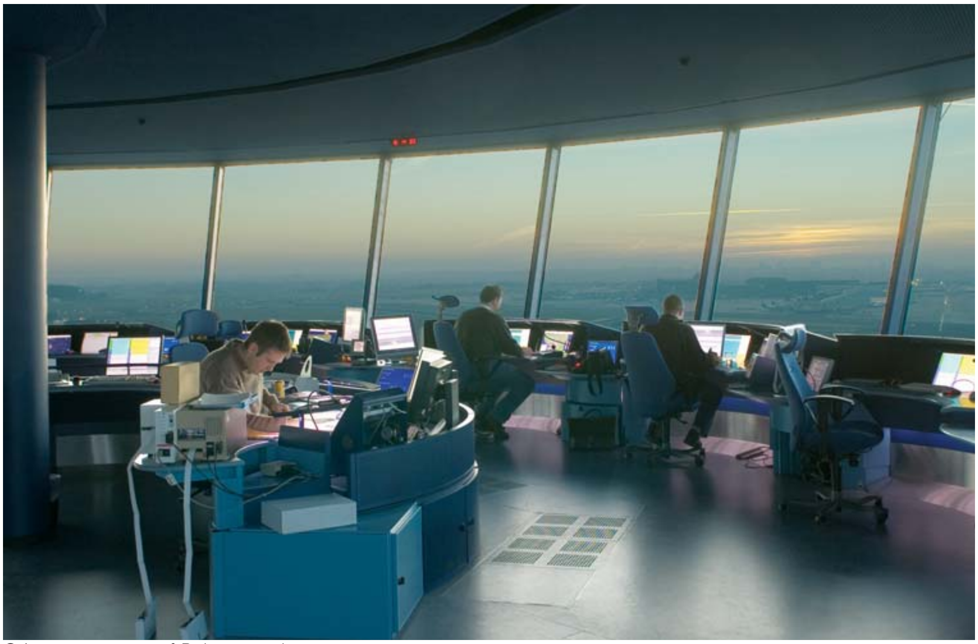
• The opening of new polar routes into Russian airspace has allowed aircraft to fly routes that are much shorter and more fuel efficient than previously; a New York to Hong Kong flight routed over the arctic will save five hours of flight time.

"However, there are currently no criteria or metrics to understand/quantify the impact of ATC procedures on emissions.It is therefore difficult for ANSPs to quantify volumes of emissions resulting from ATM procedures," according to CANSO secretary general Alexander ter Kuile. "In CANSO's view global gaseous emissions are a more serious long term issue as the growth of aviation increases the sector's contribution to global emissions. It is essential that we assess the impact of aviation global emissions and adopt appropriate mitigation strategies to reduce these impacts."

The Association recognises that as an industry body it can play a crucial role in coordinating actions and initiatives, on a global scale.

At the 2007 annual general meeting in India CANSO members committed to introducing a voluntary code of practice which establishes a framework within which ANSPs can offset the environmental impacts of growth through their own initiatives and collaboration with other industry stakeholders.

The code will support ANSPs in working effectively with regulatory bodies, such as ICAO and its Committee on Aviation Environmental Protection (CAEP), which deals with aviation environmental issues at an international level. The code will establish



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a community of like-minded ANSPs that can learn from each others' experience in environmental mitigation. It represents the first step in establishing common goals for all CANSO members to support. This framework will allow members to measure and report their progress towards these goals while acknowledging legislative and regulatory constraints and the capacity of other stakeholders to fully participate.

"CANSO has also taken the initiative to establish a practical guide to conducting environmental assessments for changes to en-route airspace design and ATM operations at airports," said Alison MacMaster, Director of Industry Affairs. "This will build on ongoing initiatives by ICAO CAEP, IPCC and CANSO member ANSPs. CANSO also plans to establish a practical guide to how ANSPs can reduce the environmental impact of their own organisations. Members plan to share experiences on the implementation and certification of environmental management systems."

CANSO is also working to ensure that if States are considering development of regulations to limit the impact of aviation on the environment this should be undertaken with close involvement of industry. The development of global standards of performance and metrics for the measurement of environmental impacts is essential if targets are to be set and improvements are to be measured. ANSPs will have to work more closely with other partners (such as defence departments to optimise civil/military airspace design, and standards agencies to develop environmental management systems) to find environmental mitigation improvements.

And there are other areas – airspace fragmentation, research and development – over which ANSPs have little control, but which require strong political commitment by governments.

In the short term there are three areas where CANSO is working directly with its members to develop solutions to environmental mitigation. The CANSO Environmental Workgroup offers the opportunity for members to exchange information on environmental mitigation best practice.

CANSO member environmental experts are currently examining ways how best they can contribute to the work of the ICAO CAEP. Within the workgroup ANSP environmental experts are working to:

- Better understand the impact of aviation on climate change and identify appropriate metrics that demonstrate ATM contribution to reducing the impact.

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Short–term ANSP environmental mitigation maeasures

At the 24 July 2007 "ICAO Friends of the President: Aviation and the Environment" meeting in Montreal CANSO secretary general Alexander ter Kuile outlined some of the short-term measures being implemented by CANSO members:

Introduce most fuel efficient routings.
Issue to be addressed: Airlines tend to fly the lowest cost (navigation charges) route not necessarily the most environmental route.

Optimise flight profiles through the use of new procedures and technology, RVSM, RNP.
Issue to be addressed: Aircraft equipage and civil/military coordination.

Flexible use of airspace and the use of temporary segregated areas.
Issue to be addressed: Civil/military coordination and flexible military/civil flight planning.

Reduced separation standards in oceanic airspace, to raise airspace capacity and operational flexibility - optimised routes and flight levels - with no reduction in safety.

Influence altitude of NOx emissions and contrail creation.
Issue to be addressed: Insufficient scientific understanding and quantification of impacts.

Develop technologies and tools to better manage aircraft movements en-route.
Issue to be addressed: Collaborative decision making.

Restrict aircraft speed.
Issue to be addressed: Economy, fuel and emissions.

Steeper glide paths of 3.5, 4 or 4,5 degree approach paths.
Issue to be addressed: ICAO standards.

Reduce airborne holding.
Issue to be addressed: Operational and procedural changes and manage trade-offs.

Arrival speed restrictions deliver significant fuel & emissions reductions.

Continuous Descent Approaches into airports with engines at flight idle (low power).
Issue to be addressed: Interrelationship between noise, emissions, air quality.

Develop technologies and tools to better manage aircraft movements on ground.
Issue to be addressed: Collaborative decision making to reduce emissions while taxiing.

Airport design inefficiencies, suboptimal runway and taxiway design.
Issue to be addressed: Collaborative decision making in airport development.

Reduced power take-offs.
Issue to be addressed: Safety, economy, environment tradeoffs.

- Develop a position paper on the opportunities to reduce noise and improve local air quality and identify the interdependencies.
- Document existing processes used by member ANSPs for conducting assessment of the impact of changes to ATM operations at airports and develop a practical guide to conducting environmental assessment for changes to ATM operations at airports.
- Document existing processes used by member ANSPs for conducting assessment of the environmental impacts of airspace changes and develop a practical guide to conducting environmental assessment for en-route airspace changes.
- Develop briefing material for CANSO member ANSPs to brief their staff on the core facts on aviation's impact on the environment and specifically the ATM contribution, and which describes successful initiatives by CANSO members in mitigating the impact.
- Develop media-friendly briefing material that states the core facts on ATM and the environment and describes successful initiatives by CANSO members in mitigating the impact.
- Conduct a stakeholder analysis to identify those bodies and organisations that CANSO and its members should engage with to influence the environmental debate.
- Support cooperative activities to share information and experience of options to mitigate the environmental impact of aviation related activities.
- Establish a process for developing clear, consistent key messages, to support effective communication.
- Establish a practical guide on how ANSPs can reduce the environmental footprint of their organisations.
- Share experiences on the implementation and certification of Environmental Management Systems.

The second measure is to increase ANSP commitment to the Voluntary Code of Practice (see www.canso.org for more details.

In summary, airspace management and design can play an important role in addressing the impact of aviation greenhouse gas emissions on the global climate. But ANSPs are not the only actors in this area: States need to address the related institutional issues

And while ATM can play a role in mitigating the environmental impact of aviation, trade-offs exist between safety, economy, capacity and environmental impact and these need careful assessment.

Airbus and the Environment:

Addressing Aircraft Noise

Airbus continues to achieve significant reductions in noise levels around airports through research into reduction-at-source and close working relationships with airlines and airports with regards to operational measures.

Noise certification procedures

Aircraft built today must meet the noise certification standards adopted by the International Civil Aviation Organization (ICAO) Annex 16.

The ICAO has strengthened the regulation by adopting Chapter 4, which took effect on January 1, 2006. Airbus has undertaken the re-certification to Chapter 4 of all of its aircraft in production and is investigating the possibility of certifying delivered aircraft to Chapter 4, thanks to advanced acoustic technologies.

Noise reduction

Airbus continues to support the ICAO's balanced approach to noise mitigation, which incorporates noise-at-source, operational procedures, land-use planning measures and operational restrictions.

Noise reduction at source

Aircraft noise can be a nuisance for people who live and work in some areas near airports. So, as an aircraft manufacturer, Airbus is addressing this issue at the source by working on solutions such as low-noise nacelle designs, acoustic treatments, optimised propulsion systems installation and overall aerodynamic efficiency.

The company is also working closely with engine manufacturers, encouraging them to develop and implement low engine noise technologies by setting challenging specifications.

Implementing innovative new technologies such as these is a complex task. Engineers must achieve both highest possible safety margins and the optimum balance between a wide range of design criteria, including noise, fuel efficiency and emissions.

There have already been significant improvements and aircraft entering service today fleets are typically 20 decibels quieter than comparable products built 30 years ago (about 75 per cent less noise annoyance).

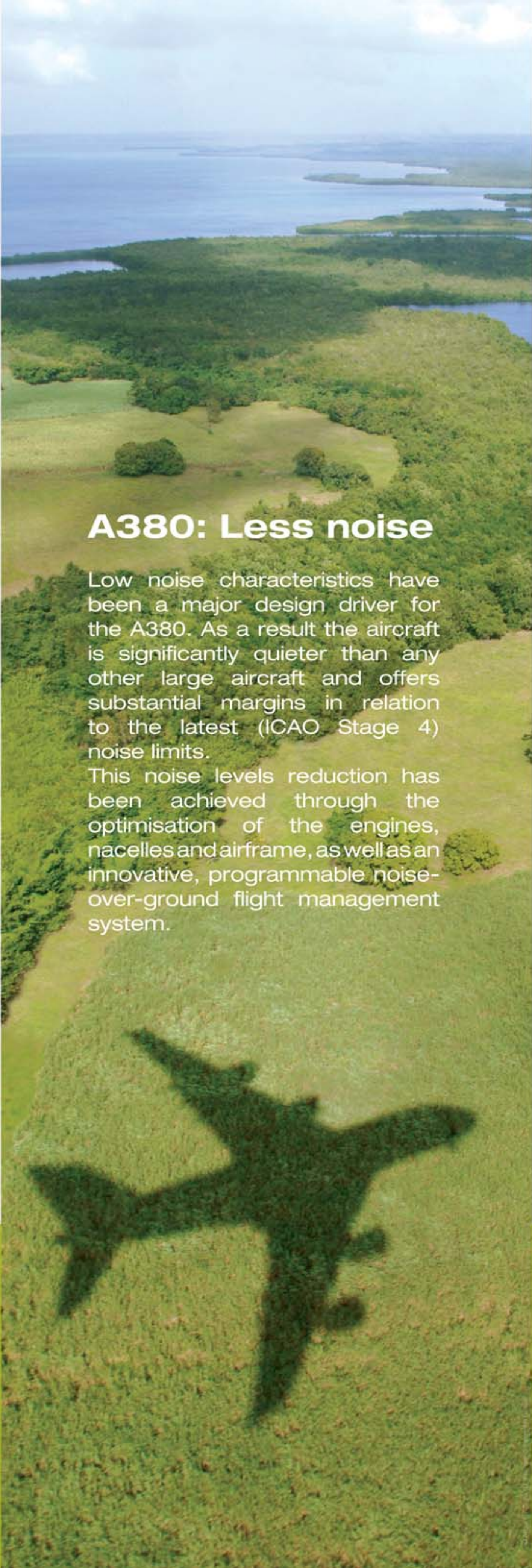
To continue this trend, Airbus is currently working on a number of research and development projects that will enable aircraft noise to be reduced by up to a further six decibels by 2008.

Operational noise-abatement procedures

Airbus works with airlines to optimise the flight paths close to airports in order to reduce the impact of aircraft noise on the ground. Since the early 1990s, Airbus has been developing

New step in SILENCE(R)

Airbus is participating in the SILENCE(R) noise research programme, which brings together 51 European organisations in the largest ever project of this kind and has created the world's first full-scale zero-splice nacelle intake, a patented concept for engine-fan noise reduction. In 2004 and 2005, the programme carried out flight test campaigns to study noise reduction. Fairings were tested on an A340, while nacelle improvements were tested using an A320. The tests demonstrated that these new technologies performed as expected in real operating conditions and are a decisive step towards their application on existing and future aircraft.



A380: Less noise

Low noise characteristics have been a major design driver for the A380. As a result the aircraft is significantly quieter than any other large aircraft and offers substantial margins in relation to the latest (ICAO Stage 4) noise limits.

This noise levels reduction has been achieved through the optimisation of the engines, nacelles and airframe, as well as an innovative, programmable noise-over-ground flight management system.

noise-level computation (NLC) software, which makes it possible to determine the optimum flight profile, in terms of noise abatement, for an Airbus aircraft. Airbus makes this package available to any airline operating its aircraft and provides specific training through its customer support specialists. The software has been used successfully by many airlines.

Airbus itself has performed special studies for different airlines aimed at reducing the impact of their trajectories on noise-sensitive airports. Whilst Airbus has no direct responsibility in this field, it is also committed to providing airports and airlines with the best technological and planning information it has available, such as future traffic forecasting, to help establish appropriate airport-noise zoning and planning.

Airbus and the Environment:
Addressing Climate Change

Airbus is the first jetliner manufacturer to be certified to international environmental standards ISO 14001, for full lifecycle coverage, including all products and manufacturing plants. This approach ensures that environmental concerns are considered at all relevant stages. When it comes to climate change, Airbus is targeting minimisation of fuel consumption and CO2 emissions from the earliest stage of aircraft design.

Climate change: a challenge for the world and the aeronautics industry

Officially in force since February 16, 2005, the Kyoto Protocol defines adjustment targets (for the period 2008-2012, compared to 1990 levels) for six main greenhouse gases (GHG) that contribute to climate change. Among them, carbon dioxide (CO_2) emitted by the engines is the only one which directly concerns aviation.

Aviation is not excluded from Kyoto agreements: CO_2 emissions from domestic aviation fall in the scope of assigned amounts attributed to states that ratified the Kyoto Protocol. For international traffic, the limitation or reduction of GHG emissions are pursued through the International Civil Aviation Organization (ICAO). Airbus is actively supporting the ICAO's work to define the framework and methodologies to mitigate these emissions, including the consideration of market-based measures.

Fuel efficiency and on-going innovation

CO_2 emissions are proportionally linked to fuel burn. Consequently, and in the absence of foreseeable alternative fuel, the reduction of CO_2 emissions will be achieved through improvements in fuel consumption, which is the core business of aircraft and engine manufacturers. Indeed, over a typical aircraft mission, the lower the fuel required, the higher the payload (passenger or cargo) on board. Thus, the economic equation goes hand in hand with the environmental interest.

By investing heavily in intensive research and developments programmes, Airbus has led the way with the progressive introduction of advanced materials and new processes, together with an optimised design, making it possible to burn less fuel and therefore reduce greenhouse gas (GHG) emissions. Tremendous achievements over the past 40 years have already enabled a 70 per cent reduction in aircraft fuel consumption.

Support operational Performance

Product performance is also about sound aircraft operation. Airbus supports its customers in deploying methods and software tools for aerodynamically clean aircraft, well-maintained engines, good flight planning and thus, emission reduction.

Improving scientific Knowledge

In a long life-cycle industry, today's solutions must not generate tomorrow's problems.

Searching alternatives to petrol-based kerosene

Airbus has actively been supporting research work on suitable alternatives to kerosene for over a decade. In particular, Airbus is currently working on alternative fuel ideas with academic research institutions and industry partners in a joint program called CALIN. This program will be extended to a far-reaching international partnership within the next several months. Airbus expects to identify promising alternatives by 2010.

A380: Less fuel burn and emissions

The A380 demonstrates a very low fuel burn of less than 3 litres per passenger per 100 kilometre. Low fuel burn means low CO2 emissions.
In fact the A380 produces 75g of CO2 per passenger per kilometre, far below the emissions generated by a mid-sized car.
To make this progress possible, the A380 has benefited from an efficient, lightweight structure the latest innovations in aerodynamics and systems and new state of the art high by-pass engines.

Louis Gallois
Airbus President and Chief Executive Officer

"I would like our industry to focus on becoming an eco-efficient one. Doing so will ensure long-term sustainable growth for both the industry and the world's economies, to which the air transport sector is a very strong contributor. A green industry must be the vision for the future of aviation".

Thus, defining the most important issues well in advance and improving scientific knowledge to avoid uncertainties is essential. Airbus therefore actively supports transversal scientific research.

Atmospheric studies

Installed on five commercial A340s, the Measurements of Ozone and Water Vapour by Airbus In-Service Aircraft (MOZAIC) system has been recording data on more than 26,000 flights in order to better understand the atmosphere in which the commercial fleet operates. Based on this intelligence, the European research project Integration of routine Aircraft measurements into a Global Observing System (IAGOS) is developing lighter and smaller instruments for measuring an extended number of gases. Airbus contributes actively to this project, together with a number of airlines and academic and scientific institutions. One of the objectives is to install this instrumentation on 10 to 20 in-service Airbus aircraft over a period of ten years or more.

Fleet emissions evaluations

Airbus is an industrial partner in the AERO2K and Scenario of aircraft emissions and impact studies on chemistry and climate (SCENIC) research projects, which aim to improve the methodologies for forecasting aircraft emissions and study scenarios of their future impact, based on a range of variables.

Quantification of the impact on the climate of all modes of transport

Airbus provides its industrial point of view, forecasts and metrics to the European programme QUANTIFY, which aims to inventory and forecast past, present and future emissions from all modes of transport.

www.airbus.com

AIRBUS

Singapore Changi Airport has defied convention. It has become one of the few airports in the world to take significant measures to be environmentally friendly.

Over at the brand new Terminal 3, Singapore Changi Airport has fitted a revolutionary roof that has made aviation experts around the world do a double take.

919 skylight openings in the Terminal 3 roof structure capture an optimal amount of sunlight in the day to fill the terminal's entire departure hall, transit mall and areas of the arrival hall with natural light while keeping out the heat. Such an earth-friendly initiative is possible thanks to intelligent reflector panels that adjust themselves according to the position of the sun and clouds so as to present a uniformly-lit, cheerful and cosy interior ambience for passengers, visitors and staff alike.

Architects have done more to save the Earth. Rather than using conventional glass, double-glazed glass panels have been used for the façade and roof skylights to minimise heat from entering the terminal, thus reducing the greenhouse effect and cutting down air-conditioning and hefty energy consumption. Artificial lights near the glass facades are computer-controlled so that they are automatically switched off when the environment is bright.

The roof of the Departure Hall may be some 17 metres high to create an airy and well-ventilated interior, but there is no need for massive amounts of air-conditioning to cool the huge hall. Instead of fitting the air-conditioning in the ceiling which would then require it to be turned on at full blast so the entire hall stays cool right down to the floor, Terminal 3 is cooled from ground up to human height at places where people dwell so that less air-conditioning is needed to produce the same cool comfort.

Building an eco-friendly terminal was the intention right from the start. "We wanted an energy-saving terminal, one that would protect the environment and keep running costs low. The way the roof has been designed is an example of how we have achieved these and helped promote Changi as an eco-friendly airport." said Mr Teoh Eng San, Project Manager for Terminal 3.

With bountiful sunlight, Terminal 3 also brings gardens indoors. One breathtaking green attraction is a vertical 5-storey high Green Wall that adds a lush, verdant touch to an otherwise all-steel and glass building. Made up of hundreds of plants that intertwine to create a pleasing warm welcome, it sits alongside sleek waterfalls above the baggage claim belts, gently nudging passengers in awe to linger for a while longer to enjoy the picturesque Changi experience.

Continuing its green efforts, Changi Airport will soon begin introducing eco-friendly hybrid tractors to transport baggage between aircraft and passenger terminals. Using a combination of electricity and diesel, these tractors will emit lesser carbon dioxide, noise and heat, especially when operating within the baggage sorting areas at the terminal.

For its part in water conservation, Changi Airport will start using treated used water from end 2007 for its air-conditioning equipment and to irrigate its indoor gardens.

The world's best airport has made it easier for passengers to travel green.

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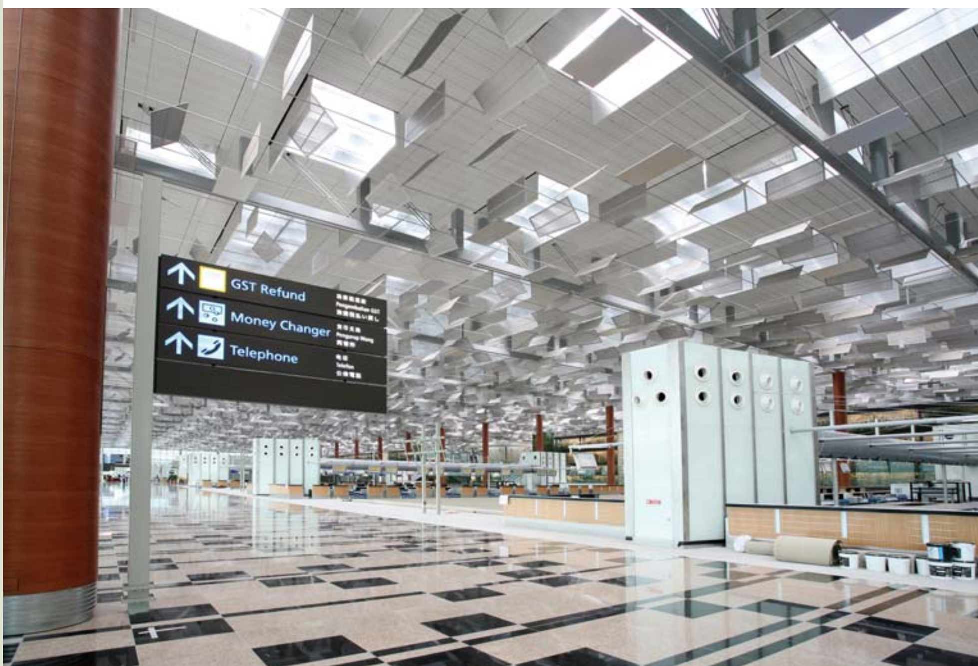

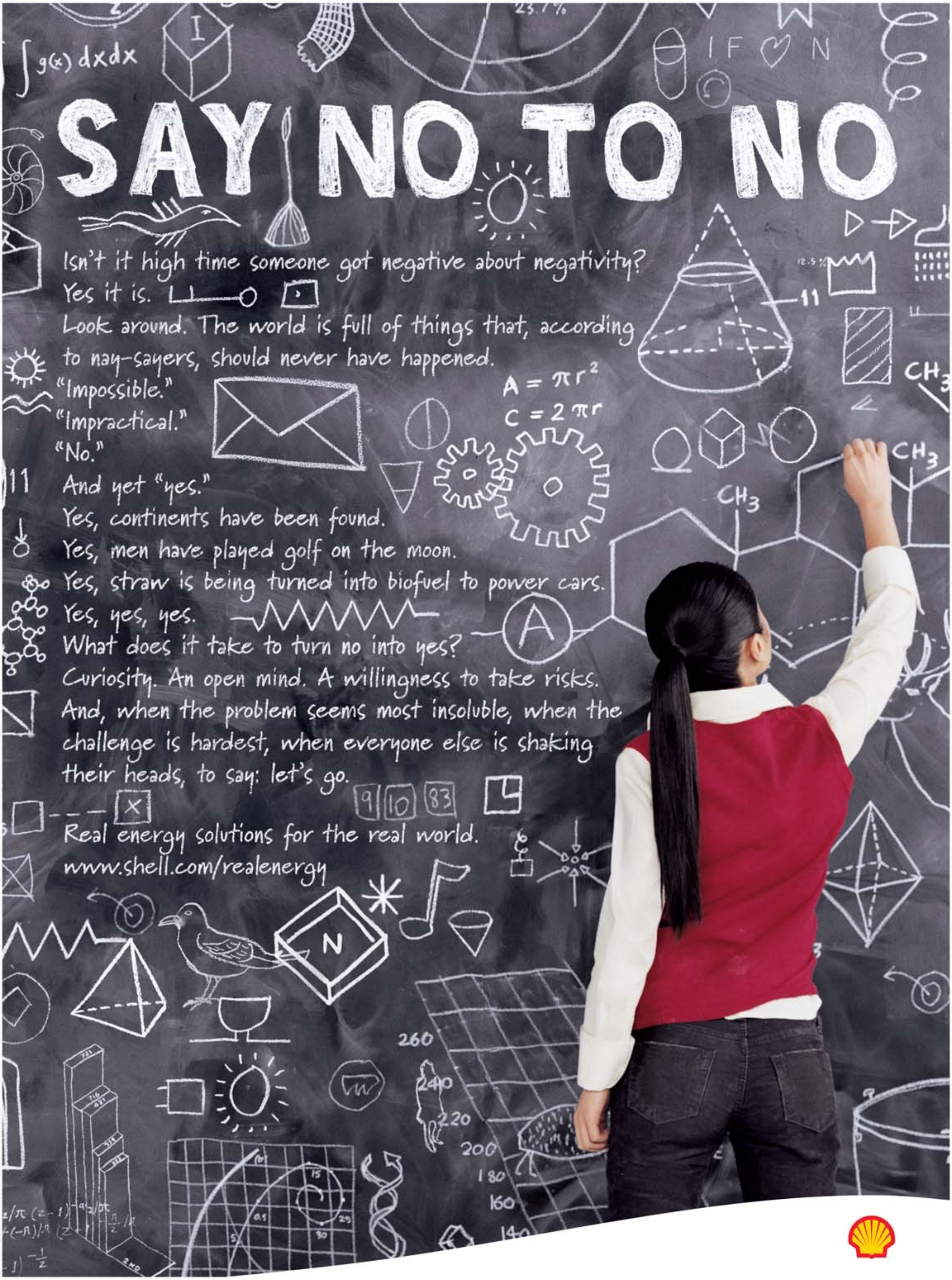

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To preserve the ice caps, we've cut down on the cubes

CO_2 is a significant factor in global warming. And air transport accounts for 2% of it. That's a figure airlines are working hard to limit - investing in new, more fuel-efficient aircraft while we push for shorter routes and improved air traffic control.

We're also making a lot of small changes that, when applied over millions of flights, make a big difference. For instance, to make aircraft lighter, we've even reviewed the number of ice cubes carried onboard.

So what's an ice cube in the grand scheme of things? At the very least, it's proof that we take our responsibilities seriously.

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