ICAO ENVIRONMENTAL REPORT 2010

AVIATION and CLIMATE CHANGE

ACT GLOBAL

ICAO: UNITING AVIATION ON CLIMATE CHANGE

Produced by the **Environment Branch**
of the **International Civil Aviation Organization (ICAO)**
in collaboration with **FCM Communications Inc.**

BAN Ki-moon

Secretary-General of the United Nations

UNITED NATIONS NATIONS UNIES

FOREWORD

International air transport has helped to bring our world closer together. From the goods we send, to the people and places we visit, air travel has shaped the quality of modern life and heightened awareness of our global society.

Yet, these advances have not been without cost. Looking forward, we must ensure that international aviation is as energy-efficient as possible and minimizes harmful impacts on our climate and ecosystems.

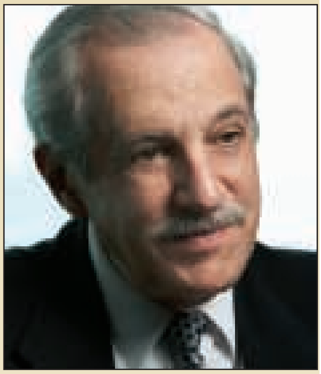
I commend efforts by the air transport sector to improve the efficiency of aircraft engines, as well as the industry's progress on developing and using sustainable fuels for aviation. I also welcome growing cooperation between governments and industry on a programme of action to reduce climate impacts from aviation emissions.

This second ICAO Environmental Report *reflects and promotes cooperation among governments, industry and members of civil society. It also showcases ideas and best practices that can accelerate efforts towards the goal of a sustainable air transport industry.*

Air travel has brought many benefits to modern life. Let us ensure that, from now on, it benefits both people and the planet.

BAN Ki-moon

MESSAGE FROM THE PRESIDENT OF THE COUNCIL OF ICAO



Roberto Kobeh González

President of the Council of the International Civil Aviation Organization (ICAO)

The future of air transport as a catalyst for the economic, social and cultural development of our global society is directly related to our collective ability to reach and maintain the sustainability of civil aviation operations worldwide.

This will require substantial, sustained and coordinated efforts by the scientific community and the air transport industry, backed by the strong political will of ICAO Member States and the commitment of concerned stakeholders. Together, we need to better understand, assess and monitor the impact of flight operations on the environment, while developing green technologies, operational measures and related policies to ensure an optimum balance between the growth of aviation and the need to protect the environment.

Addressing the myriad issues involved in dealing with climate change as a whole obviously calls for an unprecedented level of cooperation. As the official forum for international civil aviation, ICAO has led the drive for arriving at globally-harmonized solutions and for creating dynamic relationships with appropriate United Nations agencies.

The last three years have been particularly productive. Since the publication of the previous Environmental Report in 2007, ICAO adopted the Programme of Action on International Aviation and Climate Change, which included the first and only global agreement on goals for addressing climate change from a sector, and we are further exploring more ambitious goals. Consensus on the essential role of alternative fuels for aviation, coupled with significant concrete achievements in that area, opened the door to new opportunities at that can bring significant contribution to the overall sustainability of aviation.

As we move ahead, ICAO will actively pursue the formulation of a CO_2 *Standard by 2013 and new guidance to facilitate the implementation of operational measures with enhanced environmental benefits. Focus will also be placed on a global framework for market-based measures to reduce emissions – all initiatives undertaken with the support of ICAO's Committee on Aviation Environmental Protection (CAEP).*

The impressive amount of work undertaken by ICAO, its Member States and the aviation industry showcased in this ICAO Environmental Report 2010 can serve as a basis for discussions and decisions on how best to move ahead in a number of related fields.

I wish to express my personal appreciation to the experts from various disciplines and organizations who have graciously provided the fruits of their labour, in some cases over many years, so that we may move forward with renewed vigour and confidence towards realizing our common vision of sustainable aviation in the decades to come.

Raymond Benjamin

Secretary General of the International Civil Aviation Organization (ICAO)

MESSAGE FROM THE SECRETARY GENERAL

This ICAO Environmental Report 2010, dedicated entirely to the topic of climate change, builds on the first edition published in 2007, in bringing together a vast array of authoritative ideas, solutions and new challenges to feed the global discussion on how best to deal with the impact of aviation on the environment.

It begins with the acknowledgement that air transport supports economic and social development worldwide, yet contributes to the production of greenhouse gases, roughly two per cent of CO_2 emissions from human activity.

While that proportion is relatively small, it does not exclude the sector from the responsibility of setting and meeting targets. The fact that emissions will inevitably increase with the anticipated growth of air transport makes it imperative that we act.

That is why ICAO is pressing ahead with developing measures and policies to ensure the long-term sustainability of aviation. A significant milestone was the ICAO Programme of Action on International Aviation and Climate Change, the first globally-harmonized agreement, as a sector, on a goal to address aviation emissions. Our work, however, is not complete and as an Organization we are actively pursuing more ambitious environmental goals and solutions for international aviation.

For their part, manufacturers have dramatically improved the energy efficiency of aircraft engines and aircraft design, notably through the use of lighter, composite materials, more aerodynamic designs, and advanced engine technologies. Operators and air navigation services providers have done their share through streamlined operational procedures, assisted in this effort by more modern air navigation aids and procedures.

ICAO also serves the public by delivering factual information, in transparent manner, such as with this report and through the ICAO Carbon Emissions Calculator, which allows passengers to assess the carbon footprint of a flight. ICAO is leading by example by working to reduce the carbon footprint from our operations. A number of States are developing action plans to reduce emissions from there aviation activities.

The rapid pace of development of sustainable alternative fuels offers the promise of even greater environmental benefits. Economic instruments and financing are rounding out the comprehensive approach to minimizing the impact of aviation on the environment and adapting to changes.

There are a host of other initiatives that can and will be taken in the future to protect the environment, OUR environment, for generations to come.

ICAO ENVIRONMENTAL PROTECTION PROGRAMME

Folasade Odutola

Director of the Air Transport Bureau, ICAO

A brief history of ICAO's involvement in aviation environmental protection since the late 1960s emphasizes the value of a common, coordinated and global approach to addressing the impact of air transport operations on noise and local air quality around airports, and the much broader challenge of climate change.

The Organization began tackling environmental issues before it became "popular" to do so in the 1990's amid public concerns about climate change. A first major step was the creation of the Committee on Aircraft Noise (CAN) in 1970, followed by the Committee on Aircraft Engine Emissions (CAEE) in 1977. These two committees were merged in 1983 to form the existing Committee on Aviation Environmental Protection (CAEP).

The environmental programme of ICAO grew larger in scope with the coming into force of the United Nations Framework Convention on Climate Change (UNFCCC) in 1992. This created a mechanism for ICAO to interact and cooperate with other UN bodies on greenhouse gas emissions issues, while continuing to deal with an expanding list of noise and local air quality issues.

Today, environmental protection is one of the Strategic Objectives of ICAO. The overall aim is to "Minimize the adverse environmental effects of global civil aviation activity notably aircraft noise and aircraft emissions through the following measures: develop, adopt and promote new/amended measures to:

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

This mandate is carried out by the ICAO Environment Branch and through CAEP which, over the years, has evolved into a recognized international forum of environmental experts, from both regulators and industry, to deal with aviation and the environment. CAEP is tasked with the study and development of proposals according to four criteria: technical feasibility; environmental benefit; economic reasonableness and interrelationship between measures.

The ICAO Council reviews and adopts CAEP recommendations. It informs the Organization's Assembly which meets every three years and establishes policies on aviation environmental protection. The Organization also produces complementary studies, reports, manuals and circulars on the subject of aviation and environment.

The 2007-2010 triennium was particularly active in the area of aviation and climate change. ICAO multiplied its efforts in coordinating its activities with other UN bodies, States, and international organizations in this area and the UN itself also launched several initiatives related to climate change which necessitated yet more involvement of ICAO.

Environmental protection is a global problem that requires global solutions. The Organization is keenly aware of the leadership role conferred on it in this area by its 190 Member States and it is totally committed to meeting the challenge of environmental sustainability of the world air transport sector.

REPORT OVERVIEW

Jane Hupe

Chief of the Environment Branch, in ICAO's Air Transport Bureau.

Three years ago we launched the first ICAO Environmental Report, uniting for the first time in one single ICAO publication, information on scientific, technological, economic, political and regulatory aspects of aviation environmental protection. We covered a wide range of subjects related to aircraft noise and aircraft engine emissions, focusing on both local and global impacts of aviation operations. The 2007 report was very well received and became a reference publication in the field.

The fact that the report was made available free of charge and easily accessible from the ICAO public website greatly facilitated information sharing and outreach.

Building on the success of the 2007 Environmental Report, we decided to embark on our second report — this time, an edition entirely dedicated to climate change.

Many reasons led us to this decision. Climate change is without doubt one of the most relevant topics of this century and a priority for the United Nations. It is a major challenge for the sustainability of air transport, and an area where tremendous technological advancements have taken place over the last three years. In addition, quality information is the basis of sound policy development. There is no question that the 190 ICAO Member States and more than 50 International Organizations that will be involved in the ICAO climate policy discussions at the fall 2010 ICAO Assembly, will greatly benefit from receiving current and reliable information on this topic.

The ICAO Environmental Report 2010 – Climate Change, consists of eight parts which will guide the reader through descriptions and the latest assessments of the impacts of aviation on climate change, as well as the possible measures to address it, including sustainable alternative aviation fuels, and other related topics such as adaptation and financing. Because climate change is a global challenge, the Report also describes the important cooperation of ICAO with UN bodies and international organizations in this area.

Building upon the information provided in the previous report, the 2010 Report presents the results of the eighth meeting of ICAO's Committee on Aviation Environmental Protection (CAEP/8, February 2010), as well as the latest developments in the areas showcased during the ICAO Colloquium on Aviation and Climate Change (May 2010). Many of the featured articles summarize studies and reports by some of the foremost international experts and renowned scientists in their fields. Other articles highlight developments that have emanated from various UN fora such as the United Nations Framework Convention on Climate Change (UNFCCC).

A significant accomplishment of the Organization in recent years was the completion of an agreement on the ICAO Programme of Action on International Aviation and Climate Change that was adopted by the High-level Meeting on International Aviation and Climate Change (HLM) in October 2009. The full text of the ICAO HLM Declaration, along with the accompanying recommendations, is included in the Report for easy reference.

Each part of the Report begins with a summary overview to bring readers up to speed on the topic discussed, followed by subject-focused articles by various experts. The document also contains advertorials which provide an opportunity for stakeholders to promote their own perspective and activities related to climate change.

ICAO is firmly committed to ensuring that international civil aviation contributes its share to efforts that deal with climate change. As with all ICAO policies, those that address the environment are developed in keeping with the fundamental principle that aviation is a global industry and, as such, requires global solutions. It is well understood in the international aviation industry that without a global approach, unilateral actions may well lead to fragmented and ineffective measures.

As we prepare for the future, we must consider a long-term global response to climate change that is in line with the latest scientific findings and global policies in the area. We need to set development goals that are sustainable, realizing the full potential of all possible measures. Above all, we must do it together, under the leadership of ICAO and in cooperation with all stakeholders.

Acknowledgements:
ICAO wishes to thank the authors from various countries and disciplines who have kindly shared their expertise, imagination and enthusiasm. We are truly grateful to them, for we believe that their collective insights will stimulate dialogue and contribute to defining sustainable climate change solutions. We also thank those States and Organizations that supported the publishing of this report. We look forward to comments and suggestions on how we can improve future editions of the Environmental Report.

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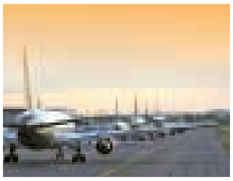

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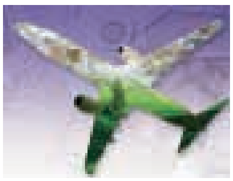


Chapter 7 FINANCING

Chapter 8 ACT GLOBAL: Uniting Aviation on Climate Change

ICAO Programme Of Action On International Aviation and Climate Change

By ***ICAO Secretariat***

At the 36th Session of the ICAO Assembly in September 2007, the 190 ICAO Member States recognized the urgency and critical importance of addressing greenhouse gas (GHG) emissions from international aviation that contribute to global climate change. They also re-emphasized the need for ICAO to continue to provide effective leadership in this area.

To achieve this, the Assembly called for the formation of the Group on International Aviation and Climate Change (GIACC) with the mandate to develop an ICAO Programme of Action on International Aviation and Climate Change. The Assembly directed the Organization to develop concrete proposals to aid the United Nations Framework Convention on Climate Change (UNFCCC) process, and additionally, it requested that ICAO convene a High-level Meeting (HLM) on International Aviation and Climate Change, at which the GIACC recommendations would be considered.

Group on International Aviation and Climate Change

The GIACC was formed in January 2008. It was comprised of 15 senior government officials representative of all ICAO Regions. GIACC deliberated and made decisions by consensus and technical support was provided by the ICAO Committee on Aviation Environmental Protection (CAEP).

The fourth and final meeting of the GIACC took place at the end of May 2009. Consistent with the ICAO Assembly Resolution, the following three key elements of an effective Programme of Action for global aviation were presented:

- Global aspirational fuel-efficiency goals;
- Suggested measures to achieve emissions reductions; and
- Suggested methods and metrics to measure aviation's progress.

The GIACC proposals were accepted by the ICAO Council, which also made recommendations on the way forward, including the convening of the HLM in October 2009 and a Global Conference on Alternative Fuels for Aviation in November 2009.

High-level Meeting on International Aviation and Climate Change

ICAO held the HLM on International Aviation and Climate Change in October 2009 with the participation of representatives from 73 Member States (accounting for 94 % of global commercial air traffic), and from various international organizations. The HLM evaluated the outcome of the GIACC and discussed areas where progress could be achieved on the formulation of proposals to address greenhouse gas emissions from international aviation.

The meeting approved a Declaration and further recommendations (see complete text at the end of this chapter) affirming the commitment of Member States to address aviation emissions that contribute to climate change by working through ICAO. This is the first globally-harmonized agreement on a goal that addresses climate impacts from a specific sector. The ICAO Programme of Action on International Aviation and Climate Change includes the following elements:

- A 2% annual improvement target in fuel efficiency globally until the year 2050;
- A decision to develop global CO_2 Standards for aircraft;
- A decision to develop a framework for market-based measures for international aviation;
- Measures to assist developing States and to facilitate access to financial resources, technology transfer, and capacity-building;

- Collection of international aviation emissions data by ICAO;
- Development and submissions to ICAO of States' Voluntary Action Plans on Emissions; and
- Continued work on alternative fuels for aviation.

The HLM also agreed to continue working on medium-term and long-term goals, including exploring the feasibility of more ambitious objectives such as carbon-neutral growth and emissions reductions, taking into account the special circumstances and respective capabilities of developing countries and the sustainable growth of the industry. It also emphasized that such fuel efficiency improvements or other emission reduction goals would not attribute specific obligations to States.

In order to monitor progress towards reaching the goals, the Declaration provides for States, on a voluntary basis, to develop and submit action plans, outlining their respective policies and actions, and annual reporting of data on their aviation fuel consumption to ICAO. Using this information, ICAO could identify specific needs of countries and assist them by facilitating access to financial resources and technologies needed to enable them to contribute to the global efforts to address greenhouse gas emissions from international aviation.

Conference on Aviation and Alternative Fuels

Complementary to the GIACC and HLM, ICAO also held a Conference on Aviation and Alternative Fuels (CAAF) in November 2009. This was an important step towards promoting an improved understanding of the potential use and emission effects of sustainable alternative fuels, and to facilitating their development and deployment. The Conference endorsed the use of sustainable alternative fuels for aviation, particularly the use of drop-in fuels in the short- to medium-term, as an important means of reducing aviation greenhouse gas emissions.

The Conference noted that the introduction of sustainable alternative fuels for aviation will help address, not only environmental issues, but also those of economics, and supply security. There is currently very limited availability of qualified alternative fuels for aviation. However, it has been demonstrated that sustainable alternative fuels for use in global aviation can be produced from a wide variety of feedstocks, suggesting that many regions are possible production locations. Those alternative fuels have the potential to offer reduced lifecycle CO_2 emissions compared with conventional aviation fuels.

The Declaration and Recommendations approved by the Conference (see Chapter 5 of this report) affirmed the commitment of States and industry groups to develop, deploy and use sustainable alternative fuels to reduce aviation emissions. To facilitate the promotion and harmonization of initiatives that encourage and support the development of sustainable alternative fuels for aviation, on a global basis, the Conference established an ICAO Global Framework for Aviation Alternative Fuels[1].

Towards the Next ICAO Assembly

ICAO was able to bring its 190 member States together and adopt the Programme of Action on International Aviation and Climate Change, and then provide it to COP15. This was the first and only globally-harmonized agreement from a sector on a goal to address its CO_2 emissions. However, due to the complex negotiating process that took place at COP15, this substantial agreement was not considered as a basis for negotiations on international bunker fuels and no specific decision was taken on how to address GHG emissions from international aviation (see Chapter 8 of this report).

The parallel tracks to an agreement on climate change taken by UNFCCC and ICAO are illustrated in Figure 1.

ICAO followed the process established by the 36th session of the Assembly in September 2007 to develop the Programme of Action, while the UNFCCC followed the decisions taken at COP13 in Bali in December 2007 for the preparation of the new climate agreement post-2012.

In light of this outcome, ICAO has continued to make further progress on the recommendations of the High-level Meeting and the Alternative Fuels Conference, toward the development of proposals for more ambitious policies on international aviation and climate change, to be considered by the next ICAO Assembly in September 2010.

To facilitate the progress, ICAO established a process and initiated the preparation of the Assembly Resolution on international aviation and climate change for presentation to the next Assembly.

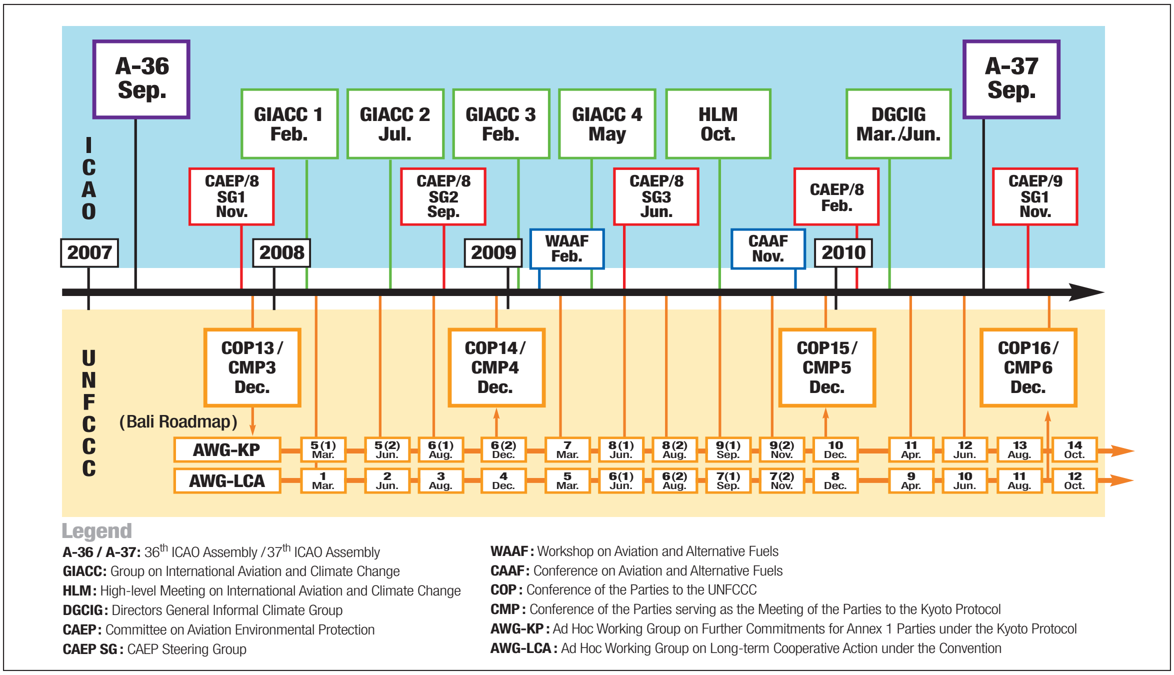


***Figure 1:** Climate change negotiation process.*

Three main areas where further progress could be achieved are:

1. Exploring the feasibility of more ambitious goals including carbon-neutral growth of the sector and long-term emission reductions, moving beyond the global commitment of a 2 per cent annual fuel efficiency improvement up to 2050;
2. Developing a framework for market-based measures in international aviation; and
3. Elaborating on measures to assist States, in particular developing States, in gaining access to financial resources, technology transfer, and capacity building; taking into account the special needs and circumstances of all member States.

ICAO also started discussions on the need to address the potential impacts of climate change on international operations and related infrastructure. Rising sea levels will threaten land facilities, including airports and fuel storage areas, while changes in weather and/or unexpected weather patterns may substantially affect aviation operations (see Chapter 6 of this report).

ICAO will continue to exercise its leadership in all matters related to international aviation, including the limitation or reduction of greenhouse gas emissions. This shall be addressed under a globally harmonized framework, with all member States and the air transport industry working together through ICAO. Policies on international aviation and climate change that are expected to be adopted by the next ICAO Assembly will be subsequently presented to COP16 in Mexico. ■

REFERENCES

1 *www.icao.int/AltFuels*

Declaration by the HLM-ENV

The High-Level Meeting on International Aviation and Climate Change, convened by the International Civil Aviation Organization (ICAO) at its Headquarters in Montreal on 7 to 9 October 2009 was attended by Ministers and other high-level officials representing 73 States (responsible for 94% of the global international aviation traffic[1]) and 26 international organizations:

Whereas the 36th Session of the ICAO Assembly requested the Council to convene a high-level meeting to review the Programme of Action on International Aviation and Climate Change recommended by the Group on International Aviation and Climate Change, taking into account that the fifteenth meeting of the Conference of the Parties (COP15) of the United Nations Framework Convention on Climate Change (UNFCCC) will be held in December 2009;

Welcoming the Decision of the ICAO Council to fully accept the Programme of Action on International Aviation and Climate Change, which includes global aspirational goals in the form of fuel efficiency, a basket of measures and the means to measure progress, as an important first step in the work of Member States at ICAO to address greenhouse gas (GHG) emissions from international aviation;

Reaffirming ICAO as the lead United Nations agency in matters involving international civil aviation, and *emphasizing* ICAO's commitment to provide continuous leadership in addressing international civil aviation matters related to the environment;

Acknowledging the principles and provisions on common but differentiated responsibilities and respective capabilities, and with developed countries taking the lead under the UNFCCC and the Kyoto Protocol;

Also acknowledging the principles of non-discrimination and equal and fair opportunities to develop international aviation set forth in the Chicago Convention;

Reemphasizing the vital role which international aviation plays in global economic and social development and the need to ensure that international aviation continues to develop in a sustainable manner;

Acknowledging that international aviation emissions, currently accounting for less than 2 per cent of total global CO_2 emissions, are projected to grow as a result of the continued development of the sector;

Recognizing that the international aviation sector must play its part to confront the global challenge of climate change, including by contributing to the reduction of global GHG emissions;

Noting the scientific view that the increase in global average temperature above pre-industrial levels ought not to exceed 2°C;

Noting the continuous efforts of the sector to minimise aviation's impact on climate change and the improvement in fuel efficiency achieved over the last 40 years, resulting in aircraft today that are 70 per cent more fuel efficient per passenger kilometre;

Affirming that addressing GHG emissions from international aviation requires the active engagement and co-operation of States and the industry, and noting the collective commitments announced by ACI, CANSO, IATA and ICCAIA on behalf of the international air transport industry to continuously improve CO_2 efficiency by an average of 1.5 per cent per annum from 2009 until 2020, to achieve carbon neutral growth from 2020 and reducing its carbon emissions by 50 per cent by 2050 compared to 2005 levels;

Recognizing the different circumstances among States in their capacity to respond to the challenges associated with climate change and the need to provide necessary support, in particular to developing countries and States having particular needs;

Recognizing that the aspirational goal of 2 per cent annual fuel efficiency improvement is unlikely to deliver the level of reduction necessary to stabilize and then reduce aviation's absolute emissions contribution to climate change, and that goals of more ambition will need to be considered to deliver a sustainable path for aviation;

Declares *that:*

1. The HLM endorses the ICAO Programme of Action on International Aviation and Climate Change as accepted by the ICAO Council;

2. In pursuing the implementation of the ICAO Programme of Action on International Aviation and Climate Change, States and relevant organizations will work through ICAO to achieve a global annual average fuel efficiency improvement of 2 per cent over the medium term until 2020 and an aspirational global fuel efficiency improvement rate of 2 per cent per annum in the long term from 2021 to 2050, calculated on the basis of volume of fuel used per revenue tonne kilometre performed;

3. Taking into account the relevant outcomes of the 15th Conference of the Parties to the United Nations Framework Convention on Climate Change, and recognizing that this declaration shall not prejudge the outcome of those negotiations, ICAO and its Member States, with relevant organizations will also keep working together in undertaking further work on medium and long-term goals, including exploring the feasibility of goals of more ambition including carbon-neutral growth and emissions reductions, taking into account the collective commitments announced by ACI, CANSO, IATA and ICCAIA on behalf of the international air transport industry, the special circumstances and respective capabilities of developing countries and the sustainable growth of the international aviation industry, for consideration by the 37th Session of the ICAO Assembly;

4. Such fuel efficiency improvements or other aspirational emission reduction goals would not attribute specific obligations to individual States. The different circumstances, respective capabilities and contribution of developing and developed States to the concentration of aviation GHG emissions in the atmosphere will determine how each State may contribute to achieving the global aspirational goals;

5. ICAO will establish a process to develop a framework for market based measures in international aviation, taking into account the conclusions of the High-level Meeting and outcome of the UNFCCC COP 15 and bearing in mind relevant ICAO Assembly resolutions and the appendices with a view to complete this process expeditiously;

6. ICAO will regularly report CO_2 emissions from international aviation to the UNFCCC, as part of its contribution to assessing progress made in the implementation actions in the sector based on information approved by its Member States;

7. States are encouraged to submit their action plans, outlining their respective policies and actions, and annual reporting on international aviation CO_2 emissions to ICAO;

8. ICAO and its Member States will strongly encourage wider discussions on the development of alternative fuel technologies and the promotion of the use of sustainable alternative fuels, including biofuels, in aviation in accordance with national circumstances.

[1] expressed in revenue passenger kilometres.

Recommendations by the HLM-ENV

In addition to the recommendations from the GIACC as accepted by the Council, the High-level Meeting on International Aviation and Climate Change recommended, in order to progress the work leading to the upcoming 37th Session of the ICAO Assembly in 2010 and beyond, that the ICAO Council:

1. *Work* expeditiously together with the industry to foster the development and implementation of more energy efficient aircraft technologies and sustainable alternative fuels for aviation;
2. *Seek to develop* a global CO_2 Standard for new aircraft types consistent with CAEP recommendations;
3. *Continue* to maintain and update knowledge of the interdependency between noise and emissions in the development and implementation of measures to address GHG emissions from international aviation;
4. *Continue* to work with relevant organizations on the scientific understanding and on measures to limit the non-CO_2 climate impacts of aviation;
5. *Intensify* its efforts in further development of Standards and Recommended Practices for technological and operational measures to reduce international aviation emissions, with the support and expertise from technical panels and committees of ICAO, in consultation with other relevant organizations, in particular on the development of new guidance on operational measures to reduce international aviation emissions;
6. *Commit*, in cooperation with the industry, to facilitate the implementation of operational changes and the improvement of air traffic management and airport systems aiming to reduce emissions from international aviation sector;
7. *Further elaborate* on measures to assist developing States as well as to facilitate access to financial resources, technology transfer and capacity building including possible application of flexible mechanisms under UNFCCC, such as the Clean Development Mechanism (CDM), to international aviation;
8. *Encourage* States and international organizations to actively participate in the Conference on Aviation and Alternative Fuels in Rio de Janeiro in November 2009 (CAAF2009) to share their efforts and strategies to promote such measures, and bring its results to COP15;
9. *Identify* appropriate standard methodologies and a mechanism to measure/estimate, monitor and verify global GHG emissions from international aviation, and States support the work of ICAO on measuring progress through the reporting of annual data on traffic and fuel consumption;
10. *Request* States to continue to support the efforts of ICAO on enhancing the reliability of measuring/estimating global GHG emissions from international aviation;
11. *Consider* a de-minimis exception for States which do not have substantial international aviation activity levels, in the submission of action plans and regular reports on aviation CO_2 emissions to ICAO;
12. *Consider*, with due priority, the allocation of resources for environment-related activities under the next ICAO Regular Programme budget and analyse the possibility of establishing voluntary contributions;
13. *Explore* the relevance of the GIACC's fuel efficiency metric to international business aviation;
14. *Explore* approaches for providing technical and financial assistance in the reporting process to developing countries; and
15. *Invite* the international air transport industry to further elaborate the implementation framework and strategies for the collective commitment of the international air transport industry.

Committee on Aviation Environmental Protection (CAEP)

*By **Jane Hupe,** CAEP Secretary*

***Jane Hupe** is the Chief of the Environment Branch, in ICAO's Air Transport Bureau. She provides advice to the Organization on aviation related environmental matters; cooperates with UN bodies and International Organizations; manages the Environment Branch and coordinates the activities of the ICAO Council's Committee on Aviation Environmental Protection (CAEP), serving as its Secretary. Jane has also worked with ICAO as a consultant to ICAO's Technical Co-operation Bureau, providing direct assistance to ICAO's Contracting States in the environmental field. For 15 years she served as an adviser on environmental protection related subjects for the Institute of Civil Aviation (IAC) in Brazil, developing policies and regulations and representing the Ministry of Aeronautics at government related environmental forums.*

Introduction

The Committee on Aviation Environmental Protection (CAEP) is a technical committee of the ICAO Council, responsible for conducting studies and recommending measures to minimize and reduce aviation's impact on the environment, including setting certification Standards for aircraft noise and aircraft engine emissions.

ICAO has three environmental goals for international aviation which aim to: 1) reduce the number of people exposed to significant aircraft noise; 2) reduce the impact of aviation emissions on local air quality; and 3) reduce the impact of aviation emissions on the global climate. In support of these goals and in its role as international aviation's leading environmental body, CAEP has adopted a structured approach to developing and delivering solutions to the air transport sector — initially by quantifying related environmental impacts and then by establishing practical mitigation measures to address them. More than 400 world renowned experts whose expertise spans environmental and technical issues related to aviation are involved in the work of CAEP.

CAEP recommendations, and in particular, its standard setting activities are considered and developed in light of four main criteria:

1. technical feasibility;
2. economic reasonableness;
3. environmental benefit; and
4. consideration of the potential interdependence (trade-offs) with other mitigation measures.

Certification Standards and Annex 16
Aircraft are required to meet the environmental certification Standards adopted by the Council of ICAO. These are contained in Annex 16 (Environmental Protection) to the Convention on International Civil Aviation. Annex 16 consists of two volumes: Volume I - Aircraft Noise *and Volume II -* Aircraft Engine Emissions*. These certification Standards have been designed and are kept up to date in order to respond to concerns regarding the environmental impact of aviation on communities in the vicinity of airports, as well as society at large.*

CAEP Membership

Currently, CAEP consists of 24 Members from all ICAO Regions and 13 Observers from States, intergovernmental and non-governmental organizations, including airlines, aircraft and engine manufacturers, airports, pilot associations, environmental NGOs and UN bodies. For the CAEP/9 cycle (2010 to 2013), experts, nominated by their respective CAEP members and observers, will participate in the various CAEP expert groups as shown in Figure 1.

CAEP Members
Argentina, Australia, Brazil, Canada, China, Egypt, France, Germany, India, Italy, Japan, Netherlands, Nigeria, Poland, Russian Federation, Singapore, South Africa, Spain, Sweden, Switzerland, Tunisia, Ukraine, United Kingdom and the United States.

CAEP Observers
Greece, Norway, Arab Civil Aviation Commission – ACAC, Airports Council International – ACI, Civil Air Navigation Services Organisation – CANSO, European Commission – EC, International Air Transport Association – IATA, International Business Aviation Council – IBAC, International Co-ordinating Council of Aerospace Industries Associations – ICCAIA, International Coalition for Sustainable Aviation – ICSA, International Federation of Air Line Pilots' Associations – IFALPA, United Nations Framework Convention on Climate Change – UNFCCC, World Meteorological Organization – WMO and ICAO Secretariat.

CAEP Structure

CAEP is the only technical committee of the ICAO Council. CAEP currently has three specialized Working Groups and four Support Groups, as well as Independent Experts and Task Groups. The structure of CAEP leading to CAEP/9 is illustrated in Figure 1.

CAEP Working Methods

CAEP usually meets once every three years, coinciding with the year the ICAO Assembly is held. At each CAEP meeting, the Committee's structure and the work programme of each of its expert groups is reviewed and updated. In addition, a Steering Group meets once a year to review and provide guidance on the progress of the activities of the expert groups.

Annex 16, Volume I Amendment 10.
Annex 16, Volume II Amendment 7.
CAEP Independent experts process for noise - Report.
CAEP Independent experts process for fuel burn - Report.
CAEP Independent experts process for NO_x - Report.
CAEP Independent experts process for operational goals - Report.
New ICAO guidance on CDA.
Revised Doc 9829 - Guidance on the Balanced Approach to Aircraft Noise Management – Amendment 2.
Revised Doc 9501 - ETM - Environmental Technical Manual, vols I and II.
Doc 9888 - Amendment to the Review of Noise Abatement Procedure Research and Development and Implementation Results.
New Environment Technical Manual – Part I and Part II – including the Guidelines on the use of Procedures in the Emissions Certification of Aircraft Engines.
Revised Doc 9750 - Global Air Navigation Plan for CNS/ATM Systems, Appendix H.
Updated Doc 9885 - Draft Guidance on the use of Emissions Trading for Aviation.
Updated Report on Voluntary Emissions Trading for Aviation.
Scoping study of issues related to linking open emission trading systems involving international aviation and the potential for the use of emissions trading for local air quality - Report.
Report on the potential of emissions to offset measures to further mitigate the effects of aviation emissions on local air quality and global climate change.
Report on offsetting emissions from the Aviation sector.
New guidance material to replace Circular 303 - Updated Operational Opportunities to Minimize Fuel Use and Reduce Emissions.
New report on the use of Environmental Managements Systems in the aviation sector.
New ICAO guidance on computing, assessing and reporting on aviation emissions at national and global level.
Doc 9889 - Update to Airport Air Quality Guidance Manual.

Table 1: *List of the publications recommended by CAEP/8*

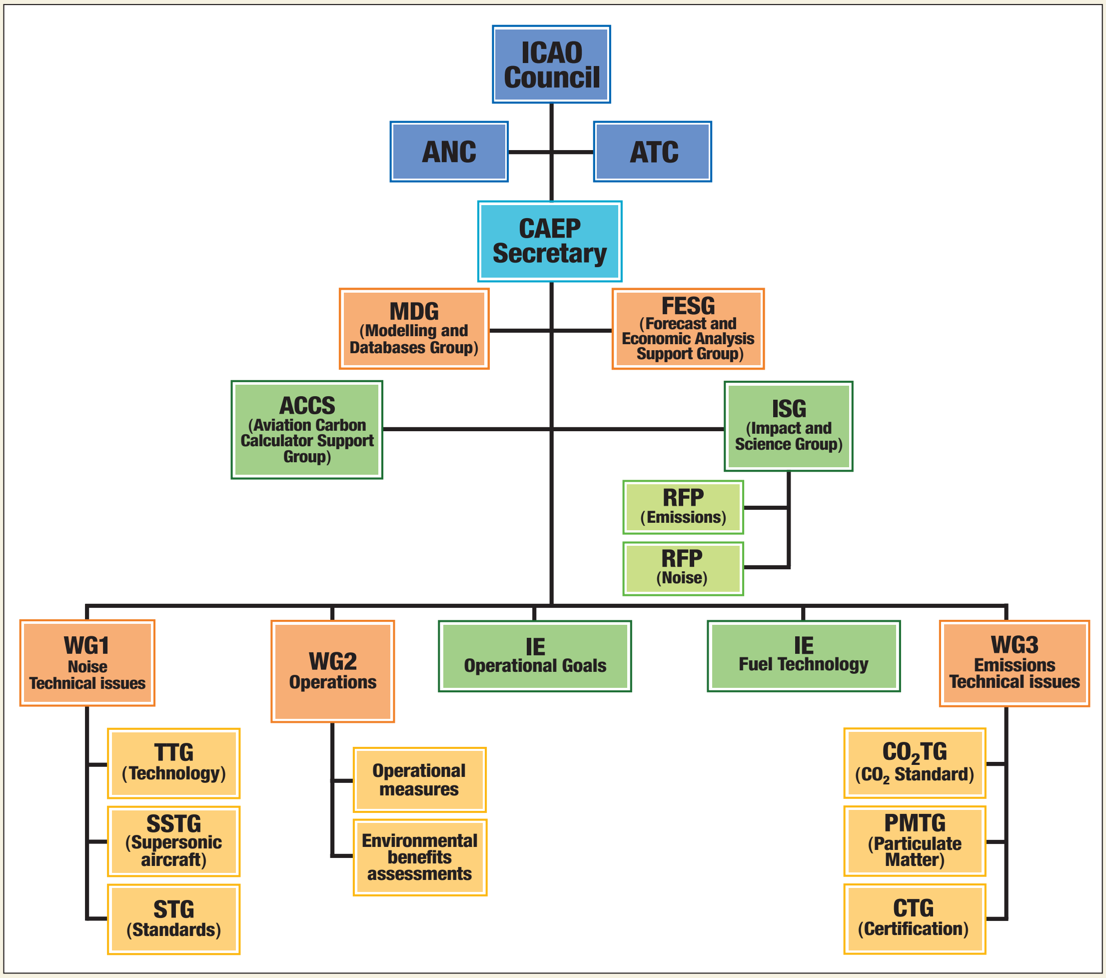


Figure 1: *CAEP working groups structure leading to CAEP/9 (2013).*

CAEP Working Groups

■ ***Working Group 1 (WG1) – Aircraft Noise Technical Issues***

The main aim of WG1 is to keep international aircraft 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.

■ ***Working Group 2 (WG2) – Operations***

WG2 addresses aircraft noise and emissions issues linked to airports and operations.

■ ***Working Group 3 (WG3) – Emissions Technical Issues***

WG3 deals with aircraft performance and emission technical matters, including the updating of Annex 16 - Volume II and the development of an aircraft CO_2 Standard.

■ ***Modelling and Databases Group (MDG)***

MDG was created at CAEP/8 and replaces the Modelling and Databases Task Force (MODTF), that was established during the CAEP/7 meeting. This new group carries out modelling efforts in support to the activities of the other CAEP groups and maintains various databases such as the movements, fleet, and population databases.

■ ***Forecasting and Economic Analysis Support Group (FESG)***

The main role of the FESG is to develop and maintain the 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.

■ ***Aviation Carbon Calculator Support Group (ACCS)***

This group was formed in 2007. It successfully developed an impartial, transparent methodology for computing the CO_2 emissions from passenger air travel which is continuously updated.

■ ***Impacts and Science Group (ISG)***

This group was established at CAEP/6 but the final Terms of Reference for the Impacts and Science Group will be further detailed in the early 2011.

■ ***Independent Experts Groups (IE)***

■ ***Task Groups (TG)***

■ ***Air Navigation Commission (ANC)***

■ ***Air Transport Committee (ATC).***

CAEP Members and Observers - CAEP/8 meeting, Montreal, February 2010.

The ICAO Council normally refers triennial CAEP reports to two main ICAO bodies, the Air Navigation Commission (ANC) and the Air Transport Committee (ATC), for the review of technical and economic aspects of CAEP recommendations, respectively. The Council then reviews and approves the CAEP recommendations, including Annex 16 Standards and Recommended Practices. In turn, the Council reports to the ICAO Assembly, where the main ICAO policies related to aviation environmental protection are defined and issued.

The eighth meeting of CAEP (CAEP/8), held in February 2010, featured a challenging agenda covering an update of NO_x Standards, a review of progress on CO_2 and particulate matter (PM) Standards, and an agreement on priorities over the next work cycle. CAEP/8 agreed on a comprehensive set of 19 recommendations which will help ICAO fulfil its mandate on the environment (see ICAO Doc 9938, *Report of the Eighth Meeting of the Committee on Aviation Environmental Protection*).

The work also results in the publication of ICAO environmental documents, including reports, guidance material, and/or specific studies. These publications help to ensure that the most up-to-date information on aviation environmental issues is fully available to State authorities and the broader aviation community for future planning and related decisions and actions (see Table 1).

CAEP/8 Outcomes

This report contains various articles related to the work of CAEP, including the assessment of trends for aircraft noise and emissions and the development of measures to address these effects. The excellent results of CAEP/8 represent another solid step towards the achievement of ICAO's environmental goals. Through the CAEP process and related activities, the Organization will continue to move environmental issues forward as a high priority, delivering concrete and actionable results that will help lead international aviation stakeholders toward a more sustainable future. ■

Introduction

AVIATION OUTLOOK

ICAO
ENVIRONMENTAL
REPORT 2010

Aviation Outlook Overview

*By **ICAO Secretariat***

This chapter presents ICAO's outlook on global demand for air transport services, as well as projections of future aircraft noise and emissions. The trends presented in this chapter were developed by ICAO's Committee on Aviation Environmental Protection (CAEP) and the ICAO Secretariat.

Air Traffic Outlook

Economic growth, fuel price volatility, airline productivity gains, the evolution of low cost carriers and the liquidity position of the air carriers are reviewed in the context of the past history and projected future trends for air traffic demand.

Noise Outlook

Although aircraft being produced today are 75% quieter than those manufactured 50 years ago, aircraft noise remains the most significant cause of adverse community reaction related to the operation and expansion of airports worldwide. This outlook reviews the tremendous progress being made in aircraft noise technology and the projected trends of aircraft noise through the year 2036.

Local Air Quality Outlook

The health and well-being of all people is affected by the quality of the air that they breathe. While aircraft emissions typically contribute a small percentage to the overall emissions loading within a region, particularly in urban areas, ICAO has set strict emissions certification requirements for nearly 30 years. This outlook reviews projected trends of aircraft emissions that affect local air quality through the year 2036.

Climate Change Outlook

As the world has become increasingly concerned with global climate change, ICAO has taken the lead in addressing international aviation's contribution, which is estimated by the IPCC to be less than 2% of global human-made CO_2 emissions. As this outlook discusses, projections of global aviation fuel consumption and efficiency through the year 2050 reveal that on a per flight basis, fuel efficiency is expected to improve over the period. However in absolute terms an emissions "gap" could exist relative to 2006 or earlier in order to achieve sustainability. For this reason, ICAO has established the first and only globally-harmonized agreement from a sector on a goal to address its CO_2 emissions and continues to pursue even more ambitious goals.

Key Points

The key points from the articles in this part of the report can be summarized as follows:

- The world's airlines carry around 2.3 billion passengers and 38 million tonnes of freight on scheduled services, representing more than 531 billion tonne kilometres combined.
- Passenger traffic is expected to grow at an average rate of 4.8% per year through the year 2036.
- Overall, global trends of aviation noise, emissions that affect local air quality, and fuel consumption predict an increase through the year 2036 at less than the 4.8% growth rate in traffic.
  - In 2006, the global population exposed to 55 DNL aircraft noise was approximately 21 million people. This is expected to increase at a rate of 0.7% to 1.6% per year through the year 2036.
  - In 2006, 0.25 Mt of NO_x were emitted by aircraft within the LTO cycle globally. These emissions are expected to increase at a rate of between 2.4% and 3.5% per year.
  - In 2006, aircraft consumed approximately 187 Mt of fuel globally.
  - International flights are responsible for approximately 62% of global aviation fuel consumption.
  - Global aircraft fuel consumption is expected to increase at a rate of between 3.0% and 3.5% per year.
- Environmental standards set by ICAO and the investments in technology and improved operational procedures are allowing aviation's noise, local air quality, and CO_2 footprints to grow at a rate slower than the demand for air travel.
- The ICAO Programme of Action on International Aviation and Climate Change, agreed in 2009, set a goal of 2% annual fuel efficiency improvement through the year 2050. It is the first and only globally-harmonized agreement from a sector on a goal and on measures to address its CO_2 emissions. ICAO continues to pursue even more ambitious goals for aviation's contribution to climate change. ■

Air Traffic Outlook

By ***ICAO Secretariat***

Historical Growth of Air Travel

Over the period 1989-2009, total scheduled traffic, measured in tonne kilometres performed, grew at an average annual rate of 4.4%. In 2009, the world's airlines carried about 2.3 billion passengers and 38 million tonnes of freight on scheduled services.

	Average annual growth (%)		
	1979-1989	1989-1999	1999-2009
Passenger-kilometres performed (PKPs)	5.3	4.7	4.3
Freight tonne-kilometres performed	7.4	6.6	2.6
Mail tonne-kilometres performed	4.0	1.2	-2.7
Total tonne-kilometres performed	5.8	5.2	3.7

Table 1 *– Trends in Total Scheduled Air Traffic (1979-2009[1])*
2009 ICAO Provisional Data

The financial crisis of 2008 followed by the 2009 recession caused a severe decline in all air transport areas and significantly impacted the average air traffic growth rates for 1999-2009 which fell compared to previous decades, as highlighted in Table 1.

However, in the last ten years, the airline industry has grown in absolute size, showing an increased diversity in the categorization of airlines operating in the different markets. Thanks to liberalization in many countries, completely new types of airlines have been entering the air transport market. These new entrants, mainly Low Cost Carriers (LCCs), which refers to their low cost operating basis, have had a dramatic impact on air traffic growth in all parts of the world.

Factors that Promote or Constrain Air Traffic Growth

Economic growth and falling ticket prices expressed in real terms are the main drivers of air traffic growth. While economic growth is largely determined outside the industry, airfares reflect many factors that are determined mostly by the industry environment.

Over the previous five decades, better aerospace technology has allowed airlines to increase their management efficiencies, thereby enabling them to lower their costs. The end result is that the passengers have been the greatest beneficiaries of these technical improvements. In parallel, liberalization of aviation markets, resulting in increased airline competition, has ensured that customers benefit from lower airline costs through lower ticket prices. A decrease in fares has encouraged people of all incomes to travel more, causing a growth in air travel demand significantly larger than what economic growth alone would have created.

Consequently, airlines have adapted their business models. LCCs started operating flights to airports that were underserved by the incumbents, building on their competitive advantage, and attractive air fares. The regional airlines continued to operate short haul routes, mainly as a feeder for the hub and spoke network of a large airline, and the legacy carriers reacted to LCCs by lowering their fares and by adopting many of the LCC's attributes. This shift has blurred the distinction between the business models of LCCs and legacy airlines.

A more liberalized regulatory environment provides stimulus to the growth of commercial aviation, but may also put pressure on aviation infrastructure, States capabilities for safety oversight and other technical regulations, operating yields of airlines (due to heightened competition) and environmental protection. The profit margin has been very small for commercial airlines. Despite some consistently profitable exceptions, most airlines have performed very poorly for investors. Average operating margins between 1999 and 2009 ranged from 3.8% to 4%; showing insufficient levels to cover overheads, generate a profit, or attract new capital. Intense price competition under liberalized regimes, including those from LCCs, coupled with increasing and widespread use by consumers of low fares rendered by internet search engines, have contributed to the reduced earnings.

On the cost side, the inherent volatility of fuel prices will continue to cause short term changes in operating costs. In early 2008 crude oil price was on average US$ 80 per barrel, before reaching in July 2008 US$ 134 and ending the year at around US$ 40. In 2008, fuel accounted for 30% of total airline operating expenses. The fuel price hedging practice was highly profitable for some carriers, enabling them to offset severe losses in their core business, while leading to large losses for other airlines.

	1979	1989	1999	2009[2]
Passenger load factor (%)	66	68	69	76
Aircraft utilization (hours per aircraft per year)	2,068	2,193	2,770	3,502
Average aircraft capacity (seats)	149	181	171	166

Table 2: *Developments in Selected Elements of Airline Productivity (1979-2009) 2009 ICAO Provisional Data,* Source – ICAO Statistics Programs

Liberalization and the severe 2009 economic downturn have encouraged airlines to optimize the use of their assets, as shown in Table 2. Higher load factors, resulting from better capacity supply management, helped airlines to maintain revenues while average ticket prices have fallen. The higher aircraft utilization resulted from greater aircraft reliability and versatility, and the decline in average aircraft capacity after 1989 could notably be attributed to the introduction of regional jets and the extended ranges of traditionally short haul aircraft.

Despite the current industry's profitability issues, ICAO's traffic forecasts are assuming that growing demand for air travel will ensure that the airline industry has continued access to capital markets, in order to enable the renewal of the different assets needed to operate an airline.

Air Traffic Forecasts

The new ICAO forecast methodology uses a sophisticated set of econometric models, combined with industry knowledge at a global and regional level. The forecasts consider both quantitative relationships, such as the impact of economic growth on traffic, and insights about the factors driving growth in each geographical market. The latter, due to their qualitative nature, could not be factored into the models. The world has been divided into 9 forecasting regions defining 53 route groups (36 international markets, 8 intra-region market and 9 domestic markets), with an additional non-scheduled segment. ICAO produces forecasts of revenue passenger-kilometres through to 2030 extended to the 2040 horizon which could be required for some environmental analysis.

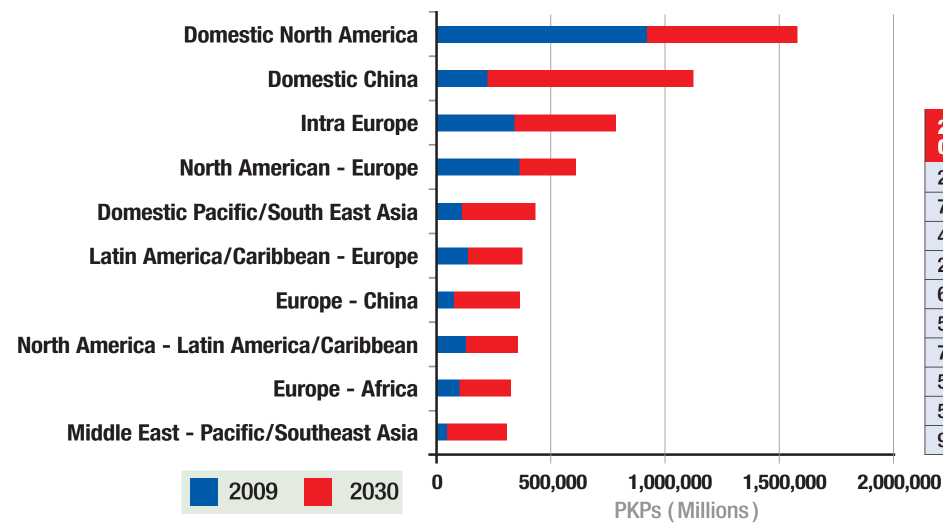
The future growth of air traffic will depend on the economic growth and on the technological advances that allow decreasing the cost of air travel. Besides, market liberalization has greatly stimulated air traffic growth in the past and will continue to do so. It has been observed that during the first steps of the liberalization process, the growth rates are the fastest and they stabilize to a standard level, after the market has absorbed the changes.

According to economic forecasters, annual economic growth between 2010 and 2030, expressed in terms of percent change in Gross Domestic Product (GDP), will range from 2% in North Asia to 6.9% in China. The developed economies of North America, Japan and Western Europe will experience slow growth because of the economic maturity of their aging labour forces. The developing areas of Asia, Latin America, Eastern Europe and Africa will see strong and sustained growth. As a result, at the world level, GDP, expressed in real terms and calculated on the basis of Purchasing Power Parity (PPP), is expected to grow on average at 4% per year.

Accordingly, the forecasts of the current top ten markets are featured in Figure 1.

Domestic services in North America will grow at the lowest rate of any of the top ten routes. However, their large magnitude – the product of a large and prosperous economy and the longest post-liberalization period (which has allowed the effects of liberalization to be felt), will preserve their leadership through to 2030. Domestic services in China will benefit from the very high growth rates that will result from economic development. The large scale of Western European traffic and the growth of Eastern Europe will together make the Intra-European market, the third largest in 2030.

Based on these route groups forecasts, ICAO is deriving both regional passenger forecasts for its statistical regions (as shown in Figure 2) and aircraft movement forecasts.



20-Year Growth %	% World PKPs
2.6%	15.0%
7.9%	10.7%
4.3%	7.4%
2.6%	5.7%
6.7%	4.1%
5.3%	3.6%
7.8%	3.5%
5.0%	3.3%
5.9	3.1%
9.0	2.9%

Figure 1: *Top 10 Traffic flows in 2030.*

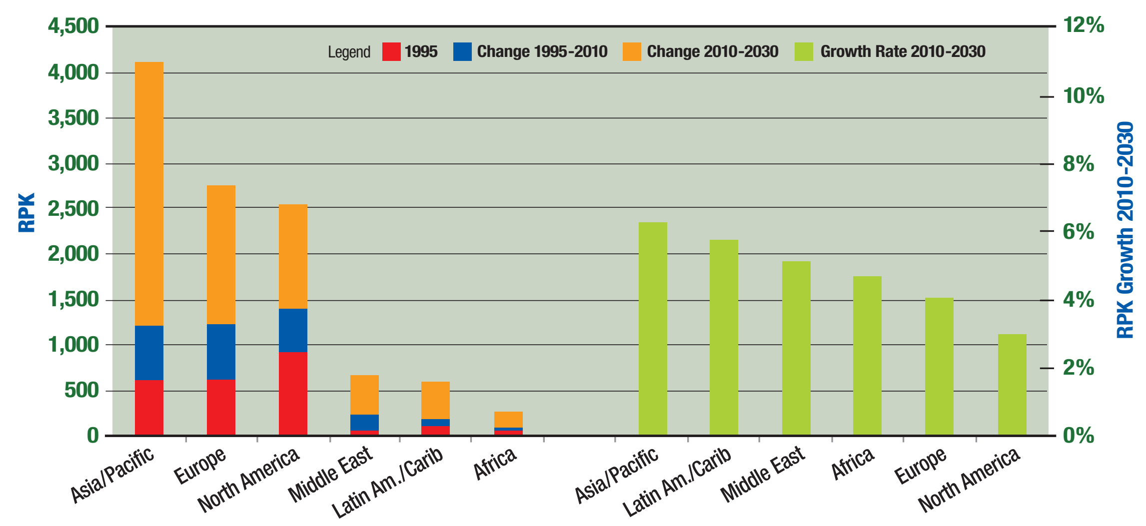


Figure 2: *ICAO Passenger Traffic Forecasts by ICAO Statistical Region.*

Air traffic will grow at rates set by, but larger than, the GDP growth in all world regions. The growth that will be registered by Asia/Pacific airlines will reflect the expansion of civil aviation in China, India and Southeast Asia. The airlines domiciled in Middle East, Latin America and Africa will experience very strong growth, although their small absolute sizes in 2010 will limit the resulting traffic increases.

The detailed regional analyses, forecasting methodologies and results for ICAO traffic forecasts are available in a forthcoming publication which will be available in November 2010.

Noise Outlook

By ***ICAO Secretariat***

Since the introduction of modern jet aircraft in the 1960s, aircraft noise has remained the most significant cause of adverse community reaction related to the operation and expansion of airports worldwide. Limiting or reducing the number of people affected by significant aircraft noise remains a key environmental goal for ICAO. The ICAO Environmental Report of 2007 provided detailed background information on the issue of aircraft noise and the Standards and Recommended Practices (SARPs) put in place by ICAO to mitigate these noise impacts. More information is also available in the report of the eighth meeting of ICAO's Committee on Aviation Environmental Protection (ICAO Doc. 9938) which contains a status update of CAEP's work on this issue. This article provides a high-level overview as well as an update on some of the issues related to aircraft noise first described in the 2007 Environmental Report.

Background

Because of improved aircraft noise SARPs developed by ICAO, the number of people exposed to significant aircraft noise has decreased by as much as 90% in parts of the world over the last half century. Tremendous technological advancements have made aircraft more than 75% quieter than they were 50 years ago. Figure 1 illustrates this point by plotting the cumulative aircraft noise relative to the Chapter 4 Noise Standard (see inset box on certification points and Chapter 4 requirements) in effective perceived noise level expressed in decibels (EPNdB[1]) by year. The aircraft are grouped by engine bypass ratio (BPR[2]), a key driver of overall aircraft noise.

On the other hand, the projected growth in air traffic means that the number of people exposed to significant aircraft noise is expected to increase in the future rather than decrease. In addition, because of the increased awareness of environmental issues, the public has become more sensitized to aviation noise. For these reasons, aircraft noise is expected to remain an environmental concern for the foreseeable future.

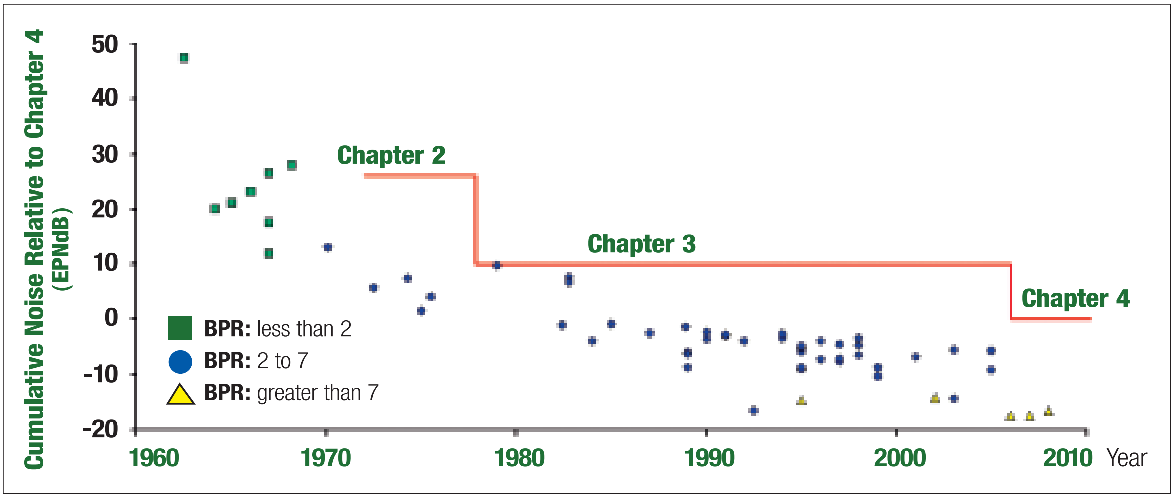


Figure 1: *Progress made in noise reduction at source since implementation of aircraft noise Standards - by engine bypass ratio (ICCAIA 2008).*

Quantifying Aircraft Noise

The level of noise that emanates from aircraft operations in and around an airport depends upon a number of factors including: types of aircraft using the airport, overall number of daily take-offs and landings, general operating conditions, time of day that the aircraft operations occur, 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 and socio-economic background as well as their psychological and physical situation. Reactions may vary from no effect, to severe annoyance, to potential health concerns.

The number of people exposed to aircraft noise is the metric normally used to estimate aircraft noise impact. In other words, the population within certain noise contours (e.g. 55dB DNL) is defined as being exposed to "significant levels" of aircraft noise. The Day-Night Average Sound Level (DNL), expressed in decibels (dB), is a 24-hour average noise level, with a 10dB penalty applied to night time noise, which is used to define the level of noise exposure on a community. Figure 2 shows an example of noise contours for an airport.

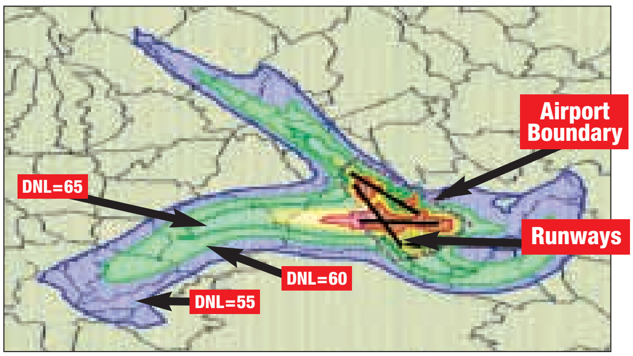


Figure 2: *Noise contours around an airport.*

Global Aircraft Noise Trends

ICAO's Committee on Aviation Environmental Protection recently completed a comprehensive global projection of future exposure to aircraft noise using several computer models developed by States or regions. To ensure the success of this assessment, an essential prerequisite was the evaluation of candidate models and databases. The complete list of models evaluated is provided in Chapter 1 of this report. Using the approved models, scenarios that included possible technology and operational improvements for the future years 2016, 2026 and 2036 were evaluated compared to a baseline year of 2006.

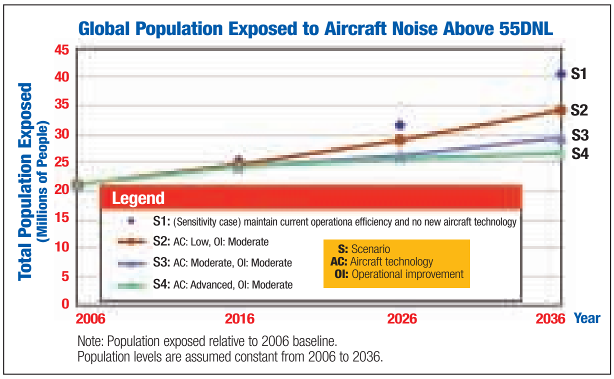


Figure 3: *Total global population exposed to aircraft noise above 55 DNL.*

Figure 3 shows that within the 55DNL significant level noise contour, the 2006 baseline value is approximately 21.2 million people worldwide exposed to that level of aircraft noise. In 2036, total population exposed to that level ranges from about 26.6 million people to about 34.1million people, depending on the scenario.

The results shown for Scenario 1 (i.e. operational improvements necessary to maintain 2006 operational efficiency levels but not including any technology improvements beyond those available in 2006) are not considered realistic, and are therefore shown without a line connecting the data for each of the computed years. Scenarios 2 and higher are assumed to be the most likely outcomes; they include the planned operational initiatives (e.g. NextGen and SESAR) and additional fleet-wide moderate operational improvements of 2% for population within the noise contours evaluated.

As is expected, as the scenario becomes more optimistic in terms of improvements, the trend line is lower in terms of population affected. Due to a lack of data on future population levels in the vicinity of airports, the population was assumed to be constant throughout the 30-year assessment period.

As noted previously, the CAEP central forecast predicted an annual growth in passenger traffic of 4.8% per year through 2036. Environmental Standards set by ICAO and the investments in technology and improved operational procedures are allowing aviation noise to grow at a rate far slower than the demand for air travel. The population exposed to aircraft noise is expected to grow at an average annual growth rate of 0.7% to 1.6% under the central forecast, and for the low demand forecast case it is possible that, following a peak in 2026, the global population exposed to significant aircraft noise may actually decline.

ICAO Work on Aircraft Noise Reduction

ICAO has been addressing the issue of aircraft noise since the 1960s.[3] The first Standards and Recommended Practices (SARPs) for aircraft noise certification were published in 1971 and have been updated since then to reflect improvements in technology. They are contained in Volume I of Annex 16 to the Convention on International Civil Aviation. Aircraft noise certification involves measuring the noise level of an aircraft in EPNdB at three points: two during take-off (flyover and sideline), and the third during the approach (see inset box on certification points and Figure 4).

Noise Certification Reference Points - Defined

For 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 levels.

The initial standards for jet-powered aircraft designed before 1977 were included in Chapter 2 of Annex 16. Subsequently, newer aircraft were required to meet the stricter standards contained in Chapter 3 of the Annex. Starting 1 January 2006, the new Chapter 4 standard became applicable to newly certificated aeroplanes.

In September 2001, ICAO established a global policy to address aircraft noise, referred to as the "balanced approach" to noise management (ICAO Doc 9829, *Guidance on the Balanced Approach to Aircraft Noise Management*). This policy has provided ICAO Contracting States with an internationally agreed approach for addressing aircraft noise problems in a comprehensive and economically responsible 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 must be done with due regard to ICAO provisions and policies, while recognizing that States may have existing constraints such as: relevant legal obligations, existing agreements, current laws and established policies on noise management. Any of these may influence the way in which States implement the Balanced Approach.

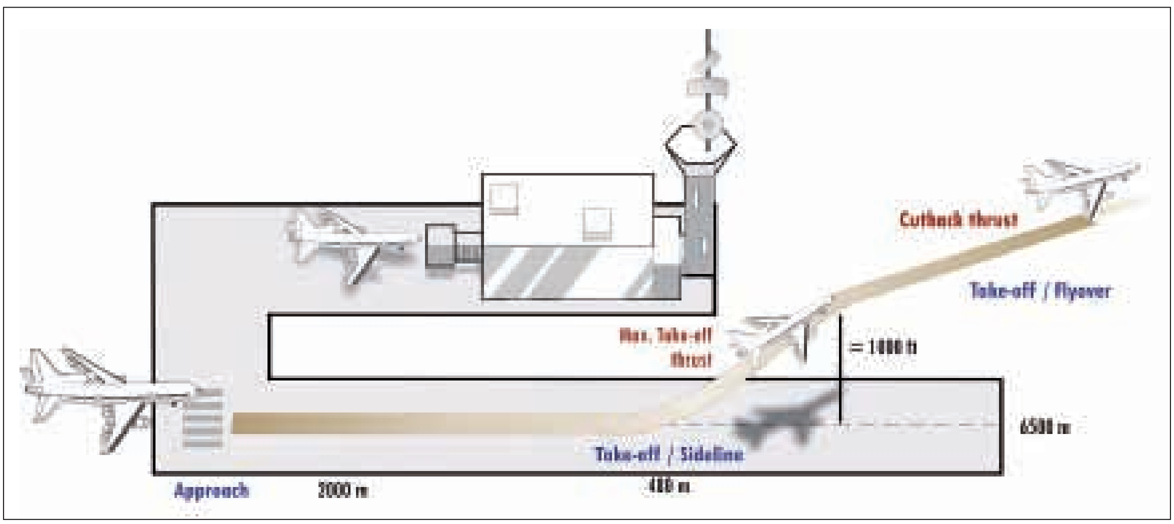


Figure 4: *Aircraft noise certification reference points.*

ICAO/CAEP - 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.

An emerging issue over the last few years has been the impact of night-time curfews related to noise at some airports on airports in other regions of the world. ICAO undertook a study to estimate the environmental impact of curfews in one region on other regions of the world. Based on case-studies, it was concluded that, while the curfews may be a contributing factor to the transfer of night-time aircraft movements from one airport to other airports, there are probably a number of other influencing factors such as time zones, airline economics and passenger demand.

Aircraft Noise Reduction Technology

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 Organization's efforts to reduce the adverse effects of aircraft noise on the public.

Over the last three years, CAEP carried out a study to review and analyze certification levels of subsonic jets and heavy propeller driven aeroplanes to understand the current state-of-the-art of aeroplane noise technology. A database of today's best practice aircraft was analyzed according to five classes each representing different market segments for airlines and manufacturers: business jets, regional jets, short-medium range jets with 2 engines, long range jets with 2 engines, and long range jets with 4 engines. A summary of these results is presented in Figure 5.

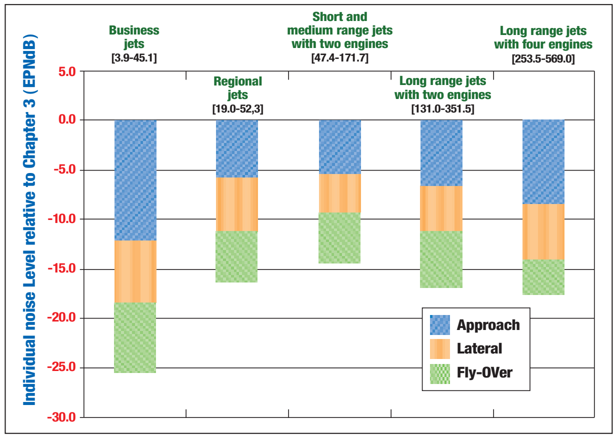


Figure 5: *Average noise margins relative to Chapter 3 limits by class of aeroplane.*

It should be noted that the wider margins that are shown for larger aeroplanes are not because of their size, but because a number of aeroplanes in this category incorporate the most recent noise reduction design concepts and technologies since the market has required the development of new models. Only incremental changes for short and medium range aeroplanes have occurred in recent years because no brand new aeroplane programme has been launched yet in this category that would enable the incorporation of the new technologies that have already been implemented in the larger aeroplanes.

As demonstrated by this comprehensive study, the aircraft industry has achieved significant noise reduction through advances in technology. One important factor that will ensure continued success is sustained research and technology funding from industry and governments. In order to complement the efforts of industry and governments and to establish targets, ICAO has introduced a process to establish medium term (10 years) and long term (20 years) goals for environmental improvements from technology and operations. These goals are based on technologies that are currently at a technology readiness level (TRL) of less than 8, but are expected to reach TRL8 at a specified time. TRL is a measure, ranging from 1 to 9, which is used to assess the maturity of evolving technologies (e.g. materials, components, devices, etc.) prior to incorporating that technology into a system.

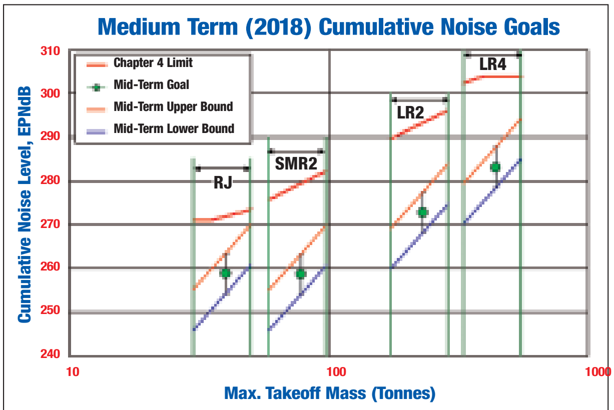
An Independent Expert (IE) Panel formed in 2008 spent a considerable amount of time analyzing various data sources and information provided by various stakeholders to recommend a set of goals for four categories of aircraft. The IE Panel identified two contributors to aircraft system source noise reduction: cycle improvements related to BPR increase and component noise reduction technologies. A modelling exercise was then undertaken to consolidate the results and to ascertain the uncertainty associated with the noise level goals. The goals are given in terms of cumulative margins relative to the ICAO Annex 16, Chapter 4 limits. These Goals are summarized in Table 1.

Independent Expert Panel aircraft noise reduction technology goals

Aircraft Category	Margin to Chapter 4 (EPNdB)	
	Medium Term (2018)	Long Term (2028)
Regional Jet	13.0±4.6	20.0±5.5
Small-Medium-Range Twin	21.0±4.6	23.5±5.5
Long-Range Twin	20.5±4.6	23.0±5.5
Long-Range Quad	21.0±4.6	23.5±5.5

Table 1: *Independent Expert Panel aircraft noise reduction technology goals.*

These goals are shown in graphical format in Figure 6.



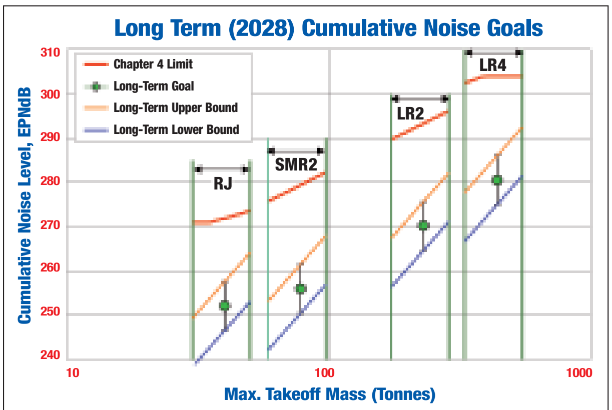


Figure 6: *Medium and long term technology goals for noise reduction technology.*

The reduction of noise at source through technology improvements has always been one of the cornerstones of ICAO's noise mitigation efforts. ICAO 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.

Next Steps

The eighth meeting of ICAO's Committee on Aviation Environmental Protection (CAEP) in February 2010, identified the need for further analyses to assess several stringency scenarios in order to potentially improve the aircraft noise Standards. The assessment results will be reviewed by CAEP/9 in 2013.

ICAO's goal of sustainable growth is directly related to noise where a major constraint on growth at the airport level is believed to be noise in the vicinity of airports. Other emerging issues in this regard include the increasing noise farther away from airports and introduction of new air traffic procedures leading to concentration of noise in certain corridors. These additional issues need to be explored and solutions provided to ICAO member States in the form of SARPs. ■

REFERENCES

1 ***EPNdB is a measure of human annoyance to aircraft noise which has special spectral characteristics and persistence of sounds. It accounts for human response to spectral shape, intensity, tonal content and duration of noise from an aircraft.***

2 ***Bypass ratio refers to how much air goes through a jet engine's propulsor versus how much air goes through its core.***

3 ***For more information on ICAO work on aircraft noise,*** *please see ICAO Environmental Report 2007, Chapter 2 – Aircraft Noise,* ***www.icao.int/env/pubs/env_report_07.pdf.***

Local Air Quality Outlook

By ***ICAO Secretariat***

The ICAO Environmental Report for 2007 provided detailed background information on the issue of aircraft emissions and the Standards and Recommended Practices (SARPs) put in place by ICAO to mitigate local air quality concerns. More information is also available in the report of the eighth meeting of ICAO's Committee on Aviation Environmental Protection (CAEP/8, ICAO Doc 9938) which contains a status update of the CAEP's work on this issue. This article provides a brief summary as well as an update on some of the issues related to aircraft emissions that affect local air quality that were first described in Chapter 3 of the 2007 ICAO Environmental Report[1].

Overview

The potential adverse effects of air pollutants released within an aircraft's landing and takeoff cycle (LTO, nominally up to 3,000 feet or 915 meters above ground level) primarily pertain to human health and welfare. 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, any engine must demonstrate that its characteristic emissions of HC (unburned hydrocarbons), CO (carbon monoxide), NO_x (oxides of nitrogen) and smoke, are below the limits defined by ICAO. The contribution of aircraft emissions during the LTO cycle to the overall emissions in a typical urban area is small and the Standards set by ICAO are designed to ensure that they remain that way. The certification process is performed on a test bed, where the engine is run at four different thrust settings (see Figure 1), to simulate the

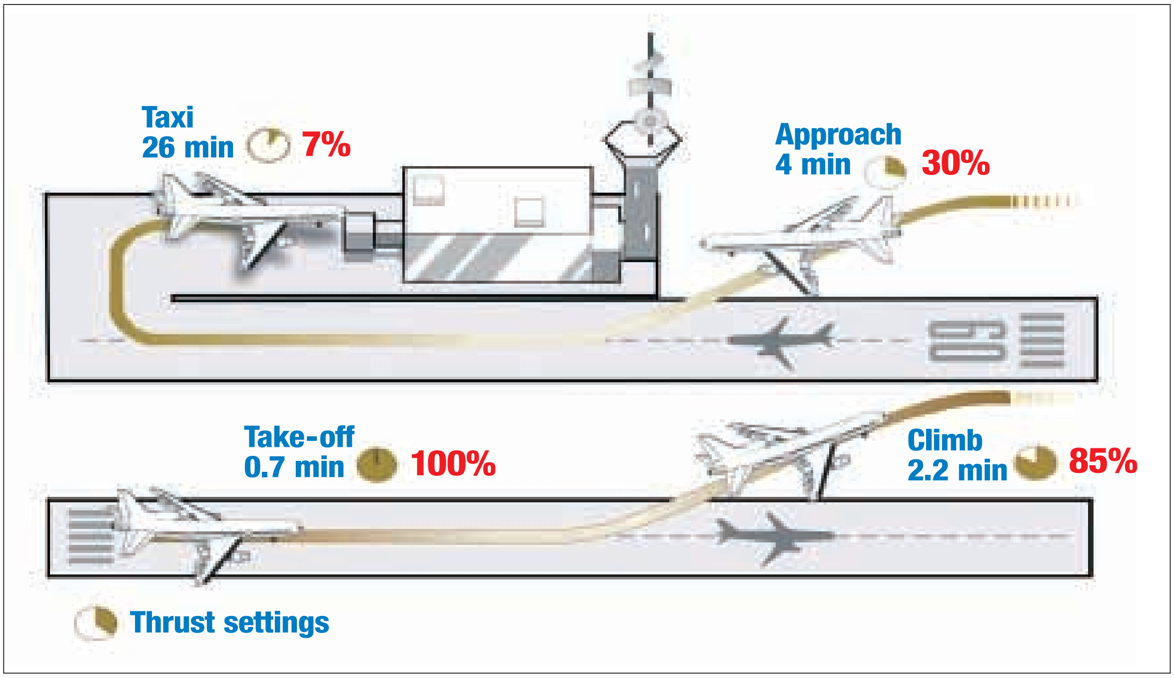


Figure 1: *Illustration of ICAO emissions certification procedure in the LTO cycle.*

various phases of flight, as follows:

- **Takeoff** (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.

Dramatic progress in reducing the emissions from aircraft engines has been made since the first Standards were set. Unburned hydrocarbons have been virtually eliminated from the exhaust stream due to improved engine technologies and visible smoke is also almost completely gone. However, ICAO's focus is now shifting to improved understanding of the formation of aircraft particulate matter (PM), which is sometimes referred to by the more general term, soot. Potential effects on human health due to various species of emissions are described in **Table 1**.

Since the original NO_x Standard was adopted in 1981, it has been made 50% more stringent. CAEP/8 in February 2010 reviewed the analyses of various scenarios of increased NO_x stringency options, and agreed on a new NO_x Standard (CAEP/8 NO_x Standard). It improves on the current CAEP/6 NO_x Standard by between -5% and -15% for small engines, and by -15% for large engines; and will be in effect on 31 December 2013. In addition, engines not meeting the current CAEP/6 Standard will no longer be produced as of 31 December 2012.

CAEP has also set mid and long-term technology goals for aircraft engine NO_x emissions through a panel of independent experts (see *Setting Technology Goals*, Chapter 3 of the 2007 Environmental Report). Although NO_x Standards were initially intended to address local air quality, they also contribute to reducing the impact of aviation on climate.

Impact of Aircraft Emissions On Local Air Quality – Trends

In 2010, CAEP completed a comprehensive global projection of future emissions trends that affect local air quality. For this analysis, the aircraft engine emissions were projected for NO_x and PM from aircraft operating at up to 3,000 feet (915 metres) above ground level. As with the noise analysis (see *Noise Outlook*, Aviation Outlook of this report), aircraft emissions were modelled for a baseline year of 2006 and then for the future years 2016, 2026, and 2036, across a range of scenarios that considered different technological and operational options, as per **Table 2**. For context, aircraft NO_x emissions contribute between 70% and 80% of total airport NOx emissions.

Aircraft NOx emissions emitted at less than 3,000 feet above ground level for those scenarios is projected to increase from 0.25 million metric tonnes (Mt) in 2006 to between 0.52 Mt and 0.72 Mt in 2036 (see **Figure 2**). These results are presented for the central demand forecast case. The analysis show that the results are particularly sensitive to the level of projected air traffic demand. This corresponds to growth in NO_x emissions of between 2.4% and 3.5% per year, which is less than the projected growth rate in traffic of 4.8% annually (see *Air Traffic Outlook*, Aviation Outlook of this report).

Pollutant	Health Effect
CO – Carbon Monoxide	• Cardiovascular effects, especially in those persons with heart conditions
HC – Unburned Hydrocarbons (a primary component of Volatile Organic Compounds, or VOC)	• Eye and respiratory tract infection • Headaches • Dizziness • Visual disorders • Memory impairment
NO_x – Nitrogen Oxides	• Lung irritation • Lower resistance to respiratory infections
O_3 – Ozone (HC is a precursor for ground-level O_3 formation)	• Lung function impairment • Effects on exercise performance • Increased airway responsiveness • Increased susceptibility to respiratory infection • Increased hospital admissions and emergency room visits • Pulmonary inflammation, lung structure damage
PM – Particulate Matter (smoke is a primary component of PM.)	• Premature mortality • Aggravation of respiratory and cardiovascular disease • Changes in lung function • Increased respiratory symptoms • Changes to lung tissues and structure • Altered respiratory defence mechanisms

Table 1: *Representative health effects from local air quality pollutants.*[2]

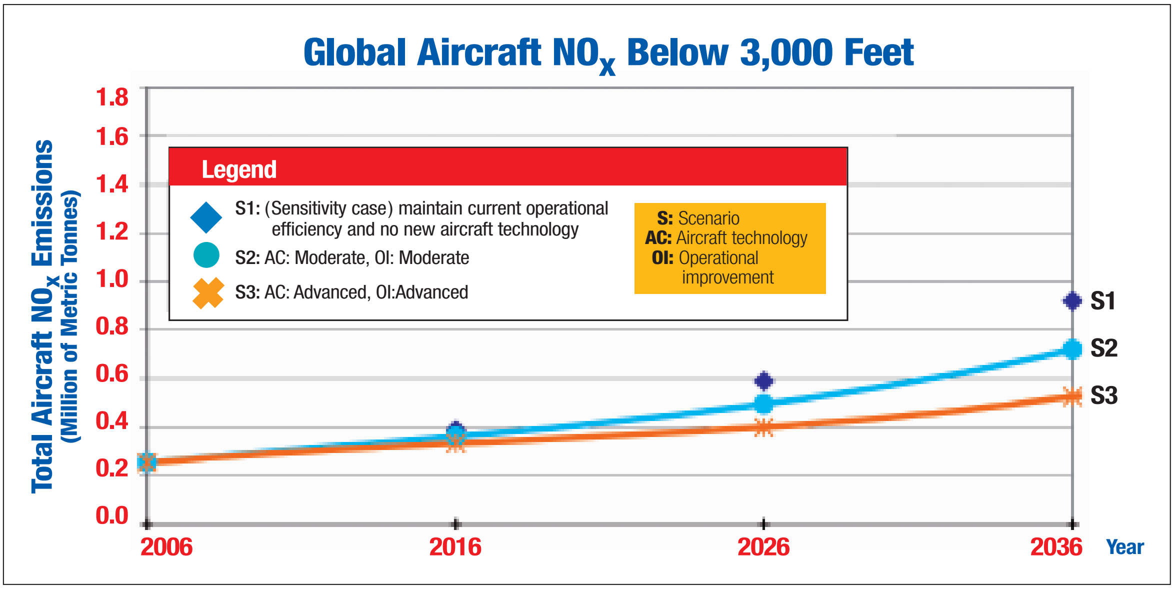


Figure 2: *Total global aircraft NO_x below 3,000 feet (915 Metres) AGL.*

Scenario 1 *is the sensitivity case that assumes the operational improvements necessary to maintain current operational efficiency levels, including the planned introduction of NextGen and SESAR, but does not include any aircraft technology improvements beyond those available in current (2006) production aircraft. Since Scenario 1 is not considered a likely outcome, it is purposely depicted with no line connecting the modelled results in 2006, 2016, 2026 and 2036.*

Scenario 2 *is the moderate aircraft technology and operational improvement case that assumes aircraft NO_x improvements based upon achieving 50% of the reduction from the current NO_x emission levels to the NO_x emissions levels set by CAEP/7 NO_x Independent Expert goals review (60% +/-5% of current CAEP/6 NO_x Standard) for 2026, with no further improvement thereafter. This scenario also includes fleet-wide moderate operational improvements by region.*

Scenario 3 *is the advanced aircraft technology and operational improvement case that assumes aircraft NO_x improvements based upon achieving 100% of the reduction from the current NO_x emission levels to the NO_x emissions levels set by CAEP/7 NO_x Independent Expert goals review for 2026, with no further improvement thereafter. This scenario also includes fleet-wide advanced operational improvements by region that are considered to be an upper bound of those improvements.*

Table 2: *Scenarios used for the NO_x analysis.*

In recent years, there has been considerable research into the formation of particulate matter (PM) and its effect on human health. ICAO sets standards for smoke from aircraft engines, but has not yet set specific requirements for PM. Since PM emissions are not currently measured directly as part of the ICAO engine certification process, they were estimated for the CAEP trends assessment using a technique called First Order Approximation. The results for PM emissions at less than 3,000 feet follow the same trends as those for NO_x, although at significantly lower levels. The 2006 baseline value is 2,200 metric tonnes and the total global aircraft PM is projected to increase at a rate of 3.3% per year to a total of about 5,800 metric tonnes in 2036.

Aircraft Airport Emissions Put Into Context

The contribution of airport emissions to the overall emissions loading in the vicinity of airports is dependent upon the emission sources surrounding the airport. For a typical urban environment, airport emissions represent approximately 10% of total regional emissions in the vicinity of airports, whereas in more rural environments airport emissions would tend to be a higher percentage. In this case, the term "region" refers to the local communities surrounding the airport (i.e. within 50 km).

Mass emissions, measured in units such as total tonnes of NO_x or total tonnes of PM, from airport sources are only a metric for comparison purposes. To understand the influence on ambient air quality, airport mass emissions must be converted to ambient concentrations, measured in units such as micrograms per cubic meter ($\mu g/m^3$) or parts per million (PPM). The incremental contribution in ambient pollutant concentrations from airport emissions decreases the further one travels away from the airport. Each airport's contribution is unique, subject to the surrounding urbanization/industrialization and meteorological conditions within the vicinity of the airport. ICAO's Airport Air Quality Guidance Manual (ICAO Doc 9889), provides detailed information on this subject.

Conclusions and Next Steps

Standards set by ICAO, coupled with investments in technology and improved operational procedures have resulted in the near elimination of some pollutants from aircraft engine exhaust and are allowing aviation's local air quality emissions footprint to grow at a rate slower than the demand for air travel. The emissions Standards 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.

Looking forward, some changes may be necessary to account for new findings. In particular, CAEP is focused on better understanding the formation of non-volatile PM and has targeted the development of a certification requirement by CAEP/9, and a certification Standard by CAEP/10. ■

REFERENCES

1 ***More information about aviation's effects on local air quality is available***
in Chapter 3 of the 2007 ICAO Environmental Report.

2 *Adapted from United States EPA,*
Evaluation of Air Pollutant Emissions from Subsonic Commercial Jet Aircraft.

Climate Change Outlook

*By **ICAO Secretariat***

Around the world, people, nations, and industries have become increasingly concerned with their contribution to global climate change. Aircraft are powered by the combustion of jet fuel and aviation gasoline, the result of which are emissions that are comprised of approximately 70% carbon dioxide (CO_2), slightly less than 30% water vapour, and less than 1% of a number of other emissions. CO_2 and water vapour are greenhouse gases (GHG). The effects of these emissions last for vastly different lengths of time with CO_2 being a very long lived gas in the atmosphere, and water vapour having a relatively short term effect. This brief outlook provides you an initial introduction to the discussion on aviation and climate change, to which this 2010 environmental report is entirely dedicated.

- Total aviation CO_2 emissions (domestic and international) are approximately 2% of the world's anthropogenic (human-made) CO_2 emissions (Figure 1);
- International flights are responsible for approximately 62% of these emissions;
- The amount of CO_2 emissions from aviation is projected to grow around 3% to 4% per year; and
- Medium-term mitigation for CO_2 emissions from the aviation sector can potentially come from improved fuel efficiency. However, such improvements are expected to only partially offset the growth of aviation CO_2 emissions.

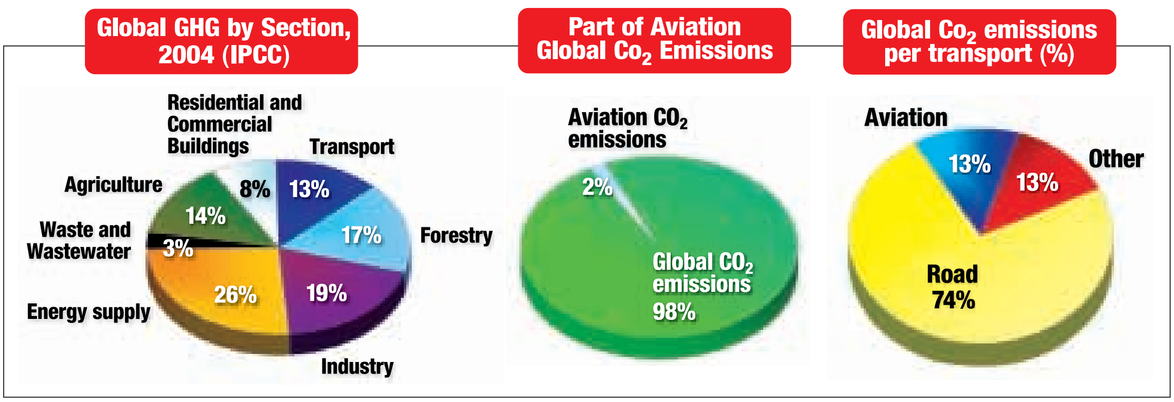


***Figure 1**: Aviation's contribution to global CO_2 emissions.*
Source: IPCC, 4th Assessment Report, 2007, WGIII, Technical Summary and IPCC Special Report on Aviation and the Global Atmosphere (1999).

Scientific Understanding

ICAO's cooperation with other United Nations bodies, in particular the Intergovernmental Panel on Climate Change (IPCC), is essential in obtaining a better scientific understanding of aviation's impact on the global climate. Main finding related to aviation emissions in IPCC Fourth Assessment Report (AR4) published in 2007 are shown in the inset box as follows.

The IPCC has initiated the preparation of its Fifth Assessment Report (AR5), which is scheduled to be completed in 2014. ICAO is participating in the IPCC process to ensure that issues related to aviation and climate change are covered in the AR5. ICAO requested that the AR5 further explore the effects of non-CO_2 aviation emissions, update the trends of aviation CO_2 emissions, include the latest ICAO work on mitigation measures, and address the life-cycle analysis of the environmental benefits on the use of alternative fuels for aviation taking into account cross-sectoral issues.

Fuel Burn / Fuel Efficiency Trends

CAEP has conducted a detailed assessment of environmental trends. Based on the unconstrained CAEP central forecast and without accounting for the lifecycle emissions reduction potential of sustainable alternative fuels (see Chapter 5 of this report), CO_2 emissions from aircraft will continue to increase even under the assumption of optimistic technological and operational advances. However, technological and operational advances will allow aviation system efficiency to continue to improve.

Figure 2 provides results for global full-flight fuel burn for 2006, 2016, 2026, 2036 and 2050. These results are for both domestic and international traffic combined. As shown in Figure 3, the 2006 baseline value is 187 Mt of fuel, with domestic traffic representing approximately 38% of this total and international traffic representing 62%.

The baseline value of 187 Mt in 2006 only includes fuel burn from the main aircraft engines of Instrument Flight Rules (IFR). It does not include fuel burn from auxiliary power units, from aviation-related operations (e.g., ground support equipment) or from visual flight rules (VFR) flights. Non-scheduled flights in regions for which radar data are not available were also not accounted for. Fuel burn from aviation-related operations, VFR flights, and non-scheduled flights may together amount to approximately 10% to 12% additional fuel burn.

The global fuel consumption is expected to grow from a baseline of 187 Mt in 2006 to between 461Mt and 541 Mt in 2036. Without considering the effects of alternative fuels,

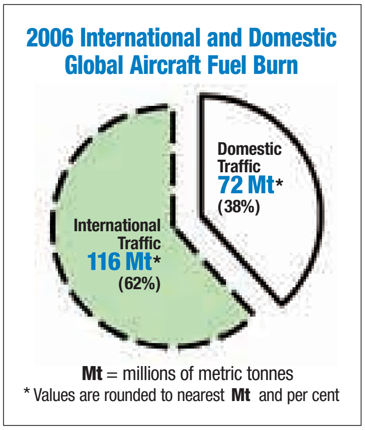


Figure 3: *International aviation represented approximately 62% of global aviation fuel consumption in 2006.*

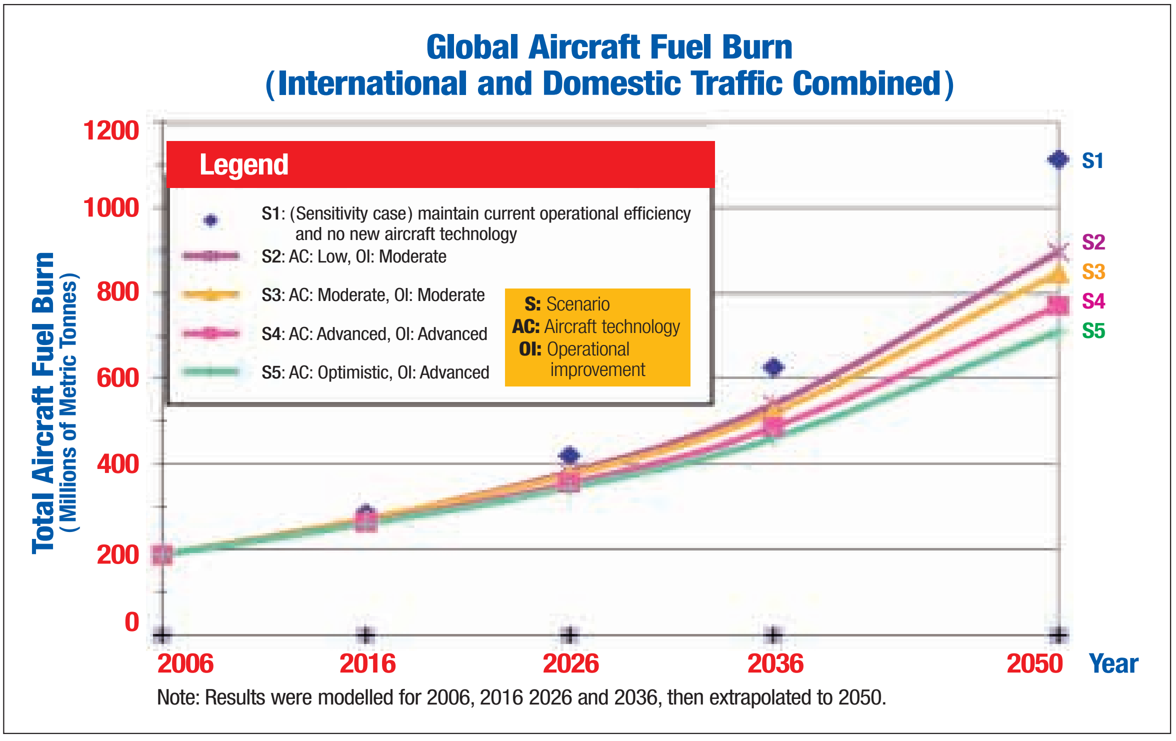


Figure 2: *Total Global Aircraft Fuel Burn 2006 to 2050.*

Fuel Burn / Fuel Efficiency Scenarios

- ***Scenario 1*** *is the sensitivity case that assumes the operational improvements necessary to maintain current operational efficiency levels, including the planned introduction of NextGen and SESAR, but does not include any aircraft technology improvements beyond those available in current (2006) production aircraft. Since Scenario 1 is not considered a likely outcome, it is purposely depicted with no line connecting the modelled results in 2006, 2016, 2026, 2036 and 2050.*

- ***Scenario 2*** *is the low aircraft technology and moderate operational improvement case that, in addition to including the improvements associated with the migration to the latest operational initiatives, e.g. those planned in NextGen and SESAR (Scenario 1), includes fuel burn improvements of 0.96% per annum for all aircraft entering the fleet after 2006 and prior to 2015, and 0.57 percent per annum for all aircraft entering the fleet beginning in 2015 out to 2036. It also includes additional fleet-wide moderate operational improvements by region.*

- ***Scenario 3*** *is the moderate aircraft technology and operational improvement case that, in addition to including the improvements associated with the migration to the latest operational initiatives, e.g. those planned in NextGen and SESAR (Scenario 1), includes fuel burn improvements of 0.96% per annum for all aircraft entering the fleet after 2006 out to 2036, and additional fleet-wide moderate operational improvements by region.*

- ***Scenario 4*** *is the advanced aircraft technology and operational improvement case that, in addition to including the improvements associated with the migration to the latest operational initiatives, e.g. those planned in NextGen and SESAR (Scenario 1), includes fuel burn improvements of 1.16% per annum for all aircraft entering the fleet after 2006 out to 2036, and additional fleet-wide advanced operational improvements by region.*

- ***Scenario 5*** *is the optimistic aircraft technology and advanced operational improvement case that, in addition to including the improvements associated with the migration to the latest operational initiatives, e.g. those planned in NextGen and SESAR (Scenario 1), includes an optimistic fuel burn improvement of 1.5% per annum for all aircraft entering the fleet after 2006 out to 2036, and additional fleet-wide advanced operational improvements by region. This scenario goes beyond industry-based recommendations for potential improvements.*

assuming that 3.16 kg CO_2 is produced for every kg of fuel burnt gives a baseline value of 591 Mt CO_2 in 2006 to between 1,450 and 1,710 Mt CO_2 in 2036. This represents an absolute growth of between 2.5 and 2.9 times over the period or an annual average growth rate of between 3 and 3.5 per cent, which is far less than the assumed growth in air traffic demand. For the 2050 results, a 2.9 per cent to 3.4 per cent annual average growth rate is predicted.

Figure 4 presents the global fuel efficiency trends for the years 2006, 2016, 2026 and 2036, using the CAEP-approved Commercial Aircraft System Fuel Efficiency (CASFE) metric. The 2006 baseline value is 0.32 kg/tonne-km. In 2036, global CASFE ranges from about 0.25 kg/tonne-km (with Scenario 2) to about 0.21 kg/tonne-km (with Scenario 5). Lower CASFE values represent more efficient operations. Also depicted in Figure 4, by a dashed line, is an approximation of the effects of the global goal of 2% annual fuel efficiency improvement agreed by the Group on International Aviation and Climate Change (GIACC) and the High-level Meeting on International Aviation and Climate Change in October 2009.

On a per flight basis, fuel efficiency is expected to improve over the period. However in absolute terms an emissions "gap" could exist relative to 2006 or earlier that would require a form of intervention in order to achieve sustainability.

CO_2 Emissions Reduction Target for Aviation

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 an irreversible change in the global climate system. In this regard all activities, independent of their share of the contribution, must pursue the means necessary to address their part of responsibility in the global picture.

Within the share of the global CO_2 emissions attributed to the aviation sector (approximately 2%), a substantial part represents domestic aviation emissions, which follow the same treatment agreed under the UNFCCC and Kyoto Protocol as other emissions of a domestic nature. Approximately 62% of aviation emissions are attributed to international aviation operations. However, as mentioned above, this amount is projected to grow at around 3% to 3.5% per year, and ICAO has been actively developing a comprehensive mitigation strategy to limit or reduce GHG emissions from international aviation.

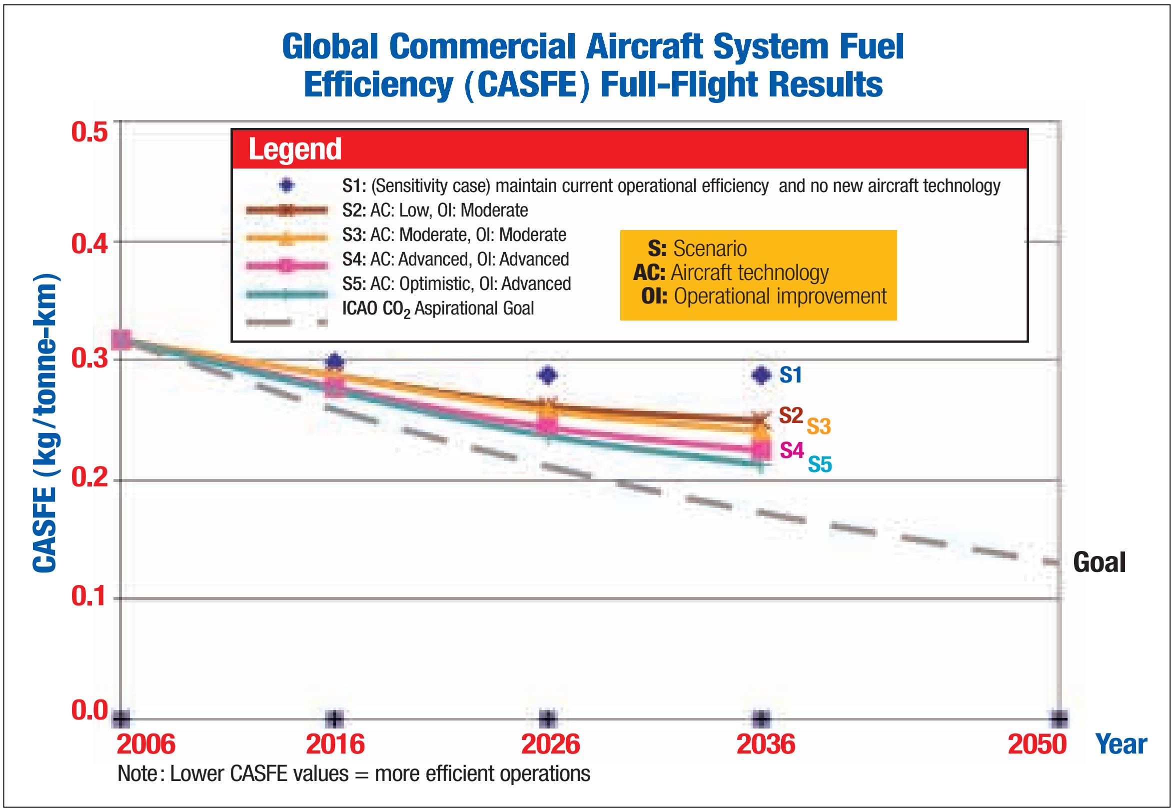


Figure 4: *Commercial Aircraft System Fuel Efficiency (CASFE) Full-Flight Results.*

A milestone in this strategy was achieved by the High-level Meeting on International Aviation and Climate Change in October 2009. The meeting agreed on a set of comprehensive measures known as the ICAO Programme of Action on International Aviation and Climate Change. It includes the agreement on a global goal of 2% annual improvement in fuel efficiency until the year 2050. It is the first and only globally-harmonized agreement from a sector on a goal to address its CO_2 emissions.

At the same time, the High-level Meeting "*noted the scientific view that the increase in global average temperature above pre-industrial levels ought not to exceed 2°C*" (9th preambular clause of the Declaration), and "*recognized that the aspirational goal of 2% annual fuel efficiency improvement is unlikely to deliver the level of reduction necessary to stabilize and then reduce aviation's absolute emissions, and that goals of more ambition will need to be considered to deliver a sustainable path for aviation*". ICAO and its member States consequently declared to undertake further work to explore the feasibility of more ambitious goals, including carbon-neutral growth of the sector and long-term emissions reduction (see inset box from excerpt from the Declaration).

Despite ICAO's success no binding agreement on global emissions reduction targets was reached in COP15. The Copenhagen Accord that was "noted" by the UNFCCC Climate Change Conference in Copenhagen (COP15) in December 2009 recognized that deep cuts in global emissions are required, as documented by the IPCC AR4, with a view to reducing global emissions so as to limit the increase in global temperature below 2°C.

As illustrated in Table 1, according to the IPCC AR4, in order for the global average temperature to not exceed 2°C, global CO_2 emissions must peak between 2000 and 2015, and be reduced in 2050 by between 50 and 85 percent compared to the 2000 level.

Excerpt from High-level Meeting Declaration
(October 2009)

__2.__ In pursuing the implementation of the ICAO Programme of Action on International Aviation and Climate Change, States and relevant organizations will work through ICAO to achieve a global annual average fuel efficiency improvement of 2 per cent over the medium term until 2020 and an aspirational global fuel efficiency improvement rate of 2 per cent per annum in the long term from 2021 to 2050, calculated on the basis of volume of fuel used per revenue tonne kilometre performed;

__3.__ Taking into account the relevant outcomes of the 15th Conference of the Parties to the United Nations Framework Convention on Climate Change, and recognizing that this declaration shall not prejudge the outcome of those negotiations, ICAO and its Member States, with relevant organizations will also keep working together in undertaking further work on medium and long-term goals, including exploring the feasibility of goals of more ambition including carbon-neutral growth and emissions reductions, taking into account the collective commitments announced by ACI, CANSO, IATA and ICCAIA on behalf of the international air transport industry, the special circumstances and respective capabilities of developing countries and the sustainable growth of the international aviation industry, for consideration by the 37th Session of the ICAO Assembly;

Category	Additional radiative forcing (W/m^2)	CO_2 concentration (ppm)	CO_2-eq concentration (ppm)	Global mean temperature increase above pre-industrial at equilibrium, using "best estimate" climate sensitivity (°C)	Peaking year for CO_2 emissions	Change in global CO_2 emissions in 2050 (% of 2000 emissions)
I	2.5-3.0	350-400	445-490	2.0-2.4	2000-2015	-85 to -50
II	3.0-3.5	400-440	490-535	2.4-2.8	2000-2020	-60 to -30
III	3.5-4.0	440-485	535-590	2.8-3.2	2010-2030	-30 to +5
IV	4.0-5.0	485-570	590-710	3.2-4.0	2020-2060	+10 to +60
V	5.0-6.0	570-660	710-855	4.0-4.9	2050-2080	+25 to +85
VI	6.0-7.5	660-790	855-1130	4.6-6.1	2060-2090	+90 to +140

Table 1: *Classification of IPCC AR4 stabilization scenarios according to different stabilization targets and alternative stabilization metrics.*
Source: IPCC, 4th Assessment Report, 2007, WGIII.

Conclusions

With the solid basis of the Programme of Action on International Aviation and Climate Change, ICAO continues to pursue even more ambitious goals to address aviation's contribution to climate change. The Organization and the industry are working aggressively toward a sustainable future for international aviation. More information on ICAO efforts to unite aviation on climate change is available from **www.icao.int/Act_Global**.

Chapter 1

AVIATION'S CONTRIBUTION TO CLIMATE CHANGE

Aviation's Contribution to Climate Change

Overview

*By **ICAO Secretariat***

The ICAO Environmental Report – 2007, provided detailed background information on the issues of aircraft emissions and climate change. This article provides a high-level overview as well as an update on the science of climate change as it relates to aircraft emissions.

According to the Intergovernmental Panel on Climate Change (IPCC), climate change refers to any change in climate over time, whether due to natural variability, or as a result of human activity. Global climate change is caused by the accumulation of greenhouse gases (GHG) in the lower atmosphere (see article *Aviation Greenhouse Gas Emissions – Overview*, Chapter 1 of this report). The GHG of most concern is carbon dioxide (CO_2).

Aviation is a small but important contributor to climate change. ICAO/CAEP's initial estimate is that the total volume of aviation CO_2 emissions in 2006 (both domestic and international) is in the range of 600 million tonnes. At present, aviation accounts for about 2% of total global CO_2 emissions and about 12% of the CO_2 emissions from all transportation sources.[1,2]

Aircraft engines produce emissions that are similar to other emissions produced by fossil fuel combustion (for technology advances in aircraft and aircraft engines, refer to Chapter 2 of this report). However, most of these emissions are released directly into the upper troposphere and lower stratospheres where they are believed to have a different impact on atmospheric composition, as shown in Figure 1. The specific climate impacts of these gases and particles when emitted and formed are difficult to quantify at present.

As Figure 1 illustrates, GHGs trap heat in the Earth's atmosphere, leading to the overall rise of global temperatures, which could disrupt natural climate patterns.

Estimating Climate Change Impacts

The range of estimated future impacts of aviation CO_2 emissions varies to a great degree, depending on the metric used (e.g. mass of CO_2 emissions, radiative forcing and temperature increase) and/or the methodology applied. Reducing uncertainty in estimating the total emissions and their impacts on the climate is the paramount factor in establishing sound policies.

For this reason, ICAO relies on the best technological and scientific knowledge of aviation's impact on climate change. ICAO has cooperated with IPCC, other international agencies and world-renowned scientists and technical experts on improving methodologies used when calculating aviation emissions and quantifying their impacts. The production of the IPCC 1999 special report on "Aviation and the Global Atmosphere" and a more recent IPCC assessment, the IPCC Fourth Assessment Report (AR4) are outstanding examples of such cooperation. The ICAO Workshop on Impacts in 2007 provided an opportunity for the best technical experts in aviation and climate change to come together and assess the latest scientific knowledge, uncertainties and gaps in quantifying climate change impacts[3]. The articles in this chapter will primarily focus on the state-of-the-art in measurement and modelling methods for quantifying aviation emissions and their impacts.

Impacts of Aviation GHG Emissions

Aviation climate impacts are due to both CO_2 and non-CO_2 emissions (see Figure 2). The non-CO_2 emissions include water vapor (H_2O), nitrogen oxides (NO_x), sulfur oxides (SO_x), hydrocarbons (HC), and black carbon (or soot) particles. Climate impacts of CO_2 emissions are well characterized and are independent of source location due to its relatively

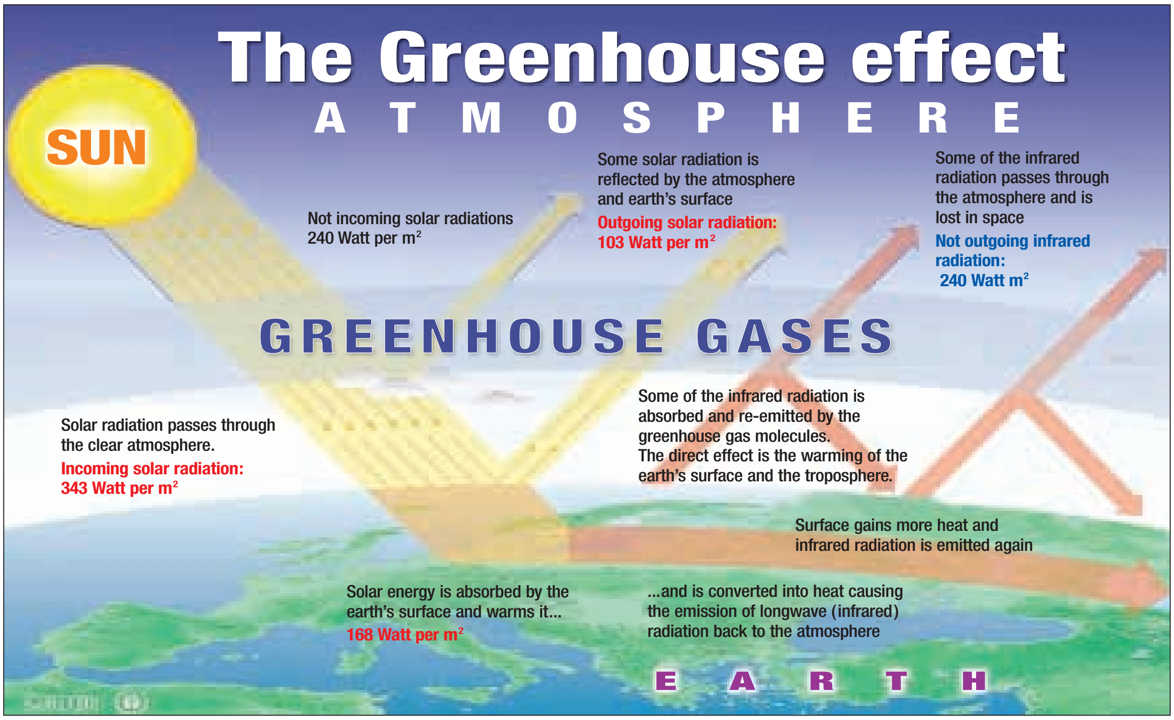


Figure 1: *The greenhouse effect on the atmosphere (IPCC Fourth Assessment Report).*

long atmospheric lifetime. On the other hand, non-CO_2 climate impacts of aviation emissions are quite variable in space and time. The primary factor for non-CO_2 emissions from aircraft is that the largest portion of these emissions are emitted in the flight corridors throughout the upper troposphere and lower stratosphere at altitudes of 8 km to 13 km (26,000-40,000 ft). The lifetime of the associated atmospheric changes ranges from minutes for contrails, to years for changes in methane.

Climate Impact Metrics:
In order to quantify the potential climate impact of changing atmospheric constituents such as GHGs, several measures can be used. Despite some of their shortcomings, these measures are convenient "metrics" that allow estimation of potential climate change in terms of such factors as global mean temperatures, from an emission of GHGs into the atmosphere.

MT (Metric ton (Mt), Million Metric Ton (MT), Giga Ton (Gt)): *Based on amounts and molecular weights of GHG compounds.*

CO_2e (Carbon Dioxide Equivalents): *"Normalizing" effects of various GHG to that of CO_2 using GWP.*

RF (Radiative Forcing): *The change in average radiation (in Watts per square metre: W/m^2) at the top of the tropopause resulting from a change in either solar or infrared radiation due to a change in atmospheric greenhouse gases concentrations; perturbance in the balance between incoming solar radiation and outgoing infrared radiation.*[4]

GWP (Global Warming Potential): *The cumulative radiative forcing effects of a gas over a specified time horizon resulting from the emission of a unit mass of gas relative to a reference gas.*[5]

Figure 2 displays a schematic of aircraft emissions and their resulting potential impacts on climate change and social welfare. Aviation CO_2, H_2O and soot emissions contribute **directly** to climate change with positive radiative forcing (net warming). Whereas, emissions of NO_x, SO_x, H_2O and black carbon aerosols contribute **indirectly** to climate change.

In general, there is a better understanding of impacts of GHG emissions that have a **direct** impact on the climate than emissions that have **indirect** impacts. For example, while the scientific understanding and modelling of NO_x effects have substantially improved over the last few years, there is still uncertainty regarding the exact extent to which NO_x emissions from air travel affect climate change through their impact on ozone formation and methane destruction. Similarly, H_2O vapor emissions can trigger formation of contrails in sufficiently cold air masses which may persist for hours and can potentially increase cirrus cloudiness. Direct emissions of black carbon and *in situ* formed aerosols can also serve as cloud condensation nuclei which, along with background aerosols, facilitate the formation of contrails and cirrus clouds. Contrails and induced cirrus clouds reflect solar short-wave radiation and trap outgoing long-wave radiation resulting in the net positive contribution to climate change.

Significant scientific advances have been made over the last decade to better characterize aviation climate impacts. However, the level of scientific understanding, particularly for quantification of the climate impacts of contrails and induced cirrus clouds remains unchanged and ranges between low and very low, respectively.[2,4] In fact, the IPCC AR4[8] did not even attempt to quantify the climate-forcing associated with aviation induced cirrus clouds. The 2007 ICAO/CAEP workshop report[3] also made similar conclusions about the understanding and uncertainties specific to non-CO_2 aviation climate impacts.

Aviation Climate Change Policies

A number of domestic and international climate-related policy actions are being presently considered that may profoundly impact the global aviation sector. A well developed suite of analysis and estimation tools, at the individual level, as well as at the national and global levels, is needed to inform optimally balanced cost-beneficial actions while accounting for system-wide environmental tradeoffs and interdependencies (see articles *Models and Databases – Review and Recommendations*, *Meeting the UK Aviation Target – Options for Reducing Emissions to 2050*, and *Greenhouse Gas Management at Airports*, in Chapter 1 of this report).

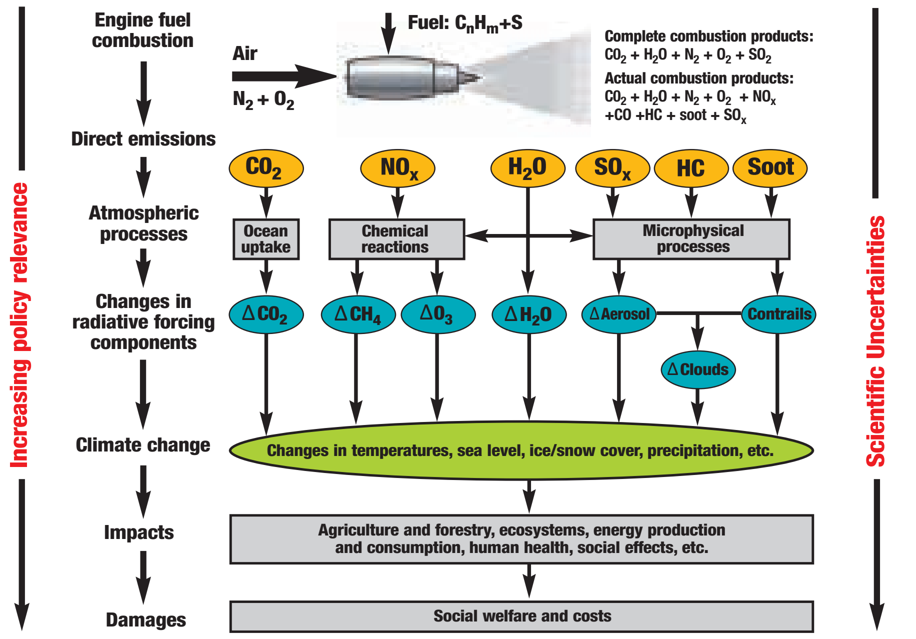
Since June 2008, the ICAO public website has included a Carbon Emissions Calculator[7], whose impartial, peer-reviewed methodology was developed through CAEP. It applies the best publicly available industry data to account for various factors such as aircraft types, route specific data, passenger load factors and cargo carried (see article *The ICAO Carbon Emissions Calculator*, in Chapter 1 of this report).

In 2006, IPCC issued its *guidelines for the national greenhouse gas inventories (2006 IPCC guidelines)*[8] in order to assist countries in compiling complete, national inventories of greenhouse gases, including those from aviation. According to the guidelines, emissions from international and domestic civil aviation include takeoffs and landings. The emissions cover civil commercial use of airplanes, including: scheduled and charter traffic for passengers and freight, air taxiing, and general aviation. The international/domestic split should be determined on the basis of departure and landing locations for each flight stage and not by the nationality of the airline. The use of fuel at airports for ground transport and stationary combustion should be excluded because they are covered under separate categories.

The *2006 IPCC guidelines* suggest collecting the fuel consumption for domestic and international aviation by surveying airline companies or estimating it from aircraft movement data and standard tables of fuel consumed, or both. As an alternative, a top down data approach could be used which involves obtaining fuel consumption data from taxation or customs authorities in cases where fuel sold for domestic use is subject to taxation and customs duties.

Next Steps

Although there is general agreement that inventories are an essential first step to quantifying impacts, there is a considerable divergence of views as to the single best approach to defining the consequent climate impacts. An "impact chain" can be defined starting from inventories, moving to regional and global indicator geophysical responses with their respective impacts on resource/ ecosystem/ energy/ health/ societal responses, and finally ending with overall social welfare/ costs responses. Although this impact chain can be described in a qualitative way, quantification of each of the steps in this chain is complex, and considerable scientific and intellectual resources are required to reach a consensus. This is a considerable challenge for society as a whole and is certainly not restricted to the debate over one sector's impacts on climate.



Sources: *Okanagan University College in Canada, Department of Geography, University of Oxford, School of Geography; United States Environmental Protection Agency (EPA), Washington; Climate Change 1995. The Science of Climate Change, contribution of Working Group 1 to the Second Assessment Report of the Intergovernmental Panel on Climate Change, UNEP and WMO, Cambridge University Press, 1996.*

Figure 2: *Schematic representation of aircraft emissions and their causal linkages with potential climate and social welfare impacts. Note that both the level of scientific uncertainties and policy relevance increase from characterization of emissions to social damage attributions. (Adapted from Wuebbles* et al.*, 2007).*[5]

Fuel Efficiency Rules of Thumb:

- On average, an aircraft will burn about 0.03kg of fuel for each kg 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.
- The total commercial fleet combined flies about 57 million hours per year; so, saving one kg on each commercial flight could save roughly 170,000 tonnes of fuel and 540,000 tonnes of CO_2 per year.
- 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 of fuel burn per nautical mile (NM) of flight : 11 kg.

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Aviation Greenhouse Gas Emissions

By ***David S. Lee***

David S Lee *is Professor of Atmospheric Science at Manchester Metropolitan University (MMU) and Director of the Centre for Aviation, Transport, and the Environment (CATE), a centre of excellence. David completed his doctoral studies in 1990 in atmospheric science and moved to the United Kingdom Atomic Energy Authority, working on various atmospheric science issues.*

David has been supporting the UK's activities in the CAEP arena since about 1995 and is a member of the UK delegation at CAEP meetings. He co-leads the new CAEP group, the Impacts and Science Group. David has specialized in research on aviation impacts on climate and was lead author for the recent ATTICA assessment. He has been a Lead Author for the IPCC since 1997.

Introduction

Aviation emits a number of pollutants that alter the chemical composition of the atmosphere, changing its radiative balance and hence influencing climate. The principal "greenhouse gas" pollutant emitted from aviation is CO_2 (carbon dioxide). Total emissions of aviation CO_2 represent ~2.0 to 2.5% of total annual CO_2 emissions (Lee et al., 2009a). Other emissions from aviation that affect the radiative balance include nitrogen oxides (NO_x, where NO_x=NO+NO_2), sulphate and soot particles, and water vapour. These lead to a variety of effects outlined later in this article.

Other papers have dealt extensively with non-CO_2 aviation emissions and effects (e.g. Lee et al., 2009b). In this article, the focus is upon CO_2 emissions, their contribution to global warming, and more importantly, what role future emissions may have in limiting warming to a policy target of an increase of no more than 2° C by 2100 over pre-industrial levels, as is the target of many countries, the European Union, and as mentioned in the Copenhagen Accord.

Aviation emissions of CO_2

The only 'greenhouse gas' emissions from aviation are CO_2 and water vapour: other emissions, e.g. NO_x and particles result in changes in radiative forcing (RF) but are not in themselves 'greenhouse gases'. Emissions of water vapour from current subsonic aviation are small and contribute (directly) in a negligible manner to warming.

Emissions of CO_2 are proportionally related to fuel usage (kerosene) by a factor of ~3.15. Figure 1 shows the development of aviation fuel usage since 1940, along with the

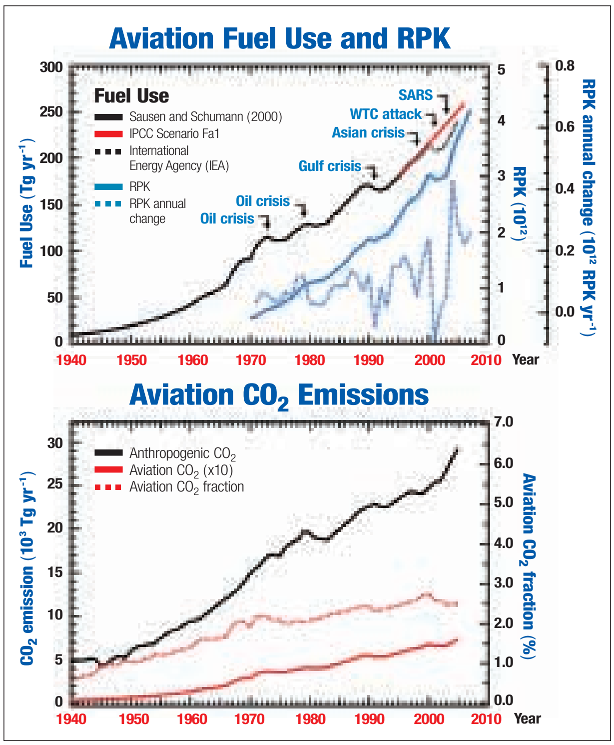

Figure 1: *Aviation fuel usage, RPK, and the annual change in RPK (Note offset zero) over time.*

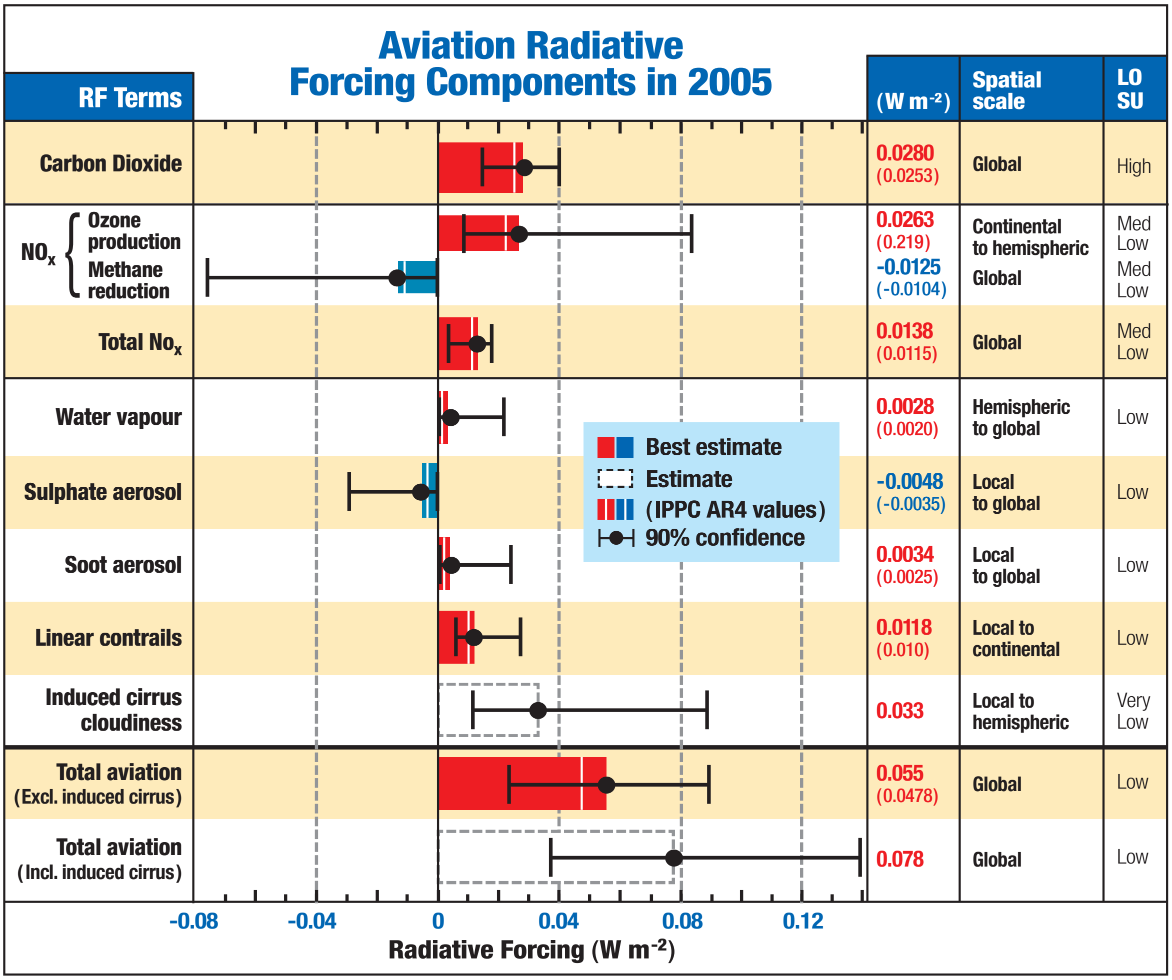

Figure 2: *Radiative forcing components for aviation in 2005 from Lee et al. (2009a) (For more details of results and calculation methodologies, see that paper).*

revenue passenger kilometres (RPK). A number of events impacting the sector (oil crises, conflicts, disease) show a response in demand and in emissions, and that the sector is remarkably resilient and adaptable to a variety of external pressures. How the current global economic crises will affect aviation remains to be seen but there are early signs of recovery. The usual pattern is a decline or downturn in demand that often recovers after 2 to 3 years, sometimes so strongly that the growth is put back 'on track'.

For example, after the early 2000s events, recovery in RPK in some subsequent years was remarkable. The lower panel of Figure 1 shows aviation CO_2 emissions in context with total historical emissions of CO_2 from fossil fuel usage. Emissions of CO_2 (total) as an annual rate increased markedly in the late 1990s and early 2000s. This was not reflected in the early 2000s by the aviation sector, because of suppression of demand in response to the events of 9-11 etc.; another reason why an annual percentage contribution of aviation emissions to total CO_2 emissions can be misleading when not placed in a longer-term perspective, as Figure 1 shows.

The lower panel of Figure 1 shows the growth in CO_2 emissions in Tg CO_2 yr^{-1} (per year) for all fossil fuel combustion and from aviation (left-hand axis), and the fraction of total anthropogenic CO_2 emissions represented by aviation CO_2 emissions (%) (right-hand axis). Note the x10 scaling of aviation CO_2 emissions. This figure was taken from Lee et al. (2009a).

Radiative Forcing

The concept of RF is used as there is an approximately linear response between a change in RF and the global mean surface temperature response. RF as a metric is inherently easier to compute than a temperature response, which adds another level of uncertainty. This is the preferred method of the IPCC in presenting impact quantification.

RF is defined as a change in the earth-atmosphere radiation balance as a global mean in units of watts per square metre, since 1750. As the earth-atmosphere system equilibrates to a new radiative balance, a change in global mean surface temperature results.

Much recent work related to climate change has considered 'metrics' (e.g. Waitz, this volume; Fuglestvedt et al., 2009). RF is a scientific metric and is fit for that purpose – other metrics for policy or emissions reductions are usually comparative, e.g. the Global Warming Potential, which compares the integrated RF of a pulse emission of a greenhouse gas over a certain time horizon to that from CO_2. Such usages and purposes of metrics should not be confused.

Aviation's RF impacts have been quantified for the year 2005 (Lee et al., 2009a) and are presented in Figure 2. It is clear, as has been the case since the IPCC assessment of aviation in 1999, that aviation's RF impacts are "more than just CO_2". However, the annual emission rates from aviation for different RF effects do not account for the accumulative nature of CO_2, when compared with shorter-term effects of NO_x, contrails, cirrus, etc. The RF for CO_2 from aviation accounts for its total emissions over time up until the present day.

Accumulation of CO_2 in the Atmosphere and the Role of Aviation

Recent policy discussions have focussed on the requirement to limit increases in global mean surface temperature (stabilization), rather than setting arbitrary emissions reductions targets that have uncertain and unpredictable outcomes. Such target-setting has already been discussed in climate science and much work has been published on this. The concept of

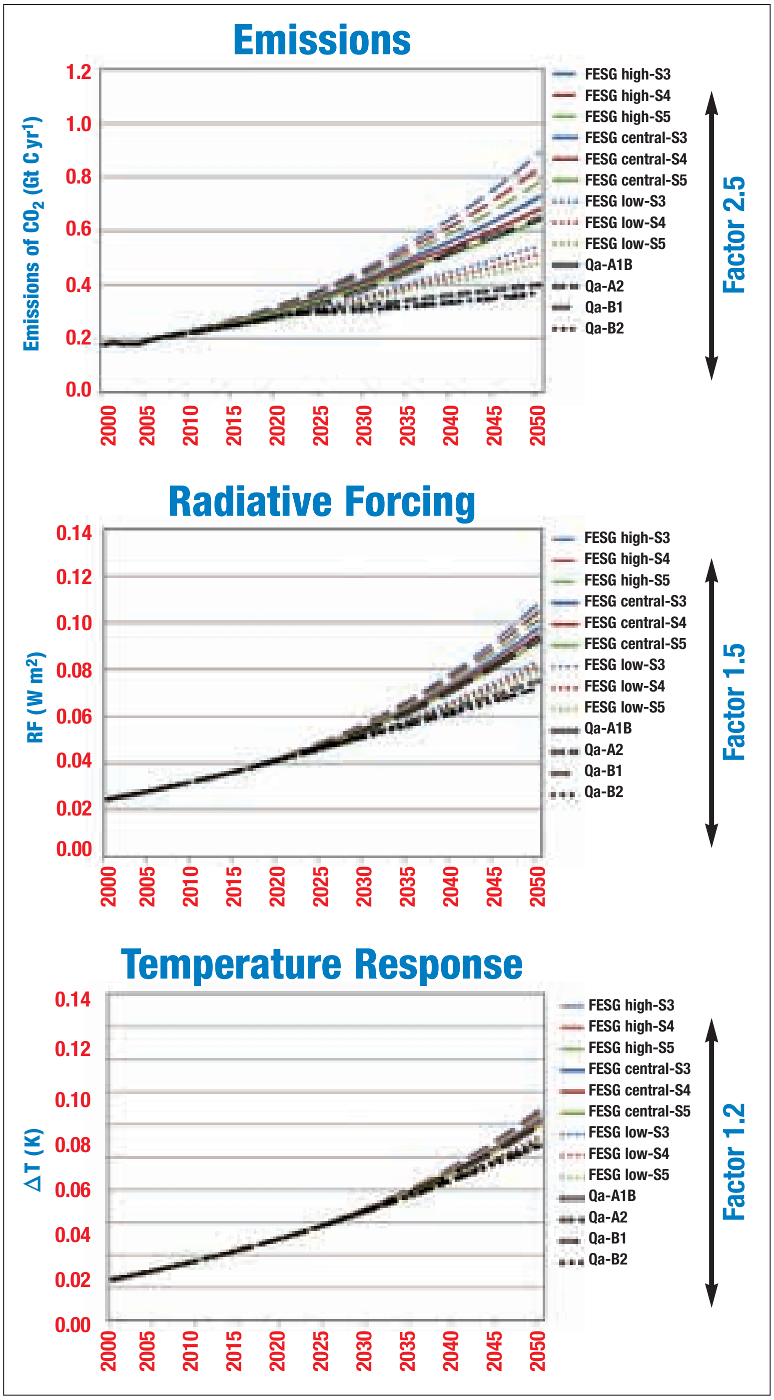

Figure 3: *Emissions of CO_2 for a range of aviation scenarios from 2000 to 2050, and their corresponding radiative forcing and temperature responses (CO_2 only).*

controlling emissions for 'stabilization' is relatively mature science, particularly for CO_2.

Total cumulative CO_2 emissions have a relationship with the temperature response of the earth-atmosphere system and it has been shown that (to a first order) limiting the total amount of CO_2 emitted is a reliable means of not exceeding some specified temperature target (e.g. Allen *et al* 2009, Meinshausen *et al* 2009, WBGU 2009).

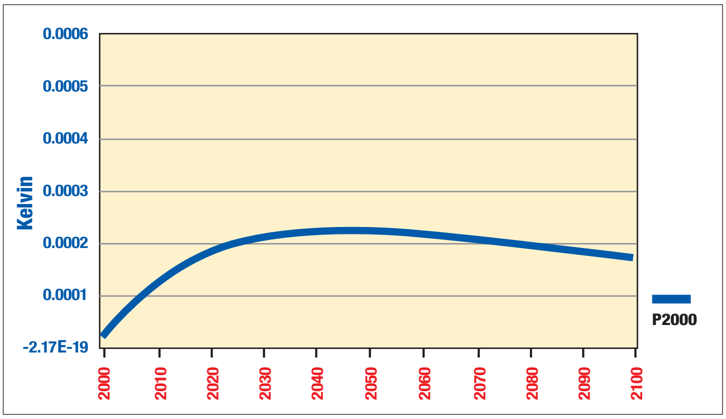

Figure 4: *Time development of the temperature response of a single year emissions from aviation in 2000.*

This makes the quantification of CO_2 emissions (past and future) a very powerful policy tool, but this must be based on total cumulative emissions, not emission rates. Currently, climate policy does not account for this, although a temperature-based target is well-suited to such a measure. Such a measure is applicable to all sectors. If a variety of future emission scenarios for aviation are selected, and their CO_2 RF and temperature response computed, it can be shown that the apparent variance between 'end-point' emissions in 2050 collapses markedly in terms of RF and temperature response.

In Figure 3, a range of currently-available aviation emissions scenarios to 2050 are utilized. The top panel shows that the 2050 end-point emissions differ by a factor of 2.5. However, when CO_2 RF response is computed, the cumulative nature of CO_2 emissions is accounted for and the end-point RF values only vary by a factor of 1.5. If the end-point temperature is then computed, this variation is reduced to a factor of 1.2 difference between these temperature responses in 2050, since another important factor, the thermal inertia of oceans is accounted for. These graphs show that differences in emissions scenarios – as an end-point – are not proportionally reflected in the temperature response and differences are much reduced.

This may be more easily understood by considering a single pulse of CO_2 emissions and observing the temperature response over subsequent decades, as shown in Figure 4. The emissions from 2000 cause this time-dependent increase and the subsequent decline in temperature. Thus, the scenario results of emissions in Figure 3 can be understood from this hypothetical case which more clearly illustrates time-dependencies of response to emissions.

In the context of CO_2 emissions and 'lifetime', it is a misconception that CO_2 has a lifetime of about '100 to 150 years'. It should be appreciated that CO_2 is more complex than other greenhouse gases and has **several** lifetimes, depending on the sink being considered. There are also biogeochemical feedbacks that affect 'lifetime'. According to IPCC (Fourth Assessment Report), 50% of an increase in concentrations will be removed within about 30 years, a further 30% being removed within a few centuries, and that the residual 20% remains in the atmosphere for many thousands of years. Thus, a simplistic concept of a simple 100 to 150 year lifetime is incorrect, and at worse dramatically underestimates impacts.

The key outcome for this methodological basis of determining how a temperature-based policy is achieved is that it is the cumulative emissions over time that matter, not the emission rate at a given future date. The science for this is mature and robust. The more contentious issue is how much CO_2 emissions (cumulative) are allocated. If a temperature-based policy is pursued, then the cumulative carbon concept is inevitable, and the science to support such a policy is mature and ready to be used. Moreover, the science can be usefully used to determine the potential impacts of sectoral reductions in emissions.

Conclusions

Aviation currently contributes around 2.0 to 2.5% of current total annual global CO_2 emissions, but discussions over such proportions are of limited value. What is important is the total of emissions over time. In the absence of policy intervention, aviation emissions of CO_2 are projected to increase over 2005 levels of 0,2 Gt C yr^{-1} by 1.9 to 4.5 fold (0.37 to 0.89 Gt C yr^{-1}) by 2050.

Emission rates are less relevant to both the effects (in terms of changes in CO_2 concentrations, RF and temperature response) and policy measures than total cumulative CO_2 emissions, since this latter measure is directly related to effects. Non-CO_2 impacts remain important and add to increases in temperature response from aviation, as long as those emissions continue but the temperature response from CO_2 persists for many thousands of years after the emission has ceased.

The amount of cumulative CO_2 emissions that will result in a 2° C temperature increase is relatively well known and quantified: one trillion tonnes of CO_2, half of which has already been emitted. The question that remains is "what proportion can aviation have of the half a trillion tonnes of CO_2 that can be emitted, before surface temperatures increase beyond 2° C?" ■

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Meeting the UK Aviation Target

Options for Reducing Emissions to 2050

By ***David Kennedy, Ben Combes*** and ***Owen Bellamy***

*The **UK's Committee on Climate Change** (CCC) is an independent statutory body established under the Climate Change Act to advise the UK Government on UK emissions targets, and to report to Parliament on progress made in reducing the UK's greenhouse gas emissions.*

*For more information please visit **www.theccc.org.uk***

Background

In January 2009 the previous UK Government decided to support the addition of a third runway at Heathrow Airport, committing to an expansion of allowable Aircraft Traffic Movements (ATMs) at Heathrow from 480,000 to 605,000 per annum. As part of that decision, the Government set a target that CO_2 emissions from UK aviation in 2050 should be at or below 2005 levels. It therefore asked the Committee on Climate Change, the Government's official climate advisers, to report on how this target could be met. The Committee set out its advice in a report published in December 2009 titled *Meeting the UK aviation target – options for reducing emissions to 2050*[1].

This article outlines the Committee's advice and assessment of the actions required to ensure that UK aviation CO_2 emissions in 2050 (domestic and international departing flights) do not exceed 2005 levels of 37.5 Mt CO_2[2]. In particular, it assesses the maximum increase in demand from current levels which is likely to be consistent with this target, given current best estimates of future technological progress.

If the target were to be achieved, it is estimated that UK aviation emissions would account for about 25% of the UK's total allowed emissions in 2050 under the economy-wide target – i.e. to cut all emissions by 80% in 2050 relative to 1990 levels – as included in the UK's Climate Change Act. This would require 90% reductions in other sectors of the economy.

Approach

In making its assessment, the Committee started by projecting the possible growth of demand and emissions if there were no carbon price constraining demand, and if no limits were placed on airport capacity expansion. It then considered scope for reducing emissions through carbon prices, modal shift from aviation to rail/high-speed rail, substitution of communications technologies such as video-conferencing for business travel, improvements in fleet fuel efficiency, and use of biofuels in aviation.

The work was concluded by setting out scenarios for aviation emissions to 2050, encompassing the range of options for reducing emissions, comparing emissions in 2050 with the target, and considering how any gap might be closed.

The potential implications of non-CO_2 aviation effects on global warming were also noted. The scale of such effects is still scientifically uncertain, and the effects are not covered by the Kyoto Protocol, the UK Climate Change Act, or the Government's aviation target. The report highlights the likely need to account for these effects in future global and UK policy frameworks, but does not propose a specific approach. The assessment of required policies was therefore focused on the target as currently defined – keeping 2050 UK aviation CO_2 emissions to no more than 37.5 Mt CO_2.

The Committee believes it to be the first of its kind. Although it relates specifically to achieving a UK target, the approach taken and methodology used are more widely applicable to developed countries with similar carbon constraints to the UK.

Key Findings

The key findings that came out of the study are as follows:

Projected Demand Growth

In the absence of a carbon price, and with unconstrained airport expansion, UK aviation demand could grow by more than 200% between 2005 and 2050:

- Demand for UK aviation has grown by 130% over the past 20 years in a context where UK GDP has increased by 54% and air fares have fallen significantly.
- Given forecast real UK income growth of around 150% in the period to 2050, and without a carbon price or capacity constraint, it is projected that UK aviation demand could grow by over 200% from the 2005 level of 230 million passengers annually to 695 million passengers by 2050.

A rising carbon price and capacity constraints could reduce demand growth by 2050 to 115%. Specifically, this decrease in demand would result from a carbon price rising gradually to £200/tCO_2 in 2050, together with limits to airport capacity expansion as envisaged in the 2003 UK Air Transport White Paper (i.e. expansion at Edinburgh, Heathrow, Stansted, and no further expansion).

Modal Shift and Videoconferencing

There is scope for a useful contribution to achieving the 2050 aviation emissions target through modal shift from air to rail and increased use of videoconferencing:

- There is scope for significant modal shift to rail/high-speed rail on domestic and short-haul international routes to Europe, which could reduce aviation demand by up to 8% in 2050.
- There is uncertainty over scope for substitution of videoconferencing for business travel. The report reflects this by using a conservative range, from very limited substitution, to a reduction of 30% in business demand in 2050.
- Together, modal shift and videoconferencing could result in a reduction in UK aviation emissions of up to 7 Mt CO_2 in 2050.

Improvements In Fleet Fuel Efficiency

Fleet fuel efficiency improvement of 0.8% annually in the period to 2050 is likely, given current technological trends and investment intentions:

- The Committee's expectation is that improvement in fleet fuel efficiency of 0.8% per annum in the period to 2050 is achievable through evolutionary airframe and engine technology innovation, and improved efficiency of Air Traffic Management and operations.
- This pace of improvement would reduce the carbon intensity of air travel (e.g. grams of CO_2 per seat-km) by about 30%.
- There would be scope for further improvement (i.e. up to 1.5% per annum), if funding were to be increased and technology innovation accelerated.

Use of Biofuels In Aviation

Concerns about land availability and sustainability mean that it is not prudent at this time to assume that biofuels in 2050 could account for more than 10% of global aviation fuel:

- It is likely that use of aviation biofuels will be technically feasible and economically viable.
- However, there will be other sectors which will compete with aviation for scarce biomass feedstock (e.g. road transport sector for use in HGVs, household sector biomass for cooking and heating, power generation for co-firing with CCS technology).
- It is very unclear whether sufficient land and water will be available for growth of biofuels feedstocks given the need to grow food for a global population projected to increase from the current 6.7 billion to around 9.1 billion in 2050.
- Biofuel technologies that would not require agricultural land for growth of feedstocks (e.g. biofuels from algae, or biofuels grown with water from low-carbon desalination) may develop to change this picture, but were considered speculative at this point.
- Given these concerns, it was not prudent at this time to plan for high levels of biofuels penetration. It was therefore assumed that 10% penetration is the most 'likely' scenario.

Aviation Non-CO_2 Effects

Aviation non-CO_2 effects (e.g. linear contrails, induced cirrus cloudiness and water vapour) are also likely to result in climate change and will therefore need to be accounted for in future international and UK frameworks. This may have implications for the appropriate long-term UK aviation target:

- The UK Government's aviation emission reductions target excludes these additional non-CO_2 effects, consistent with international convention and the UK Climate Change Act, as they do not derive directly from emissions of Kyoto gases.
- Aviation non-CO_2 effects are however almost certain to result in some additional warming, but with considerable scientific uncertainty over their precise magnitude.
- It will therefore be important, as scientific understanding improves, to account for aviation non-CO_2 effects in the future international policy framework and in the overall UK framework for emissions reduction.
- The implications for appropriate emissions reduction across different sectors of the economy are unclear, but some further reduction in aviation emissions may be required.

Achieving the UK Aviation Emissions Target

Given prudent assumptions on likely improvements in fleet fuel efficiency and biofuels penetration, demand growth of around 60% would be compatible with keeping CO_2 emissions in 2050 no higher than in 2005:

- The 'likely' scenario shown in Figure 1, assumes improvement in fleet fuel efficiency and biofuels penetration that would result in annual carbon intensity reduction of around 0.9%.
- The cumulative carbon intensity reduction of around 35% in 2050 provides scope for allowing an increase in demand while achieving the emissions target. This carbon intensity reduction allows for around 55% more UK ATMs with increasing load factors over the period, resulting in around 60% more UK passengers in 2050 than in 2005.
- Given the previous Government's capacity expansion plans, coupled with a demand response to the projected carbon price and to some of the opportunities for modal shift, UK demand could grow by around 115% between now and 2050 (Figure 1).
- Constraints on UK aviation demand growth in addition to the projected carbon price would therefore be required to meet the 2050 aviation target.

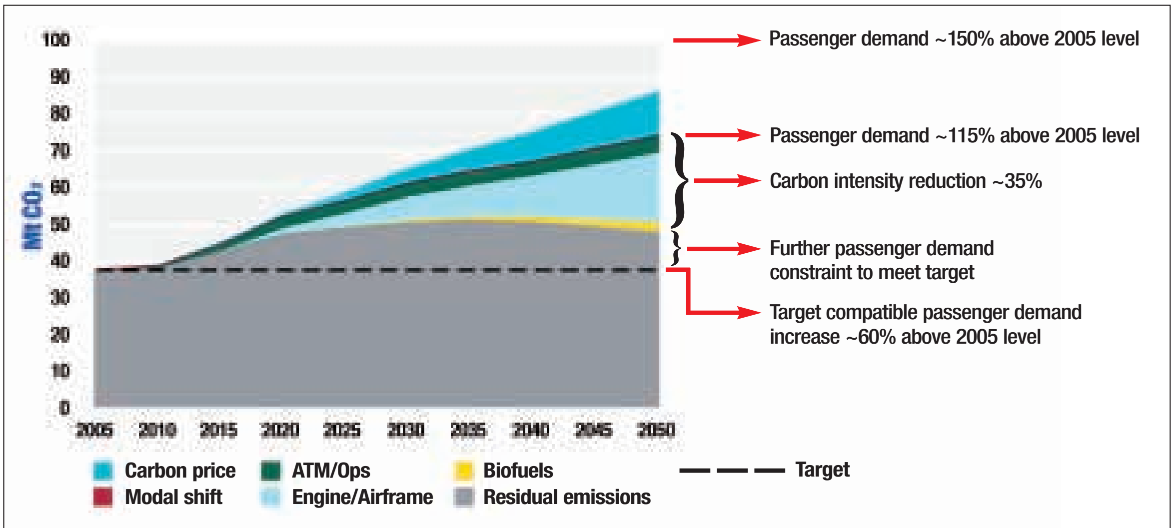

Figure 1: *UK aviation emissions to 2050 – CCC Likely scenario.*

Future technological progress may make more rapid demand growth than 60% compatible with the UK target; but it is not prudent to plan on the assumption that such progress will be achieved:

- It is possible that improvements in fleet fuel efficiency will progress more rapidly than anticipated, and/or that the prospects for sustainable biofuels will become more favourable.
- Unless and until emerging evidence clearly illustrates that this is the case, however, it is prudent to design policy around a maximum aviation demand increase of 60%.

A 60% increase in total UK aviation passenger demand could be consistent with a range of policies as regards capacity expansion at specific airports:

- The maximum increase in ATMs compatible with the emissions target is around 3.4 million per year in 2050, compared with around 2.2 million per year in 2005.
- Total current theoretical capacity at all airports in the UK is around 5.6 million ATMs per year, but demand cannot be easily switched between different geographical locations and capacity utilization differs hugely between hub and regional airports.
- Optimal capacity plans at specific airports therefore need to reflect factors other than total national demand levels, and it was not the Committee's role to assess such factors.
- The combination of different policies (e.g. tax and capacity plans) should however be designed to limit total demand increase to a maximum of around 60%, until and unless technological developments suggest that any higher figure would be compatible with the emissions target.

The UK In Context

Throughout the Committee's analysis, it was assumed that UK action would be in the context of an international agreement which limits aviation emissions in all countries:

Action at the European level is required in order to avoid leakage from UK airports to hubs in other ICAO Member States.

Action at a Global level is required in order to constrain aviation emissions in a way that is consistent with achieving broader climate change objectives, which the Committee set out in its recommendations to the previous UK Government on an international deal for aviation. Key points of that were:

- Aviation CO_2 emissions should be capped, either through a global sectoral deal or by including domestic and international aviation emissions in national or regional (e.g. EU) emissions reduction targets.
- The level of emissions reduction targets under any international agreement should be no less than that already agreed by the EU (i.e. developed country net emissions in 2020 should be no more than 95% of average annual emissions from 2004-2006).
- Emissions trading will be useful for an interim period in providing flexibility to achieve cost-effective emissions reductions, subject to the caveat that carbon prices in trading schemes provide strong signals for demand side management and supply side innovation.
- The aviation industry should also plan, however, for deep cuts in gross CO_2 emissions relative to baseline projections (e.g. for developed country aviation emissions to return to no more than 2005 levels in 2050), which will be required as a contribution to meeting the G8's agreed objective to reduce total global emission levels in 2050 by 50%.

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Greenhouse Gas Management at Airports

By ***Xavier Oh***

Xavier Oh *has been the Environment Manager at ACI since September 2005 and is based in the ACI Montreal Bureau, located near ICAO Headquarters.*

As an industry association, ACI is an official Observer at ICAO's Committee on Aviation Environmental Protection (CAEP). Xavier is the ACI representative.

As the Secretary of ACI's World Environment Standing Committee, one of his main tasks is developing, coordinating and implementing policy on all issues relating to the environment and airports. Noise and gaseous aircraft emissions are the main global issues, but local issues such as air and water quality, energy efficiency and land management also have global significance.

Introduction

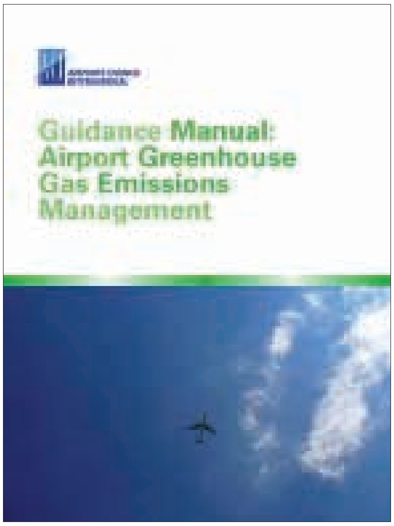
In addition to their passenger processing role, airports act as an interface between aviation and ground transportation. Because of this, there are a myriad of vehicles and activities that generate greenhouse gases (GHG) at airports, ranging from aircraft and ground support equipment (GSE) to ground transport, heavy machinery and power stations. Furthermore there are many different owners and operators of the various airport-related emission sources including the airport operator, airlines, concessionaire tenants, ground handlers, public transport providers, as well as travellers and well-wishers.

This article outlines Airports Council International's (ACI) recommended approach for an airport to address and manage its own GHG emissions and those of others associated with the airport. Additional information is available in the ACI document *Guidance Manual: Airport Greenhouse Gas Emissions Management (2009)* which is freely available at **www.aci.aero**.

Categorizing Emissions Sources

Given the complexity of the types and ownership of different emissions sources it is helpful to start by drawing a few distinctions among the various sources at an airport.

Firstly, aviation emissions need to be distinguished from airport emissions. Aviation emissions are those emissions produced by the aircraft main engines and auxiliary power



units (APU) when it is in-flight or taxiing. This means that total aviation emissions are directly correlated to the total fuel loaded onto aircraft. This is a necessary distinction given that the Kyoto Protocol did not include emissions from international aviation in national inventories and targets.

Secondly, airport emissions can be divided into two categories: those produced by activities of the airport operator, and those produced by other "airport-related" activities. This helps to separate emissions that are the direct responsibility of the airport operator from other activities such as airlines (including some aircraft activity), ground handlers, concessionaires, private vehicles, etc.

The World Resources Institute (WRI) document *Greenhouse Gas Protocol, a Corporate Accounting and Reporting Standard" (WRI 2004)* provides a useful framework by dividing emissions into three scopes based on the ownership and control of airport sources that are defined as follows.

Scope 1 - GHG emissions from sources that are owned or controlled by the airport operator.

Scope 2 - GHG emissions from the off-site generation of electricity (and heating or cooling) purchased by the airport operator.

Scope 3 - GHG emissions from airport-related activities from sources not owned or controlled by the airport operator.

The ACI Manual recommends the further division of Scope 3 sources into two subcategories - Scopes 3A and 3B.

Scope 3A - Scope 3 emissions which an airport operator can influence, even though it does not control the sources.

Scope 3B - Scope 3 emissions which an airport operator cannot influence to any reasonable extent.

This Scope 3A-3B distinction is made in order to identify those sources which an airport operator can choose to include in its emissions management programme. For any particular type of source, the degree of influence will vary among airports. By categorizing a source as Scope 3A, the airport operator indicates that it believes it can work with the owner of the source to achieve emissions reductions.

Airport Emissions Inventory

Examples of the main airport and airport-related sources in each scope category are given in Table 1. At some airports, certain sources may be placed in different categories.

Calculation Methods

There are several key documents available that provide guidance on the calculations of airport and airport-related GHG emissions.

- The Airport Cooperative Research Program (ACRP) Report 11 *Guidebook on Preparing Greenhouse Gas Emissions Inventories (2009)*, provides detailed information on how to calculate the emissions from each source at an airport including aircraft, APU, GSE, ground access vehicles, stationary sources, waste management activities, training fires, construction activities, and others. Factors to use for converting non-CO_2 emissions to a CO_2-equivalent mass are also provided.
- Emissions conversion factors that are used in many countries for converting the volume of various fuels used into CO_2 mass, as well as for calculating the mass of CO_2 emitted for each kWh of electricity, are available at **www.airportcarbonaccreditation.org**
- Airport Air quality guidance manual ICAO Doc 9889, which was developed mainly for the calculation of local air quality emissions, provides detailed methodologies for calculating emissions from a variety of airport sources including aircraft engine start-up. It is also recommended that airports refer to any national reporting guidelines, such as UK DEFRA Greenhouse Gas Protocol **(http://www.defra.gov.uk/environment/business/reporting/carbon-report.htm)**.

Emissions from the combustion of renewable or biomass fuels, such as wood pellets or bio-derived fuels, will need careful consideration. In general, the contribution of GHG emissions from these non-fossil fuels will have a near zero net effect on the CO_2 levels in the atmosphere, because the equivalent CO_2 was removed from the atmosphere during their production.

Reduction of Airport Operator Emissions

Some examples of measures that can be implemented for **Scope 1 and 2** emissions reductions include the following:

- Modernization of the power, heating and cooling plants.
- Generation or purchase of electricity, for heating and cooling systems, from renewable energy sources including wind, solar, hydroelectric, geothermal and biomass sources.
- Retrofitting of "smart" and energy efficient buildings and component technologies, including double glazing, window tinting, variable shading, natural lighting, light emitting diode (LED) lighting, absorption-cycle refrigeration, heat recovery power generation and the like. LEED and BREEAM building certification programmes can provide guidance.

- Modernization of fleet vehicles and ground support equipment, and the use of alternative fuels for buses, cars and other air and land-side vehicles. Alternative fuel sources could include compressed natural gas (CNG), hydrogen, electricity, compressed air and hybrid technologies.
- Driver education about fuel conservation driving techniques and implementation and enforcement of a no-idling policy.
- Solid waste management that includes recycling and composting, and reduces volume of waste going to landfills. Reusing excavation and demolition materials on-site also reduces transportation emissions.

Source	Description
Scope 1: Airport Owned or Controlled Sources	
Power plant	Airport-owned heat, cooling and electricity production
Fleet vehicles	Airport-owned (or leased) vehicles for passenger transport, maintenance vehicles and machinery operating both airside and landside
Airport maintenance	Activities for the maintenance of the airport infrastructure: cleaning, repairs, green spaces, farming, and other vehicles
Ground Support Equipment (GSE)	Airport-owned equipment for handling and servicing of aircraft on the ground
Emergency power	Diesel generators for emergency power
Fire practice	Fire training equipment and materials
Waste disposed on-site	Airport-owned waste incineration or treatment from airport sources
Scope 2: Off-site Electricity Generation	
Electricity (and heating or cooling) generation	Emissions made off-site from the generation of electricity (and heating or cooling) purchased by the airport operator
Scope 3: Other Airport-Related Activities and Sources	
Scope 3A: Scope 3 Sources an Airport Operator Can Influence	
Aircraft main engines	Aircraft main engines during taxiing and queuing Some airports may include the LTO (Landing Take-off) cycle
APU	Aircraft Auxiliary Power Units (APU)
Landside road traffic/ground access vehicles (GAV)	All landside vehicles not owned by airport operator, operating on airport property
Airside vehicle traffic	All vehicles operated by third parties (tenants, airlines, etc) on airport airside premises
Corporate Travel	Flights taken on airport company business
Ground support equipment (GSE)	Tenant or contractor owned GSE for the handling and servicing of aircraft on the ground, if airport could provide alternative fuels or otherwise influence operation
Construction	All construction activities, usually conducted by contractors
Scope 3B: Scope 3 Sources an Airport Operator Cannot Influence	
Aircraft main engines	Aircraft main engines in the LTO cycle, excluding taxiing
	Aircraft emissions during cruise on flights to or from airport
Landside road traffic/gound Access vehicles (GAV)	All landside vehicles related to the airport, operating off-site and not owned by airport operator, including private cars, hotel and car rental shuttles, buses, goods delivery trucks, freight trucks
Electricity and other external energy	Emissions from generation of electricity, heating and cooling purchased by tenants including airlines
Aircraft and engine maintenance	Airline or other tenant activities and infrastructure for aircraft maintenance: washing, cleaning, painting, engine run-ups
Rail traffic	Rail traffic and other ground transport related to the airport
Waste disposed off-site	Off-site waste incineration or treatment from airport sources

Table 1: *Examples of Scope 1, 2, 3A and 3B emissions sources.*

Reduction of Other Airport-Related Emissions

Non-aviation emissions are dominated by ground transportation in **Scope 3A**. GHG mitigation measures can also include the following:

- Provision of energy efficient public transport and rapid transit to and from the airport including buses, coaches, light rail and trains.
- Implementation of educational campaigns (or using by-laws) to reduce vehicle idling, taxi dead-heading (one way trips), and individual passenger drop-off and pick-up.
- Consolidating hotel and rental car agency shuttle bus services.
- Encouraging the use of alternative fuel or hybrid taxis, rental and other cars; using incentives such as priority queuing, parking cost reduction, and priority parking areas.
- Providing infrastructure to fuel and power low emission vehicles, including recharging stations.

Reduction of Aviation Emissions at Airports

Airport operators can contribute to improvements in the aircraft activities of taxiing and APU usage with various mitigation measures including:

- Providing (and enforcing the use of) fixed electrical ground power (FEGP) and pre-conditioned air (PCA) supply to aircraft at terminal gates, that allow APU switch-off.
- Improving aircraft taxiways, terminal and runway configurations to reduce taxiing distance and ground and terminal area congestion.
- Implementation of departure management techniques, including holding aircraft at the gate (with APU switched off) until departure slot is ready. Such practices can also encompass virtual queuing and collaborative decision-making.
- Use of arrival management techniques that provide gates for aircraft that are located to minimize taxiing distance after landing.

Certification Programme

In June 2009, ACI launched its Airport Carbon Accreditation programme which provides a framework for airport operators to address their carbon dioxide emissions and obtain certification for reduction milestones reached. The scheme is voluntary, and for each of the four (4) levels attainable an airport operator must submit proof of certain actions, which are then audited and verified.

There are four levels of certification, whose requirements are briefly summarized as follows:

Level 1 – Mapping: An inventory of sources and annual quantities of CO_2 emissions under an airport operator's direct control (**Scope 1** and **2** sources) with options to include some **Scope 3** sources and non-CO_2 GHGs. A list of other emissions sources (**Scope 3**) is also required.

Level 2 – Reduction: As well as the Level 1 inventory, a Carbon Management Plan for **Scope 1** and **2** sources should be developed and implemented, and evidence of measurement, reporting and ongoing emissions reductions must be provided.

Level 3 – Optimization: The inventory must be extended to include some **Scope 3** sources including (at least) aircraft Landing and take-off (LTO), APU, surface access and corporate travel. The Carbon Management Plan must be extended to include further stakeholder engagement, and ongoing emissions reductions must be demonstrated.

Level 3+ - Neutrality: In addition to the Level 3 requirements, the airport operator must demonstrate that it has offset its residual **Scope 1** and **2** emissions and has thus achieved true "Carbon Neutrality."

More information on the programme is available at **www.airportcarbonaccreditation.org**

Example Inventories

In closing, the summaries of 3 airport inventories are presented in **Table 2**. The Zurich and Stansted inventories were conducted according to regulatory requirements, while Seattle-Tacoma's was made on a voluntary basis. The format allows for some comparisons between airports and, importantly, the avoidance of inappropriate comparisons. One example benefit of the Sea-Tac inventory was the identification of the high emissions of hotel shuttle buses which resulted in the airport operator initiating a project to encourage the consolidation of services.

Airport	Zurich Airport, Switzerland	
Study Year	2008	
Movements	274,991	
Passengers	22.1 million	
Cargo (t)	419,843	
Scopes	**Mass / Species**	**Comments**
Scope 1	30,788 t CO_2	Includes own power plant, furnaces, emergency power and own vehicles and machinery
Scope 2	2,639 t CO_2	
Scope 3A	112,260 t CO_2	Includes aircraft taxiing, APU, GPU for handling, 3rd party construction and access road traffic in airport perimeter: - Aircraft taxi: 89,149 t
Scope 3B	2,899,331 t CO_2	Landing and whole of departing flights to destination (performance based), GSE, other furnaces, aircraft maintenance, fuel farm, access train traffic - Performance based LTO (excl taxi): 159,555 t - Performance based whole flight (excl LTO): 2,720,002 t
Total Airport	3,045,018 t CO_2	

Airport	Stansted, UK	
Study Year	2008	
Movements	166,493	
Passengers	22.3 million	
Cargo (t)	198,054	
Scopes	**Mass / Species**	**Comments**
Scope 1	3,511 t CO_2	Gas, wood pellets, Refrigerants, Company vehicles and airside fuel use
Scope 2	51,314 t CO_2	Electricity
Scope 3A	248,626 t CO_2	Aircraft Taxi, Hold, APU, Staff vehicles, waste, business travel
Scope 3B	134,876 t CO_2	LTO (excl. taxi, hold, whole of flight), Passenger GAV, Third party airside fuel
Total Airport	438,327 t CO_2	

Airport	Seattle Tacoma, USA	
Study Year	2006	
Movements	340,058	
Passengers	30 million	
Cargo (t)	341,981	
Scopes	**Mass / Species**	**Comments**
Scope 1	40,000 t CO_2	Stationary sources, GSE, GAV (including employee vehicles, shuttle buses) on airport land
Scope 2	26,000 t CO_2	Electricity
Scope 3A	592,000 t CO_2	Aircraft taxi and delay, Employee vehicles off site, Shuttle buses off site
Scope 3B	3,996,000 t CO_2	Landing and whole of departure flights to destination (based of fuel dispensed), Passenger vehicles off site
Total Airport	4,654,000 t CO_2	

Table 2: *Examples of Airport Greenhouse Gas Inventories.*

Models and Databases
Review and Recommendations

By ***ICAO Secretariat***

One main task of ICAO's Committee on Aviation Environmental Protection (CAEP) is to identify and carry out analyses of the future trends and various options available to limit or reduce the current and future 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, as well as the trade-offs of the options considered. In doing so, CAEP has relied on the use of a variety of computer-based simulation models and databases offered by Member States and international organizations that participate 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.

To support the analyses for the eighth meeting of CAEP/8 in February 2010, a thorough evaluation of the proposed models and databases was carried out. The goal of this evaluation was to advise CAEP as to which tools are sufficiently robust, rigorous, transparent, and appropriate for which analyses (e.g. stringency, CNS/ATM, market-based measures), and to understand any potential differences in modelling results. Evaluation teams were established for each of the modelling areas: noise, local air quality, greenhouse gas emissions, and economics. A common methodology was developed to ensure consistency in the model evaluation process across the four modelling areas, which included a review of the key characteristics of a robust model or database, as shown in Table 1.

The models were then used to assess two sample problems: the effects of reduced thrust takeoff, and the effects of a hypothetical NO_x stringency. One of the goals of the sample problems was to advance candidate model evaluation and development by practicing on a set of problems that are similar to those that were considered as part of the CAEP/8 work programme. The practice analyses were accompanied by a rigorous assessment process, so that the strengths and deficiencies in the models could be identified, and appropriate refinements and improvements implemented. This ensured that the models were sufficiently robust and well understood to support a broad range of CAEP/8 analyses.

The models that were approved for use by CAEP/8 are shown in Table 2. Each model and database has its strengths and weaknesses, and the use of multiple models provided CAEP insight into sensitivities of the results. Going forward, the model evaluation process developed for CAEP/8 has established a framework for the future evaluation of new models and updates to the existing tools.

Of key importance is the fact that the input databases were common to all of the models. This allowed, for the first time, exploration of the interrelationships between noise, local air quality, and greenhouse gas emissions. As experience is gained investigating these interdependencies, and as the models mature further, more advanced decision making on aviation environmental protection will become possible.

Capabilities	• Does the model do what is needed to answer the potential questions posed by CAEP?
	• What are the limitations of the model?
	• What new capability does the model bring to policy assessment? Does this capability bring added value?
	• How well can the model frame quantitative estimates of uncertainty as part of the output?
	• Conduct sensitivity tests to understand the tool structure, as well as the main sources and degree of uncertainty.
Data requirements to support interaction with forecasting activities	• Does the tool produce the noise, emissions, and fuel flow data required by FESG for the economic analyses of the CAEP/8 policy studies?
	• Does the tool generate the data in the format required by FESG?
Methodologies	• How does the model work, and does it comply with applicable standards?
	• What data are required?
	• Where do these data come from?
	• How easy is it to change assumptions, baseline data, scenarios, etc.?
Readiness	• What is the likelihood that a tool under evaluation will be ready in time for application to the CAEP/8 policy studies?
	• Assess the labour and funding commitment to the development.
	• Assess the state of software development.
	• Assess the maturity of the methodologies.
	• Assess the maturity of the models V&V activities.
	• Assess the number of innovations that have yet to be incorporated and tested.
Transparency	• Are system architecture, functional requirements, algorithm description, data description, and other software design related documents available to CAEP?
	• Are there technical reports, which describe research and V&V supporting the algorithms and methodologies, available to CAEP?
Fidelity	• Are the methods and algorithms to generate the noise, emissions, and fuel use data reasonable?
	• Where the requirement is to assess interdependencies, does the tool reasonably represent trends and relationships among environmental factors?
Usability	• Who is to use the model, and what training is required?
	• What is the level of accessibility and availability?
	• What role is CAEP to have during input processing and running?
	• How will MODTF interface with FESG during processing and running?
Validation and verification (V&V)	• Is there a "gold standard" and how does the tool compare?

Table 1: *Characteristics of a robust model or database.*

Modelling Area	Model / Database Name	Release	Sponsoring Organization
Noise	AEDT/MAGENTA	**1.4**	US FAA
	ANCON2	**2.3**	UK DfT
	STAPES	**1.1**	EUROCONTROL
Local air quality	ADMS	**3.0**	UK DfT
	AEDT/EDMS	**1.4**	US FAA
	ALAQS	**NOV08**	EUROCONTROL
	LASPORT	**2.0**	Swiss Federal Office for Civil Aviation (FOCA) German Ministry of Transport (BMVBS)
Greenhouse Gas	AEDT/SAGE	**1.4**	US FAA
	AEM III	**2.0**	EUROCONTROL
	Aero2k	**2.0**	UK DfT
	FAST	**-**	UK DfT
Economics	APMT/Economics	**4.0.3**	US FAA
	NOx Cost	**4.0**	CAEP
All	Airports Database	**1.5.4**	US FAA, EUROCONTROL
All	Common Operations Database	**2.0**	US FAA, EUROCONTROL
All	2006 Campbell-Hill Fleet Database	**CAEP/8**	CAEP
All	2006 Campbell-Hill Fleet Database Extension	**CAEP/8**	US FAA
All	Population Database	**1.0**	US FAA, EASA
LAQ, GHG	ICAO aircraft engine emissions databank (EDB)	**16A**	UK DfT, CAEP **www.caa.co.uk/EDB**
Noise	ICAO Noise database (NoisedB)		France DGAC **http://noisedb.stac.aviation-civile.gouv.fr/**
All	ANP - Aircraft Noise and Performance	**1.0**	EUROCONTROL
All	Base of Aircraft Data (BADA)	**3.6**	EUROCONTROL
All	Forecasting and Operations Module (FOM)	**2.3.2**	US FAA
All	FESG Traffic Forecast (pax. + cargo)	**CAEP/8**	ICAO Secretariat, CAEP, ICCAIA
All	FESG Retirement Curves	**CAEP/8**	ICCAIA, CAEP
All	Growth & Replacement Database	**7**	ICCAIA, CAEP

Table 2: *Summary of models and databases approved for CAEP/8 use.*

The ICAO Carbon Emissions Calculator

By ***Tim Johnson***

Tim Johnson *has been working in the national and international aviation environmental policy field for over twenty years, as Director of the UK-based Aviation Environment Federation and as a consultant. He is the CAEP Observer on behalf of the International Coalition for Sustainable Aviation (ICSA) and is co-rapporteur of the Aviation Carbon Calculator Support group (ACCS). ICSA is a structured network of environmental non-governmental organizations working in the field of aviation and environmental protection.*

In 2006, members of the public and organizations interested in understanding the size of their air travel carbon footprint were faced with hundreds of websites offering calculators that delivered estimates that could vary widely for a given flight. With the users unable to find detailed documentation regarding the data and methodologies used by those calculators, it was impossible to know which estimates to trust. Recognizing the need for a fully transparent and internationally approved calculator, ICAO began work on a methodology through its Committee on Aviation Environmental Protection (CAEP).

ICAO launched its Carbon Emissions Calculator in June 2008. Positioned prominently on the Organization's home page, the Calculator uses the best publicly available data to provide the public with an easy-to-use tool to deliver consistent estimates of CO_2 emissions associated with air travel, that is suitable for

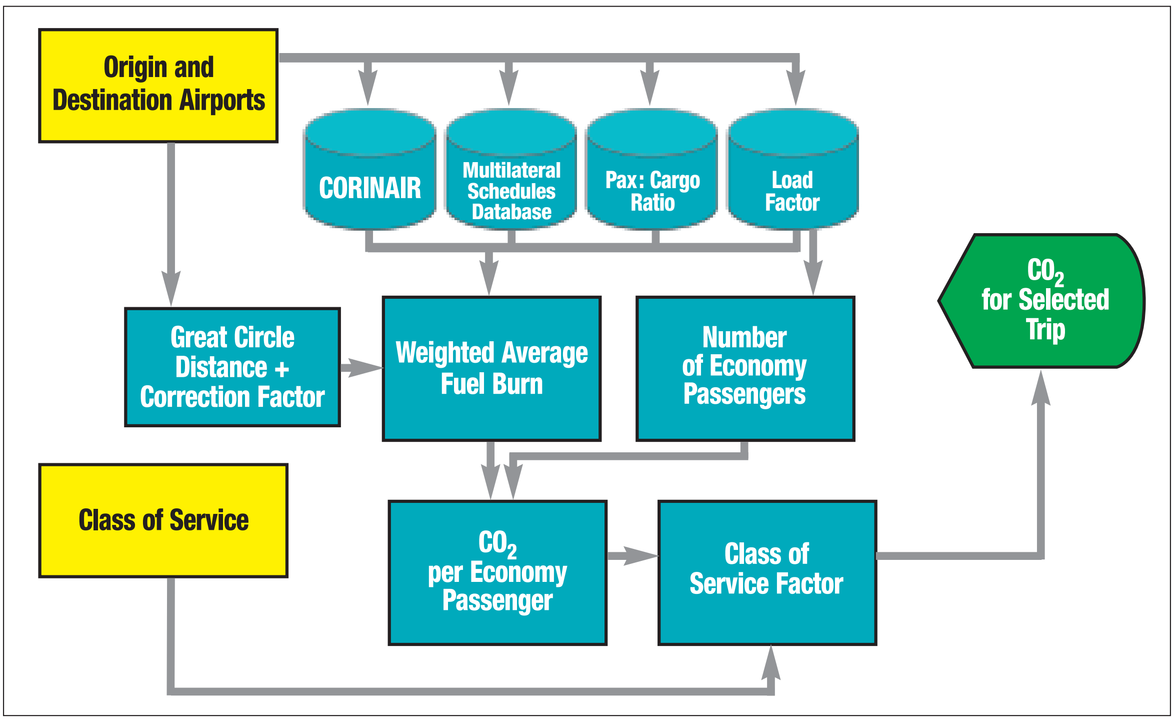


Figure 1: *ICAO Carbon Emissions Calculator methodology.*

use with offset programs. Furthermore, in the interest of maintaining transparency, the Calculator is accompanied by full documentation of the methodology that explains the variables behind every calculation (such as load factors and cabin class) as well as the data sources used. Unlike the many calculators available to compute aviation CO_2 emissions, the transparent ICAO Carbon Emissions Calculator, which exclusively uses publicly available data, is not a black box.

Methodology

The Calculator methodology, which is illustrated in Figure 1, was developed through CAEP by a team of experts from the ICAO Secretariat, Member States, universities, air carriers, aircraft manufacturers, and NGOs. It underwent significant review prior to publication, which resulted in it being internationally recognized and accepted.

While the diagram in Figure 1 appears complex, the Calculator is in fact easy to use with the user only having to provide the origin and destination airport along with the class of service flown. The user friendly web interface, shown in Figure 2, along with its transparency and positive international reviews, have brought the Calculator widespread recognition and acceptance (see *Building on the ICAO Carbon Calculator to Generate Aviation Network Carbon Footprint Reports*, in Chapter 1 of this report and *IATA's Carbon Offset Programme*, in Chapter 4 of this report).

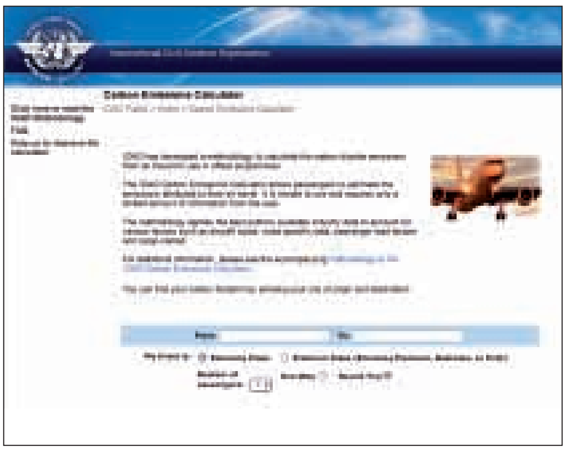


Figure 2: *ICAO Carbon Emissions Calculator Web interface (www.icao.int).*

Early Adopters

In April 2009, the UN Environment Management Group (EMG), a body overseeing the "greening of the UN" with the ultimate objective of moving toward climate neutrality across all its organizations and agencies, adopted the ICAO Calculator as the official tool for all UN bodies to quantify their air travel CO_2 footprint. The Calculator is currently being used throughout the UN system to prepare annual air travel greenhouse gas (GHG) inventories. But the tool is not only of interest for the compilation of inventories; some UN travel offices have integrated the Calculator directly into their travel reservation and approval systems, providing real-time information to assist travel planning decisions (see *Accounting for the UN System's Greenhouse Gas Emissions article*, Chapter 8 of this report).

With similar applications in mind, and with the goal of facilitating the use of the Calculator as the source of emissions information for offsetting initiatives, ICAO and Amadeus, a global technology and distribution solutions provider for the travel and tourism industry, have signed an agreement for ICAO to supply Amadeus with an interface to the Calculator for their reservation system.

Gathering User Feedback

Since its launch, the Calculator has continued to evolve. In response to public feedback, something that is invited through a user feedback facility on the website, several user interface improvements have been made. This includes the ability to enter airport codes or city names for the origin and destination of the trip, and the ability to compute both return trips and multi-city flights. The reaction from users also highlighted two issues that were referred to the CAEP Aviation Carbon Calculator Support group (ACCS) for its consideration. Both of these issues were frequently cited by respondents; the first relating to why the Calculator did not provide information regarding the non-CO_2 effects of flights, and the second regarding the absence of any information about the potential to offset emissions.

To help explain these issues to the public, a *Frequently Asked Questions* section was added to the website. While the accuracy of the Calculator makes it very relevant as a tool to calculate offsetting requirements, ICAO cannot recommend specific services offered by commercial entities. However, the user is still aided by information that will help in choosing an offset provider, including how the carbon credit is generated, whether it conforms to a recognized standard and has been audited or verified, and whether it provides transparency. In relation to accounting for the effects of greenhouse gases other than CO_2, the scientific community has not yet reached consensus on an appropriate metric for this purpose. ICAO is working in collaboration with Intergovernmental Panel on Climate Change (IPCC) on this subject and will adopt a "multiplier" methodology in due course.

Future Enhancements

Clearly, the best source of aviation CO_2 emissions data is based on the actual fuel consumption of aircraft along a given route. ICAO is actively working to move the Calculator toward the use of measured fuel consumption data, with the requirement that it be verified in an open manner and made publicly available in order to maintain the Calculator's full transparency.

While efforts to allow the public disclosure of fuel consumption data by aircraft operators continues, further improvements and refinements are planned for the Calculator over the next couple of years. The eighth meeting of CAEP in February 2010 agreed to assess and develop several different approaches to further enhance the accuracy of the methodology. The three approaches agreed to, which will be developed in parallel, will utilize the latest information available to ICAO.

For the first approach, ACCS will focus on updating the current database. Some aircraft types are not currently in the database and have no substitute type available (a substitute uses an existing aircraft type supported in the database with similar performance characteristics, or data from a previous generation). ACCS plans to work with aircraft manufacturers to address this issue, prioritizing those new aircraft types that have entered the market and which are used extensively on some routes. Other database goals include incorporating city-pair level load factor data collected by ICAO, and with industry assistance, air carrier level seating configuration data, where available. When using the Calculator, the user is asked to input his or her class of travel. The Calculator currently distinguishes between classes on the basis of the relative space occupied, but ACCS will consider refining whether weight offers improved accuracy.

The second approach takes advantage of the wealth of models available to CAEP and used by its Modelling and Databases Group. These models have already been evaluated and used to generate greenhouse gas forecasts to support ICAO's work. The results from these models can be merged into a single ICAO database of modelled, flight-level fuel consumption (or CO_2 emissions), that could enhance the Calculator's performance.

With the third approach, the Calculator ultimately aims to rely on measured fuel consumption data at the city pair level, differentiating where possible between the types of fuel used as alternative fuels for aircraft become more common.

Obtaining this data will require close co-operation with industry partners covering scheduled, low cost and business aviation operations, subject to their willingness to disclose the information. This disclosure will be crucial, as the full transparency of the calculator cannot be compromised. Another source of information may come from a new data collection form being developed by ICAO.

Through these initiatives, ICAO hopes to provide continuous assurance that the Calculator remains an accurate, transparent and tested means of estimating the CO_2 generated by air travel.

REFERENCES

ICAO Carbon Emissions Calculator Methodology
http://www2.icao.int/en/carbonoffset/Documents/ICAO%20methodologyV2.pdf

Building on the ICAO Carbon Emissions Calculator to Generate Aviation Network Carbon Footprint Reports

By **Dave Southgate** and **Donna Perera**

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 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.

Donna Perera *works in the Aviation Environment Policy Section in the Australian Government Department of Infrastructure, Transport, Regional Development and Local Government. She helped develop the Transparent Noise Information Package (TNIP) for producing rapid analyses of aircraft noise. She is now engaged in examining policy options for managing aviation carbon emissions and is developing concepts for monitoring and reporting of Australia's aviation carbon footprint. Donna has a postgraduate science degree from the University of Sydney.*

In recent years the aviation industry has received a significant amount of public pressure arising from a perception that the industry is taking inadequate steps to address its growing carbon footprint. It has become very evident that robust quantitative carbon footprinting tools for aviation are needed to facilitate policy development by ensuring that discussions and negotiations are based on facts rather than perceptions.

The importance of transparency and public confidence in carbon footprinting was recognized by ICAO in 2007 when it initiated work on the ICAO Carbon Emission Calculator. The calculator was publicly released on the ICAO website in June 2008. In Australia the Department of Infrastructure, Transport, Regional Development and Local Government has developed a software tool, built on the algorithms within the ICAO Carbon Emission Calculator, to compute and report carbon footprints across aviation networks.

Computing the Carbon Footprint

The aviation carbon footprinting tool that has been developed in Australia – *TNIP Carbon Counter* – is a Microsoft Access software application based on flight-by-flight carbon aggregation concepts. It is a generic tool that can be used to compute carbon footprints across any aviation network.

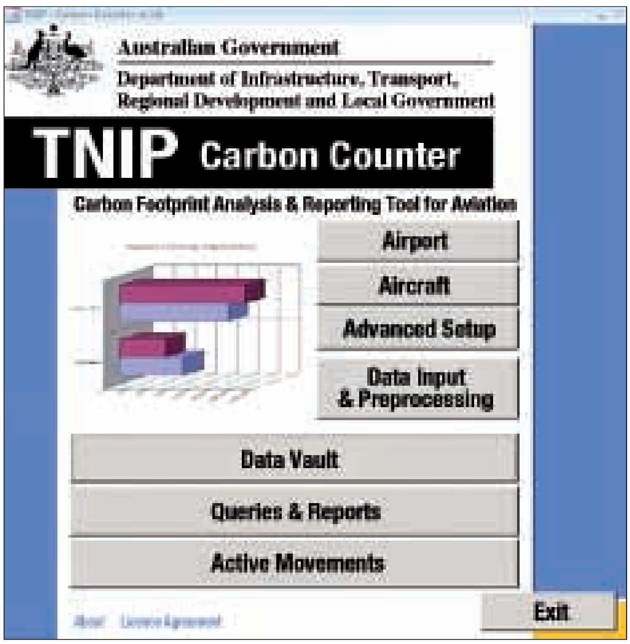


Figure 1: *TNIP Carbon Counter main user interface.*

When data is loaded into the application it generates an archive which contains a separate folder of movements for each of the airports in the input data set. During the data import process the program computes the CO_2 for each entry in the aircraft operations file. Each flight is identified as being domestic or international through the ICAO codes of the origin and destination airports. The fuel used, and hence CO_2 generated, for each flight is computed using the CORINAIR dataset[1].

This computation is the same as that carried out by the ICAO Carbon Calculator to compute carbon footprints. *TNIP Carbon Counter* applies the ICAO Carbon Emission Calculator great circle distance adjustment in its computations.[1]

Once the archive of movements is set up, the user is able to rapidly generate filtered subsets of the datasets using simple interfaces. This enables the user to rapidly generate a wide range of reports, both numerical and graphical, involving detailed subsets or high level generic divisions of the whole database. Examples of possible outputs are shown later in this article.

Input Data

Network carbon footprint reporting for Australia is based on the operational dataset for Australian airspace provided by Airservices Australia, the air navigation service provider for Australia. An extract of the input data for the Financial Year (FY) 2008-09 is shown in Figure 2.

The application also requires the input of specific set up data: latitude and longitude of each airport to compute (adjusted) great circle distances; information on the number of seats in each aircraft type; and the load factor on particular routes, to report total CO_2 loads on a per person basis.

The dataset for FY 2008-09 contains approximately 1.1 million aircraft departures and about 1,700 Australian airports and landing areas.

Validation

Validation of the computations for the Australian network footprint (i.e. fuel uplifted in Australia) has been carried out through comparing published fuel sales data from official government statistics with the TNIP computed footprint.

In many areas of the world, it is not feasible to use national fuel sales data for validation purposes because aircraft carry out operations in one country using fuel picked up in another country. However, given that Australia is a geographically isolated island continent there is little likelihood of a significant amount of this 'tankering' of fuel taking place between Australia and other countries. Accordingly, it is believed that validation based on comparison between computed and actual fuel sales is valid in the case of Australia. Figure 3 shows that over the FY 2008-09 the cumulative difference between actual and computed fuel use is minimal (just over 2%).

While recognizing that further validation studies are required, the level of agreement shown in Figure 3 would appear to indicate that robust carbon footprinting across networks can be achieved using great circle computations (incorporating adjustment algorithms such as those used by ICAO). This obviates the need for gathering and manipulating large amounts of complex input data (e.g. radar, aircraft thrust settings, etc.) in order to carry out system carbon footprinting. It is important to point out that great circle computations, which involve the aggregation of average carbon footprints, cannot be used for computing/optimizing the carbon footprints of individual flights.

	A	B	C	D	E	F	G
1	DATE	TIME LOCAL	ORIGIN AIRPORT	DESTINATION AIRPORT	AIRCRAFT TYPE	MTOW	AVTUR
2	1/06/2009	00:08	YPPH	FAJS	A346	365000	Y
3	1/06/2009	00:14	YMML	WSSS	B772	294835	Y
4	1/06/2009	00:17	YMML	VHHH	A333	233000	Y
5	1/06/2009	00:19	YBBN	VTBS	B773	286897	Y
6	1/06/2009	00:22	YPPH	WSSS	A320	71500	Y
7	1/06/2009	00:27	YPPH	VHHH	A333	233000	Y
8	1/06/2009	00:34	YMML	WMKK	B772	286897	Y
9	1/06/2009	00:50	YMML	VHHH	B744	397210	Y
10	1/06/2009	01:03	YBBN	VHHH	A343	276500	Y

Figure 2: *Extract of a TNIP input data file.*

Month	Avtur (megalitres)			Cumulative monthly avtur totals (megalitres)		
	Sales (less 8% military)	TNIP (computed)	Difference (%)	Sales (less 8% military)	TNIP (computed)	Difference (%)
Jul 2008	494.841	476.825	-3.6	494.841	476.825	-3.6
Aug 2008	481.928	467.576	-3.0	976.770	944.402	-3.3
Sep 2008	475.186	452.660	-4.7	1,451.955	1,397.062	-3.8
Oct 2008	481.288	474.593	-1.4	1,933.243	1,871.655	-3.2
Nov 2008	470.908	461.396	-2.0	2,404.151	2,333.050	-3.0
Dec 2008	497.564	481.897	-3.1	2,901.715	2,814.948	-3.0
Jan 2009	478.787	474.407	-0.9	3,380.502	3,289.355	-2.7
Feb 2009	424.707	426.307	0.4	3,805.209	3,715.661	-2.4
Mar 2009	441.433	473.422	7.2	4,246.642	4,189.083	-1.4
Apr 2009	483.608	465.098	-3.8	4,730.250	4,654.181	-1.6
May 2009	469.916	452.957	-3.6	5,200.166	5,107.138	-1.8
Jun 2009	478.899	445.086	-7.1	5,679.064	5,552.225	-2.2

Figure 3: *Comparison of computed jet fuel usage with actual jet fuel sales for Australia, 2008-09.*

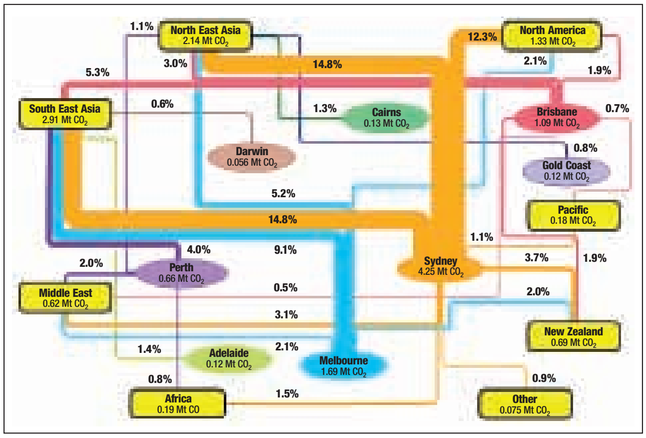


Figure 5: *Distribution of CO_2 emissions from international aircraft departures from Australia's international airports, 2008-09.*

Note: *To reduce the complexity of the diagram, only routes with greater than 40 kilotonnes CO_2 are shown. These routes comprised 98% of CO_2 emissions arising from total fuel uplifted in Australia for international departures.*

Reporting Concepts

At present, concepts are being trialled to best present comprehensive and comprehensible pictures of system-wide carbon footprints. This is a challenge given the very significant amount of disaggregated carbon footprint data that can be generated for an aviation system and the wide range in information needs of different audiences. Clearly, some form of layered approach to carbon footprint reporting is required. An example of a layered approach to carbon footprinting is shown in Figures 4 and 5.

Figure 4 gives an overview of the carbon footprint of aircraft departing from Australia to international ports shown in regional groupings. In Figure 5 this footprint is broken down on a route by route basis to the same regionally grouped international destinations.

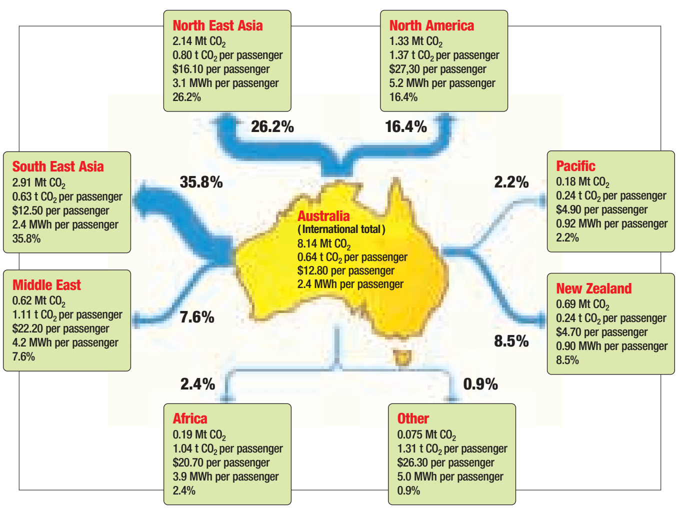


Figure 4: *CO_2 arising from international aircraft departures from Australia, 2008-09.*

Interrelationship Between Movements and CO_2

It is commonly noted that gauging the magnitude of the carbon footprint for a particular route, or a particular sub-group of operations is not intuitive – there is an extremely poor correlation between the number of operations and the size of the footprint for a given set of movements. For example, it can be seen from Figure 6 that across aircraft operations within the Australian network, about 7.5% of the movements (international operations) generate about 57% of the carbon footprint. Conversely, about 58% of the movements only contribute about 11% of the footprint.

Understanding this relationship is important when examining options for managing carbon footprints. For example, a commonly promoted strategy for minimizing the carbon footprint of aviation is to reduce the amount of 'inefficient' short-haul aviation travel by diverting passengers away from aviation to other modes of transport. However, preliminary analysis for Australia indicates that while short-haul operations make up a significant proportion of the flights they constitute a very small contribution to the total carbon footprint.

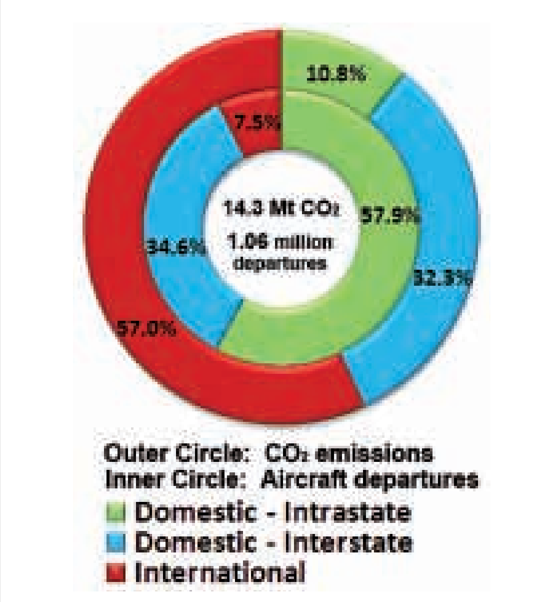


Figure 6: *Breakdown of Australia's carbon footprint and aircraft departures into intrastate, interstate and international contributions, 2008-09.*

Moving Forward – CO_2 Goals

Much of the debate within ICAO on establishing goals to reduce international aviation impact on climate change has focussed on improving fuel efficiency. At the present time ICAO has endorsed a goal of an annual 2% improvement in fuel efficiency up to the year 2050. Such a commitment requires that fuel efficiency be quantified and reported over time in order to transparently show the progress that is being made toward achieving this fuel efficiency goal.

The trend in fuel efficiency over a ten year period for international aircraft departing from Sydney Airport is shown in Figure 7. This illustrates the case that, despite the improvement in fuel efficiency over time, the total fuel consumed continues to grow. The fact that the footprint is continuing to grow underpins the discussion that is now ongoing within ICAO about the need for goals which go beyond simple fuel efficiency.

Various goals ranging from efficiency improvement, through carbon neutral growth, to emissions reductions are being considered within ICAO. If any of these goals are going to be adopted, there needs to be very clear and robust reporting on the actual (gross) carbon emissions and the extent to which any carbon credits are purchased in order to reach the agreed target. That is, there is a need to compute and report both *gross* and *net* carbon footprints. Developing these reporting concepts is a key area of future work.

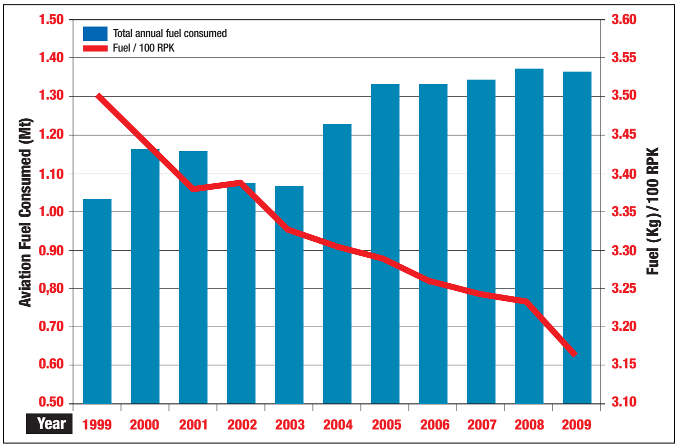


Figure 7: *Sydney Airport – Annual Fuel Consumption and Efficiency for International Aircraft Departures, 1999-2009.*

Conclusions

The development of the ICAO Carbon Emission Calculator has been a very important step in facilitating transparent and readily accessible carbon footprinting. Experience to date indicates that carbon footprint computations based on great circle methods can deliver very robust results.

Application of the concepts and algorithms underlying the ICAO Carbon Emission Calculator can provide a great deal of useful carbon footprint information using simple, transparent, and readily available, input data. These concepts facilitate rapid footprint reporting using common spreadsheet, database and graphics tools.

REFERENCES

CAEP/8-IP/41: Carbon Footprinting: Tools and Reporting Concepts Being Trialled In Australia,
presented by the Member of Australia at CAEP/8.

1 ***ICAO Carbon Emissions Calculator, Version 2, May 2009, (http://www2.icao.int/en/carbonoffset/Documents/ICAO%20MethodologyV2.pdf).***
The modified CORINAIR dataset is shown in Appendix C, *while the Great Circle Distance adjustment is on page 8 of the ICAO Carbon Emission Calculator Methodology.*

Chapter 2

AIRCRAFT TECHNOLOGY IMPROVEMENTS

Technology Improvements

Overview

*By **ICAO Secretariat***

Aircraft provide a fast, reliable mode of transport with no comparable alternative for long distance travel. Throughout the years, technology improvements have been made to aircraft and engines to make them more fuel efficient. Today's aircraft are designed for more than 15% improvement in fuel burn than comparable aircraft of a decade ago, and will deliver 40% lower emissions than aircraft previously designed. Figure 1 provides an illustration of the tremendous improvements in fuel efficiency that have been achieved on a fleet wide basis since the 1980s. On a per-flight per-passenger basis, efficiency is expected to continue to improve through 2050.

ICAO projections (see Figure 2) show that the commercial aircraft fleet is expected to increase to about 47,500 by 2036, of which more than 44,000 (94%) aircraft will be new generation technology. Even under the most aggressive technology forecast scenarios, the expansion of the aircraft fleet, as a result of air traffic demand growth, is anticipated to offset any gains in efficiency from technological and operational measures. In other words, the expected growth in demand for air transport services, driven by the economic needs of all ICAO Member States, is outpacing the current trends in efficiency improvements. As a result, the pressure will increase to deliver even more ambitious fuel-efficient technologies – both technological and operational – to offset these demand-driven emissions, thus creating the need for new technologies to be pursued.

Overall fuel efficiency of civil aviation can be improved through a variety of means such as: increased aircraft efficiency, improved operations, and optimized air traffic management. Most of the gains in air transport fuel efficiency so far have resulted from aircraft technology improvements.

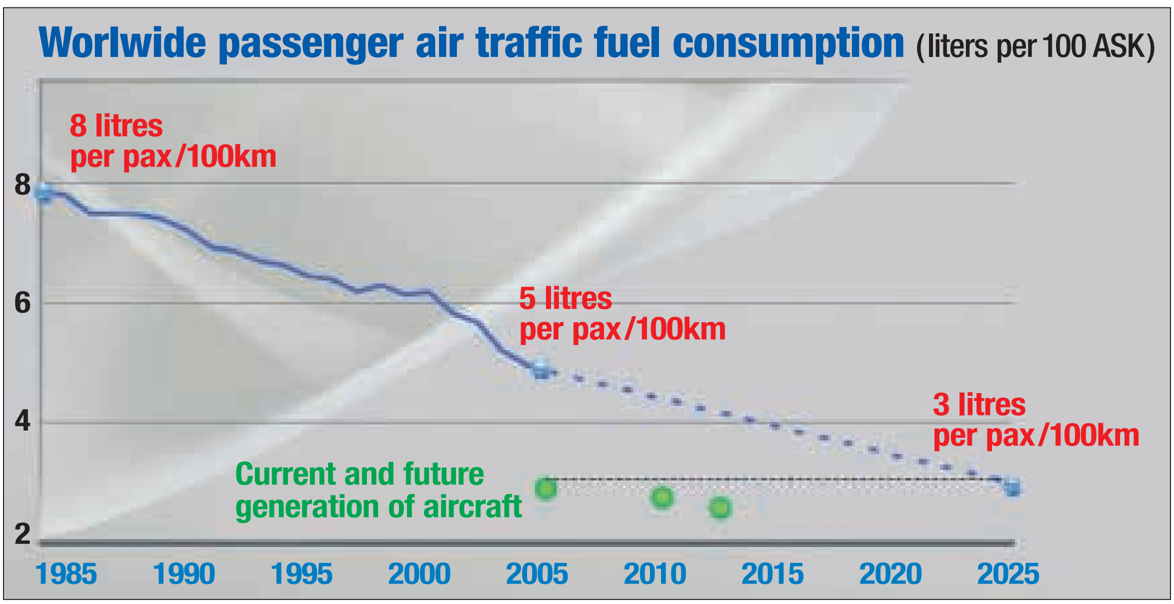


Figure 1: *Air traffic fuel efficiency trend and today's aircraft (source ICCAIA).*

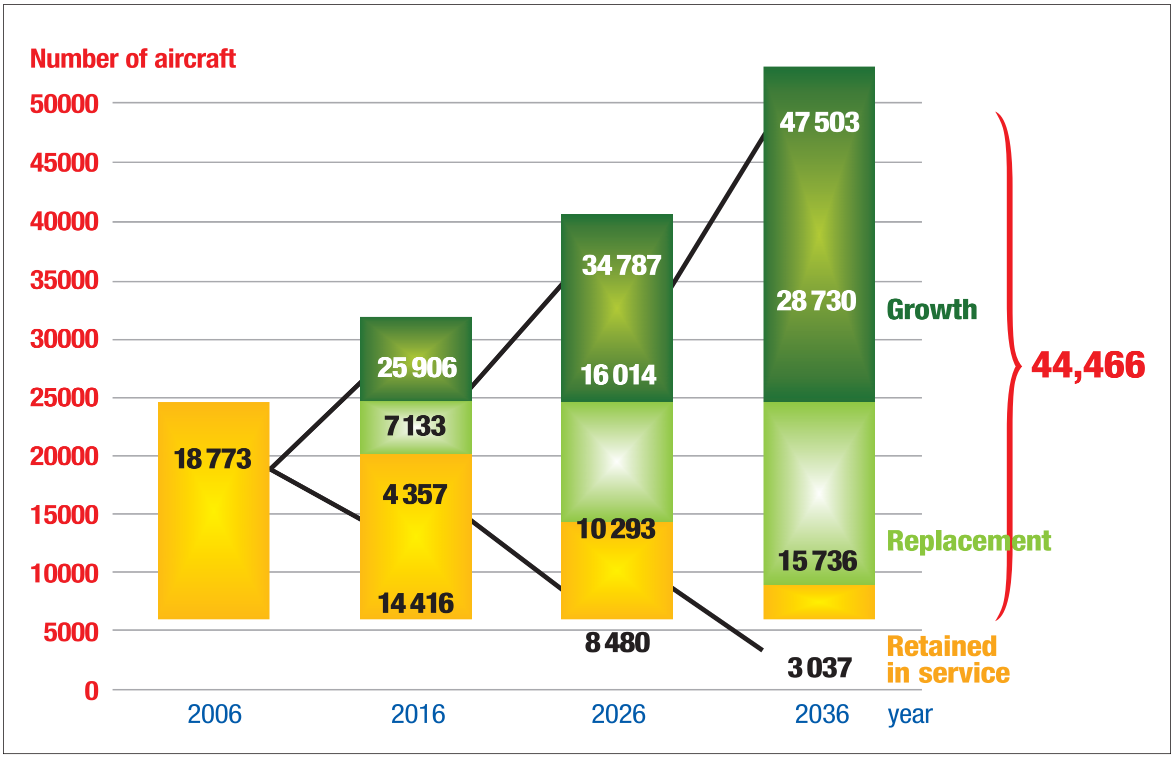


Figure 2: *More than 44,000 new aircraft are expected to be introduced by 2036.*

The articles in this Chapter of the report provide an overview of technology advances in aircraft and engine developments that have taken place and provide a high-level summary of goals that are expected to go beyond the current trends.

Background

Over the years, market pressure has ensured that aircraft continually become more fuel efficient. Since CO_2 production is directly related to fuel consumption, these economic pressures have also served to reduce CO_2 emissions. However, the concern over climate change over the last decade has meant additional pressure for solidifying the gains aviation has already made and to demonstrate the aviation sector's commitment to reducing its impact on global climate change. ICAO is cognizant of the global need for aviation to respond to these growing concerns.

A Programme of Action on International Aviation and Climate Change was adopted by the ICAO High-level Meeting on International Aviation and Climate Change in October 2009. A key component of this Programme of Action is the reliance on technological means including the development of a CO_2 emissions Standard for aircraft (see the article *Development of an Aircraft CO_2 Emissions Standard*, in Chapter 2 of this report). The programme includes a multi-faceted approach to reduce CO_2 emissions: technological advances, operational improvements, market-based measures, and alternative fuels. As mentioned before, the articles in this chapter provide an overview of technological advances.

Standards and Goals

Conscious of technology developments and the environmental needs, ICAO continuously reviews its environmental Standards, promoting more efficient and cleaner aircraft. Standards for emissions of NO_x, HC, CO and smoke from aircraft engines have been in place since the early 1980s. During this period, stringency in the NO_x Standard has increased by 50%. ICAO has also initiated work on certification Standards for non-volatile particulate matter (PM) emissions in light of the increasing scientific evidence linking PM emissions to local air quality and climate change issues.

Following the mandate from the 2009 ICAO High-Level Meeting, the eighth meeting of ICAO's Committee on Aviation Environmental Protection in February 2010 established a plan that aims to establish an aircraft CO_2 emissions Standard by 2013. More details on CAEP's work on a CO_2 Standard can be found in the article *Development of an Aircraft CO_2 Emissions Standard*, in Chapter 2 of this report.

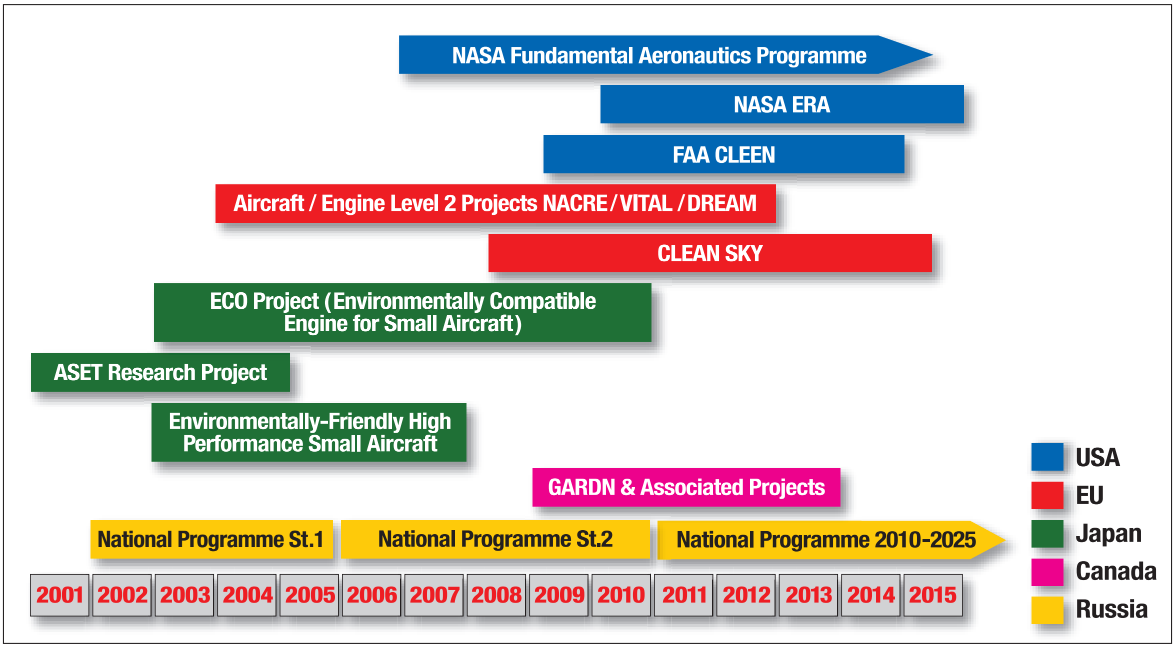


Figure 3: *National and regional research programs, worldwide (2001 to 2015). (adapted from an ICCAIA chart).*

Complementing the effort to establish a CO_2 Standard, CAEP had also requested advice from a panel of Independent Experts (IEs) on the prospects for reduced aviation fuel burn from technology advances, over ten and twenty years. This is to be based on the effects of "major technologies" on fuel burn/efficiency, as well as combinations of improvements from both aircraft and engines, including best possible integration. The IEs were requested to focus their analyses only on technologies, and not on operations, or new types of fuels, while quantifying interdependencies as much as possible. The objective of this effort is to complement the various research initiatives that are currently underway or planned in various regions of the world, as summarized in Figure 3.

It should be noted that some new initiatives have been launched whereby the research in the traditionally strong aerospace manufacturing regions has been sustained and generally expanded.

An overview of some of these research programs was presented at a workshop held in London in early 2009. In addition, the manufacturers provided detailed reviews of the work underway to improve the fuel efficiency of aircraft and engines. The article, *Pushing the Technology Envelope*, in Chapter 2 of this report gives a summary of the technology advances achieved by the manufacturing organizations and outlines the design process to optimize the overall performance of an aircraft.

The IEs augmented the expected technology improvements presented by research organizations and manufacturers with information collected from industry (e.g. IATA Teresa Project), and from some other sources in academia and research organizations. The IEs agreed on the necessity to do some modelling in parallel with that done by industry, in order to independently explore the effect of fuel burn using various technology configurations. Consequently, several academic and research institutions (e.g. Georgia Institute of Technology, DLR, Qinetiq, ICCT) are carrying out this task, thus complementing the industry modelling expertise. All organizations involved in detailed modelling efforts are ensuring that assumptions are consistent across all models.

A formal independent expert led review was held in May 2010. There, it was agreed that the independent experts group would need to consider "packages" of changes. For example, if one moves to an open rotor design, one cannot put an open rotor on an existing aircraft; it has to be a different design of aircraft. Similarly, a change to the aircraft design would be required if one moves to very high bypass ratio engines.

Of particular relevance to the 20-year goals, the IEs will consider three technology scenarios (TS) as follow:

TS1: Evolutionary technologies with low to moderate pressure for improvement.

TS2: Aggressive evolutionary technology development and insertion with high pressure for improvement.

TS3: Revolutionary technologies, doing things differently, with severe pressure for improvement.

Since the CO_2 Standard setting process has not yet been completed, a standard metric for fuel efficiency or fuel burn is not available. For this reason, IEs agreed that the fuel burn goals should be based on fuel quantity (kg) burned per available-tonne-kilometre (ATK) flown, namely kg/ATK. For this analysis, ATK is preferable to revenue-tonne-kilometre (RTK) because the IEs are looking at the technology and not at the operations. IEs adopted this metric as an interim measure; it is not intended to pre-empt the other work which is going on to formulate standards for aircraft CO_2 emissions.

The formal IE review in May 2010 was successful in gathering more information and outlining preliminary results which will help in ensuring that all modellers work from the same assumptions and uniform sets of technologies provided by IEs. The IEs plan to deliver a preliminary report for the first meeting of CAEP/9 Steering Group in late autumn 2010.

Future Directions

The current drawing boards of aircraft and engine developers contain blueprints for blended-wing-body airframes and ultra-high bypass ratio engines including open rotor and geared turbo-fans. These technologies are maturing and, depending on trade-offs with existing infrastructure and other environmental parameters, may soon be flying the skies. These technologies, together with improvements in operational procedures and deployment of alternative fuels, are helping to reduce aircraft emissions and their climate impacts.

At the same time, there have been exciting breakthroughs towards the development of radically new concepts that aim to drastically reduce or eliminate carbon footprints of aircraft. An example is the development of revolutionary conceptual designs for future subsonic commercial transports by an MIT team under a NASA contract (see article *Subsonic Civil Transport Aircraft for a 2035 Time Frame*, in Chapter 2 of this report). Another ambitious concept was demonstrated by a solar-powered airplane that took flight in July 2010. That experimental airplane with a huge wingspan completed its first test flight of more than 24 hours, powered overnight solely by batteries charged by its 12,000 solar panels that had collected energy from the sun during the day while aloft over Switzerland. The entire trip was flown without using any fuel or causing any pollution.

Technology advances in aircraft have been the major factor in improving the efficiency of air transport. Continued economic growth tied in with air traffic growth necessitates a multi-faceted approach to meeting the challenge of increasing emissions. ICAO is leading the way by establishing goals and developing standards based on the latest technologies that will pave the way towards zero-emissions aircraft of the future.

Pushing the Technology Envelope

By ***Philippe Fonta***

Philippe Fonta *was appointed Head of Environmental Policy of the Airbus Engineering's Center of Competence (CoC) Powerplant in March 2010. In this role, he leads the development and implementation of the environmental policy of the CoC Powerplant, which encompasses acoustics and engine emissions matters, from technological goal setting processes, associated research programs to certification and guarantees to customers. Mr. Fonta is also Chairman of the environmental committee of the International Coordinating Council of Aerospace Industries Associations (ICCAIA). Since 1999, Philippe Fonta is Airbus' representative in the ICAO FESG (Forecasting and Economic Analysis Support Group).*

The ***International Coordinating Council of Aerospace Industries Associations*** *(ICCAIA) was established in 1972 to provide the civil aircraft industry observer status as a means to be represented in the deliberations of the International Civil Aviation Organization (ICAO).*

Today ICCAIA provides an avenue for the world's aircraft manufacturers to offer their industry expertise to the development of the international standards and regulations necessary for the safety and security of air transport.

Airframe and engine manufacturers continuously strive to develop innovative technology and implement it into the eco-efficient design, development and manufacture of aircraft. This task involves compromises among many challenges, particularly on technical, economic and environmental issues; with safety remaining paramount. Continuous improvement is ensured through regular upgrades of the in-service fleet, and also to a wide extent, through the introduction of brand new aircraft types into the fleet. Over time, this results in remarkable continuous improvement evolution with respect to comparable previous generation aircraft.

Continuous Improvement - Ongoing Research For Better Technologies

Air transport's overall mission is to carry safely the highest commercial value, in passengers and/or freight, over an optimized route between two city pairs, with the minimum environmental impact. In that context, market forces have always ensured that fuel burn and associated CO_2 emissions are kept to a minimum. This is a fundamental impetus behind designing each new aircraft type. Historic trends in improving efficiency levels show that aircraft entering today's fleet are around 80% more fuel efficient than they were in the 1960's (see Figure 1), thus more than tripling fuel efficiency over that period. The two major oil crises, first in 1973, followed by the early 1980's, kept pressure on the industry to continue its ongoing pursuit of fuel efficient improvements. However, the impact of these crises on these ongoing efficiency improvements to the commercial fleet is hardly noticeable, demonstrating that market forces are the dominant driver of fuel efficiency improvements.

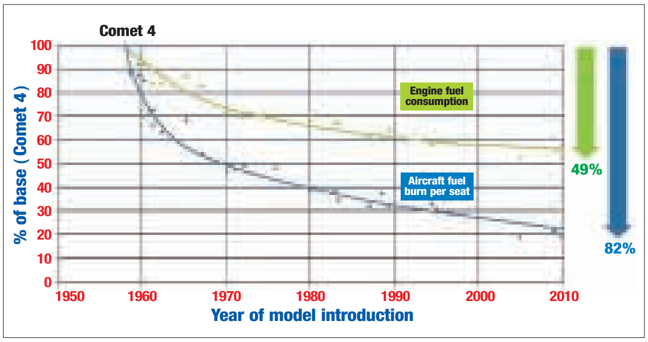


Figure 1: *Commercial aircraft fuel efficiency curve over time.*

Since the turn of the century, environmental awareness has increased and attention has increasingly been on CO_2 emissions, thus maintaining the incentive of manufacturers to achieve ever lower aircraft fuel burn.

In terms of practical measures, the Advisory Council for Aeronautics Research in Europe (ACARE) has established its Vision 2020, that targets an overall reduction of 50% in CO_2 emissions, coupled with a 50% reduction in the perceived noise level, and a reduction of 80% in NOx emissions. These ACARE objectives are technology goals that should be mature enough for introduction into an aircraft by 2020[1]. To achieve these goals, extensive, continuous, and consistent research programmes and joint initiatives are currently under way. Two significant examples are the Clean Sky Joint Technology Initiative (JTI) - one of the largest European research projects ever[2] - and the Single European Sky ATM Research project (SESAR)[3]. In North America, taking advantage of a single sky, continuous transformation of the Air Traffic Management (ATM) is, however, necessary to provide environmental protection that allows sustained aviation growth. This will be done mainly through the NextGen project, in cooperation with the aviation industry and comparable objectives to the European ones have been established in the US through extensive research programmes such as the US Federal Aviation Administration (FAA) CLEEN programme[4] and the NASA Environmentally Responsible Aviation Program[5].

In addition, some cooperation initiatives exist as a common goal to mitigate or reduce the impact of aviation on the environment. For instance, the Atlantic Interoperability Initiative to Reduce Emissions (AIRE) is a programme designed to improve energy efficiency and aircraft noise. It was launched in 2007, with cooperation between the FAA and the European Commission.

Understanding the Basics

Comparing different generations of aircraft is more difficult than it may seem because progress in design and technology is not made in isolation but rather, concurrently. For example, such elements as: structures, aircraft systems, aerodynamics, propulsion systems integration, and manufacturing techniques, all interact with one another, in a way that is specific to each product. Nevertheless, some significant key levers exist that will improve overall aircraft performance:

- Reducing basic aircraft weight in order to increase the commercial payload for the same amount of thrust and fuel burn.
- Improving the airplane aerodynamics, to reduce drag and its associated thrust.
- Improving the overall specific performance of the engine, to reduce the fuel burn per unit of delivered thrust.

The following paragraphs provide elaboration on how these factors affect the design and technology of an aircraft.

Weight Reduction

Generation after generation, aircraft manufacturers have demonstrated impressive weight reduction results due to the progressive introduction of new technologies such as: advanced alloys and composite materials, improved and new manufacturing processes and techniques (including integration and global evaluation simulation), and new systems (e.g. fly-by-wire). For instance, aircraft designed in the 1990's were based on metallic structures, having up to 12% of composite or advanced materials. In comparison, the A380, which has been flying since 2005, incorporates some 25% of advanced lightweight composite materials generating an 8% weight savings for similar metallic equipment. Aircraft that will enter the fleet in the next few years (e.g. Boeing 787, Airbus A350, Bombardier C-Series, etc.) will feature as much as 70% in advanced materials, including composite wings and parts of the fuselage, increasing the weight savings as much as 15% for this new level of technology. An illustration of this evolution is given in Figure 2 below.

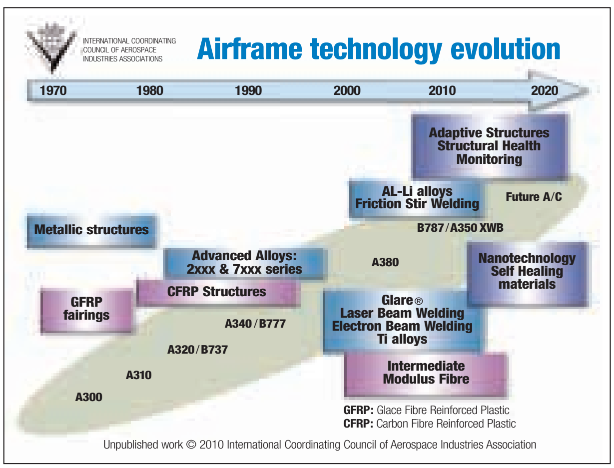


Figure 2: *Airframe technology evolution.*

Innovative manufacturing techniques have already been implemented, including advanced welding technologies such as: laser beam (see Figure 3), electron beam[6], and friction stir welding[7]. These innovations remove the need for traditional rivets, reducing aerodynamic drag, lowering manufacturing costs, and decreasing aircraft weight.

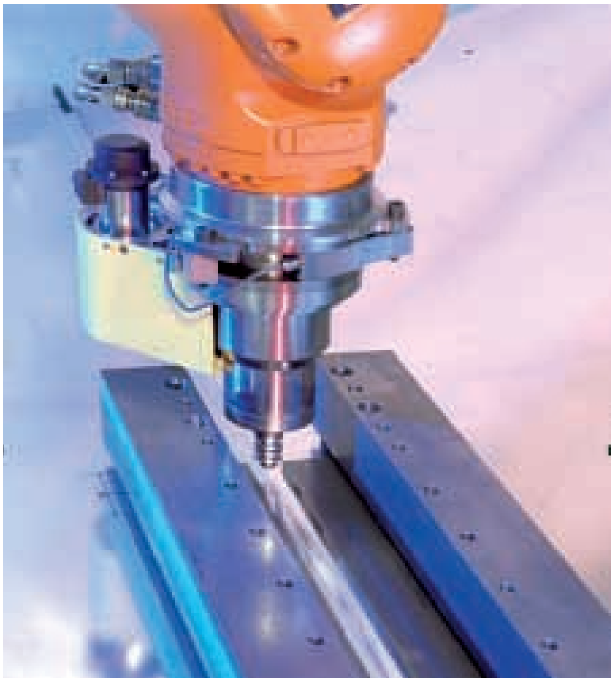


Figure 3: *Laser beam welder.*

Aerodynamic Improvements

The typical breakdown of total aircraft drag, in cruise mode, is shown in Figure 4.

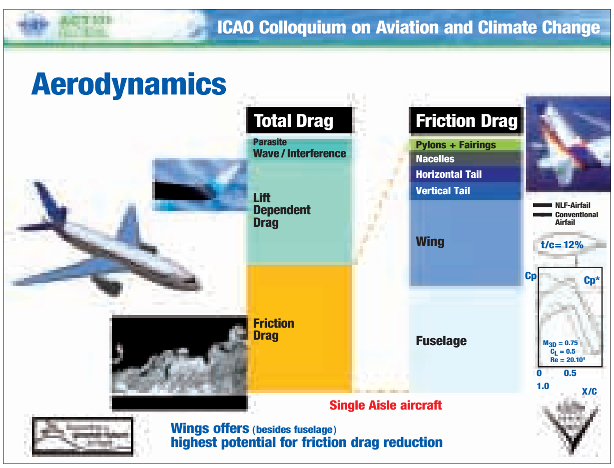


Figure 4: *Aerodynamic drag elements of a modern aircraft.*

Friction and lift-dependent drag are, by far, the largest contributors to aerodynamic drag. Advances in materials, structures and aerodynamics currently enable significant lift-dependent drag reduction by maximizing effective wing span extension. Wing-tip devices can provide an increase in the effective aerodynamic span of wings, particularly where wing lengths are constrained by airport (and/or hangar) gate sizes.

Friction drag is the area which currently promises to be one of the largest areas of potential improvement in aircraft aerodynamic efficiency over the next 10 to 20 years. Possible approaches to reduce it are to:

- Reduce local skin friction by maintaining laminar flow via Natural Laminar Flow (NLF) and Hybrid Laminar Flow Control (HLFC), thus reducing turbulent skin friction (e.g., via riblets).
- Minimize wetted[8] areas while minimizing/controlling flow separation and optimize surface intersections/junctures and fuselage aft-body shape.
- Minimize manufacturing excrescences (including antennas), and optimize air inlet/exhaust devices.

Potential NLF and HLFC application areas are wings, nacelles, empennages and winglets. The net fuel burn benefit depends on the amount of laminar flow achieved versus the extra weight required to maintain laminar flow.

NLF and HLFC have been demonstrated in aerodynamic flight demonstration tests on various components including: 757HLFC-wing, F100NLF-wing, Falcon900 HLFC wing, A320HLFC-empennage, and nacelles. Practical achievement of optimal laminar flow requires structures, materials and devices that allow manufacturing, maintenance and repair of laminar-flow surfaces.

Potential technologies have been presented by ICCAIA (see Figure 5) in the frame of the ICAO Fuel Burn Technology Review process, carried out under the leadership of independent experts, in May 2010. The level of technology maturity is expressed through the Technology Readiness Level (TRL) scale and the applicability to regional jets (RJ), single aisle (SA) and/or twin aisle (TA) aircraft is systematically looked at and indicated.

INTERNATIONAL COORDINATING COUNCIL OF AEROSPACE INDUSTRIES ASSOCIATIONS

Aerodynamic Technologies Considered by ICCAIA for 2010 Review

Technology	TRL	Improvement	Application	Caveats/notes
Riblets	Low/Med (4-6)	L/D: 1% to 2%	RJ, SA, TA	Material development: riblet material need to last longer than demonstrated in previous flight tests. Need to address installation and maintenance issues.
Natural Laminar Flow	Med (4-6)	L/D: 5% to 10%	RJ, SA, TA	Surface quality; design space, integration. Manufacturing, operational, and maintenance considerations.
Hybrid Laminar Flow Control	Low/Med (3-5)	L/D: 5% to 10+%	SA, TA	Need for simple suction-system design. Manufacturing, operational, power and maintenance considerations
Excescence Reduction	High (8)	L/D: 1%	RJ, SA, TA	Trade of benefit vs. manufacturing and maintenance cost
Variable Camber	Med/Hi (6-8)	L/D: 2%	RJ, SA, TA	Variable camber can also affect induced drag

- Only technologies that currently have TRL levels of a least 3 are considered here
- Benefits cannot be simply added (there can be aerodynamic interdependencies)

Figure 5: *Aerodynamic technologies for Fuel Burn Technology Review.*

Engine-Specific Performance

Engine manufacturers invest in technology to provide clean (i.e. for local air quality and global emissions), quiet, affordable (i.e. acceptable ownership costs), reliable (i.e. limited disruptions and maintenance costs), and efficient power. All trade-offs have to be properly handled and considered in evaluating an engine when it is being integrated into an airframe. This is a continuous process, and regular investments are made to maintain and improve the overall performance of in-service and in-production aircraft. For instance, multiple engine upgrade programs have been achieved in the last decade that delivered up to 2% fuel burn improvement (e.g. CFM56-5B Tech insertion, V2500 Select One, Trent 700 EP, GE90-115B Mat'y, etc.). Measurements, data gathering and analysis of in-service engines are regularly carried out, and scheduled maintenance (such as engine wash) is performed to keep engines operating at peak efficiency levels.

To support the development and testing of alternative fuels, some component, rig and engine ground tests have already been performed to determine engine performance and operability using blends of jet fuel and alternative fuels. In addition, engine and airframe manufacturers have been deeply involved with airlines in flight test demonstrations using alternative fuels over the past years. This major effort has led to the recent fuel type certification of up to 50/50 Fischer-Tropsch blend (ASTM7566 Annex 1 approval). Further certifications will be granted as other bio-jet fuels are tested and made ready for use.

As far as new products are concerned, engines and auxiliary power units (APUs) for new aircraft designs are expected to provide a minimum of 15% fuel savings with regards to the aircraft they replace. Some project and/or development aircraft (from business aeroplanes through regional and long-range aircraft, worldwide) are expected to bring significant benefits when they enter into revenue service in the near future. Engine technologies (e.g. materials, coatings, combustion, sensors, cooling, etc.) are modelled, tested and implemented as soon as they become mature. These technologies have a positive impact on:

Thermal Efficiency: higher operating pressure ratios (OPR) are targeted to improve combustion, and some engine cycle refinements are envisaged. All this must be balanced with the potential risks of increased maintenance costs, and weight and/or drag due to engine complexity in an overall context of maximum reliability.

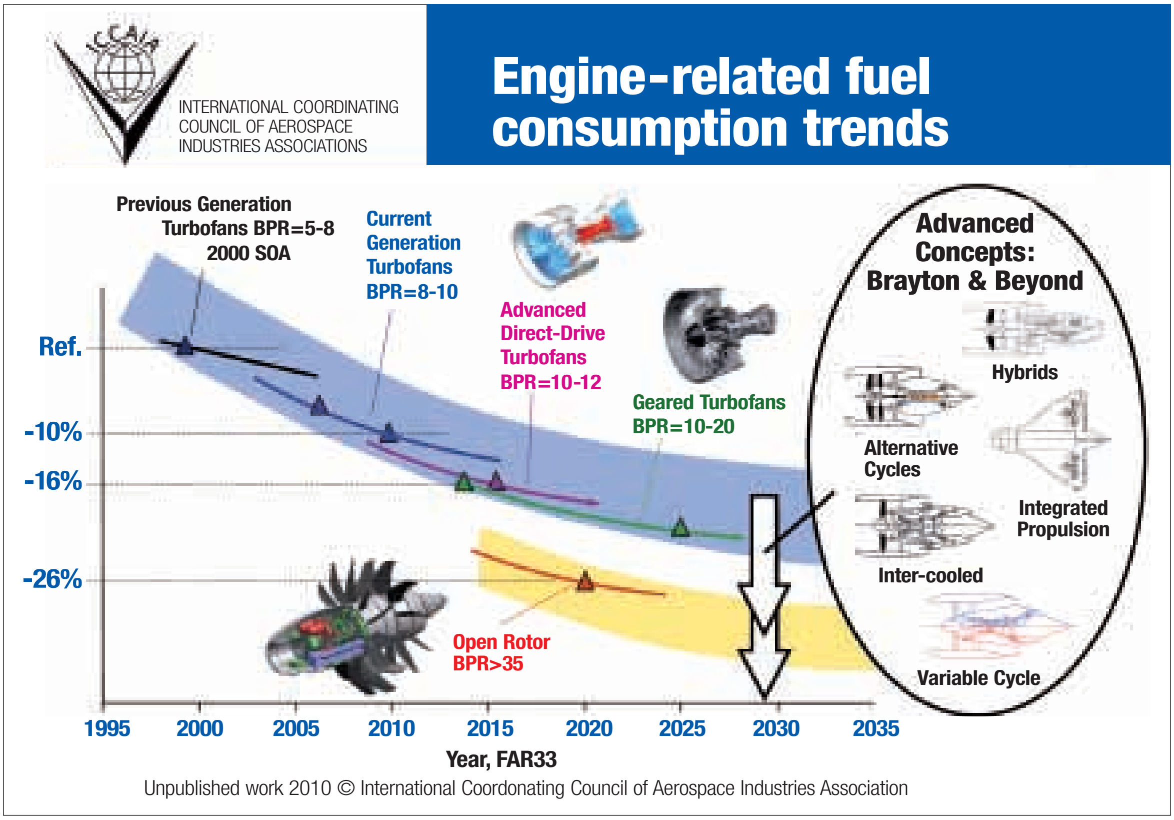


Figure 6: *History and future of engine fuel consumption trends.*

Transmissive Efficiency: through new components and advanced engine architecture.

Propulsive Efficiency: engine architectures are evolving (e.g. advanced turbofan), some different concepts are emerging (e.g. advanced geared turbo-fans, open-rotors, hybrids, etc.); each with their own multi-generation product development plans (see Figure 6).

In order to achieve the optimum improvements, massive investments have to be made in research programmes, and public/private partnerships are therefore essential.

New Design Methodologies

Due to non-linearity and strong interactions among components, the overall aircraft optimum is not obtained by simply summing the optimal solutions for each individual component.The design of a given component has to be directly driven by the benefits after integration.

Therefore, performance is gained by moving from a component-based design to a fully integrated design: wing, tail, belly fairing, pylon, engine, high lift devices, etc. Numerical simulation around complex geometries requires the development of new testing methodologies so that the behaviour and performance of the complete aircraft can be simulated. Within the next decade, simulation capabilities will be increased by up to a million times, to achieve that result.

Throughout the process of merging technology elements and design features to achieve the 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), keeping in mind that safety must and will remain the overarching requirement. Any new design needs to strike a balance between technological feasibility, economic reasonableness, and environmental benefit. The environmental requirements necessitate a balance in order to bring performance improvements across three dimensions: noise reduction, emissions reduction, and minimized overall 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 finally result in a fuel consumption increase.

Stable Regulatory Framework and Dependable Scientific Knowledge

Technological improvements are a key element of mitigating the impact of aviation on the environment. New products must be continuously developed and regularly introduced into the fleet to reduce aviation's environmental impact globally. However, significant global improvement is a long process. While the current and future generation of commercial transport aircraft will eventually burn less than 3 litres of fuel per passenger, per 100 kilometres, achieving this average fuel consumption for the worldwide fleet will take approximately 20 years.

Indeed, it can take up to 10 years to design an aircraft. Then, production can run over 20 to 30 years with each aircraft having a service life of 25 to 40 years. In an industry with such a long product life-cycle, today's choices and solutions must be sustained over several decades. Therefore, in order to make sound decisions for investments in future technologies, aircraft engine and airframe manufacturers need a stable international regulatory framework based on dependable scientific knowledge. Improved scientific understanding of the impact of aviation emissions on the Earth's atmosphere is key to optimizing priorities and assigning weight factors for prioritizing research, trade-offs, and mitigation measures.

The role of the manufacturers is stimulated and enhanced by their deep involvement in ICAO's Comittee on Aviation Environmental Protection (CAEP) activities and their participation in the achievements of that group in developing standards and recommended practices in a context that facilitates international harmonization and fruitful cooperation. ICAO has recently developed a basket of measures to reduce the impact of aviation on climate change and one element of this basket is the "development of a CO_2 standard for new aircraft types, consistent with CAEP recommendations", as highlighted in the recommendations of the ICAO High-level Meeting on International Aviation and Climate Change (HLM) in October 2009.

Aircraft and engine manufacturers are committed to working on the various steps that need to be achieved towards that new CO_2 standard. They also agree with the HLM recognition that a CO_2 standard for new aircraft is only one element of a series of measures that will need to be taken. Indeed, they welcome the additional HLM recommendations to "foster the development and implementation of more energy efficient aircraft technologies and sustainable alternative fuels for aviation" while recognizing the need to fully assess "the interdependencies between noise and emissions."

Climate change is a global issue that needs a global solution. Each stakeholder has a role to play in meeting the challenge, and no single player has the capability to solve the problem alone. It is understood that all parties involved: aircraft and engine manufacturers, their supply chain, airlines, airports, air traffic management services, research institutes, and civil aviation authorities; will have to work together towards their common objective – to reduce the overall impact of aviation on the environment. The industry (ICCAIA, IATA, ACI, CANSO) has presented a common position at various high level political meetings, advocating for a global solution to a global issue in which ICAO would play a leading role. This united position consists of three main elements:

- An average improvement of 1.5% per year in terms of fuel efficiency.
- Carbon neutral growth from 2020 onwards.
- An absolute reduction of net CO_2 emissions by 50% in 2050, compared to 2005 levels.

This united strategy will be based on aircraft and engine technology, together with operations and infrastructure measures. However, as can be seen in Figure 7 below, a 50% reduction of CO_2 emissions by 2050 cannot be achieved by advances in technology and operations alone. Alternative fuels and additional (yet to be developed) technology improvements will be required in order to achieve that aggressive goal.

Conclusion

Currently, policy makers are experiencing pressure from society to find rapid measures to mitigate the impact of aviation on the environment, and particularly on climate change. Meanwhile, industry is constrained by having to operate within the unchanged rules of physics.

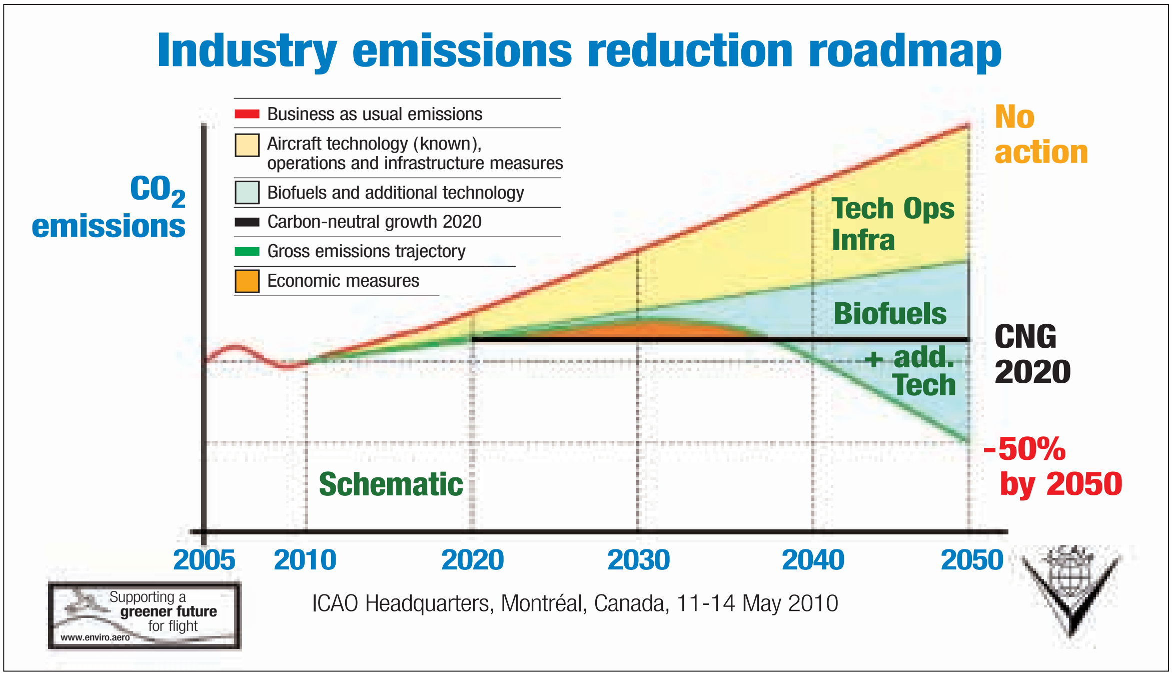


Figure 7: *CO_2 emission reduction measures over time.*

This environmental objective will not be achieved without cooperation between the industry and policy makers so that industry leaders can best anticipate the current and future expectations of society and devote significant resources to meet them. As indicated above, this will be achieved as a result of extensive research programs and their implementation in the design of aircraft and their engines. Governments must support the research programs so that the technology is ready as soon as it matures. Industry has a key role to play by putting forward the proposals and guiding the research, since these technologies will ultimately be incorporated into aircraft and engine designs.

This cooperation must balance short-term pressure-driven expectations with the need for technological breakthroughs in this long life-cycle industry. Resources must be enhanced and optimized, and new opportunities (such as alternative fuels) must continue to be explored. Some of the aircraft development projects that are currently envisaged will remain on the drawing board, while others will develop into real aeroplanes with substantial improvements that will ensure the environmental sustainability of aviation.

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1 With the conditions of operations of 2020, by comparison of a comparable aircraft technology, having been implemented in 2000 (with the operating conditions of 2000).

2 A budget of €1.6 billion, over the period 2008 – 2013, is equally shared between the European Commission and industry.

3 SESAR represents the technological dimension of the Single European Sky initiative, aimed at providing Europe with a high-performance air traffic control infrastructure which will enable the safe and environmentally friendly development of air transport.

4 FAA CLEEN (Continuous Lower Energy, Emissions and Noise) Programme Objectives are: 32 dB lower than Chapter 4, 60% lower NOx vs. CAEP/6, 33% lower fuel burn and use of alternative fuels.

5 Objectives are: 42 dB lower than Chapter 4, 70% lower NOx vs. CAEP/6, 50% lower fuel burn.

6 Directing a beam of fast-moving electrons at the metal surface –used on titanium components of the pylon for example.

7 A high-speed tool used to create heat through friction to join surfaces.

*8 In **aircraft**, the **wetted area** is the area which is in contact with the external airflow. This has a direct relationship on the overall drag of the aircraft.*

ICAO Technology Goals for NO_X Second Independent Expert Review

By ***Malcolm Ralph*** and ***Samantha Baker***

Malcolm Ralph *has longstanding connections with CAEP; most recently as an independent expert for Fuel Burn and* NO_x *Goals. Malcolm's working life has been mostly in aerospace, though he spent some years in the Air Pollution Division of WSL. He began his career working in transonic wind tunnels, and after studying mechanical engineering and post-graduate aerodynamics he rose to Technical Director Aerospace and Defence in the Department of Industry. There he was closely involved in launching many aircraft and aero-engine projects, and also worked on environmental matters. In 1999 he left that position to work as an independent consultant. Malcolm was elected Fellow of the Royal Aeronautical Society in 2000.*

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Samantha is actively engaged in CAEP, and currently leads a number of tasks including work on fuel burn technology goals. She has previously held posts in the UK Department of Energy and Climate Change and the UK Department for Environment, Food and Rural Affairs where she engaged with other UN organizations including UNFCCC and UNECE.

Background and Introduction

A certification Standard to control the amount of oxides of nitrogen (NO_X) permitted to be produced by civil turbo-jet and turbo-fan aircraft engines was first adopted by ICAO in 1981. The stringency of that Standard was successively increased at CAEP/2, 4, 6, and most recently at CAEP/8 in 2010. The introduction of a standard to control NO_X production was originally driven by concerns relating to surface air quality (SAQ) where NO_X is implicated in the production of ozone in the vicinity of airports. (see Local Air Quality Overview, Aviation Outlook of this report)

Consistent with these concerns, the Standards were set with reference to the amount of NO_X produced during a landing and take-off (LTO) cycle. Due to the accepted broad correlation between the amount of NO_X produced during the LTO cycle and that produced at cruise altitude, the standards also help to limit emissions at altitude. This is important, since scientists have linked NO_X emissions from aircraft engines to global climate change (GCC) and the production of particulate matter[1,2].

To complement the Standard-setting process, CAEP agreed in 2001 to pursue the establishment of technology goals over the medium and long term. These were to be challenging yet achievable targets for researchers and industry to aim at, in cooperation with States. Also they provide policy makers with a view of what technology could be expected to deliver for emission reductions in the future. The first of these reviews was to focus on NO_X, and to help achieve this, a panel of Independent Experts (IEs) was appointed and tasked with:

- Leading a review of technologies for the control of NO_X.
- Recommending technology goals for NO_X reduction from aircraft engine technologies over the 10 year and 20 year time horizons.

The first report of the IEs was presented to CAEP/7[3,4] in 2007 and the NO_X goals that were recommended - the first of their kind for ICAO – were adopted. The process has since been extended to include goals for noise, operations, and fuel burn. As part of the CAEP/8 cycle, progress towards the NO_X goals was reviewed once again by a panel of IEs to ensure transparency and involvement from all stakeholders[5]. As before, presentations were received from industry, research focal points, science focal points, NASA and EU researchers.

The Independent Expert Panel for NO_x

- Malcolm Ralph (Chair)
- John Tilston
- Paul Kuentzmann
- Lourdes Maurice

Recap of the NO_x Goals

The first NO_x IE review, conducted in 2006, proposed goals which were adopted at CAEP/7. The goals were defined as bands rather than single lines.

The goals can be seen in Figure 1, which is taken from the 2006 report of the IEs, together with goals proposed by the EU Advisory Council for Aeronautics Research in Europe (ACARE) and the US Ultra Efficient Engine Tecnology (UEET). It is important to note that these other goals were not used to influence the CAEP goals and were plotted simply for comparison. The graph also illustrates the historic ICAO NO_x Standards and highlights the large gap between the goals and the latest standard. It is important to note that the goals indicate that significant NO_x reductions are achievable over the 10 and 20 year timescales based on the leading edge of control technologies; while standards on the other hand are based on already certified technology.

Figure 1 uses the recognized NO_x certification metrics, and shows the amount of NO_x produced from an LTO cycle on the vertical axis (grams per kN of thrust), and the engine overall pressure ratio (OPR) at the take-off condition on the horizontal axis. It is evident that the larger, higher thrust engines operating at higher pressure ratios, and consequently at higher thermal efficiencies, produce greater amounts of NO_x. Note the slight change of slope of the Standard introduced at CAEP/4 at OPR 30. This explains why the IEs chose to define the goals as percentage reductions referenced against characteristic NO_x at OPR 30, as the goal bands did not mirror this change of slope. In relation to the degree of uncertainty, it should be noted that the band width was greater for the longer time period. The medium term (MT) goal for 2016 was agreed at 45% ± 2.5% below CAEP/6 at OPR 30, and the long term (LT) goal for 2026 at 60% ± 5% below CAEP/6 also at OPR 30.

Second NO_x IE Review

The second NO_x review was intended to be less extensive and was focused on what had changed in the intervening three years since the first review.

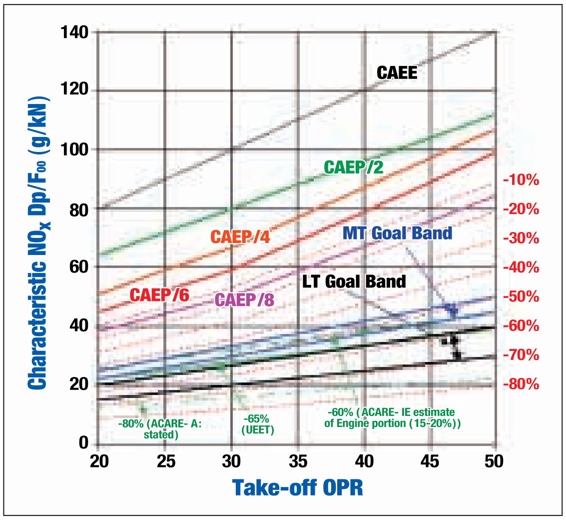

Figure 1: *Historical ICAO certification Standards together with the 2006 MT & LT goals.*

The IEs were asked to specifically include the following in their review:

- Science (global climate change and surface air quality).
- Technology progress towards the MT and LT goals.
- The validity of the goals.

However, in practice once the review got under way, in order to work through some difficult issues, the IEs extended the task list to also include:

- Small and mid OPR engines.
- Whether to change the definition of when a goal is met.
- Cruise NO_x.

Key discussion points and findings from the review are summarized below.

Science (Global Climate and Air Quality)

The IEs concluded that the scientific evidence supports continued efforts to reduce aircraft NO_x emissions and that the evidence of impact of aircraft NO_x on both surface air quality and global climate change was, if anything, more compelling than during the first review. Nevertheless, given the still considerable uncertainty about the quantification of these impacts, the IEs recommended continued research on NO_x emissions, and other emerging concerns such as particulate matter (PM), and the role of NO_x in PM formation. As in the 2006 report, it was again concluded that for SAQ, NO_x continues to be an important pollutant and in the context of Global Climate Change (GCC) its ranking versus CO_2 continues to depend crucially on the length of the time horizon. It appears that NO_x is more important in shorter time periods, with CO_2 dominating in the longer term, and then continuing to do so over many hundreds of years.

Progress Towards the Medium and Long Term Goals

Since 2006, further significant reductions in NO_x emissions have been evident, something for which manufacturers should be congratulated. Even further reductions are predicted using combustors still under development.

Advanced combustors can be categorized into two broad types: RQL systems (rich burn, quick quench, lean burn), and staged-DLI (direct lean injection), also called staged-lean burn systems. In very simple terms, RQL combustors control NO_x production through a series of changes to the air to fuel ratio as the combustion air progresses through the combustor. Staged-DLI combustors operate quite differently with NO_x control being achieved by switching (staging) between pilot and main burner zones arranged in concentric circles. Although reductions in NO_x production were shown to have been achieved by both types of combustor, neither was deemed to have met the goals set at the first review - defined as having reached Technology Readiness Level 8 (TRL8)[6] - although they were possibly close to that.

Figure 2 provides a summary presentation of the test data results received for this review with the two types of combustor identified separately; the data points coloured grey being for RQL combustors, and those in red being for the new staged-DLI combustors. As with the first review, the conclusion reached was that RQL combustors appear likely to meet the MT goal, though a significant challenge remains, but the LT goal may not be achievable particularly for high OPR engines. Dramatic reductions in NO_x production from the use of new generation staged DLI combustors were in line with the expectations recorded in the 2006 Report, although the migration towards the LT goal was not expected so soon. However, the wide spread of NO_x performance raised questions about how such families of engines might be handled in the future within a goals setting process.

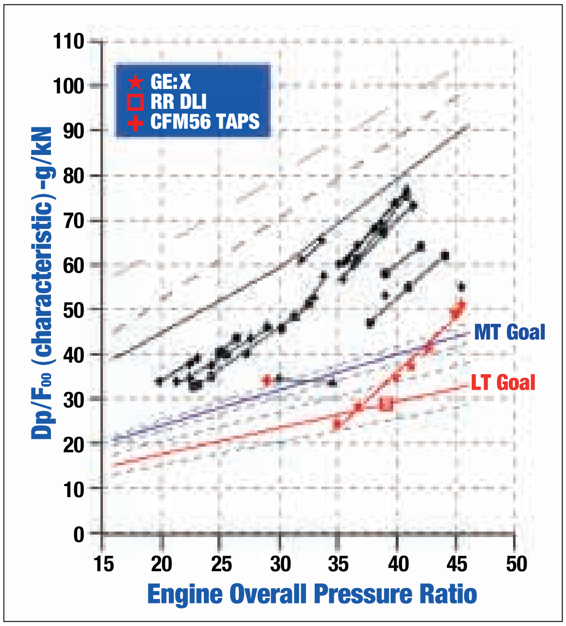

Figure 2: *2009 Review data with RQL combustors in grey and new generation staged DLI combustors in red. Note these data points are a mixture of certificated engines and high TRL developments.*

Mid and Low OPR Engines

Referring again to Figure 2 but this time focusing on engines below OPR 35, there are only three data points at or near the MT goal band, two coloured grey, using RQL combustors, and one red data point depicting staged-DLI. The two RQL (grey) points at around OPR 30 and OPR 34 are members of one engine family at TRL6 maturity and are shown as predicted to lie close to the top and bottom of the MT band. Uniquely, these are geared fan engines and it is thought likely that overall engine cycle effects may have contributed to these impressively low LTO-based results.

The staged-DLI, mid-OPR, single data point lies just above the MT band at just below OPR 30 and shows a prediction extrapolated from current TRL6 maturity. This was the only new generation staged-DLI demonstrator for which information was received for mid-OPR engines. No data was available to give confidence that staged-DLI combustors could sensibly be fitted to smaller (low OPR) engines, at least in the shorter term.

Validity of The Goals

Information presented for advanced RQL combustors was believed not to challenge the definition, or levels, of the goals established at the first review. The somewhat limited information relating to the new generation staged-DLI combustors however was thought to offer something of a challenge to both the definition and the goal levels. Nevertheless, since they are untested in commercial service, the IEs decided not to change the goals at this review but to wait until further experience had been gained. It was concluded that staged-DLI combustors were likely to be essential to meet the LT goal, particularly at high OPRs. A critical factor for future goal setting will be the extent to which advanced RQL and staged-DLI systems can be made to work effectively for (smaller) low and mid-OPR engines.

Cruise NO_x

Currently, there is an accepted broad correlation between the amount of NO_x produced during the heavily prescribed LTO cycle used for certification, as compared with the amount produced at cruise , but for which no standard exists or database is available. As in the first IE report, concern was expressed about future uncertainties with this relationship due to the significantly different behaviour of staged-DLI combustors, and the potential change in cruise characteristics of possible new engine architectures such as open rotor engines, and also possibly, geared turbo-fans.

Staged-DLI combustors have the potential to considerably reduce NO_x at cruise levels, but the IEs noted that, because the current NO_x Standard is LTO-based, manufacturers may trade off cruise NO_x if they need to address problems with meeting LTO NO_x for certification. IEs have therefore recommended that CAEP considers further scientific advice on the relative importance of cruise NO_x and then return to this issue for advanced combustors and engine architectures.

Conclusions

In light of the above, a number of conclusions can be made based on the second IE review of technology goals for NO_x:

- Evaluation of progress towards the goals is a key part of the goal-setting process, and the second NO_x review was able to take into account new developments in technologies as more information became available.
- The technology goal-setting process is of value. The goals provide challenging, yet reasonable targets for researchers and industry to aim at in cooperation with States, and they inform policy makers of what technology could be expected to deliver emissions reductions in the future.
- For RQL combustors, considerable progressive improvements were noted, although the IEs considered that these did not challenge the goals established at the first NO_x review.
- The first NO_x review anticipated that a significant change in technology through the use of staged combustors would occur in the future. At that time it was difficult to understand how these would impact the goals but data presented during the second review indicated that significant improvements are now more likely.
- IEs recognized that considerable progress had been made since the first review, but decided not to recommend a change, either to the goals or the definition of their achievement, in order to avoid hasty, and possibly ill-conceived changes to what were intended to be mid and long term targets.
- IEs were particularly concerned that sufficient time be allowed for the potential of staged-DLI combustors to be clarified, and also to await further evidence on the applicability of both advanced RQL and staged-DLI combustors to smaller low and mid-OPR engines. If precluded from these categories, there could be significant implications for future goals.
- IEs recommended that a further review be considered in about three years when, in all probability, it will be possible to resolve most of these outstanding issues.

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Report of the Independent Experts on the 2006 NO_x Review, Appendix 2; and the 2009 Report, Appendix A

Advision Council for Aeronautic Research in Europe (ACARE)
Ultra Efficient Engine Technology (UEET)
Global Climate Change (GCC)

Environmental and Economic Assessment of NO_X Stringency Scenarios

By ***Gregg Fleming*** and ***Urs Ziegler***

*As Director of the Environmental and Energy Systems Center of Innovation at the Volpe Center, **Gregg Fleming** has almost 25 years of experience in all aspects of transportation-related acoustics, air quality, and climate issues. He has guided the technical work of numerous, multi-faceted teams on projects supporting all levels of Government, Industry, and Academia, including the Federal Aviation Administration, the Federal Highway Administration, the National Park Service, the National Aeronautics and Space Administration, the Environmental Protection Agency, and the National Academy of Sciences. Mr. Fleming currently co-chairs ICAO's Modeling and Databases Group and represents the FAA at the UNFCCC. He is also Chairman Emeritus of the Transportation Research Board's Committee for Transportation Related Noise and Vibration.*

*After receiving his doctoral degree in earth sciences **Urs Ziegler** worked in the field of environmental protection for a Swiss civil engineering company. Later he joined the Swiss Office for Environmental Protection where he worked for more than 10 years. During this time Mr. Ziegler also acquired a masters degree in public administration. In 2005 he joined the Swiss Federal Office of Civil Aviation FOCA as Head of the Office's Environmental Affairs Section. He is the actual Swiss member in the International Civil Aviation Organization's Committee for Aviation Environmental Protection CAEP within which he currently co-chairs the Modelling and Databases Group. He also represents FOCA in various international bodies dealing with aviation and climate change.*

Introduction

This article presents an overview of the analysis conducted by CAEP of the cost impacts, emissions reductions, and environmental trade-offs of the NO_X stringency scenarios that were considered by the eighth meeting of the Committee on Aviation Environmental Protection (CAEP/8). In addition to examining the environmental benefits and associated environmental tradeoffs, the cost effectiveness for a range of scenarios was also considered. Cost-effectiveness results are presented as costs per tonne NO_X reductions during the ICAO Landing and Take-Off (LTO) cycle. The primary goal of conducting such an analysis is to indentify scenarios that result in substantial environmental benefits at reasonable costs.

In total, 10 scenarios were considered for modelling, as shown in Table 1. Small and large engine categories were assessed, and reported separately, to better understand if a

NOx Stringency Scenario	Small Engines	Large Engines	
	[26.7 kN / 89 kN Foo][1,2]	OPR[3] >30	Slope[4]
1	-5% / -5%	-5%	2
2	-10% / -10%	-10%	2.2
3	-10% / -10%	-10%	2
4	-5% / -15%	-15%	2.2
5	-15% / -15%	-15%	2.2
6	-5% / -15%	-15%	2
7	-15% / -15%	-15%	2
8	-10% / -20%	-20%	2.2
9	-15% / -20%	-20%	2.2
10	-20% / -20%	-20%	2.2

Methodology

[1] Foo – Thrust rating. For engine emissions purposes, the maximum power/thrust available for takeoff under normal operating conditions at ISA (International Standard Atmosphere) sea level static conditions without the use of water injection as approved by the certificating authority. Thrust is expressed in kilonewtons (kN).

[2] Incremental stringency options defined for small engines with thrust ratings (Foo) comprised between 26.7 kN and 89 kN.

[3] OPR – Overall Pressure Ratio. This engine pressure ratio is defined as the ratio of the mean total pressure at the last compressor discharge plane of the compressor to the mean total pressure at the compressor entry plane, at the engine takeoff thrust rating (in ISA sea-level static conditions).

[4] Slope of the line of the NO_X stringency options at engine pressure ratio (PR) greater than 30.

***Table 1:** NO_X Stringency scenarios examined.*

given stringency scenario resulted in an inequity between the small and large engine categories. The 10 stringency scenarios were analyzed for the years 2016, 2026 and 2036, for two stringency introduction dates: 31 December 2012 and 31 December 2016.

Methodology

A Modification Status (MS) methodology was developed by CAEP to assess engine technology responses to the various NO_x stringency scenarios. The three MS technology response levels are: Minor Changes (MS1), Scaled Proven Technology (MS2), and New Technology (MS3). The MS methodology covers the situation where an engine family fails to meet a NO_x stringency scenario and a different category of response is proposed that may bring it into compliance with the stringency scenario. Only MS1 and MS2 technology responses were needed for the small engine group to meet the NO_x stringency scenarios, while all three MS technology responses were needed for the large engine group at the higher stringency scenarios, as shown in Figure 1.

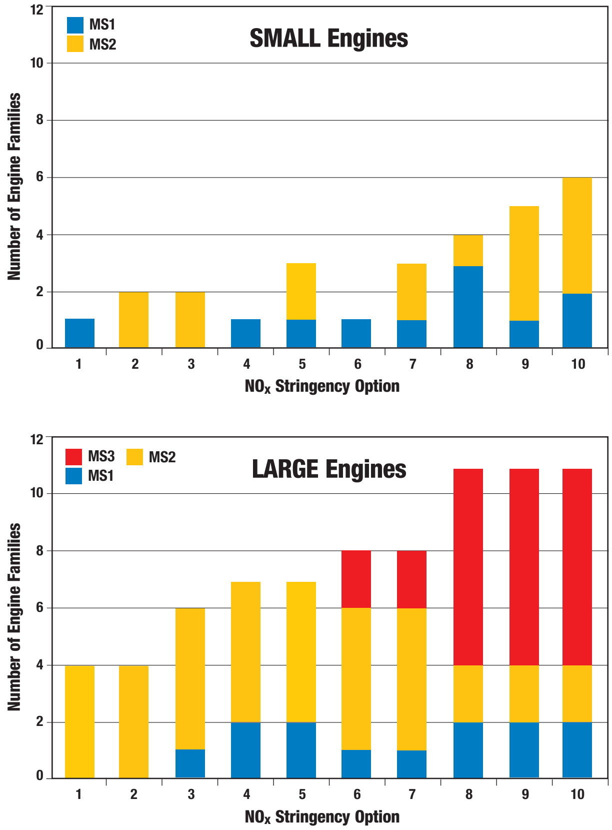


Figure 1: *Number of engine families requiring an MS technology response.*

Emissions Reduction Results

Figure 2 shows the total NO_x reductions for all engines for the below 3,000 ft case. Similar results were computed separately for large and small engines. The total savings for the large engines are about two orders of magnitude higher than for the small engines — large engines accounting for about 99% of the total NO_x savings across all scenarios. For the all-engines grouping, total NO_x reductions computed for the below 3,000 ft case range from about 6,300 metric tonnes to over 114,000 metric tonnes, or from 1.4% to 9.8% below the baseline "no stringency" case.

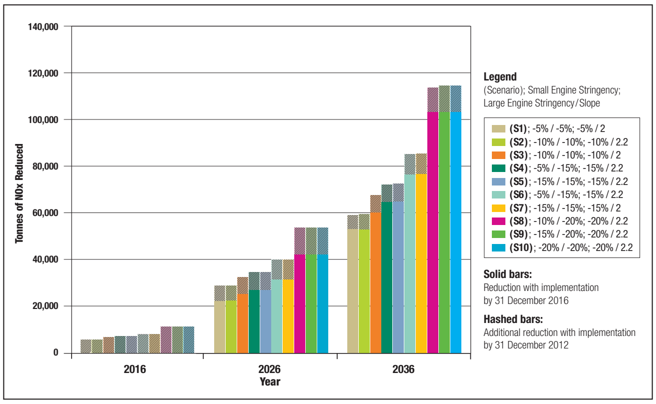


Figure 2: *Total below 3,000 ft. - NO_x reductions relative to baseline - all engines.*

The total NO_x reductions for the above 3,000 ft case range from about 54,000 metric tonnes to over 773,000 metric tonnes for all-engines, or from 1.5% to 10.1% below the baseline "no stringency" case – about the same percentage range as for the below 3,000 ft case.

Cost Results

Cost impacts were estimated for each stringency scenario listed in Table 1 for the two implementation dates, for both small and large engine categories separately. A range of values was used for a number of key assumptions, including: non-recurring costs, fuel burn penalty, fuel price, loss of resale value (LRV), and a variety of discount rates.

A 30-year time horizon through 2036 was used to calculate and assess the Net Present Value (NPV) of industry costs and to aggregate NO_x emissions reductions. The aggregate NO_x emissions reductions were computed using the modelled results from 2006, 2016, 2026 and 2036.

Table 2 summarizes total cost impacts for small and large engines combined. For stringency scenarios 1 through 5 they are broadly similar, but for scenarios 6 through 10 costs increase sharply, driven by non-recurring costs for engines under the MS3 technology response.

NOx Stringency Scenarios	Low Cost Estimate ($M) 3% discount, 2016, LRV	High Cost Estimate ($M) 3% discount, 2016, LRV
1-5	$ 1,922	$ 2,500
6-7	$ 6,412	$ 9,470
8-10	$ 10,878	$ 21,507

Table 2: *Cost results – large and small engines combined.*
LRV *– Loss in Resale Value.*

While efforts were made to comprehensively quantify all cost impacts, some costs were not included. For example, increased industry operational costs for scenarios involving higher fuel burn were partially itemized to include fuel costs and costs associated with loss in payload for payload limited flights. However, carbon costs for additional CO_2 emissions such as those resulting from the inclusion of airlines in the EU Emissions Trading Scheme were not itemized, and consequently were not included in the cost roll-up, although its effects could be assumed to be approximated by the sensitivity cases for the fuel prices.

Environmental Trade-Offs

An important part of the NO_x stringency assessment is the consideration of environmental trade-offs between the various NO_x stringency scenarios, fuel burn, and noise. The CAEP emissions technical group recommended a fuel burn penalty range of between 0% and 0.5% for engine families requiring a major modification (MS3). Figure 4 presents the maximum potential fuel burn penalty for the full-flight case.

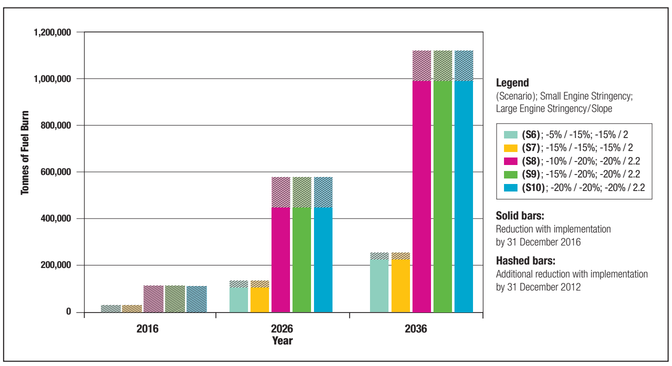


Figure 3: *Maximum potential full flight fuel burn penalty relative to baseline - all engines.*

In accordance with the CAEP emissions technical group recommendations, the MS3 fuel burn penalty only applies to large engines and only for scenarios 6 through 10. As can be seen in Figure 4, the maximum potential fuel burn penalty ranges from about 28,000 metric tonnes to 1.1 Mt (1.1×10^6 metric tonnes), which equates to between 0.01% and 0.19%, relative to the baseline "no stringency" case. This translated into additional CO_2 emissions of between 88,000 metric tonnes and 3.5 Mt. In accordance with the technical group's recommendations, the minimum fuel burn penalty is zero.

The noise technical group recommended a noise penalty range of between 0 decibels (dB) and 0.5 dB per certification point for 10% of engines requiring a major (MS3) modification, i.e. 10% of all engines. As with fuel burn, the MS3 noise penalty only applies to large engines and only for scenarios 6 through 10. The effect of the MS3 noise penalty on the 55, 60 and 65 Day-Night Noise Level (DNL) contour areas expressed as a percentage change was less than 0.12%. Based on these findings, it was concluded that the analysis indicated that there is **no** noise trade-off associated with **any** of the NO_x stringency scenarios. This conclusion has been verified at the global, regional, and airport levels.

Cost-Effectiveness Results

The cost-effectiveness results are dominated by large engines which, as stated earlier, account for approximately 99% of the benefits. Scenarios 1 through 5 are the most cost effective, all providing relatively low cost per tonne of NO_x reduction levels. For scenarios 6 and 7, cost per tonne of NO_x reductions increased by a factor of 3 to 4, using a 3% discount rate. Scenarios 8, 9 and 10 result in a further doubling of cost per tonne of NO_x reductions. Cost-effectiveness rankings for large and small engines are shown in Tables 3 and 4, respectively.

Although the analysis concentrates on NO_x reductions up to 3,000 ft, stringencies also have an effect on climb/cruise NO_x emissions. If these were taken into account, the total reductions achieved would increase by an approximate factor of 7 to 8, and the costs per tonne would diminish accordingly.

The early implementation date of 2012 gives overall lower values for the costs per tonne of NO_x reductions. This is due to the additional four years of NO_x reductions that would be gained, compared with 2016 implementation, coupled with roughly the same costs for both implementation dates. This

Ranking	Stringency Reference	NOx Reduction % Slope of Dp/Foo
1	NS01, NS02, NS03, NS04, NS05	-5% / 2.0, -10% / 2.2, -10% / 2.0, -15% / 2.2
2	NS06, NS07	-15% / 2.0
3	NS08, NS09, NS10	-20% / 2.2

***Table 3:** Cost-effectiveness ranking - large engines.*

Ranking	Stringency Reference	NOx Reduction %
1	NS01, NS04, NS06	-5% / -5%, -5% / -15%
2	NS08	-10% / -20%
3	NS02, NS03	-10% / -10%
4	NS010	-20% / -20%
5	NS09	-15% / -20%
6	NS05, NS07	-15% / -15%

***Table 4:** Cost-effectiveness ranking - small engines.*

implies that an early implementation year would be more cost effective. However, in the approach used, it is assumed that the non-recurring costs for the technology responses needed to start four years in advance of implementation (from 2009). This may mean that, in practice, a date somewhat later than 2012 is more reasonable, particularly for those scenarios involving MS3 modifications.

Figures 4 and 5 present NO_x cost-effectiveness results for large engines and small engines, respectively. Figure 4 includes large engine results for both 2012 and 2016 implementation dates. The gold columns represent cost uncertainty bands for the 10 stringency scenarios based on a 2016 implementation date; whereas, the red columns represent the uncertainty bands for a 2012 implementation date. The sloped "fan lines" indicate lines of constant cost per tonne of NO_x reductions.

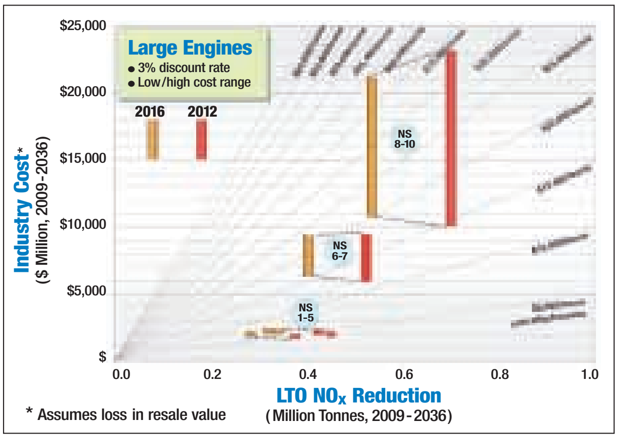


***Figure 4:** NO_X cost-effectiveness results – large engines.*

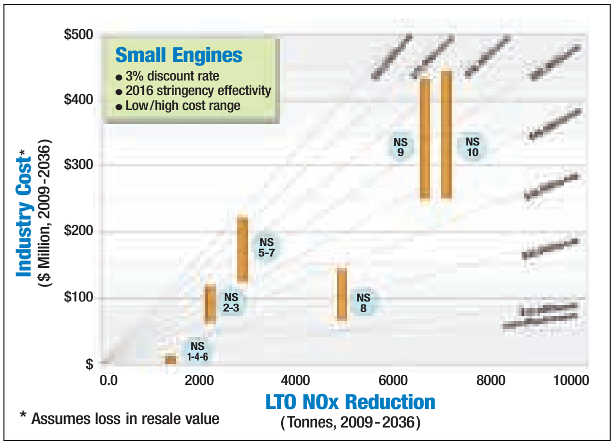


***Figure 5:** NO_X cost-effectiveness results – small engines.*

Conclusions

The environmental and economic analysis that was conducted informed CAEP/8 of the emissions reduction potential, environmental tradeoffs, and cost effectiveness of the NO_X stringency scenarios under consideration.

The analysis revealed that small engine aircraft contribute approximately 1% of the aggregate NO_X reduction benefit. Additionally, while the total costs to make small engines compliant are low, their cost-effectiveness is weak, by a factor ranging from 30% to as high as 200%. It was also found that the discount rate does not affect the ranking of NO_X stringency scenarios, but higher discount rates give lower present value to the NO_X reduction in the future years. Similarly, none of the other sensitivity tests performed influence the ranking of scenarios.

Development of An Aircraft CO_2 Emissions Standard

By ***Curtis A. Holsclaw***

***CURTIS A. HOLSCLAW** is the Manager of the Emissions Division in the FAA's Office of Environment and Energy. In that capacity he manages a staff that is responsible for the policy, regulatory, and technical aspects of aviation emissions as it relates to engine emissions, air quality, and global atmospheric effects. This includes research, engineering and development activities to advance the characterization of aircraft emissions, computer-modeling techniques and methodologies to better estimate the environmental and health impacts of aviation related emissions and to assess measures to reduce those impacts. He has about thirty years of experience in aircraft noise and engine emissions certification. In addition, he has been actively involved in CAEP activities for about twenty five years in order to develop noise and emissions certification standards for commercial transport aircraft and engines.*

Background

The eighth meeting of ICAO's Committee on Aviation Environmental Protection (CAEP/8) held in February 2010, made important decisions regarding technological means to reduce the impact of aviation on climate change. The meeting established a timeline for the development of a CO_2 certification Standard (see Figure 1). In addition, agreement was reached on increased stringency for aircraft NO_x emissions Standards, which also has an effect on global climate.

Considerable work has been carried out in the past by CAEP technical experts, especially over the last three years, which has enabled ICAO to adopt this promising timeline.

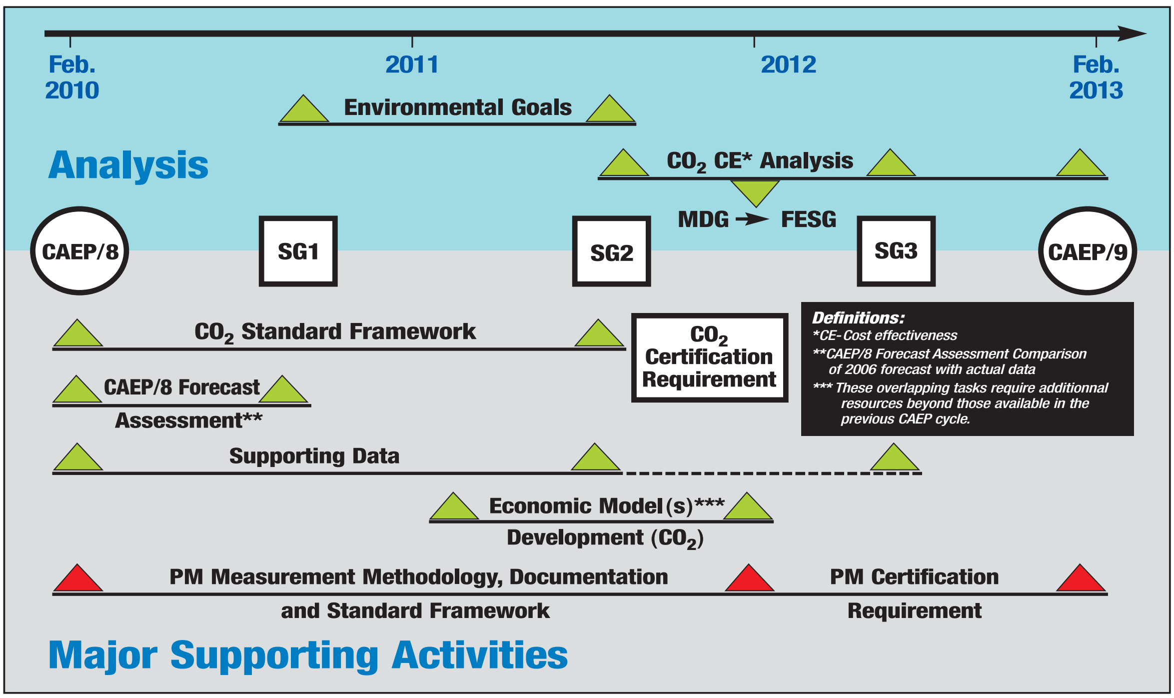


***Figure 1:** CAEP/8 established timeline for an aircraft CO_2 emissions Standard.*

Introduction

Initial discussions within the CAEP technical expert group on emissions were held in order to clarify the high-level objective of the task. It was agreed that the effort would be referred to as a "CO_2 Standard" based on "fuel efficiency concepts" within the certification requirement metric. This was decided in order to ensure the necessary transparency and public understanding that is essential to demonstrate that this work is contributing to efforts to reduce aviation's impact on climate change.

It was also agreed that any mitigation of aircraft CO_2 emissions through the production and use of alternative fuels would be considered via a full life-cycle analysis, which was deemed to be outside the scope of the immediate work item. It is believed that, if alternative fuels are developed in the future with specifications significantly different from current aviation kerosene, then this would need to be addressed separately.

Specific issues addressed by technical experts during the scoping analysis were as follows:

- Historic CAEP work in this area.
- Terminology and high-level objectives.
- Scope of requirements/priority.
- Metric requirements and characteristics.
- Certification procedure options.
- Applicability.
- Certification instrumentation and measurement methodology.
- Regulatory level.
- Manufacturer compliance.

Historic CAEP Work In This Area

Work done previously by CAEP related to this issue needed to be considered first in order to benefit from critical lessons already learned and to avoid duplicating previous discussions and work efforts. Accordingly, a thorough review of the previous work resulted in the following points being agreed upon:

- A certification requirement allows differentiation of products with different technology.
- Any fuel efficiency certification requirement should be aircraft based.
- A certification scheme needs to be based on certified aircraft/engine parameters.
- There is a need to explore a range of possible aircraft fuel efficiency metrics, identifying their positive and negative aspects, before making a final choice.
- The choice of a representative mission or reference point (certification procedure) is a complex issue due to the wide range of aircraft types and operational missions.

Terminology

The following terminology was agreed to as a working basis for future discussions on this subject:

Standard – combination of a certification requirement and a regulatory level.

Certification requirement – the combination of metrics, procedures, instrumentation, measurement methodology(ies), and compliance requirements.

Parameter - a measured or calculated quantity that describes a characteristic of an aircraft (e.g. MTOW, Optimum Cruise Speed).

Metric – a certification unit consisting of one or more measurement parameters (e.g. Dp/Foo).

Procedures – specific certification procedures, including applicability requirements (e.g. Annex 16 Volume II, Chapter 2).

Instrumentation and measurement methodology – technical measurement procedures (e.g. Annex 16 Volume II, Appendix 3).

Certified level – approved for a specific product by a certification authority to demonstrate compliance with a regulatory level, as determined by the certification requirement.

Regulatory level – a limit which a certified level must meet (e.g. CAEP/6 NO_x).

High-Level Objectives

The following high-level objectives for an aircraft CO_2 emissions Standard were identified in order to assess future proposals and, as far as practicable, identify an optimum way forward:

- Provide an additional incentive to improve aircraft fuel efficiency, and thus, global fleet fuel burn performance.
- Measure fuel burn performance and relevant capabilities (e.g. range, size, speed) across different aircraft types.

- Ensure it is technically robust (now and future) with an acceptable level of accuracy.
- Maintain equity across products and manufacturers.
- Represent key aircraft design characteristics and environmental performance with respect to individual design philosophies (e.g. 2/3 spool engines or regional jet, narrow body, wide body aircraft types).
- Permit flexibility in aircraft design to comply with requirement.
- Minimize counterproductive incentives.
- Minimize adverse interdependencies.
- Base it on existing certified data.
- Account for proprietary data protection concerns.
- Not require an inappropriate level of resources on the part of national airworthiness authorities and the ICCAIA to implement.
- Be simple, transparent, and easily understood by the general public.
- Develop a Standard as soon as reasonably practicable to ensure that ICAO maintains its leadership in addressing aviation emission issues.

Scope of Requirement/Priority

The scoping study group agreed that there was need to prioritize the category of aircraft to be considered in the initial CO_2 Standard development task in order to improve the probability of agreement by CAEP/9 in 2013, while maintaining the expected level of quality. It was agreed that this could be achieved by focusing on the aircraft categories that burn the largest proportion of aviation fuel globally, and therefore reduce the number of affected industry stakeholders (engine and airframe manufacturers in particular), thereby simplifying and expediting the process for completion of the CO_2 Standard.

In considering the initial step above, major aircraft categories were identified as: subsonic jets, heavy propeller driven aeroplanes, light propeller driven aeroplanes, helicopters, tilt rotors, and supersonic aircraft. Of these major types, subsonic jet aircraft indisputably account for the vast majority of global aviation fuel use (approximately 95% according to MODTF 2006 data used in the CAEP/8 Environmental Goals Assessment). For that reason, the ad-hoc group agreed to limit the scope of the work to that category only.

Metric Requirements/Characteristics

The metric(s), should be objective and reflect fuel efficiency at the aircraft level. Improvements in fuel efficiency observed in the certification procedure and metric(s) should correlate, as far as practicable, with actual improvements in aircraft fuel efficiency (i.e. reductions in CO_2 emissions) during operational conditions. This analysis does not exclude the potential need to define and select multiple metrics for various type of aircraft or operations (e.g. passenger v. cargo, commercial passenger versus business).

The metric(s) should be based upon certified parameters to ensure commonality among different manufacturers. If this requires the certification of additional parameter(s) compared with existing practices, then an assessment of the implications (e.g. technical feasibility, workload, process) should be conducted.

The parameters that compose the metric should be easily measurable at the certification stage, or derived from engineering data, and should consider the industry standard practices of measurement and adjustment. In order to ensure the successful implementation of a CO_2 Standard, there is a need to limit the regulatory burden associated with obtaining and tracking information to a reasonable level.

The metric should be robust in order to minimize the potential for unintended consequences. The use of poorly defined metrics to establish policies can create equity issues and can result in the emergence of opportunities to influence the system in a way that may reduce the effectiveness of the policies and have the potential to drive the system to a different operating point than the one originally intended.

To the extent practicable, the metric should be fair across the set of stakeholders covered by the CO_2 Standard, including the distribution of cost and benefits, both when initially applied and with respect to the future.

The metric should limit interdependencies and any influence on other Standards (e.g. emission, noise Standards) in order to minimize unintended consequences. The construction and selection of a metric should minimize the effects on other performance indicators covered by other Standards.

Certification Procedure Options

The procedure ultimately recommended for demonstrating compliance with a CO_2 Standard will require key decisions and agreements in several respects. For example, a reference mission or operating mode could be defined in order to reduce the variation in aircraft operation during the certification process. At this time the exact approach and best definition is not known and must be further studied by the technical expert group on emissions.

The certification procedure will also need to incorporate certain aspects of relevant aircraft design characteristics. These parameters will be required, as appropriate, to provide information to the certification metric as discussed previously. Several aircraft design characteristic parameters may be considered during certification metric and methodology development, such as cruise conditions, operating range, and weight, etc.

Applicability

The Group on International Aviation and Climate Change (GIACC) Programme of Action recommended that CAEP seek to develop a CO_2 Standard for new aircraft types. While there has been general agreement within CAEP that the initial focus should be on new aircraft types, it was agreed to defer further debate and discussion to a wider group of experts during the next CAEP cycle.

In defining applicability requirements, there is also a need to examine and agree on when modified existing products are considered to have no change to their certified levels, when they need to demonstrate continued compliance with their existing certification basis, and when compliance with a new CO_2 Standard is required. This should take into account existing certification practices and procedures within this area.

Certification Instrumentation and Measurement Methodology

The scoping study group agreed that the measurement methodology and required instrumentation for a CO_2 Standard (e.g. Annex 16 Volume II, Appendices 2 and 3 for Smoke Number and Gaseous Emissions, respectively) would be highly dependent on the discussions concerning the certification metric and procedure.

While it was perceived as a subsequent issue which would be driven by the discussions in other areas, certification instrumentation and measurement methodology should be borne in mind at all times to ensure that proposals are technically feasible, appropriately quantify CO_2 emissions, and do not create an unreasonable regulatory burden.

As with the other emissions requirements, it was recognized that there may also be a need to consult with expert technical groups outside the CAEP domain (e.g. SAE International's E-31 Committee).

Regulatory Level

The terms of reference and underlying principles that have guided the CAEP work program, as they relate to the gaseous emissions engine certification requirements contained in Annex 16, Volume II (i.e. technological feasibility, economic reasonableness and environmental benefit in setting new Standards, noting also the environmental interrelationships and tradeoffs), have been a cornerstone of CAEP and ICAO decision-making as it relates to the setting of Standards.

It was recognized that the immediate priority was the development of a robust certification requirement against which a regulatory level may be applied. To the degree possible, work on assessing regulatory level options should be done in parallel to enable the earliest possible implementation once key elements of a certification requirement have been agreed. Ideally, the regulatory level should provide positive incentives for industry stakeholders to improve fuel efficiency while also improving the overall commercial performance of aircraft through the implementation of new technology.

Manufacturer Compliance

Historically, an aircraft type certification approach with a simple pass/fail criteria has been the primary means of implementing Standards to control engine emissions from all transport modes, including aviation. Compliance with LTO NOx, CO, HC and smoke regulatory levels has been demonstrated through measurement of the emissions at the engine exhaust, along with analysis and correction of these emissions to reference standard day conditions. The results also take into account statistical compliance factors, depending on the number of engine tested. For aircraft, this approach has served primarily as a cap on emissions rather than as a technology forcing method. This application of type certification is well understood by the aviation community, and a CO_2 Standard which follows this approach may be more easily implemented within the industry's current institutional structure.

Next Steps

During the CAEP/8 meeting in February 2010 there was discussion and agreement on the way forward pertaining to the development of an aircraft CO_2 emissions Standard, taking into account the scoping analysis described above.

It was agreed that this effort would constitute the highest priority in the work program for the CAEP/9 cycle and that a CO_2 Standards task group would be formed to carry out the work program.

The CAEP/9 work program calls for the certification requirement to be presented to the CAEP Steering Group in 2011. In addition, there is the intention to produce a recommendation on the Standard, including applicability, during 2013, adjusting programme plans as necessary, while ensuring quality and effectiveness. ■

Subsonic Civil Transport Aircraft for a 2035 Time Frame[1]

*By **Elena de la Rosa Blanco** and **Edward M. Greitzer,** © 2010 Massachusetts Institute of Technology*

***Elena de la Rosa Blanco** is a Research Engineer in the Gas Turbine Laboratory of the Aero/Astro Department. A Cambridge PhD, she was a member of the Cambridge-MIT Silent Aircraft Initiative project before coming to MIT.*

***Edward Greitzer**, the project Principal Investigator, is the H. N. Slater Professor of Aeronautics and Astronautics and the former Director of the Gas Turbine Laboratory. He is a Fellow of the ASME, the AIAA, a member of the National Academy of Engineering and an International Fellow of the Royal Academy of Engineering.*

[1] *The following article appears in the 2009-2010 issue of **AeroAstro**, the Massachusetts Institute of Technology Department of Aeronautics and Astronautics annual publication. ©2010 Massachusetts Institute of Technology*

In October 2008, NASA awarded four research contracts aimed at defining the advanced concepts, and identifying the enabling technologies that need to be put in place, for subsonic civil aviation in the 2035 timeframe. The work was part of the NASA N+3 program, where N+3 refers to aircraft three generations beyond those currently flying. The contracts were awarded to teams led by Boeing, Northrop Grumman, GE, and MIT, all of whom have since developed their different views of what the future aircraft might be. Aurora Flight Sciences and Pratt & Whitney were partners on the MIT team, the only team led by a university. As described in this article, collaboration between these three organizations (MIT/Aurora/P&W) has resulted in the development of revolutionary conceptual designs for future subsonic commercial transports.

Four metrics had been set by NASA for the design concepts: aircraft noise, engine emissions (as expressed in terms of the oxides of nitrogen (NO_x) produced during landing and take-off), fuel burn, and runway length for take-off. The targets were aggressive, for example the fuel burn goal was a reduction of 70% for a reference aircraft and the noise goal was comparable with that of the Silent Aircraft Initiative, namely aircraft noise imperceptible outside of the airport perimeter. A fifth metric, the global average surface temperature change due to the aircraft emissions, which reflected the aviation impact on climate change metric, was also included by the team as part of the concept aircraft evaluation.

Project Scope and Approach

The MIT-Aurora-Pratt collaboration applied its multi-disciplinary expertise to determine, in a rigorous and objective manner, the potential for improvements in noise, emissions, fuel burn, and airport use for subsonic transport aircraft. The project incorporated assessments of technologies in aerodynamics, propulsion, operations, and structures to ensure that a full spectrum of improvements was identified, plus a system-level approach to find integrated solutions that offer the best balance in performance enhancements. This assessment was enabled by a first-principles methodology, which allowed simultaneous optimization of the airframe, engines, and operations. The overall exercise also contained an assessment of the risks and contributions associated with each enabling technology, as well as roadmaps for the steps needed to develop the levels of technology required.

As the initial task — to frame the type of aircraft that would be most appropriate — the team defined a scenario for aviation in 2035: estimates of passenger demand, fuel constraints, airport availability, environmental impact, and

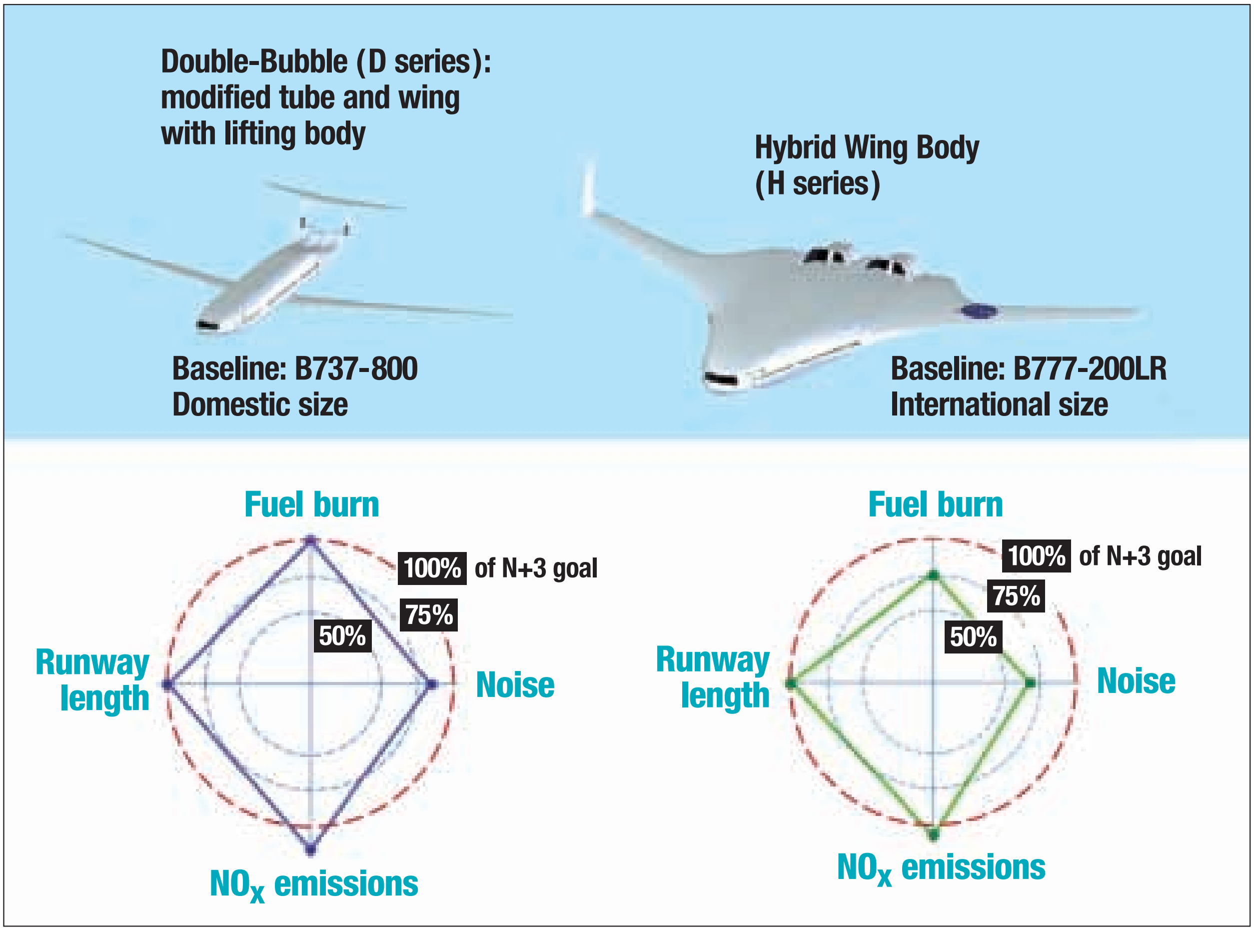


Figure 1: *(Upper) Double-bubble (D Series) and hybrid wing body (H Series) conceptual aircraft; (Lower) Comparison of aircraft attributes with NASA targets.*

other relevant parameters. This scenario, plus the NASA requirements, led to two conceptual aircraft designs. Their missions were selected from different market segments, but chosen so that, together, the two aircraft would represent a substantial fraction of the commercial fleet; implying that adoption of such designs could have a major impact on fleet-wide fuel burn, noise, emissions, climate, and airport use.

Features of the Concept Aircraft

One of the two designs is aimed at the domestic market, flights from 500 nautical miles up to coast to coast across the US. It represents a 180-passenger aircraft in the Boeing 737 or Airbus A320 class, which make up roughly a third of the current fleet. This concept is denoted as the "D Series," because of its "double-bubble" fuselage cross-section. The other conceptual aircraft, denoted as the "H series," for "Hybrid Wing-Body," is defined for international routes. This latter design, envisioned as a Boeing 777 aircraft replacement, features a triangular-shaped hybrid wing body that blends into the wings. It would accommodate 350 passengers in a multiclass configuration with cargo, and having a range of at least 7000 nautical miles.

The two aircraft concepts are illustrated in Figure 1, with the D Series on the left and the H Series on the right. The bottom of the figure gives information about the estimated aircraft attributes compared against NASA N+3 targets. The red dashed line shows 100 percent for each of the four NASA metrics, meaning that the goal has been met. The other lines are 50 percent and 75 percent of the goals respectively. The points on the solid line show, at the four points of the compass, the calculated aircraft performance for each of the four metrics. The D Series can be seen to have achieved three of the NASA metrics and nearly achieved the fourth (noise). The H Series meets only two of the target goals, but there are substantive gains towards the others. The performance levels achieved by the two configurations are the first major finding from the project.

A more in-depth view, which also provides some context for the changes compared to current aircraft is shown in Figure 2, which presents a schematic of a Boeing 737-800 aircraft (entry into service in 1998) on the left and a D Series aircraft on the right. Each aircraft has three views, a side view, a cross-section of the fuselage, and a top view showing the cabin layout. Both the 737-800 and the D Series are designed for 180 passengers.

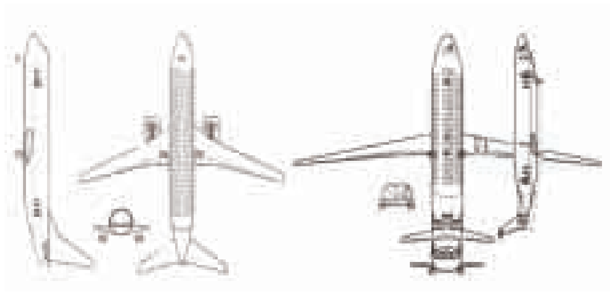


Figure 2: *Schematic of the 737-800 (on left) and D Series aircraft (on right)*

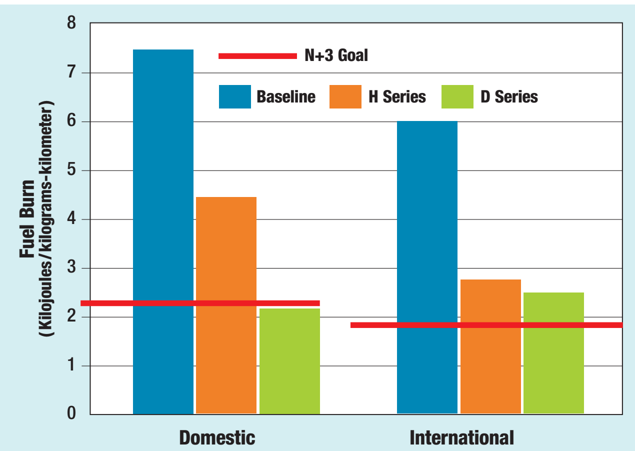


Figure 3: *Fuel burn performance of double-bubble (D Series) and hybrid wing body (H Series) aircraft.*

The D Series aircraft fuselage is shorter and wider than a 737's. It provides roughly 18 percent of the overall lift, whereas the 737 fuselage provides only 6 percent. While both aircraft can be classed as "tube and wing," the D series features a double-bubble (two parallel tubes) fuselage cross-section. The wider fuselage also allows two aisles, a possible time saver for passenger loading and unloading. A D series aircraft has three engines, placed above the aircraft, between the vertical tails. These engines ingest the slower moving (because of viscous effects) fluid from the fuselage boundary layer, providing an advantage from a fuel burn perspective. However the ingestion creates a non-uniform flow into the engines, and the integration of the aircraft and this unconventional propulsion system is one of the technical challenges that needs to be addressed. The D Series flies at a slightly slower (approximately 10 percent) speed than the 737 so that the wings on the former, which have a much higher (29 vs.10) aspect ratio require less sweep back than the latter's. The lower speed also allows numerous other changes that result in a lighter, more efficient aircraft, leading to the 70 percent fuel burn reduction mentioned earlier.

The studies conducted show that the two D and H aircraft configurations behave differently as the range and payload are varied. An example is given in Figure 3, which shows the fuel burn for the conceptual aircraft for the two missions described. The double-bubble exhibits a greater fuel reduction, compared to current aircraft, at the B737 (domestic) payload and range than at the higher payload mission. In contrast the hybrid wing-body achieves its best fuel burn at the B777 payload and range. Even at the larger payload (and aircraft size), however, the double-bubble configuration was found to give essentially the same performance (NASA metrics) as the hybrid-wing body. A second major finding, therefore is that although both configurations gave substantial benefits compared to the baselines, for the aircraft considered the double-bubble configuration exhibits better performance (or equal performance for large payload / range) compared to the hybrid wing-body.

Benefits of (i) Technology and (ii) Configuration

A third result stems from the investigation of specific contributions to the performance of the D8 Series aircraft. The benefits seen in the N+3 aircraft concepts are from two sources. The first is advances in specific technologies, such as stronger and lighter materials, higher efficiency engine components, turbine materials with increased temperature capability. The second is the inherent benefit of the *aircraft configuration*. In other words, even given today's technologies (aluminum wings and fuselage, current technology engines with current bypass ratios, etc.), there is a major performance benefit from the use of the configuration alone.

This finding relating to the benefit of the configuration change is shown in Figure 4, which compares benefits of configuration change with benefits due to advanced technologies for fuel burn, noise, and NO_x (all D Series aircraft meet the takeoff runway length goal). There is a 49 percent reduction in fuel burn compared to the baseline, and a 40 decibels decrease in noise and 52 percent reduction in landing and take-off NO_x relative to current noise and emission certification limits. The technology improvements then bring this number to the total level of improvements implied by Figure 1 (e.g., 70 percent decrease in fuel burn rather than 49 percent). The configuration includes the benefits of boundary layer ingestion on the top surface of the fuselage, a slightly increased engine pressure ratio from the baseline aircraft, and a present day but optimized engine cycle. The significant step change in capability provided by the D Series configuration is perhaps the most important finding of this project. It implies that an aircraft configuration change has the potential to alter the face of commercial aviation. Further, this change could occur on a much shorter time scale than required for maturation of many separate technologies

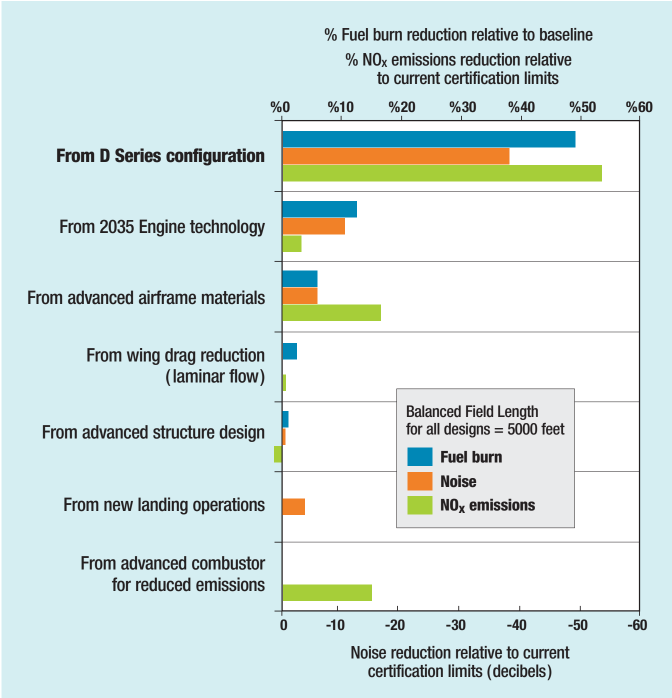


Figure 4: *Benefits to N+3 metrics – configuration change vs. technology advances.*

University-Industry Collaboration

Finally, two aspects of the university-industry collaboration are worth describing. The first was the virtually seamless interaction between the different organizations. The second, enabled by the first, was the strong emphasis on what is perhaps best described as the *primacy of ideas* rather than of organization or hierarchy. In other words, concepts and suggestions were considered directly on merit (e.g. content, strategic value, or impact) rather than the originator of the idea, or the legacy of the idea. From the start of the project, this was emphasized and fostered explicitly in team discussions. The consequence was that the team functioned with open-mindedness to new ideas and, as a direct corollary, a willingness to subject even cherished concepts to in-depth scrutiny. In sum, the goal was to create a team in which “the whole was greater than the sum of the parts” because of strong interactions between participants. The achievement of this goal in an enterprise involving students, staff, faculty, and engineers in industry from a number of fields, with benefits to all parties involved, is also a major finding of the project.

Team Members

Although this article was written by the two authors listed, it cannot be emphasized too strongly that the project was a team effort, with different faculty and staff, as well as engineers from Aurora and Pratt & Whitney, taking the major role on various aspects as called for. In this regard it is appropriate to list the MIT faculty and staff participants — Mark Drela, John Hansman, James Hileman, Robert Liebeck, Choon Tan — and to state that Jeremy Hollman and Wesley Lord were the team leads at Aurora Flight Sciences and Pratt & Whitney, respectively. The analyses and design information described came from all of these, from the students on the project (Chris Dorbian, David Hall, Jonathan Lovegren, Pritesh Mody, Julio Pertuze, and Sho Sato), and from many others at Aurora and Pratt & Whitney.

Chapter 3

OPERATIONAL OPPORTUNITIES

ICAO
ENVIRONMENTAL
REPORT 2010

Operational Opportunities
Overview

*By **ICAO Secretariat***

The term "operations" in the context of aviation can be used to describe a broad range of activities including: the flying of the airplane, the control and/or monitoring of the aircraft by the air traffic management system, and the conduct of various airport activities. Operations begin with planning activities even before the passengers and cargo are loaded, through the entire flight, until after the passengers have disembarked and the cargo has been unloaded. One constant that applies whenever it comes to defining operational procedures, is that safety must always come first.

Reducing aircraft emissions, whether for an individual flight or globally, can be achieved through various means, including aircraft technologies (see Chapter 2 of this report), the use of sustainable alternative fuels (see Chapter 5 of this report), economic instruments (see Chapter 4 of this report), and by means of operational improvements, which are discussed later in this chapter of the report. While aircraft technologies alone can determine the theoretical environmental performance of the aircraft, the actual performance will be the result of how the aircraft is operated subject to the constraints imposed by air traffic services and the supporting infrastructure.

The operational opportunities to reduce emissions that are described in this chapter of the report are delivered through optimized ground and in-flight procedures that do not compromise safety. In reality, they represent a double win-win solution. First, based on the premise that the most effective way to minimize aviation emissions is to minimize the amount of fuel used in servicing and operating each flight, environmental benefits that are achieved through reduced fuel consumption also result in reduced fuel costs. Second, operational measures do not necessarily require the introduction of new equipment or the deployment of expensive technologies. Instead, they are based on different ways of operating aircraft that are already in service. For instance, some States have implemented training courses in environmentally friendly piloting techniques. This chapter of the report describes numerous examples of aircraft operating in an environmentally optimized fashion; all of which showcase the potential for improvement with existing technology.

ICAO is working to deliver an interoperable global air traffic management (ATM) system, for all users during all phases of flight (see *ICAO's Global Air Traffic Management (ATM) Operational Concept and Global Air Navigation Plan Both Support Fuel and Emissions Reductions*, later in this chapter of the report). An important step toward realizing this vision was the endorsement of the ICAO Global ATM Operational Concept in 2003, which is an integral part of all major ATM development programmes including NextGen of the United States (see *NextGen and the Environment – The U.S. Perspective*, later in this chapter of the report), and the European SESAR (see *SESAR and the Environment*, also later in this chapter of the report).

The importance of the interoperability of the Global ATM System has been highlighted through a number of cooperative demonstrations, such as the Atlantic Interoperability Initiative to Reduce Emissions (AIRE) and the Asia and Pacific Initiative to Reduce Emissions (ASPIRE), both of which are described later in this chapter of the report. Domestic initiatives such as those in New Zealand (see *Operational Measures to Reduce Carbon Dioxide Emissions from Aviation: Initiatives from New Zealand*, later in this chapter of this report), and Brazil (see *Environmental Benefits of New Operational Measures - A Case Study: Brasília Terminal Area*, also later in this chapter of the report) both highlight, not only the benefits that can be delivered quickly through improved operations, but also the interrelationships among noise, local air quality, and emissions.

Looking to the future, ICAO's panel of independent experts developed operational efficiency goals for the global ATM system (see *Opportunities for Air Traffic Operations to Reduce Emissions – Mid-Term and Long-Term Operational Goals*, Chapter 3 of this report). The realization of the targets set by the independent experts will depend on the successful delivery of the Global Air Navigation Plan.

In 2003, ICAO first published 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 in civil aviation operations and is aimed at: airlines, airports, air traffic management and air traffic service providers, airworthiness authorities, environmental agencies, and various government bodies. The Committee on Aviation Environmental Protection (CAEP) developed rules of thumb to assist States with estimating the potential environmental benefits from the implementation of new operational procedures (see *Aviation's Contribution to Climate Change – Overview*, Chapter 1 of this report).

As the articles in this chapter of the report illustrate, aircraft operations are being optimized today to improve environmental performance while maintaining safety. With the realization of a global, interoperable, ATM system, in combination with technological advances, the eventual achievement of future goals for aviation environmental performance will become possible. ■

ICAO's Global Air Traffic Management (ATM) Operational Concept and Global Air Navigation Plan

By ***ICAO Secretariat***

ICAO is the driving force for the ongoing development of a global air traffic management 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 Global ATM Operational Concept is a key component of the mitigation measures to address noise, gaseous emissions and other environmental issues. This article explains the background of the Global ATM Operational Concept and illustrates how it takes into account aviation environmental concerns and priorities.

Global ATM Operational Concept

ICAO effort's to continually improve the ATM system are focused on the Global ATM 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 NextGen of the United States and the European SESAR.

The global ATM system envisaged in the operational 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.

Global Performance of the Air Navigation System

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 ICAO 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 process.

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 key outcomes that must be considered.

In an effort to assist planners in weighing outcomes and making appropriate decisions, the *Manual on Global Performance of the Air Navigation System* was developed. The guidance contained in that document supports an approach to planning, implementation, and monitoring that is based on performance needs, expected benefits, and achievement timelines. Such explicit planning and management of ATM performance will be needed to ensure that throughout the transition process towards the Global Air Navigation System, as envisaged by the Global ATM Operational Concept, the expectations of the entire community will be met.

The Global Air Navigation Plan and the Planning Process

The Global Air Navigation Plan will be revised to assist States and regional planning groups in identifying the most appropriate operational improvements and to make sure it considers regional programmes that are already in place such as NextGen and SESAR. To support the implementation process, the revised Plan will clearly describe a strategy aimed at achieving near- and medium-term ATM benefits on the basis of available and foreseen aircraft capabilities and ATM infrastructure. The Global Plan will therefore pave the way for the achievement of the vision established in the Global Concept.

The set of initiatives contained in the Global Plan are meant to facilitate and harmonize the programmes and work that are already underway within the regions, and to bring needed benefits to all the aviation community 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 will begin with application of available procedures, processes and capabilities. The evolution progresses through the application of emerging procedures, processes and capabilities, and ultimately, migrates to the ATM system, based on the operational concept. All regions have well established implementation plans 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 have differing performance demands of the system. All have either an explicit or implicit expectation of safety. Some have explicit economic expectations, others want efficiency and predictability, and of course others have the environment as their main concern. For optimal system performance, each of these sometimes competing expectations needs to be balanced. Interests must be considered on the basis of a weighted "desired outcome contribution". As stated previously, the environment is one of the key issues to be considered. The operational concept outlines a total system performance framework to assist in the process and recognizes that the ATM system needs to 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.

Since 2006, when the ICAO Council approved the Global Plan Initiatives as part of the Global Plan, Planing Implementation Regional Group (PIRG)s initiated the adoption of a performance framework, performance objectives, and implementation timelines, along with the development of a comprehensive schedule and programme of work planning activities to guide their work.

A series of workshops for ICAO regions were held with the objective of providing detailed guidance to States on the development of national performance frameworks for air navigation systems. The workshops, that covered almost all ICAO Regions, were held in 2009/2010. Similar workshops will be conducted in the remaining regions during the following years to increase their knowledge and assist them with timely implementation of the measures that will, among others benefits, support the reduction of the impact of aviation on climate change.

The means and tools to establish performance targets and measure performance are being used by several groups both within and outside of ICAO.

Reduced Vertical Separation Minimum

Reduced Vertical Separation Minimum (RVSM) facilitates 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 and consequently emissions. RVSM was first implemented in 1997 in the airspace of the North Atlantic and is forecast to be completed at a Global level by 2011 when the Eurasia region will implement it with guidance provided by ICAO.

Following the implementation of RVSM in various ICAO Regions, environmental studies have concluded that RVSM implementation led to significant environmental benefits. All the reports state that total fuel burn, NO_x emissions, CO_2 emissions, and H_2O emissions were reduced, which also translates into reduced costs for airlines operating in the RVSM airspace. The study reports go on to state that the environmental benefits were even more positive for the high altitude band along and above the Tropopause, at an altitude between 8 and 10 kilometres.

ICAO's role in supporting the realization of RVSM was and continues to be significant. From the detailed safety related work, 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.

Performance Based Navigation

Performance Based Navigation (PBN) allows aircraft to fly even closer to their preferred 4D trajectory. Developed, after the improvement of the air navigation system in the vertical plane, PBN improves the efficiency in the horizontal plane. The PBN concept is being used to implement more flexible use of the airspace and optimize the operations to meet the expectations of the aviation community in terms of safety, efficiency, predictability, among others. These can be directly translated into environmental benefits through reduced aircraft flying distances and/or times when compared with the legacy systems that are based solely on ground based navigation aids.

Continuous Descent Operations

Continuous Descent Operations (CDO) allow the arrival, approach and landing of the aircraft with a more efficient profile, thus reducing the need for energy use. The increased use of these types of operations is anticipated because they meet the expectations of the aviation community in terms of reduced fuel burn and emissions.

Through different operational improvements and initiatives the ATM system is being updated to allow more use of continuous descent operations taking into consideration that it also impacts other areas related to air navigation.

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 RVSM , which yielded significant operational benefits to the aviation community in terms of reduced fuel burn, availability of optimal flight levels, increased capacity, as well as significant spin-off environmental benefits.

ICAO plays a central role 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 adopted 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. 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 yield near- and medium-term benefits, while integrating those programmes with the extensive work that has already been accomplished. ■

Opportunities for Air Traffic Operations to Reduce Emissions

Mid-Term and Long-Term Operational Goals

*By **Alan Melrose**, Chair of Independent Expert Operational Goals Group-IEOGG*

***Alan Melrose** has 38 years experience in environmental management in a wide range of private and public sector organisations. Establishing Manchester Airport's Environmental Control Department in 1988, he was actively involved in delivering Manchester's Second Runway and helped to secure several 'world firsts' in environmental management.*

Alan joined EUROCONTROL 9 years ago and leads projects including the Continuous Descent implementation initiative, Collaborative Environmental Management roll-out and environmental training. Alan supports various ICAO activities including the development of CDO guidance and is a task leader in CAEP Working Group 2 including chairing the Independent Expert Operational Goals Group.

Introduction

In support of the Committee on Aviation Environmental Protection (CAEP) work programme, a panel of Independent Experts (IEs) was tasked to undertake a review of NO_x technologies that would culminate in recommendations for medium (10 year) and long term (20 year) goals for NO_x control (see article *ICAO Technology goals for NO_x*, Chapter 2 of this report). In 2007, CAEP/7 agreed that this NO_x review was to be treated as a reference point for similar efforts in other areas such as noise, fuel burn, and operational goals, where reviews had been requested. During the CAEP/8 cycle, reviews for NO_x, noise, and operational goals were held, and their respective IE Groups presented reports to CAEP/8 in February 2010

The Independent Expert Operational Goals Group (IEOGG) was tasked, based on the independent expert (IE) process, to examine and make recommendations for noise, NO_x and fuel burn with respect to air transport operational goals in the medium term (2016) and the long term (2026), based on a 2006 base-year. The work was further focused on ATM operations.

IEOGG produced a detailed report that summarizes future environmental goals for air traffic management (ATM) operations. That report provides an initial range estimate of operational efficiency and noise mitigation goals, assuming that the maximum ATM improvements possible by 2026 are fully implemented. Achieving this will require delivery of the ICAO Global Air Navigation Plan including the SESAR and NextGen programmes as a minimum.

Independent Expert Operational Goals Group Composition

To conduct this work, IEOGG members were selected as individual experts, and not as representatives of their home organizations. IEOGG comprised 10 individual experts from three national authorities and four different industry groups, so there was a broad range of operational, institutional, academic and technology skills available. Because IEs came from a variety of different expertise domains, their consensus can be taken as being fairly representative of the overall expert community perspective.

Process and Challenges

IEOGG used a top-down approach to identify the total potential operational benefit pool available within which to set ambitious goals. The experts agreed that there will always be some operational inefficiency that is very difficult or impossible to address such as that caused by: noise routes, airspace constraints, unplanned military events, safe separation, requirement, severe weather events, etc.

This top-down approach was considered to be more robust than to simply aggregate the total expected benefits for all planned operational improvements, since that would merely be an accounting exercise for existing plans and therefore would not necessarily be challenging. Also, the experts felt that aggregating the benefits from known technologies, techniques, enablers and institutional arrangements was not possible in the timeframe available for the IEOGG since such a summation would be very complex. Nevertheless, it became clear that at some stage in the future this additional work will be required in order to validate any aspirational goal and to allow progress to be tracked, and gaps or variances addressed.

In terms of challenges, IEOGG determined operational efficiency by comparing the actual horizontal trajectory of a flight with the Great Circle route between terminal areas. While this method is reasonably robust, the experts identified that it does not account for other operational performance parameters such as: auxiliary power unit (APU), vertical inefficiency, speed control, wind assistance and additional contingency fuel uplift due to lack of predictability, etc.

They identified that information on total operational performance simply does not exist at a global level. However, it was recognized that if such information does become available it will either affect the assessment of base-case efficiency, or it will increase the total impact of operations, rather than require an adjustment to any aspirational goal. Because of lack of data on the base-case (i.e., future do-nothing scenario) known, it was decided to set an aggressive **aspirational** total operational efficiency target of 95% operational efficiency by 2026. To ensure clarity for the scope of this target, 100% operational efficiency was defined as being the achievement of the perfectly fuel efficient profile for each flight in the entire gate-to-gate and enroute-to-enroute concepts.

Key Inputs

The main sources of input used by the IEOGG in its work included: ICAO Global Air Navigation Plan, SESAR deliverables, NextGen documentation, an IATA review of operational opportunities and the CANSO report "ATM Global Environment Efficiency Goals for 2050". The CANSO report was used as the starting point because it had also used a top-down approach to estimate how much inefficiency existed within the existing system. Before agreeing to use that report as the basis for its deliberations, the IEOGG had a vigorous debate to ensure that the CANSO assumptions and assessments were valid and acceptable as the foundation for the IEOGG collective approach.

Operational Efficiency Goals and Findings

The key influencing elements that contribute to the total "flight fuel efficiency" were identified in order to establish the context for the 'operational efficiency' analysis paradigm, as shown in Figure 1.

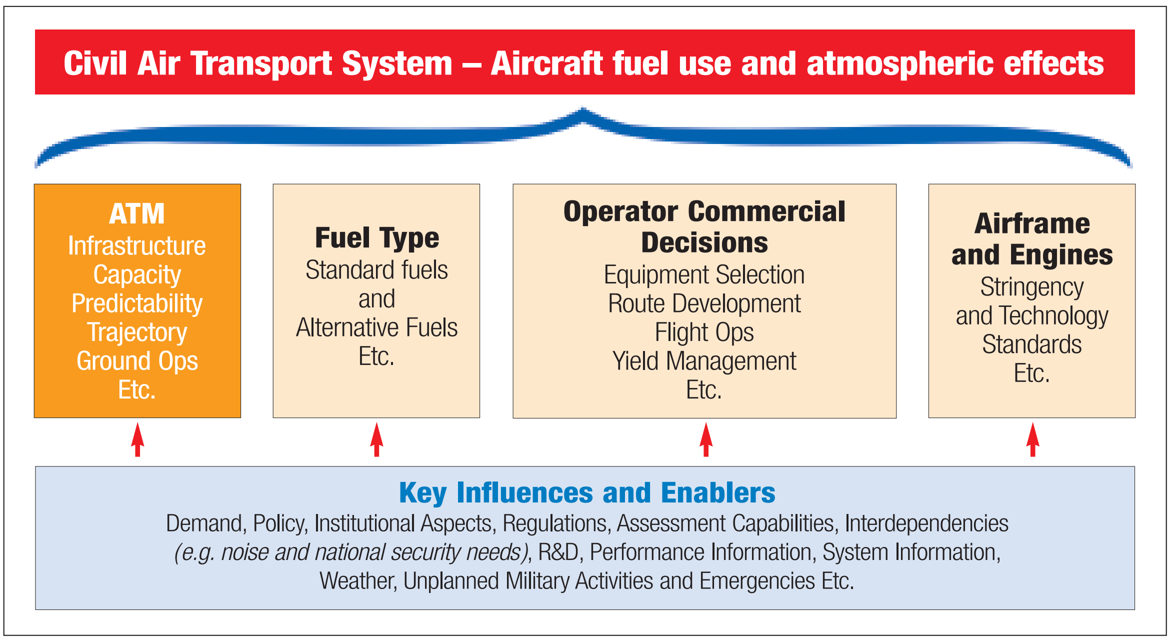


Figure 1: *Civil Air Transport System – fuel use and atmospheric effects; key influencers and enablers.*

The two components shown at either end of that list, ATM operations, and airframe and engine technology, are two of the main areas which are already covered by CAEP IE Groups. However, IEOGG also identified areas that CAEP was not covering (e.g. fuel-type), and other areas that would be outside of the scope of ICAO (e.g. operator commercial decisions). No globally-accepted goals for these elements have yet been set. While the IEOGG tried to be consistent with the technology goals activities, there is at least one critical difference. That is, growth that stimulates additional demand for new aircraft also accelerates the adoption of new technology. Hence, growth actually improves efficiency per flight due to new technologies. On the other hand, growth in operations puts ever-increasing pressure on airspace, and it works against efficiency. Thus, goals for technologies may never be fully consistent with goals for operations.

The conceptual diagram in Figure 2 shows the limited degree to which operational efficiency can be improved over the present case by ATM improvements. It also illustrates that the value of maintaining operational efficiency increases over time, as ever more growth is accommodated. In other words, merely maintaining operational efficiency is an immense challenge. Trying to accommodate growth without aggressive performance improvements would ultimately result in degraded efficiency. There could eventually be a situation of '*un-accommodated demand*' which would result in much higher costs (e.g. from delays or adverse economic impacts), than the additional fuel costs incurred due to loss of efficiency alone.

Defining the base-case against which to measure the goal represented a significant challenge for the IEOGG. In the end, it was thought that it would be misleading to quote a percentage change figure over the current performance level, considering the potential for efficiency to degrade over time with the do-nothing scenario. This decision was reinforced when it became clear that adequate global information on the non-great circle inefficiencies was not available. It is common practice when comparing future proposal assessments, to compare the future case with the proposal against the future case without the proposal. However, for operations, the global future do-nothing scenario is not yet defined. This was another key knowledge-gap that the IEOGG had to deal with and something that IEOGG would need to be addressed in the future.

The other key difference that was encountered when comparing with the technology goals, relates to the fact that the IEOGG was expected to produce two technology scenarios; a less aggressive option, and a more aggressive option. However, the group decided that the most aggressive operational

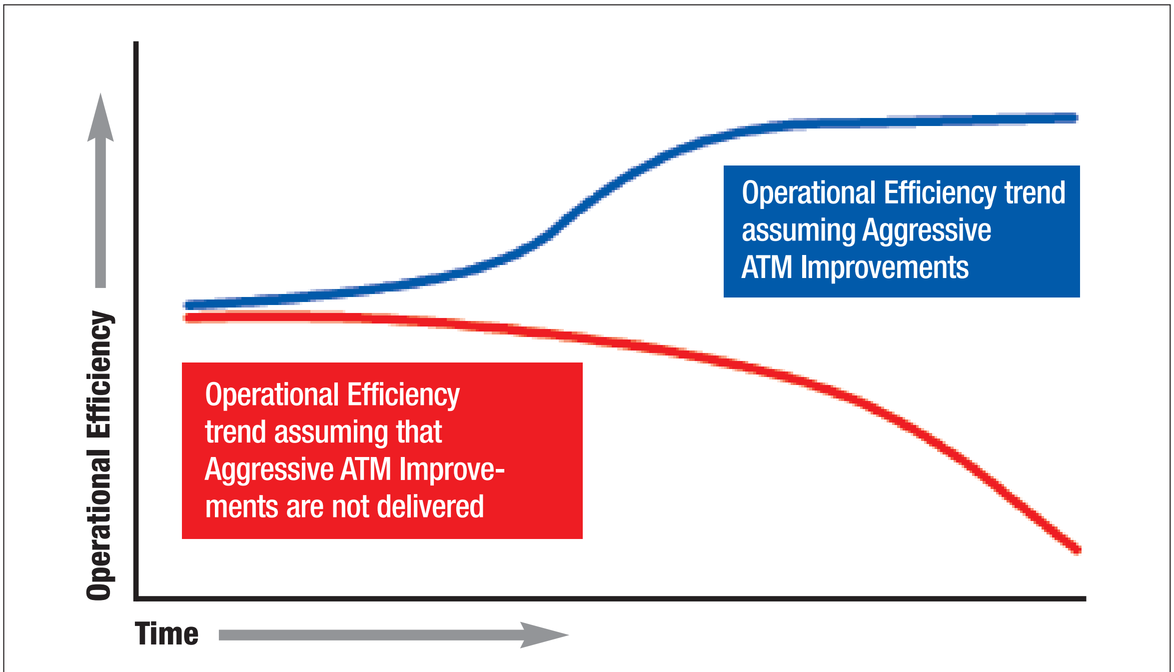


Figure 2: *Operational efficiency over time - with and without ATM improvements.*

Canso Region	ICAO Region	% of global aircraft movement in 2006	Basis of Goal Setting (Sources of inefficiency covered)						Estimated Base Level Efficiency	Operational Efficiency Goals	
			Great Circle Route	Delays and Flow	Vertical Flight	Airport & Terminal Area	Wind Assisted Routes	Contingency Fuel Predictability	2006	2016	2026
World		100%	assessed	assessed	assessed	assessed	not assessed	not assessed	92-94 %	92-95 %	93-96 %
US		35%	assessed	assessed	assessed	assessed	not assessed	not assessed	92-93 %	92-94 %	93-96 %
	North America		assessed	assessed	assessed	assessed	not assessed	not assessed	92-93 %[1]	92-94 %	93-96 %
ECAC		28%	assessed	assessed	assessed	assessed	not assessed	not assessed	89-93 %[2]	91-95 %	92-96 %[3]
	Europe		assessed	assessed	assessed	assessed	not assessed	not assessed	89-93 %	91-95 %	92-96 %
Other Regions		37%	estimated	estimated	estimated	estimated	not estimated	not estimated	**91-94 %**	94-97 %	95-98 %
	Central America / Caribbean		estimated	estimated	estimated	estimated	not estimated	not estimated	**93-96 %**	94-97 %	95-98 %
	South America		estimated	estimated	estimated	estimated	not estimated	not estimated	**93-96 %**	94-97 %	95-98 %
	Middle East		estimated	estimated	estimated	estimated	not estimated	not estimated	**92-94 %**	94-97 %	95-98 %
	Africa		estimated	estimated	estimated	estimated	not estimated	not estimated	**90-93 %**	94-97 %	95-98 %
	Asia/Pacific		estimated	estimated	estimated	estimated	not estimated	not estimated	**91-94? %**	94-97? %	95-98? %

Figure 3: *Operational efficiency goals (great circle), 2016-2026.*

1 This is a direct copy of the US figures and, as a general principle, regional goals should not be applied to individual states.
2 This IPCC based estimations of the base-case matches the EUROCONTROL PRR07 report.
3 This figure extrapolated from the CANSO report is used for consistency, but may be conservative when compared to work by SESAR on 'Gate-to Gate fuel efficiency'.

performance improvement is the **only** option for ATM if threefold demand is to be accommodated while improving all 11 ATM Key Performance Areas. It is believed that the ICAO Global Air Navigation Plan, SESAR, NextGen, and all of the other ATM initiatives, are the most aggressive operational programmes possible, and a goal necessarily has to be in-line with these aggressive initiatives.

With reference to Figure 3, the first thing that was done was to rationalize the CANSO report regions to match the ICAO regions to suit CAEP needs. This included a series of assumptions, such as the CANSO US ATM efficiency estimate which was used as a proxy for North America. It is interesting to note that there is a massive variance in different parts of the world in terms of current ATM system efficiency. For example, because of the lack of fragmentation in Australian airspace, that country is probably already operating at about 98% efficiency; so in this case a target of 95% is not applicable. This raises a very important caveat that a global goal should not be applied equally to each region or state, as their base levels could be different.

For flight efficiency (i.e. fuel burn and CO_2) it was agreed that a global goal of 95% operational efficiency by 2026 would be a very challenging but realistic goal, and its simplicity would help to ensure its consistent use. A detailed definition of what that level of efficiency means in operational terms is contained in the report.

IEOGG could not define a global base-case efficiency level or an expected percentage increase in operational efficiency due to the paradigm that is shown in Figure 2 which indicates that efficiency will drop off. In addition, global data for many of the operational inefficiencies that affect the base-case is not yet available. So, the goal had been based on a required percentage performance improvement over the present day, and if new knowledge about the base case was uncovered later, then the expected benefits pool would change and the goal itself would also shift. This would make such a percentage performance improvement based goal very difficult to follow from a policy perspective. For that reason, the single simple absolute efficiency based objective was chosen by IEOGG.

ATM system Global Operational Efficiency Goal

'That the global civil ATM system shall achieve an average of 95% operational efficiency by 2026 subject to the following notes':

Note 1	This goal should not be applied uniformly to Regions or States;
Note 2	This is to be achieved subject to first maintaining high levels of safety and accommodating anticipated levels of growth in movement numbers in the same period;
Note 3	This ATM relevant goal does not cover air transport system efficiency factors that depend on airspace user commercial decisions (e.g. aircraft selection and yield management parameters etc.);
Note 4	This operational efficiency goal can be used to indicate fuel and carbon dioxide reductions provided fuel type and standards remain the same as in 2008. The goal does not indicate changes in emissions that do not have a linear relationship to Fuel use (such as NO_x); and
Note 5	This assumes the timely achievement of planned air and ground infrastructure and operational improvements, together with the supporting funding, institutional and political enablers.

Figure 4: *Operational efficiency goal of 95% by 2026; with caveats.*

The 95% operational efficiency goal stated in Figure 4 includes a series of caveats, and the IEOGG report goes to great lengths to specify that this target should never be considered without these caveats being included. That is because it would be very easy to take this goal out of context. Also, if the goal-setting process is repeated in the future the caveats may well change. The requirement to periodically update this goal was subsequently ratified by CAEP/8.

Conclusions and Challenges for Future Work

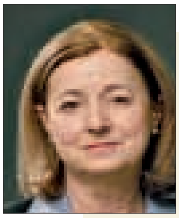
Given the limited time available, coupled with some of the data availability constraints, the IEOGG reached consensus that the 95% global operational efficiency goal by 2026 is a reasonably robust target.

It is important to note that the proposed relatively modest gain in efficiency over current levels is actually an important incremental gain relative to the current high level of operational efficiency. The value and challenge of this improvement is actually very ambitious and aggressive when considering that at the same time a threefold growth in aircraft movement numbers will be accommodated.

The lack of required information needs to be addressed. Also, measuring progress towards the target will be difficult because the information for some parts of the world is not yet available. The future do-nothing base-case, as well as the bottom-up evaluation of operational improvements which were not available, need to be developed, as do the assessment methods and performance metrics. This data requirement includes information on inefficiencies in the system, which are not great circle inefficiencies such as: vertical inefficiencies, ground operational inefficiencies, unnecessary fuel uplift and transportation due to lack of predictability, etc.

NextGen and the Environment
The U.S. Perspective

*By **Victoria Cox** and **Nancy LoBue***



*As the Air Traffic Organization's Senior Vice President for NextGen and Operations Planning, **Vicki Cox** provides increased focus on the transformation of the nation's air traffic control system by providing systems engineering, research and technology development, and test and evaluation expertise. She is also responsible for the NextGen portfolio and its integration and implementation.*

Within the FAA, Cox has served as the Director of the ATO's Operations Planning International Office, the Director of Flight Services Finance and Planning and the Program Director of the Aviation Research Division.

She has a certificate in U.S. National Security Policy from Georgetown University and is a DOD Level III Certified Acquisition Professional in Systems Planning, Research, Development and Engineering. She also earned her private pilot's license in 1985.

***Nancy D. LoBue** joined FAA's Office of Aviation Policy, Planning & Environment in 2003 as Deputy Assistant Administrator. The office leads the agency's strategic policy and planning efforts, which includes the agency's performance metrics known as the "Flight Plan", develops the agency's reauthorization legislative proposals, oversees the aviation insurance program, and is responsible for national aviation policies and strategies relating to environment and energy.*

Prior to that, Ms. LoBue spent almost 20 years in FAA's Office of the Chief Counsel in various positions while managing attorneys involved in environmental review and litigation, airport financing and government contracts.

The world has arrived at a consensus on the need to arrest climate change and global warming. Aviation technology, advancing on its own separate track, promises to enable the world's aircraft operators to do their part to limit the aviation industry's environmental footprint.

NextGen Overview

In the United States, these advanced technologies, and the operational innovations associated with them, are known collectively as NextGen — the Next Generation Air Transportation System. NextGen will transform aircraft surveillance from radar to global positioning system (GPS) satellites which will change navigation from zigzagging segments into more direct trajectories. Under NextGen, much of the air-ground communications will move from voice to data. It will create a data system that provides all stakeholders with the same information at the same time. These new technologies will also help develop more fuel efficient airframes and engines and will help in the development and deployment of sustainable alternative fuels — all aimed to reduce greenhouse-gas (GHG) emissions.

Environmental benefits from the many NextGen operational initiatives are part of a scenario that offers several co-benefits. For example, most of what the FAA does to increase efficiency and curb delays will also reduce fuel consumption. This in turn will shrink the operating costs of airlines and other airspace users. More important from an environmental perspective, reduced fuel consumption will mean reduced emissions of carbon dioxide and other greenhouse gases.

NextGen systems and procedures will enable simpler, more direct trajectories throughout all phases of flight, including surface operations before takeoff and after landing. Collaboration between air traffic controllers, aircraft operators, airline flight operations centers and airport operations managers will move departing aircraft to their takeoff positions and arriving aircraft to their gates or parking assignments faster and more efficiently. System-wide management and sharing of information will make improved surveillance, communications and weather reporting and forecasting available to all these parties in a common format, enabling everyone to see and act on the same data at the same time.

Performance Based Navigation

On departures and approaches, more accurate surveillance and Performance Based Navigation (PBN) procedures will give controllers and operators options to vary flight paths for increased system efficiency and reduced distance, time in flight, and fuel consumption. On aircraft approaches, PBN will enable operators to throttle their engines down during their descent, offering the co-benefit of reducing noise exposure on the ground as well as emissions.

From the standpoint of the environment, some of the most beneficial of these PBN procedures require flight-path changes that trigger extensive environmental reviews. For example, diverging approaches and ascents create new, fuel-efficient trajectory options for controllers and operators, and in some cases they eliminate delays due to conflicts in routes to and from closely spaced airports. Because these types of flight paths differ from the current ones, the FAA must analyze its environmental impact to satisfy exacting standards. The agency's environmental management system is a key part of the strategy in such cases.

The FAA has begun implementing PBN and some of NextGen's other advanced capabilities, notably the Automatic Dependent Surveillance-Broadcast (ADS-B) system, which provides more accurate surveillance than radar and increases the situational awareness of pilots of properly equipped aircraft. ADS-B is operational in Louisville, Kentucky; Philadelphia, Pennsylvania; and Juneau, Alaska. Last December, ADS-B began operations over the Gulf of Mexico, off the U.S. southern coast, an area that was never served by radar.

NextGen Demonstrations

The FAA and its aviation community partners are demonstrating capabilities now that will begin delivering many of NextGen's most significant operational benefits during the next several years. Among these are collaboration in airport surface operations, PBN approaches and departures, reduction of in-trail separation requirements, fuel-saving en-route operations, and the beginnings of data communications. The FAA plans to reach operational status this winter for tailored arrivals at suitable locations. The agency has been demonstrating these capabilities for years at Miami, Florida, and San Francisco and Los Angeles, California.

Demonstrations are valuable in many ways. They help refine plans for developing and implementing systems and procedures. They open the door for operations personnel from the FAA and prospective user organizations to participate in planning, provide insights into development requirements, and understand innovations that they will encounter in the field. They also provide evidence of the benefits that users can expect following deployment, which in turn helps them develop a business case for investing in the aircraft equipment needed to take advantage of NextGen capabilities. The benefits of these will be substantial.

For example, demonstrations have established that collaboration among operators and controllers can reduce taxi-out times at busy airports substantially - by as much as 15 percent in one exercise. As part of the NextGen-SESAR Atlantic Interoperability Initiative to Reduce Emissions (AIRE) program - in 52 flights during 2009, Lufthansa and Air Europa avoided an average of more than 1.5 tons of CO_2 per flight. These and other demonstrations help refine the FAA's model-based overall estimate of NextGen benefits.

Environmental Benefits

The FAA expects environmental benefits from NextGen systems and procedures to help offset the expected growth of flight operations. Although aviation growth in the United States has been held down during the past decade, the FAA's Aerospace Forecast for Fiscal Years 2010-2030 (March 2010), envisions annual growth of 1.3 percent in total aircraft operations at airports with traffic control services (2.0 percent counting airline operations alone), and 2.3 percent in the number of aircraft operating with instrument flight rules handled at en route centers (3.2 percent in airline aircraft).

Airline takeoffs and landings in the United States are forecast to approach 19.5 million in 2030 vs. 15.2 million in 2000. The 30-year increase is expected to be more than 28.5 percent. Additional operational measures are needed to counter the offset from NextGen's environmental gains that this growth will cause, and the FAA is pursuing them aggressively.

Measuring and Managing Performance

With respect to environmental performance, the FAA currently uses an aviation fuel efficiency metric to measure progress in energy efficiency and emissions. The agency has an ongoing project to review which metrics to use for future measurements of NextGen environmental performance in the areas of climate, energy, air quality and noise.

To give environmental and efficiency performance a high priority, the FAA will use an environmental management system (EMS) approach to integrate environmental performance objectives into NextGen programs and systems. An EMS is intended to ensure that the agency does everything possible to integrate environmental considerations into day-to-day decisions and long-term planning.

Looking Forward

Looking beyond improved flight operations, we believe that advances in engine and airframe technologies and renewable alternative fuels will provide important environmental benefits. Historically, the greatest reductions in aviation's environmental impact have come from new technologies, and we expect aviation's proven aptitude for technological innovation to be a continuing strength.

Our principal effort to develop new technologies to reduce aviation's environmental impacts is the Continuous Lower Energy, Emissions and Noise (CLEEN) program, launched in 2009. The FAA and the aviation industry are partnering and sharing costs on work to develop and mature promising subsonic jet aircraft and engine technologies that industry can commercialize. Options for development work include composite structures, ultra-high-bypass-ratio and open rotor engines, advanced aerodynamics and flight management systems technologies. Our objective is to demonstrate a high level of technology readiness for selected initiatives within five years, so that industry can apply them commercially within five to eight years.

Jet fuels made from renewable sources are the most promising for reducing aviation's CO_2 footprint. Sustainable jet fuels also offer the co-benefits of advancing energy security and economic development. CLEEN is also pursuing development and maturation of sustainable alternative jet fuels. Since 2006, the FAA has worked with airlines, manufacturers, energy producers, researchers and U.S. and other government agencies in the Commercial Aviation Alternative Fuels Initiative (CAAFI) on sustainable alternative aviation fuels development and deployment. In September 2009, the first alternative jet fuel specification won approval, enabling the use of a 50 percent blend of synthesized hydrocarbon fuel from biomass, gas or coal mixed with Jet A. CAAFI is working with ASTM International to secure approval of a second alternative fuel blend of hydrotreated renewable jet biofuels and Jet A by 2011. Other fuels will follow.

The timing of the CLEEN and CAAFI research programs complements that of our NextGen operational improvements. As we continue deploying systems and procedures, we will reach in 2018 what we consider the mid-term, a point at which we envision cumulative fuel savings of 1.4 billion gallons, equivalent to avoiding 14 million tons of CO_2. More environmentally friendly aircraft technologies and sustainable aviation jet fuels will further allow us to make progress toward meeting ICAO's aspirational goal of enhancing aviation fuel efficiency by 2% per year and the U.S. goal to achieve aviation carbon neutral growth by 2020 using 2005 as a baseline and net reductions by 2050.

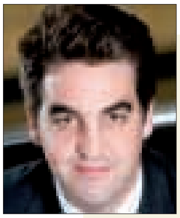
Benefits

NextGen and efforts like it promise to be substantial contributors to mitigating aviation's environmental impacts. As the FAA continues to deploy NextGen systems and procedures, cumulative fuel savings will reach 1.4 billion gallons by 2018, equivalent to avoiding 14 million tons of CO_2. More environmentally-friendly aircraft technologies and sustainable aviation jet fuels will further enable the aviation community to make progress toward meeting ICAO's aspirational goal of enhancing aviation fuel efficiency by 2 percent per year and to achieve the U.S. goal of aviation carbon neutral growth by 2020 and net reductions by 2050 (using 2005 as a baseline).

The FAA's multi-layered approach to greening aviation, and comparable initiatives being pursued throughout the world, are critically important to our collective efforts to make aviation a constructive partner in the global effort to reduce greenhouse-gas emissions and reverse global warming.

SESAR and the Environment

*By **Alain Siebert** and **Célia Alves Rodrigues***



__Alain Siebert__ is the Chief, Economics & Environment at the SESAR Joint Undertaking based in Brussels, Belgium. He is responsible for all economic and environmental aspects for this new, ambitious European program recently launched by the European Commission, Eurocontrol and the industry.

Alain started his career as a Management Trainee at Air France and later joined SAS Group as Executive Assistant to the Chief Financial Officer. He was later assigned Head of Strategic Development & Fuel Conservation under the responsibility of the Chief Operating Officer. There he supported the senior operations management team in strategic business planning and execution with main responsibility for Fuel Conservation.

See AIRE article for __Célia Alves Rodrigues__ biography.

Introduction

Air Traffic Management (ATM) determines when, how far, how high, how fast and how efficiently aircraft fly. These parameters in turn influence how much fuel a given aircraft burns, the release of greenhouse and other gases from the engines, and of course, how much noise the aircraft makes.

An Oxford University study has found[1] that the quickest way to reduce aircraft emissions is better flight management. According to that study, ATM enhancements through the optimization of horizontal and vertical flight profiles have the potential to trim down the in-flight CO_2 emissions accumulated over the 2008 to 2020 period by about 50 Million tons.

This article presents the European Union's Single European Sky initiative and its technical pillar, the Single European Sky ATM Research programme (SESAR). It provides an update on its implementation status (by mid-2010), focusing on its environmental perspective, without providing an exhaustive summary of the entire SESAR work programme. For more detailed information please visit **www.sesarju.eu**.

Single European Sky and SESAR

The Single European Sky is an ambitious initiative launched by the European Commission in 2004 to reform the European ATM system. It sets a legislative framework to meet future capacity and safety needs at a pan-European level. The Single European Sky is the political transformation of the European ATM system.

SESAR on the other hand, is the operational and technological dimension of the Single European Sky. It will help create a "paradigm shift", supported by state-of-the-art and innovative technologies designed to eliminate fragmentation in the future European ATM system. SESAR is composed of three phases and will be implemented in steps as shown in Figure 1.

***Figure 1:** SESAR implementation phases, 2004 to 2020 and beyond.*

The European ATM Master Plan defines the "path" towards the achievement of performance goals as agreed at EU ministerial level (horizon 2020, baseline 2005) as follows:

- Enable a 10% reduction in CO_2 emissions per flight;
- Reduce ATM costs by 50%;
- Enable a threefold increase in capacity;
- Improve safety by a factor of 10.

The European ATM Master Plan also defines which operational, technological and regulatory changes are needed, where and when they are needed (including links to ICAO regulation to ensure consistency), together with a risk management plan and a cost/benefit assessment.

The SESAR Joint Undertaking (SJU) was established in 2007 as a new EU organization. It was founded by the European Commission and Eurocontrol, with the main responsibility to:

- Execute the European ATM Master Plan;
- Concentrate and integrate R&D in Europe (budget of 2,1 EUR Billion broken down as below).

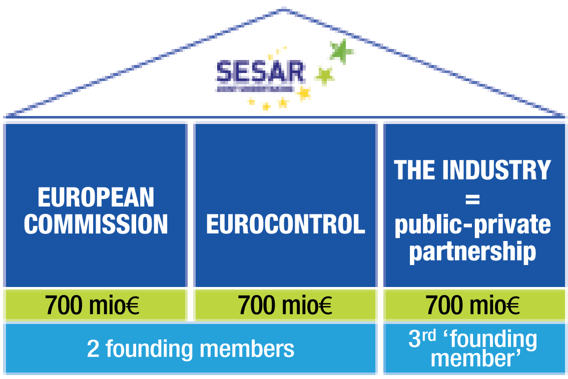


Figure 2: *Single European Sky ATM Research programme (SESAR), R & D budget breakdown.*

Environment - A SESAR Priority

Before the end of 2011, the SESAR programme will implement an advanced validation methodology that will ensure end-to-end consideration of environmental issues in all SESAR research and development (R&D) activities conducted within that timeframe. At the same time, SESAR operates in close cooperation with other European and international initiatives regarding the integration of new, environmentally friendly solutions for the aviation sector. One such project is the European Union's Clean Sky Joint Technology Initiative that will develop breakthrough technologies to significantly improve the environmental performance of aircraft. Besides enabling the ambitious environmental objectives outlined in the European ATM Master Plan, SESAR's objectives beyond 2011, are to:

- Improve the management of noise emissions and their impacts through better flight paths, or optimized climb and descent solutions.
- Improve the role of ATM in enforcing local environmental rules by ensuring that flight operations fully comply with aircraft type restrictions, night movement bans, noise routes, noise quotas, etc.
- Improve the role of ATM in developing environmental rules by assessing the ecological impact of ATM constraints, and, following this assessment, adopting the best alternative solutions from a European sustainability perspective.

The SESAR R&D Capability Is In Place

SESAR is all about partnership in practice. For the first time, all aviation players (i.e. airport operators, air navigation service providers, and the manufacturing industry) are involved in the definition, development and deployment of a pan-European modernization project right from the start. Fifteen members have joined the SJU to date: AENA, Airbus, Alenia Aeronautica, DFS, DSNA, ENAV, Frequentis, Honeywell, Indra, NATMIG[2], NATS, NORACON[3], SEAC[4], SELEX Sistemi Integrati and Thales. Several of those members represent consortia, which brings the total number of organizations directly and indirectly bound to SESAR to 35. These companies also have affiliates and sub-contractors. As a result, a total of 70 companies from 18 countries are participating in SESAR, demonstrating the impact of the programme on ATM R&D activities in Europe. In addition, the SJU programme actively involves key stakeholders such as airspace users, staff and professional associations, as well as regulatory authorities and the military through ad hoc working arrangements.

The negotiation process with SJU members was completed in June 2009 and already 80% of the 300 projects comprising the SESAR Work Programme have been launched. As a result, more than 1,500 engineers and experts from all the partner organizations, located in 17 countries, are already participating in SESAR.

Partnership In Practice - Delivering Green Results Today

The SESAR programme aims to define and validate a first set of solutions that should be delivered and ready for implementation by 2013. In the meantime, the focus is on capitalizing on current aircraft capabilities through industry leadership and partnership in order to achieve quick gains. In this respect, the activities performed under the umbrella of the Atlantic Interoperability Initiative to Reduce Emissions (AIRE) have shown very encouraging results and that programme will be further expanded (see *AIRE article*, Chapter 3 of this report).

Importance of International Cooperation and Interoperability Through Standards

SESAR is fully committed to working together on the implementation of a single strategy to effectively address the global impact of aviation. Harmonization is essential to ensure that the same aircraft can safely fly throughout the world with airborne equipment that is interoperable with any ground ATM system. This is also one of the key requirements for new ATM systems from airspace users. Interoperability requires internationally agreed standards, and SESAR works in the context of the ICAO's Global ATM Operational Concept to deliver the technical basis for defining standards through ICAO SARPs (Standards and Recommended Practices) and coordinated industry standards. The existence of such common standards will also lower costs for the manufacturing industry which will be able to design equipment for a global market. This requires collaboration with other parts of the world that are implementing change initiatives, such as NextGen in the US. The role of ICAO is pivotal towards facilitating this collaboration.

The work being done by SESAR and its environmental targets are both fully aligned with ICAO's strategic objective to minimize the adverse effects of civil aviation on the environment. Its new concepts and procedures will, to the greatest extent possible, be developed in coordination with CAEP and other technical panels to ensure global harmonization and acceptability from the outset.

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Conclusions

Ambitious environmental targets are set for the European ATM system by 2020, making environment a priority for SESAR. The European ATM Master Plan defines the roadmap for the step-by-step evolution of the ATM System in Europe and the achievement of the environmental targets. Effective funding and governance arrangements to concentrate R&D activities and execute the European ATM Master Plan have been implemented in Europe with the establishment of the SESAR Joint Undertaking. First technological solutions will be validated by 2012. In the meantime, AIRE has demonstrated that green results can be achieved today. Public-private partnerships and international cooperation are key success factors for the programme.

The SESAR Joint Undertaking is committed to support ICAO in effectively responding to the environmental challenges that global aviation is facing today.

The Environmentally Responsible Air Transport (ERAT) Project

The Environmentally Responsible Air Transport (ERAT) project is a research project, co-funded by the European Commission under the Sixth Framework Programme which addresses the ATM community's need to reduce the environmental impact per flight to allow for sustainable growth. The project is carried out by a consortium of 11 project partners: Airbus, DLR, ENVISA, EUROCONTROL Experimental Centre, LFV, Lufthansa, National Company Bucharest Airports, NATS, NLR, Snecma, To70. The objective of ERAT is to improve the environmental performance of air transport by developing and validating Concept of Operations (CONOPS) for two airports, London Heathrow and Stockholm Arlanda. Both CONOPSs aim for environmental benefits from the top of descent, to touchdown, by focusing on more efficient operations (i.e. less radar vectoring and holding), and enabling Continuous Descent Approaches and Continuous Climb Departures.

The initial results for the London Heathrow concepts showed that the small environmental benefits in terms of less fuel burn, emissions and noise, are at the expense of runway capacity. The London Heathrow concept is planned to be refined and assessed in the fourth quarter of 2010. Two sets of real-time simulations concepts are planned in the second half of 2010 to assess the concept of operations for Stockholm Arlanda, and the results are expected to be available at the end of 2010.

Project ERAT website: **http://www.erat.aero**

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Airtel ATN of Ireland, Northrop Grumman Park Air Systems of Norway, Saab of Sweden and SINTEF of Norway.

3 ***NORACON, the NORth European and Austrian CONsortium, consists of eight European ANS providers:***
Austro Control (Austria) and the North European ANS Providers (NEAP) including AVINOR (Norway), EANS (Estonia), Finavia (Finland), IAA (Ireland), ISAVIA (Iceland), LFV (Sweden) and Naviair (Denmark).

4 ***Six major European airport operators form the SEAC consortium***
SEAC includes BAA Airports Ltd, Flughafen München GmbH, Fraport AG Frankfurt Airport Services Worldwide, Schiphol Nederland B.V., Aéroports de Paris S.A. and Unique (Flughafen Zürich AG).

The Atlantic Interoperability Initiative to Reduce Emissions - AIRE

*By **Célia Alves Rodrigues,** SESAR JU*

***Célia Alves Rodrigues** has been the Environment Officer at the SESAR Joint Undertaking based in Brussels, Belgium since March 2010. SESAR's mission is to develop a modernized air traffic management system for Europe for the next thirty years. Célia is SESAR's focal point for environmental issues. As a member of the Economics and Environment Unit she provides guidance on the various projects to ensure that the environmental objectives of the programme are achieved. She is also responsible for the programme management of the Atlantic Interoperability Initiative to Reduce Emissions (AIRE). Célia served at ICAO as an Associate Environmental Officer in 2007, and prior to that she worked with the noise and health unit at the World Health Organization from 2002 to 2006.*

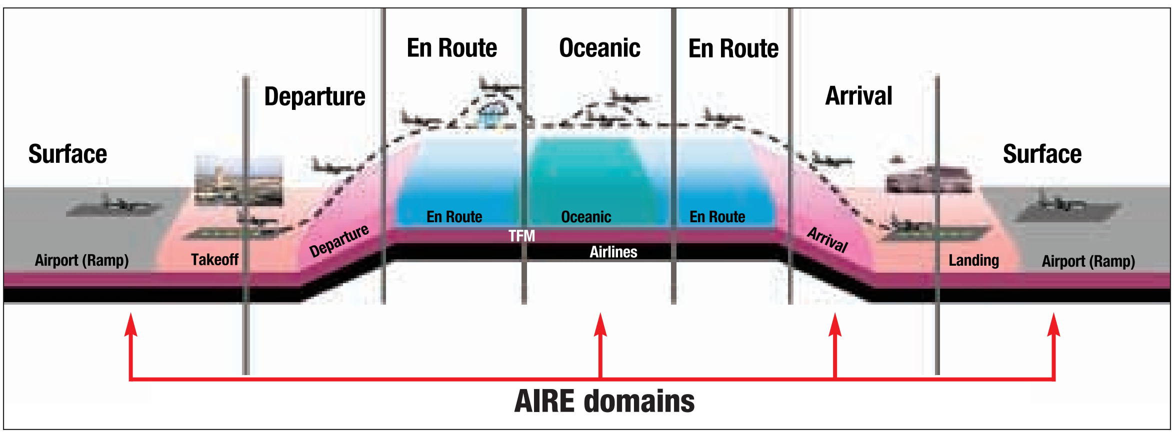
Introduction

The growth of aviation calls for global efforts to efficiently address and mitigate the sector's contribution to climate change and also to reduce local impacts on noise and air quality. In the spirit of partnership and in an effort to undertake concrete action towards the sustainable growth of aviation, the European Commission (EC) and the Federal Aviation Administration (FAA) signed a cooperative agreement establishing the Atlantic Interoperability Initiative to Reduce Emissions (AIRE) in June 2007. AIRE is part of SESAR and NextGen joint efforts to hasten environmental improvements.

AIRE aims to improve energy efficiency, lower aircraft noise, enhance ATM interoperability through the acceleration of the development and implementation of environmentally friendly procedures for all phases of flight (gate-to-gate), and validate continuous improvements with trials and demonstrations. This article presents the AIRE trials conducted during 2009, on the European side, managed by the SESAR Joint Undertaking (SJU). More details can be found on the AIRE executive summary available at **www.sesarju.eu/environment**.

2009 Flight trials

Under the framework of the AIRE programme, approximately 1,150 demonstration trials for 'green' surface, terminal and oceanic procedures took place in five locations, involving 18 partners. Additionally, two full 'green' gate-to-gate flights, from Paris Charles de Gaulle (CDG) to Miami, took place in April 2010.



These trials represented not only substantial improvements for the greening of air transport, but the motivation and commitment of the teams involved, and created momentum to continue to make progress on reducing aviation emissions.

Domain	Location	Number of trials performed	CO_2 benefit flight
Surface	Paris, France	353	190 –1,200 kg
Terminal	Paris, France	82	100 – 1,250 kg
	Stockholm, Sweden	11	450 – 950 kg
	Madrid, Spain	620	250 – 800 kg
Oceanic	Santa Maria, Portugal	48	90 – 650 kg
	Reykjavik, Iceland	38	250 – 1,050 kg
Total		**1152**	**390 tons**

Table 1: *Summary of AIRE trials for 2009.*

Ground movements

The AIRE ground movements' project was conducted by a consortium involving Aéroports de Paris, the French Direction des Services de la Navigation Aérienne (DSNA) and Air France. The positive results of the trials demonstrated that the necessary steps toward deploying and routinely using the tested procedures (planned for the summer of 2010) have already been taken .

Three types of innovative ground movement measures were evaluated: "Departure taxiing with one or two engines off," with the objective of measuring fuel savings; "Minimising arrival taxi time," with the objective of reducing arrival taxi time, when possible; and "Minimising departure taxi time," with the objective of optimising the sequence of departures to reduce the waiting time at the departure threshold.

Regarding "Departure taxiing with one or two engines off," for the four engine aircraft (B747), the observed fuel consumption reduction was about 20 kg/minute with two engines off and 10 kg/minute with one engine off. For the "Minimising arrival taxi time," benefits came from a mean reduction of taxi-in time of about 1min. 45s per aircraft parking in specific areas and also on a positive in-flight impact of 30 seconds (two miles) on the assigned aircraft approach trajectory. For the A320 family, benefits were estimated at about 50 kg fuel savings per arrival flight taxiing to parking area, equivalent to 160 kg CO_2 savings. For "Minimising departure taxi time," the departure taxi time was reduced by an average of 45 seconds per flight in nominal conditions, and by about one minute per flight in non-nominal conditions. The estimated total fuel savings for these limited trials were approximately six tons, equivalent to 19 tons of CO_2 savings. According to ATC, such benefits could be reproduced for the four most important departure peak periods.

Terminal

Three consortiums in three different locations carried out projects for the terminal area. In **Stockholm, Sweden**, AVTECH, the LFV Group, Novair, Egis Avia, Thales, and Airbus, with the contribution of an Expert Advisory Group, carried out the Minimum CO_2 in the TMA (MINT) project. Optimised (addressing both lateral as well as vertical parts of the approach) aircraft operations during descent into Stockholm Arlanda airport were performed by combining benefits from using the aircraft Required Navigation Performance (RNP) capability with benefits from flying efficient Continuous Descent Approaches (CDAs). The project identified 165 kg of potential fuel savings for the 01R runway when arriving from the south and 140 kg potential savings if also including other directions and other runways to the baseline performance. The observed lateral navigation precision of flight of the aircraft was excellent. The RNP procedure also proved itself to be a strong tool for addressing noise distribution problems by enabling circumnavigation of the areas. From an operational perspective, no problem was identified in implementing the new procedure which is planned to enter into normal operation very soon, during low traffic periods.

The **Paris** project was conducted by a consortium composed of the French DSNA and Air France. The demonstrations included: Continuous Climb Departure (CCD) from Charles de Gaulle (CDG) and from Orly (ORY) to North West; Tailored Arrivals to CDG and to ORY from North West; and CDA to ORY from South West.

The "CCD to North West" showed about 30 kg of fuel savings per flight at CDG and about 100 kg of fuel savings at ORY (about 100 kg and 300 kg of CO_2 savings, respectively). For "Tailored Arrivals from the North West", the procedures included an enhancement of the vertical profile from cruise to an Initial Approach Fix. In addition, for ORY it involved an optimisation of the downwind leg by raising a flight level constraint. The results varied from 100 kg to 400 kg of fuel savings per aircraft at CDG, depending on the West or East configuration, and about 200 kg of fuel at ORY (on average about one ton and 600 kg of CO_2 savings respectively). The demonstrations of the "CDA to ORY from South West" showed about 175 kg of fuel savings per flight (i.e. about 530 kg of CO_2 savings).

In **Madrid, Spain**, Air Navigation Service Provider and Airports Operator of Spain (AENA), Iberia and INECO conducted the RETACDA project. The objective was to perform integrated flight trials and demonstrations in the Terminal Area (TMA) using a CDA, with the aim of reducing CO_2 emissions and of optimising the fuel consumption in the TMA around Madrid-Barajas airport. CDA procedures were performed at night using A320 and A340 Iberia fleet in a North configuration. Data from other flights in the same fleet, not performing CDAs, was used as a baseline to compare the CDA fuel savings benefit, estimated at approximately 80kg. For the four engine aircraft (A340), the fuel consumption reduction was about 260kg. For both types of aircraft, around 25% less fuel during descent was consumed performing "CDA" rather than "non-CDA". Translated to emissions reductions, the results show that the potential savings per flight are about 250 kg and 800 kg of CO_2 respectively.

Oceanic

Two projects in two different locations tested the optimisation of flight profiles. In **Santa Maria, Portugal** the NATCLM Project was conducted by a consortium composed of Adacel (ATM system supplier), Air France, NAV Portugal and TAP Portugal. Several demonstration flights with Air France B777 and TAP Portugal A330 provided data and derived results for the project. Flights were from Paris to the Caribbean West Indies and also between Portugal and North, Central and South America. The demonstrations were carried out inside the Santa Maria Oceanic Flight Information Region (FIR) (ICAO NAT region) managed by NAV Portugal. The FAA supported some of the flights, allowing the extension of the flight profile optimisation from Santa Maria FIR to inside the New York Oceanic FIR.

The vertical (cruise climb) optimisation demonstration was performed with a manual cruise climb like function with a sequence of 100 ft climbs. Overall, an estimation of savings relative to cruise climb showed potential savings of 29 kg of fuel (i.e. savings of approx. 90 kg of CO_2) compared to a 2,000 ft step climb or 12 kg (i.e. savings of approx. 40 kg of CO_2) or two 1,000 ft step climbs (i.e. six kg of fuel per each 1,000 ft climb performed in 100 ft steps). For lateral optimisation (horizontal), the pilot was allowed to optimise the route with the most up-to-date meteorological information. With the updated met data, a new flight plan could be calculated in-flight. In some cases, the route could be optimised and thus a different route was flown. The fuel savings using this technique varied, with values of up to 90 kg (i.e. savings of approx. 300 kg of CO_2) saved for an Airbus A330 flying from Lisbon to Caracas. For the longitudinal optimisation (time, cost index – Mach number), the study used the comparison of the flight plans computed with derived constant Mach number and the actual cost index (CI). By definition, flying at economic speed (i.e. at the given cost index) minimises total costs and therefore determines the cost savings obtained by flying at that given cost index when compared to flying at a constant Mach number. Significant savings have been computed in the range of 130 kg to 210 kg of fuel per flight.

Since the end of the demonstrations, several airlines are being cleared by Santa Maria FIR on a daily basis to perform profile optimisations. The enhancements identified are expected to bring a valuable contribution by allowing aircraft to fly as close as possible to their business trajectory and consequently, maximise fuel efficiency and minimise CO_2 emissions.

The Oceanic-Nat ADSB Project in **Reykjavik, Iceland** was conducted by a consortium composed by the Service Provider ISAVIA, Icelandair and TERN Systems. The project aimed at demonstrating, through simulations and flight trials, the environmental benefits that can be achieved by pursuing more optimal flight profiles using cruise climb, direct routing, and variable speed in ISAVIA's proposed ADS-B oceanic corridor within the Reykjavik Control Area (CTA).

Icelandair ran 38 flight trials on the Keflavik – Seattle route between October 2009 and January 2010. Icelandair's flight control evaluated each flight and executed step climbs, with a reduced rate of climb (approximation of optimised cruise climb), direct routing, and/or variable speed when desirable. Fuel data was logged and compared to baseline fuel consumption using a statistical approach. For the variable speed, flight trial savings results are inconclusive, as the comparison to aircraft supposed to fly at a constant Mach did not actually fly at a fixed Mach number. This led to unreliable data on consumption even though earlier results from Icelandair flying cost/index showed considerable fuel savings. In the current environment and with some adaptation of the Flight Data Processing System, it may be possible to use the procedure insofar as its use is limited to the Reykjavik CTA low density area of the airspace and within the surveillance corridor.

The vertical (limited cruise climb) optimisation demonstration was performed with vertical speed of 100 ft per minute and 1000 ft step climbs. Overall, an estimation of savings relative to cruise climb showed potential savings of 330 kg of fuel (i.e. saving approx. 1040 kg of CO_2). For direct routings, flight trial savings are reported at approximately 80 kg fuel reductions or 252 kg of CO_2. Medium savings were obtained mainly because the Reykjavik CTA already offers maximum flexibility within the NAT structure.

Full gate-to-gate flights

The two first complete (gate-to-gate) green transatlantic flights were operated in April 2010 from CDG to Miami airport. The flights were carried out by Air France (6 April) and American Airlines (7 April). During the approximately nine hours of flight, enhanced procedures were used to improve the aircraft's energy efficiency. These procedures, applied at each flight stage and coordinated among all project participants, reduced fuel consumption (and hence CO_2 emissions) throughout the flight, from taxiing at CDG to arrival on the parking stand in Miami. During the departure and arrival phases, the procedures helped minimise noise levels. Air France estimates that applying these optimisations to all Air France long-haul flights to and from North America, would result in a reduction of CO_2 emissions by 135,000 tons per year, with fuel savings of 43,000 tons.

Conclusions

In 2009, having performed 1,152 trials, the AIRE programme was successful in demonstrating that significant savings can be achieved using existing technology. CO_2 savings per flight ranged from 90 to 1,250 kg and the accumulated savings during trials were equivalent to 400 tons of CO_2. Another positive aspect was the human dimension - the projects boosted crew and controller motivation to pioneer new ways of working together focusing on environmental aspects and enabled cooperative decision making towards a common goal.

Lessons learned and best practices from the AIRE trials are also going to be implemented in the SESAR work programme, thus, allowing the broad deployment and standardisation of these procedures. In January 2010, a new call for tender was launched by the SJU for AIRE allowing the performance of more green operations and significant fuel savings to take place in 2010 and 2011. The new AIRE projects cover all of the North Atlantic, are closely linked to deployment and place a greater focus on gate-to-gate solutions.

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The ASPIRE Project

*By **Japan Civil Aviation Bureau***

__Hideki Sugai__ is Director of the Air Traffic International Affairs Office, JCAB. He has extensive experience in Air Traffic Control of terminal, en-route, and oceanic airspace. From 1998 to 1999 he worked in Nepal to assist the implementation of Kathmandu airport's terminal radar control. He was also a member of the ICAO Obstacle Clearance Panel (OCP) from 2001 to 2003. Just before his current post, he was an administrator of Matsuyama airport. He studied Russian and politics at the Kobe City University of Foreign Studies. He is also a semi-professional jazz bassist.

Introduction

The air transportation industry is essential for global future economic growth and development. In 2007, more travellers than ever before, nearly 2.2 billion people, flew on the world's scheduled air carriers, with predictions of 9 billion passengers by 2025. In the Asia Pacific region, the rapid movement of people and materials provided by aviation will be crucial to continued economic growth over the next few decades.

In 2008, Airservices Australia, Airways New Zealand and the Federal Aviation Administration (US-FAA) joined forces to create the Asia and South Pacific Initiative to Reduce Emissions. Since the group inception the ANSP membership has expanded with the inclusion of Japan Civil Aviation Bureau (JCAB) in 2009 and the Civil Aviation Authority of Singapore (CAAS) in 2010. The project is now known as the ASia Pacific Initiative to Reduce Emissions (ASPIRE).

The ASPIRE project

ASPIRE is a collaborative approach to the environmental stewardship of Asia and South Pacific aviation. The joint venture is designed to lessen the environmental impact of aviation across Asia and the South Pacific with each partner to focus on developing ideas that contribute to improved environmental standards and operational procedures in aviation. Working closely with airline partners, Air New Zealand, Qantas, United Airlines, Japan Airlines and Singapore Airlines, ASPIRE will measure the efficiency of every aspect of the flight from gate-to-gate. ASPIRE is committed to working closely with airlines and other stakeholders in the region in order to:

- Accelerate the development and implementation of operational procedures to reduce the environmental footprint for all phases of flight, from gate-to-gate;
- Facilitate the use of environmentally friendly procedures and standards world-wide;
- Capitalise on existing technology and best practices;
- Develop shared performance metrics to measure improvements in the environmental performance of the air transport system;
- Provide a systematic approach to ensure appropriate mitigation actions with short, medium and long-term results; and
- Communicate and publicise ASPIRE environmental initiatives, goals, progress and performance to the global aviation community and the general public.

Operational measures

ASPIRE promotes recommended procedures, practices and services that have demonstrated or shown the potential to provide efficiencies in fuel and emissions reductions. These encompass all phases of flight from gate-to-gate, and are designed to reflect the unique nature of the Asia and Pacific region, where international flights often exceed 12 hours in duration.

Pre-flight operations are enhanced with:

- *the use of more accurate estimations of loaded fuel;*
- *the weight reduction of cargo containers and of onboard loaded material;*
- *the extended use of ground electricity; and*
- *the engine washing.*

Ground operations are also improved by:

- *tailoring water uplift;*
- *just in time fuel loading; and*
- *optimizing ground traffic control mangement.*

After shortening the distance to reach the optimum cruising altitude after take-off, *air navigation* improvements fall into two categories: the oceanic flight and the arrivals management. User Preferred Routes, Dynamic Airborne Reroute Procedures, Performance Based Navigation (PBN) Separation Reductions, Reduced Vertical Separation Minima (RVSM) and flexible track systems are implemented during oceanic flight phases. Continuous Descent Arrivals, Tailored Arrivals, PBN Separation and Required Time of Arrival management are part of the operational measures used in the arrival flight phase.

Demonstration flights

As part of establishing a baseline for air traffic management performance and carbon emissions, the initial ASPIRE partners undertook a series of 3 trans-Pacific flights operating a B777, an A380 and a B747-400 aircraft to demonstrate and measure gate to gate emissions and fuel savings using existing efficiency procedures. Each flight was managed by an ASPIRE founding member air navigation service provider and involved close collaboration with the airline partners. These three flights resulted in a total fuel saving of 17,200 kg representing a CO_2 emissions reduction of 54,200 kg. Two additional demonstration flights, conducted by JCAB and CAAS in sequence, both operating a B747-400 aircraft, showed fuel savings of about 15,600 kg representing a CO_2 emissions reduction of about 47,000 kg.

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Operational Measures to Reduce Carbon Dioxide Emissions from Aviation: Initiatives from New Zealand

*By **Shannon Scott**, Civil Aviation Authority of New Zealand*

__Shannon Scott__ joined the Civil Aviation Authority of New Zealand (CAA) in 2009 as Senior Policy Adviser for Aviation Environment. He joined the CAA from the Ministry of Research, Science and Technology, where he was responsible for developing international science cooperation programmes with partners in North Asia. Prior to joining the public service, Shannon managed an International Programmes team at the University of Canterbury, New Zealand, providing customised education and training programmes for international clients in areas such as environmental management and public sector management.

Shannon has degrees in Geography (with a focus on Climatology) and Chinese language, and has also completed an FAA-approved aircraft dispatcher certificate course.

Aviation is extremely important to New Zealand, both economically and socially. Because the country is geographically remote from major world centres, international aviation helps it stay connected, carrying more than two million visitors each year. Domestic air transport helps overcome New Zealand's mountainous island terrain with speed and efficiency. General aviation is also a significant component of aviation in New Zealand. Altogether, there are more than 4,400 aircraft on the New Zealand register, one for every 1,000 residents.

At the same time, the country's environmental assets are of enormous value to it. Tourism relies heavily on the quality of the environment, and is New Zealand's second largest export earner. There is therefore a strong interest in ensuring the sustainability of aviation in New Zealand.

This article presents an overview of operational measures that the New Zealand aviation industry has introduced to reduce emissions. It concludes with a brief look at some of the advantages of Performance Based Navigation (PBN), which will be an important factor in future efficiency gains, and New Zealand's development of an Airspace and Air Navigation Plan.

Air Traffic Management

Airways New Zealand (Airways) is the body that provides air navigation services for aircraft flying in most of the airspace administered by New Zealand, which covers an area of 30 million square kilometres. Airways's Vision 2015 document, *A Strategic Vision of Air Traffic Management in New Zealand to 2015 and Beyond*[1], has been prepared to guide its long-term development. Vision 2015 envisages an operating environment where an aircraft's profile is managed from departure gate to arrival gate, with a shift in the primary role of air traffic management from tactical control towards strategic control and exception management – *or air traffic enabling*. Emissions management is one of the core elements of this new system, which may incorporate systems and tools that minimize intervention, minimize flight time, and facilitate best-economy power setting wherever possible.

Collaborative Flow Manager

One of the initiatives supporting Vision 2015 is Collaborative Flow Manager (CFM). This system, previously known as Collaborative Arrivals Manager (CAM), helps airlines and controllers avoid unnecessary airborne delays and holding during bad weather and at peak times, by sharing real-time flight information through a web-based interface. It allows decisions to be made to hold flights on the ground rather than incur in-flight holding and delay vectoring.

CFM has been implemented at Auckland and Wellington airports, but the benefits of reduced disruptions have spread across the entire network. Before CFM was introduced in September 2007, monthly airborne delays at Auckland and Wellington added up to an average of about 28,000 minutes; this figure fell to less than 5,000 minutes in 2009. Airways estimates that CFM saved emissions of 25,000 tonnes of CO_2 during 2009 for domestic flights into Auckland and Wellington, and 32,000 tonnes of CO_2 across the network, including international flights into Auckland (Figure 1).

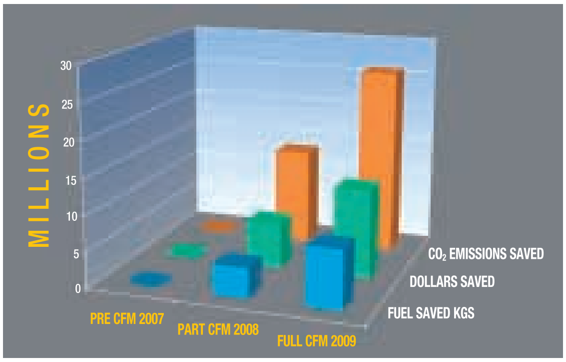

Figure 1: *Fuel and CO_2 savings from Collaborative Flow Manager (CFM).* Courtesy of Airways New Zealand.

Airlines have seen measurable benefits from CFM. Pacific Blue recorded a decrease in airborne delays of almost 15,000 minutes between 2008 and 2009 on their fleet of 737-800s, as the use of CFM became fully embedded in their operations (Figure 2).

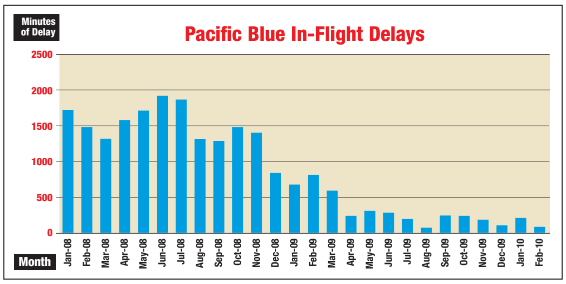

Figure 2: *In-flight delays incurred by the Pacific Blue fleet.* Courtesy of Airways New Zealand and Pacific Blue.

With CFM, international arrivals are visible to controllers two hours away, so controllers can make better flow assessments to manage these flights. As a result, airborne delays incurred by international arrivals into Auckland have been reduced from an average of 1,600 minutes per month, to 400 minutes under CFM (Figure 3).

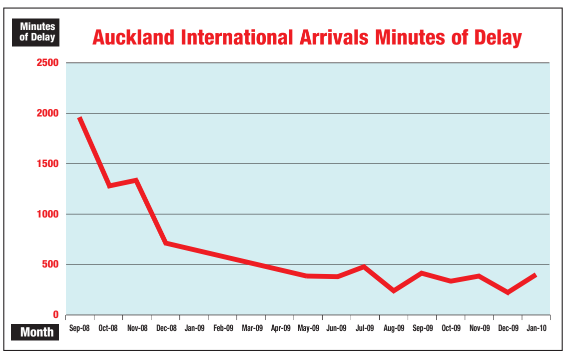

Figure 3: *Minutes of in-flight delay incurred by international arrivals at Auckland International Airport.* Courtesy of Airways New Zealand.

Oceanic

Airways New Zealand's Oceanic Control System (OCS) manages aircraft flying through the Auckland Oceanic Flight Information Region (FIR). The OCS incorporates a range of measures to enable safe and efficient flight profiles, facilitated by an automated conflict detection system. These measures include reduced horizontal air traffic separation to 30 nautical miles longitudinal and lateral (30/30 separation, first implemented in New Zealand Oceanic airspace), flexible track systems, dynamic airborne reroute procedures (DARPs) and user-preferred routes (UPRs).

UPRs are available for all flights in the Auckland FIR. In 2008, Air New Zealand reported that UPRs were saving them an average of 616 kg of fuel per flight to Japan and Shanghai, a total of over 1 million kg of fuel per year[2].

ASPIRE

Airways is a founding member of the Asia and Pacific Initiative to Reduce Emissions (ASPIRE) partnership, which now includes the US Federal Aviation Administratio (FAA), Airservices Australia, the Japan Civil Aviation Bureau, and the Civil Aviation Authority of Singapore[3]. The partnership aims to demonstrate and implement operational procedures that reduce aviation's environmental footprint and also increase its efficiency.

Air New Zealand operated the first ASPIRE demonstration flight, on a Boeing 777 from Auckland to San Francisco, on 12 September 2008. This first flight saved an estimated 3,500 kg or 4% of fuel, equivalent to a reduction in emissions of 11,000 kg of CO_2. The results of these "ideal flights" are forming the basis of benchmark metrics for fuel and emissions, which will be presented in the 2010 ASPIRE Annual Report. One of the next challenges for ASPIRE is to insert the benefits of the "ideal flights" fully into daily operations, something which is planned to begin in 2010 with daily ASPIRE flights on selected routes.

Airline Operations

Air New Zealand has either implemented or has under way 40 to 50 projects to reduce fuel use and associated greenhouse gas emissions. Since 2005, excluding new aircraft purchases, their operational fuel savings initiatives have reduced total fuel burn by 4.5% across the fleet, equivalent to 130,000 tonnes of CO_2. The savings for the domestic Boeing 737-300 fleet have been even greater, reaching 6%.

The airline has introduced a range of techniques to optimize operations, including:

- Continuous descents and tailored arrivals (where available), with the ultimate aim of implementing 4-dimensional trajectory (4DT) approaches using required navigation performance – authorisation required (RNP AR) to minimise track distances.
- Flying aircraft slower, and using delayed flap approaches.
- Reverse idle thrust on longer runways, and single engine taxi-in.
- Reducing the use of auxiliary power units (APUs).
- Just-in-time fuelling.

Air New Zealand recently installed blended winglets on its fleet of five B767-300s. These 3.4 metre high extensions, developed by Aviation Partners Boeing, are helping the airline save an average of 5.5% in fuel burn, equivalent to over 18,000 tonnes of CO_2 emissions a year.

The airline is a launch customer of the B777-200 performance improvement package, which is expected to save 1% of fuel. The package includes three technical modifications that reduce airplane drag: drooped ailerons, lower-profile vortex generators, and an improved ram air system for the environmental control system. They have also installed zonal driers on their B767s and A320s to remove the weight of excess moisture from fuselage insulation. Installation of zonal driers on the B777-200s is currently under development.

Upgrades to the airline's fleet are expected to deliver a significant change in efficiency beginning with the first delivery of new aircraft at the end of 2010. In November 2010, B777-300s will begin taking the place of B747-400s. The new aircraft are up to 15% more fuel efficient per passenger. The airline is the launch customer for the new "sharklet"-equipped A320, which will be delivered starting in 2012. Airbus expects that the "sharklets", a type of winglet, will reduce fuel burn by up to 3.5% over longer sectors. In addition, the airline is the launch customer of the Boeing 787-9. It has eight aircraft on order to replace its fleet of B767s, with an associated estimated fuel efficiency gain of around 20%.

Airport Operations

Although airport operators make a small overall contribution to aviation's total emissions, their significance as gateways to communities, cities and nations can give them a visible leadership role when they undertake emissions reduction measures.

Christchurch International Airport, the largest airport in the South Island, was the first airport in the Southern Hemisphere to gain carbon-neutral certification. This was achieved in 2008 through CarboNZero[4], a leading programme set up by one of New Zealand's government-owned research institutes, Landcare Research.

As well as measuring emissions, the CarboNZero programme also requires the airport to reduce its emissions. The airport operator has undertaken a range of projects to achieve this, including:

- Identifying and addressing energy inefficiencies in the terminal building.
- Using groundwater as a heat sink for air conditioning systems.
- Using a lower-temperature paving system and recycling asphalt during runway maintenance.
- Establishing a comprehensive recycling system for public areas.

Auckland International Airport, the country's main international gateway, participates in the Carbon Disclosure Project's annual survey of companies. The company has also been listed on the FTSE4Good index in the UK on the strength of their sustainability reporting and carbon disclosure. Their emissions reduction projects include:

- Introducing low-emission vehicles, which reduced greenhouse gas emissions by 67 tonnes over two years.
- Establishing an airport-wide staff travel and car pooling programme, now involving over 800 staff from more than 20 companies. This programme is potentially reducing CO_2 emissions from staff travel to and from work by up to 70 tonnes per annum.
- Installing a 300m^2 solar photovoltaic array, one of New Zealand's largest, on the roof of the international arrivals area. The array is saving up to 49,500 kWh of electricity supply a year.

- Installing solar hot water panels to supply passenger facilities, generating electricity savings of up to 15,000 kWh per year.
- Undertaking a detailed energy audit of the international terminal, which identified potential energy savings of 22%, equating to a potential reduction in total carbon footprint of 13%.

Next Steps

Performance Based Navigation

PBN , with its reduced reliance on ground-based navigation aids, will be a major component of future efficiency gains. Procedures under the two sets of PBN standards – area navigation (RNAV) and required navigation performance (RNP) – have been implemented in New Zealand airspace at selected airports and on selected routes, including in Oceanic airspace.

RNAV standard terminal arrivals (STARs) have been introduced at the three main international airports of Auckland, Wellington and Christchurch. The Wellington RNAV STAR saved an estimated 1,170 tonnes of CO_2 over the first nine months of 2009, due to the shorter distances flown by arriving aircraft.

Queenstown Airport, located in a mountainous region, was the first New Zealand destination to have required navigation performance – authorization required (RNP AR) approach procedures defined. These procedures are helping Qantas and Air New Zealand avoid costly flight diversions when visibility at Queenstown is low. During the first 12 months of Air New Zealand's B737 operations into Queenstown using the new procedures, the airline avoided 46 diversions and 40 cancellations of inbound flights. In nearly seven years of RNP AR operations into the airport, Qantas has recorded only four diversions, none of which were directly related to visibility.

A second RNP AR approach was published in April 2010 for Rotorua Airport, which is also terrain-constrained. New Zealand will be working to roll out additional PBN procedures over the coming years, as detailed in the New Zealand PBN Implementation Plan[5].

Airspace and Air Navigation Plan

The Civil Aviation Authority of New Zealand (CAA) is now in the process of developing a national airspace and air navigation plan. This will set a framework for airspace and air navigation in New Zealand in alignment with the ICAO Global Air Navigation Plan. The plan will be aimed at maintaining an accessible, integrated, safe, responsive and sustainable system, with high levels of efficiency, safety, security and environmental protection. This will help ensure that the New Zealand industry can make the best use of new technologies such as PBN, and ensure full interoperability with the rest of the world.

Conclusion

Given New Zealand's reliance on efficient air transportation, the aviation industry is very active in a broad range of measures to reduce emissions from operations. These initiatives will all help maintain the industry's performance and resilience in the years ahead.

While individual organizations can and do make a difference, a whole-of-system approach will increasingly be needed to achieve the greatest possible efficiencies. The New Zealand Airspace and Air Navigation Plan, with environmental performance as one of its cornerstone elements, is one measure that will assist in achieving this in New Zealand.

The author wishes to acknowledge the assistance of the following organisations in the preparation of this paper

Airways Corporation of New Zealand, Air New Zealand, Pacific Blue, Qantas Airways, Christchurch International Airport, Auckland International Airport.

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Environmental Benefits Of New Operational Measures
A Case Study: Brasília Terminal Area

By ***Jorge Silveira, Rafael Matera, Daniel Nicolato, Luiz Brettas, Wilton Vilanova Filho and Cesar Rosito*** *from ANAC and* ***Júlio Cesar Pereira, McWillian de Oliveira and Ronaldo da Silva*** *from DECEA*

National Civil Aviation Agency *(ANAC – Brazil)*
ANAC is the Brazilian civil aviation authority. The Agency is responsible for the regulation and the safety oversight of civil aviation. Established in March 2006, ANAC incorporated the staff, the structure and the functions of the Air Force's Civil Aviation Department (DAC), the former civil aviation authority.

Department of Airspace Control *(DECEA – Brazil)*
DECEA is a governmental organization, subordinate to the Ministry of Defense and to the Brazilian Air Force, that gather human resources, equipment, accessories and media infrastructure aimed to establish security and fluidity of the air traffic in Brazilian airspace and, at the same time, ensure its defense.

This article briefly describes some of the recent changes in air navigation and airport operations at President Juscelino Kubitschek International Airport, in Brasília, the Brazilian capital. These changes include the implementation of Performance-Based Navigation System, and changes in runway and taxiway management. The improvements achieved also contribute to the mitigation of environmental impacts in the area.

Background

The Brazilian Civil Aviation sector has recently been experiencing a period of significant growth. The volume of domestic and international aviation traffic increased approximately 25% during the years 2000-2008. With 2.1 million annual movements, the aircraft traffic in 2008 was the most since 2001. Brasília's international airport ranks third in Brazil in terms of aircraft movements and passengers. Due to its strategic location, the site is now becoming one of the main hubs of the country.

The Brasília Terminal Area (TMA) is located right in the middle of Brazilian territory. It acts as a hub for much of the national air traffic and connects the North and Northeast cities to the South and Southeast regions, playing a crucial connecting role in the territory. In addition, all of the international flights originating in Central and North America that are destined for the main airports in the southern region of the continent are controlled by this area. In this broad context, the consideration of environmental issues is important because the massive amount of operations that take place in this area have the potential to generate a significant environmental impact, both locally and globally.

This article presents a case study of the environmental impacts of operational changes made at Brasília airport and the surrounding terminal area. This includes a description of the recent and planned improvements, both in the airspace concept and airport airside operations, as well as the effects of these changes related to emissions and noise impacts. Specifically, it presents a brief assessment of the effects on carbon dioxide emissions derived from those changes.

Operational Improvements

The growth of air traffic and the volume of operations at the Brasília Airport have been accompanied by an increase in environmental problems. The initial concern was about noise complaints, but more recently, concerns have also been raised about engine emissions. In order to address these impacts, technical and operational measures have been implemented at the airport and in the general terminal area.

Two specific examples of recent operational improvements in the airport and TMA are presented in this article and their environmental implications are described. The first one refers to the recent redesign of the airspace at the Brasília Terminal Area, from sensor-based to performance-based navigation (PBN), aimed at producing more efficient, streamlined and safe use of airspace. The second one refers to some ongoing modifications in runway and taxiway management, introduced to optimize the taxiing operations, thus reducing taxiing time and the concomitant fuel burn.

Terminal Area Airspace Concept Improvements

Air navigation in Brazil is currently undergoing significant technology-related changes. This revolution has been made possible by a number of factors including: technological advances in aircraft, improved air navigation hardware and software, and development of more precise satellite positioning systems. These changes have been facilitated by increased investments that resulted from new political decision-making frameworks. As a result, Brazil is in the middle of a transition from sensor-based navigation to PBN. *(This is fully explained in ICAO Doc. 9613, Performance-based Navigation Manual: a Component of CNS ATM).*

The PBN concept is based on the use of area navigation capabilities and monitoring/alerting systems that are installed in modern aircraft. These elements allow improvements in airspace design by reducing the constraints on flight paths that were previously imposed by land-based navigational aids. This framework allows airspace planners to pursue specific goals, not only in terms of operational capacity and safety levels, but also with respect to environmental targets like fuel efficiency and fuel savings.

The implementation of these new airspace concepts in Brazil, including PBN, started in 2010. A multi-phase program is being implemented, the first stage of which involves the Brasília and Recife Terminal Areas. The new routes in these areas were implemented in April 2010.

The design of the Brasília airspace concept takes into account the central location of the airport in the country and other significant features. The model used is called a "four corners scheme", with entry points concentrated approximately in ordinal directions[1] and exit points in cardinal directions[2]. The design process for this system involved extensive use of both real and fast-time simulations, as well as ongoing input from airlines and other stakeholders.

With respect to air navigation, the adoption of this concept involved a very subtle change in the length of actual flight paths. The main reason this was relatively minor was because the airspace of the area was already well designed prior to the implementation of PBN. Nevertheless, important gains were obtained in fuel savings and reductions of greenhouse gas emissions. Other important benefits were also obtained such as improved traffic control and safety, as well as reductions of the workload of pilots and air traffic controllers.

The next step on the implementation of the PBN program will be the design of new airspace concepts for the São Paulo and Rio de Janeiro terminal areas, the busiest TMAs in Brazil.

Runway and Taxiway Management Improvements

In 2005, the second runway of the Brasília Airport (11R/29L) was opened, significantly increasing the overall capacity of the runway system. This also caused changes in the take-off operations that were transferred to the new threshold 11R. A special noise abatement procedure was created which required all aircraft to make a right turn after take-off, avoiding the overflight of populated areas. This measure represented a very effective way to meet a strategic objective set by ICAO, namely "*to limit or reduce the number of people affected by aircraft noise.*"

The change, however, involved trade-offs between noise and emissions. Indeed, the new configuration resulted in increased taxiing distances, and consequently, increased fuel burn and engine emissions.

In view of this fact, ATC recently adopted new procedures for the use of runways. A new schedule was adopted between 06:00h and 22:00h (local time). During this period the take-offs will occur on the runway 11L. The aircraft will take-off with a steeper climb until reaching 6,000 feet (about 1,800 meters) above sea level. The main objective of this procedure is to leave the residential area as quickly as possible. Only after reaching the recommended altitude, is the pilot allowed to manoeuvre toward the planned route of the flight. Advantages of using this procedure are shorter taxiing distance and reduced noise disturbance in the neighbourhood.

Between 22:01h and 05:59h (local time), the airport will operate with all take-offs on Runway 11R and the landings on 11L, in order to avoid night-time noise impacts. In this case, even with the higher fuel consumption generated by the greater taxiing distance, it is believed that the environmental trade-off is positive. The benefits are related to the avoidance

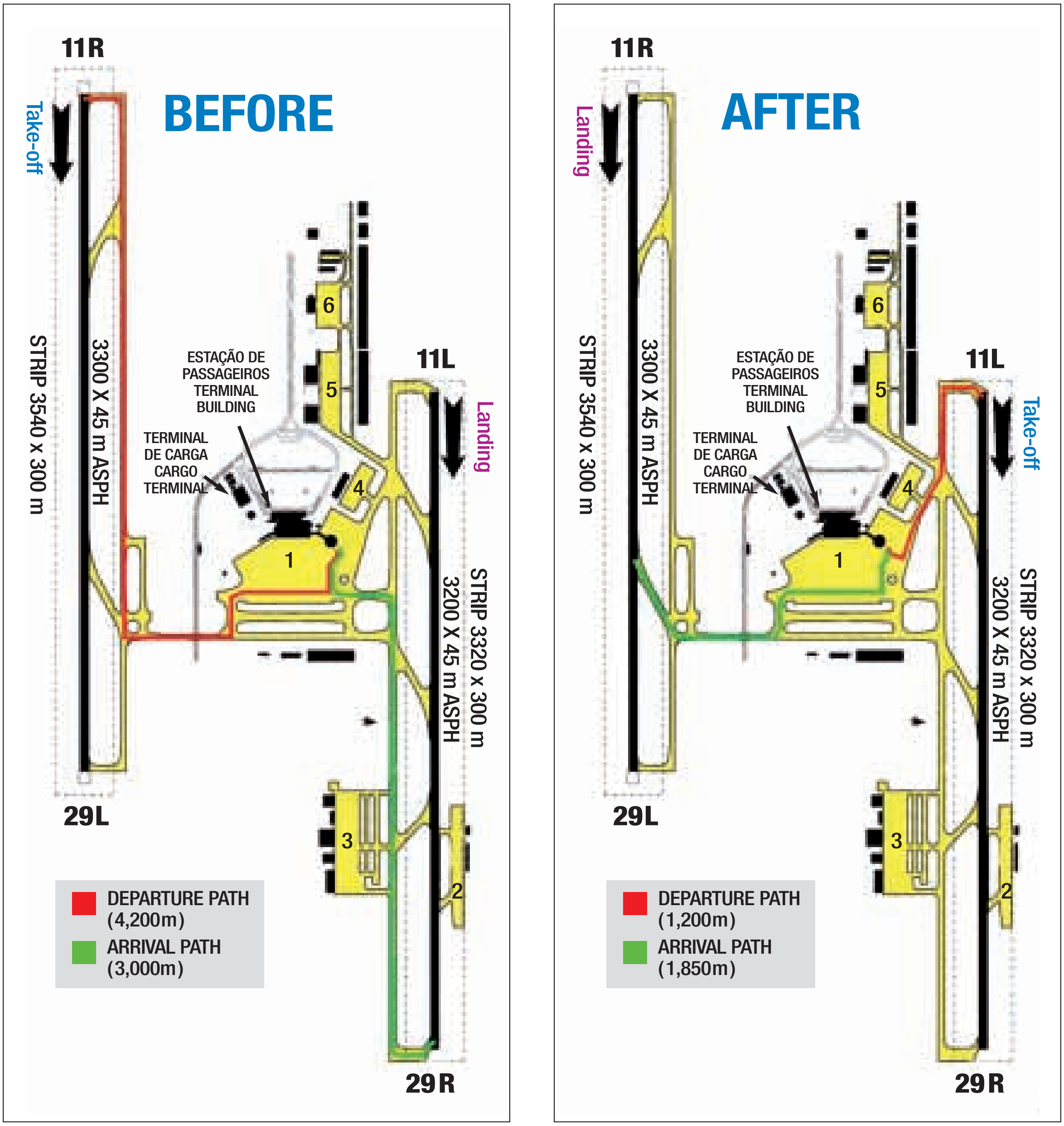

Figure 1: *Brasilia International Airport – Runway operations changes. Adapted from AIP (DECEA).*

of populated areas during the departure procedures and the reduced number of operations during the night period.

These procedure modifications were based on the fact that, the aircraft fleet operating nowadays in Brazil is one of the most modern in the world. As a result, the aircraft are quieter than the old ones operated at the time when the original procedures were established for noise mitigation.

Assessment of Impacts On Emissions

The assessment of the environmental impacts of these changes is in its preliminary stages, as the implementation of the new Brasília TMA PBN concept is quite recent. Nevertheless, first simulations indicate important potential savings in fuel consumption and reduction in emissions.

The simulations to evaluate the impacts of the implementation of PBN were performed using fast-time simulation techniques with the Total Airspace & Airport Modeler (TAAM). For the baseline simulation, March 18, 2008 was used as the representative day, with 270 movements including landings and take-offs. Runway 11L was used for landings and Runway 11R for take-offs, corresponding to the "usual" operation. The fuel savings were estimated and then converted into carbon dioxide reductions.

The simulation showed a small reduction of about 75,500 kg of CO_2 per day in the emissions from aircraft operating in the terminal area, or approximately 0.11% of all daily carbon dioxide emissions. This reduction, although small, is equivalent to the fuel use and emissions, of about 10 flights of a Boeing 737 from São Paulo to Brasília.

TAAM was also used to evaluate the changes in runway and taxi areas. Moving the landings to Runway 11R and take-offs to Runway 11L resulted in an average shortening of 2.5 km in taxiing distances, resulting in matching fuel savings.

In terms of emissions, this represents a daily saving of about 63,000 kg of jet fuel, due to reduced taxi times. This works out to an equivalent reduction of 198,000 kg of CO_2 emissions, or about 72,000 tons/year of CO_2 emissions around the airport. This is a substantial result that may be even more important in terms of its impact on overall local air quality.

Summary and Conclusions

Brazilian aviation is experiencing significant growth, which reflects the recent boom in economic development but can also generate environmental negative impacts. The increase in the number of aircraft and operations has generated a rise in the emissions of greenhouse gases and aircraft noise rates.

In order to establish a process that makes this growth compatible with the environmental demands, it is necessary to improve the management of airspace and the ground operations.

The coordinated management of these two elements enhance the efficiency and the sustainability of air transport. As described above, preliminary assessments of such operational changes at Brasília Airport Terminal have shown that reductions in greenhouse gases and noise can be achieved. Even if the individual savings are relatively small, each one of these elements contributes to a net reduction in GHG emissions and noise.

Finally, it should be noted that environmental impacts are not the only concern motivating operational changes. Furthermore, as the design of the airspace is shifting to a performance-based paradigm, it is possible to obtain further improvements in operations by aiming at higher environmental standards in the future. ■

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Chapter 4

ECONOMIC INSTRUMENTS

ICAO
ENVIRONMENTAL
REPORT 2010

Economic Instruments
Overview

*By **ICAO Secretariat***

Introduction

Market-based measures refer to policy tools as well as market and economic instruments. They include: emissions trading, emission-related levies - charges and taxes, and emissions offsetting; all of which aim to contribute to the achievement of specific environmental goals, at a lower cost, and in a more flexible manner, than traditional command and control regulatory measures. Market-based measures are among the elements of a comprehensive mitigation strategy to address greenhouse gas (GHG) emissions from international aviation that are being considered by ICAO.

The articles in this chapter provide an overview of ICAO's work on developing policies, guidance material and technical and economic studies, as well as collecting information on various market-based measures. They also provide information on the recent developments on market-based measures in the context of the ICAO Programme of Action on International Aviation and Climate Change.

Background

ICAO has a long history dealing with economic instruments such as taxes and charges related to international aviation operations. Other market-based measures, however, have only recently become available options, and are now being considered by the international aviation sector. Over the last five to six years, governments and airline operators have started to explore emissions trading and various offsetting schemes as part of their efforts to limit the impact of aviation on the global climate.

GHG emissions trading and offsetting were introduced in 1997 as part of the Kyoto Protocol, which provided for three distinct mechanisms:[1]

1. **Emissions Trading**: a market mechanism through which a developed country may transfer Kyoto units to, or acquire units from, another developed country.
2. **Clean Development Mechanism (CDM)**: a project-based mechanism involving developed and developing countries. CDM credits are generated from the implementation of emission reduction projects or from afforestation and reforestation projects in developing countries.
3. **Joint Implementation (JI)**: a project-based mechanism by which one developed country can invest in a project that reduces emissions or enhances sequestration in another developed country, and receive credit for the emission reductions or removals achieved through that project.

The development of the three Kyoto mechanisms together with the emissions limitation and reduction commitments have triggered the establishment of what is commonly referred to as the global carbon market. Since 2000, the global carbon market (including: allowances markets such as EU-ETS, CCX; spot and secondary Kyoto offsets; and project-based transactions) has continued to grow, reaching a value of US$144 billion in 2009 according to estimates of the World Bank[2]. For more details on the three Kyoto mechanisms and on the carbon market, see articles *Status and Structure of the Carbon Market*, *Introduction to Carbon Markets and the Clean Development Mechanism and Designing an Emissions Cap and Trade Program*, Chapter 4 of the report.

Types of Market-based Measures

Emissions Trading

Under the emissions trading mechanism of the Kyoto Protocol, a developed country, in order to meet its emissions limitation/reduction targets, may transfer Kyoto units[3] to, or acquire Kyoto units from, another developed country. Emissions trading does not affect the total emissions "allowances" assigned to all developed countries collectively; rather, it redistributes the allowances among them. A country may acquire an unlimited number of units. However, the number of units that a country may transfer to other countries is limited by the country's minimum level of units that it must hold in its national registry at all times.[4]

Domestic or regional schemes for entity-level emissions trading could be implemented by countries under their own authority and responsibility. Any transfer of units between entities in different countries under such domestic or regional trading systems is also subject to Kyoto Protocol rules. The European Union emissions trading scheme (EU ETS) is one example of a regional trading system operating under the Kyoto Protocol umbrella.

To respond to a request of the ICAO Assembly, the *Guidance on the Use of Emissions Trading for Aviation* (Doc 9885) was prepared under the Committee on Aviation Environmental Protection (CAEP). That document identifies options and recommendations on various elements of a trading scheme including accountable entities, emissions to be covered, trading units, types of trading systems, allowance distribution, monitoring and reporting, and geographical scope. On the subject of geographical scope, the Guidance document recommends that the implementation of an emission trading system for international aviation should be on the basis of mutual consent among States involved, as reflected in the Assembly Resolution A36-22 Appendix L[5].

CAEP also developed a *Report on Voluntary Emissions Trading for Aviation* in 2007, and it was updated in 2010 (see article *Market Based Measures Task Force - Overview of Reports From CAEP/8,* Chapter 4 of this report). That report described the general nature of various types of voluntary emissions trading schemes, summarized a number of practical experiences currently implemented throughout the world, and discussed the possible future development of such schemes involving aviation. Additionally, CAEP conducted a scoping study on issues related to *Linking Open Emissions Trading Systems involving International Aviation*, and the study report was approved in 2010 (see article *Market Based Measures Task Force - Overview of Reports From CAEP/8,* Chapter 4 of this report).

Emissions-related Levies

Levies generally refer to charges or taxes designed to address emissions from international aviation. They have potential advantages compared with other market-based measures, in terms of simplicity for administration, quickness of implementation, and low transaction costs (see article *A taxing question ...* Chapter 4 of this report).

ICAO policies make a conceptual distinction between a "charge" and a "tax". A charge is a levy that is designed and applied specifically to recover the costs of providing facilities and services for civil aviation. On the other hand, a tax is a levy that is designed to raise national or local government revenues which are generally not applied to civil aviation in their entirety or on a cost-specific basis.

The Council convened a Special Group in 2005 to address legal issues related to whether emission-related levies would be consistent with the Chicago Convention and ICAO policies. The conclusions of the Special Group were divided. Some States believed that if charges were linked to the quantity of emissions they would be consistent with Article 15 which deals only with charges for the use of airports and air navigational services. Other States believed that emisssions charges would not be consistent with Article 15 because they had no link to the recovery costs of providing facilities and services. The first group of States held the view that, in cases where charges were related to fuel consumption they would not be contrary to the Article 24 exemption of fees on fuel. The second group disagreed, finding that charges based on the quantity of fuels would constitute a fuel-based tax which would be incompatible with Article 24. In this context, there remains a legal issue to be resolved on the development and implementation of levies on GHG emissions from international aviation.

In 2007, Assembly Resolution A36-22 Appendix L affirmed the continuing validity of ICAO Council's Resolution of 9 December 1996, wherein the Council strongly recommended that any emission-related levies 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.

Emissions Offsetting

An offset represents the reduction, removal, or avoidance of GHG emissions as a result of a mitigation project that is used to compensate for GHG emissions that occur elsewhere as opposed to Emissions trading which is the process through which emission reductions or removal units are traded in a market environment. Specifically for aviation; emissions offsetting involves compensating for the emissions resulting from aviation operations with an equivalent amount of emissions reductions or investment in specific mitigation projects.

The correct estimation of emissions specifically from air travel is essential to identify the amount of emissions to be offset. With a view to providing appropriate and harmonized information on CO_2 emissions from air travel and thus avoiding the proliferation of different methodologies, ICAO developed a globally accepted *Carbon Emissions Calculator* which is available on the ICAO website **(http://www.icao.int/)**.

CAEP also examined the potential for Emissions Offsetting for Aviation, and the report was approved in 2010 (see article *Market Based Measures Task Force - Overview of Reports From CAEP/8,* Chapter 4 of this report). The report concluded with a discussion of potential opportunities to use offsetting for the aviation sector in the future. At the passenger level, it is possible to draw on the current voluntary experience. However, there is also the possibility of using offsetting at a global sectoral level, either in a regulated emissions trading system or through an emissions charge. Offsetting can also be applied at an air carrier level rather than at the passenger level. These options offer some interesting possibilities for the future (see article *IATA's Carbon Offset Program*, Chapter 4 of this report).

Voluntary Measures

Voluntary agreements between governments and industries to limit or reduce aviation GHG emissions are often considered as market-based measures because they constitute an alternative to regulation. In 2004, CAEP developed a template for voluntary agreements to facilitate the implementation of such agreements. Since then, it has been collecting and compiling information on voluntary measures, including voluntary agreements between governments and the industry (see article *Market Based Measures Task Force - Overview of Reports From CAEP/8* and article *Voluntary Measures to Address Aviation Greenhouse Gas Emissions*, Chapter 4 of this report).

Toward a Global Framework for Market-Based Measures

While the 36th Session of the ICAO Assembly in 2007 generally agreed on the technical and operational aspects of mitigation measures to address GHG emissions from international aviation, the question of how to accommodate the views of different States on market-based measures for international aviation remained one of the most important and contentious issues. In an effort to continue to bridge the different views among States, the Assembly established the Group on International Aviation and Climate Change (GIACC) with the mandate to develop a Programme of Action on International Aviation and Climate Change.

During the GIACC process, a wide variety of market-based measures were identified and reviewed. GIACC acknowledged that there remained disagreement on the application of market-based measures across national borders. It also recognized that market-based measures implemented by States or by Regions with different policies and parameters, in the absence of a framework developed by ICAO, were far from optimal. GIACC consequently recommended the development of "a framework for market-based measures in international aviation".

At the High-level Meeting on International Aviation and Climate Change convened in October 2009, discussions on the application of market-based measures reflected the divergent views expressed during the GIACC deliberations. Many States expressed the need for ICAO to undertake the necessary steps to develop the framework for market-based measures.

Emerging national and regional measures involving aviation, as listed in Figure 1 (see article *Status and Structure of the Carbon Market*, Chapter 4 of this report), could be a knowledge basis for ICAO in identifying key elements of the framework for market-based measures, including the issues of compatibility and equivalency of measures. The main objective would be to avoid the patchwork or duplication of measures, thus facilitating the harmonization among States as part of a global approach to address emissions from international aviation.

As the forum for all matters involving international aviation, ICAO will continue to strive to make further progress towards global solutions to address GHG emissions from international aviation with the highest degree of harmonization and cooperation among its 190 member States and the aviation industry. The development of a global framework for market-based measures needs to be persued in a constructive and forward-looking manner to bridge the views of different States moving towards a globally accepted solution. ■

Emerging national and regional trading schemes

European Union Emissions Trading Scheme (EU-ETS)

- Since 2005, 11,000 industrial installations in 27 EU member States, covering the most energy-intensive sectors, representing about half of European GHG emissions
- Domestic and international aviation to be included from 2012

New Zealand – stage implementation of national ETS

- A staged rollout of national ETS across different sectors, with forestry already covered since 2008, most stationary and transport-related energy and industrial processes being added in mid-2010, and agriculture to be added in 2015
- Purchasers of aviation jet fuel can opt into the scheme, and so far Air New Zealand is the only airline to opt in

Japan – voluntary national ETS

- Trial of a voluntary ETS for 2008-2012 to gather experience, allowing voluntary participants to set their emissions reduction targets and trading their allowances among participants (Japan Airlines and All Nippon Airways are voluntarily participating in the scheme)
- New legislation with references to a mandatory ETS is being considered by national parliament

United States

- Cap and Trade legislation is being considered at federal level

Australia

- Cap and Trade legislation consideration postponed

Figure 1: *Emerging national and regional trading schemes.*

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3 Kyoto units refer to assigned amounts, certified emission reductions (from CDM projects), emission reductions units (from JI projects), removal units (from afforestation or reforestation projects).

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5 42 Contracting States expressed their reservation on the text contained in the A36-22 Appendix L.

Status and Structure of the Carbon Market

By ***Andrew Howard,*** *UNFCCC*

Andrew Howard *has been instrumental at the UN Climate Change Secretariat in the development and implementation of the Kyoto Protocol, in particular emissions trading and the CDM. He supported the inter-governmental negotiations that set down the rules for these mechanisms and has led projects to establish key components of the trading infrastructure underlying the carbon market.*

He now manages the Strategy and Policy Development Unit in the market mechanisms arm of the secretariat and leads its support for the further negotiation and development of market-based instruments for the post-2012 period.

Uncertain Directions

Back in 1997, it took only a few paragraphs in the Kyoto Protocol to lay out a new concept and give birth to an innovative market in environmental protection. Today, the carbon market is like a budding teenager, sufficiently confident that it has a place in the world, but unsure which direction to take.

Few of the delegates negotiating in Kyoto would have been aware of what was to come. The World Bank estimates that carbon market transactions around the globe totalled US$144 billion (€103 billion) during 2009, with 8.7 billion units (each representing one tonne of CO_2 equivalent) being traded[1]. The European Union's emissions trading system remained the most significant global player, making up 82% of market value. The primary market for Kyoto's Clean Development Mechanism (CDM) represented around 2% of global value and made up 5% the year before.

Overall, this amounts to a 6% growth in the value of the carbon market in 2009, but this is considerably lower than the double-digit growth that became the norm in earlier years. It also masks a significant drop-off in prices since the peak in oil prices and the onset of the economic downturn. EU allowance prices fell from over €30 in mid-2008 to €8 in early 2009, before stabilizing in a €13-16 range. Prices for CDM credits have followed a similar path.

These signals may be seen positively. They are a sign that the carbon market, or at least elements within it, are acting as one would expect mature markets to act – falling in a global economic crisis when the pressure to emit carbon is weak, and then rising again as economic prospects improve.

As quickly as it began, however, people have begun announcing the market's demise. The emission targets set for developed countries under the Kyoto Protocol only cover until 2012, we are reminded. The eyes of the world were on governments when they were unable to agree on new emission commitments in Copenhagen in December 2009. How should we reconcile this with the generation of managers and entrepreneurs that have now begun to engage with the climate change issue and are starting to voluntarily extend their actions beyond what regulators oblige them to do?

This still maturing carbon market is still uncertain as to where best to focus its energy. Will it languish until policymakers set a new direction? When it matures, will it be accepted by society as a responsible and effective way to address climate change?

Market Origins

The Kyoto Protocol set out an international architecture for combating climate change that incorporated market instruments as one of its defining features. The Protocol established quantitative emission targets for developed countries during the first commitment period (2008-2012) and also made provisions to allow flexibility as to how they would meet these targets. Most developed countries committed to keep their emissions below their 1990 levels by 6-8% over this period.

Underlying this system of targets is the concept of "assigned amount" (see Figure 1). This expresses the quantity of emissions permitted under each target as an assigned number of units. Each developed country must hold and "retire" one assigned amount unit (AAU) for each tonne of CO_2 equivalent greenhouse gases that it emits. The finite number of AAUs held by the country acts to constrain its emissions. A number of flexibility provisions were embodied within the overall Kyoto architecture.

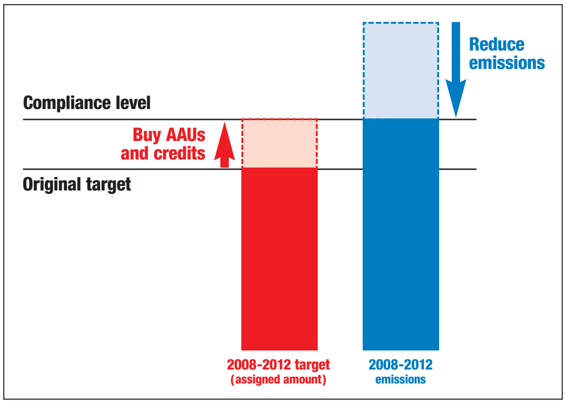

Figure 1: *Compliance with flexibility under the Kyoto Protocol.*

Firstly, the sequestration of greenhouse gases through land use and forests may be credited as removal units (RMUs). Secondly, through the Clean Development Mechanism (CDM), developed countries may undertake projects in developing countries that reduce emissions or increase sequestration there. The impacts on emissions are quantified and credited as certified emission reductions (CERs) that may also be retired against the countries' Kyoto targets.

Thirdly, developed countries may engage in projects under the "Joint Implementation (JI) mechanism" and in "emissions trading", under which they may obtain AAUs and credits from other developed countries where this is less expensive than making the reductions at home. Other countries, where they could reduce emissions more cheaply, would do so and make AAUs and other credits available for sale.

The carbon market is not an add-on to Kyoto — rather, it is an integral and defining feature of its architecture. Emission targets create market demand while the supply is provided through countries with more cost-effective mitigation opportunities.

While none of this flexibility removes the need for developed countries to radically alter their own emissions behaviour, they are seen as important means for directing efforts towards cost-effective mitigation opportunities and enabling developed countries to take on more stringent emission targets.

Regulating Business

Countries have sought to adopt the same market-based policies towards the private sector by introducing cap-and-trade systems. By setting emission targets for major emitters and allowing them to trade emission allowances issued against them, the incentives to reduce emissions are pushed downwards to the large and diverse range of economic actors whose decisions collectively determine national emission levels.

The EU emissions trading system, that covers 27 member States, 3 other European Economic Area countries, some 11,000 installations, and about half of Europe's greenhouse gas emissions, has been the main driver of what we know today as the carbon market. It is now well into its second phase (2008-2012), and the rules have been established for its third phase (2013-2020). The EU ETS has also been the main driver for the growth of the CDM and JI under Kyoto, by allowing credits from these mechanisms to be surrendered against EU company-level targets.

The decrease in emissions due to the economic downturn has left EU allowance prices low and caused some concerns as to the efficacy of trading approaches in reducing emissions. Though it can be argued, in retrospect at least, that the targets should have been tighter, the trading system is still delivering the emission results asked of it, and EU emission data indicates that allowance prices are prompting real reductions in emissions.

Other countries have also taken steps to introduce emissions trading systems at the national level. New Zealand has become the first country outside Europe to adopt an economy-wide, regulated system. It envisages a staged rollout of the system across different sectors, with forestry already being covered since 2008, most stationary and transport-related energy and industrial processes being added in mid-2010, and agriculture to be added in 2015.

Japan has experimented with emissions trading on a limited and voluntary basis now for several years, with much speculation brewing on whether a mandatory system will be introduced. Legislation introduced this year contains new references to such a system, although the fate of this legislation is still under much uncertainty, particularly in light of recent political changes within the Japanese government.

In the USA, successive attempts have been made to pass cap-and-trade legislation at the federal level. Although the House of Representatives passed a bill in 2009 that would have established a wide-ranging cap-and-trade system, the Senate remains divided on the best way to proceed. Several variants have emerged in the Senate with each embodying more or less of the cap-and-trade approach. At the time of writing, it is unlikely that progress will be made in 2010. Meanwhile, State-level trading systems continue to be developed and are in some cases already operational.

In Australia, the Carbon Pollution Reduction Scheme was defeated twice at the Senate level in 2009. It was more recently announced there that the legislation would not be considered again until 2012, although recent changes in government leadership suggest this may now be accelerated.

The experience in many countries shows the difficulty in uniting behind consensus legislation. Domestic cap-and-trade systems are typically affected by domestic concerns and political compromises that need to be made at the national level. The EU has called for the establishment and linking of cap-and-trade systems across OECD countries by 2015. However, as linking different systems depends on being able to achieve at least a minimum level of harmonization in the design of each individual system, this goal appears some way off from being achieved.

Kyoto's Project-Based Mechanisms

CDM projects in developing countries must lead to emission reductions or removals that are additional to any that would have occurred without the project. To demonstrate this, projects must fulfil robust requirements for validation and registration and the ensuing reductions or removals of emissions must meet monitoring and certification standards before CERs are issued.

The CDM has grown beyond expectations since taking its first steps in late 2001. At the time of writing, there were 2,250 registered CDM projects in 68 developing countries. United Nations Environment Programme (UNEP) Risoe estimates that registered projects represent an investment in developing countries of about US$67 billion[2]. Around 730 of these projects have already received credits for emission reductions, with some 420 million CERs having been issued. As well as reducing emissions, such projects have a key function in transferring technology and capacity to developing countries and contributing to their overall sustainable development.

Beyond the number of CDM projects that are already registered, the volume of projects still undergoing development is more difficult to estimate. Around 3,000 further projects have already reached the validation stage or are currently undergoing registration. If these were all to come to fruition, it is estimated that between 1 and 3 billion CERs would be issued for the period up to the end of 2012 and that investment flows through the CDM would exceed US$150 billion.

With so much activity being attracted, much market and government attention is focused on the efficiency of the regulatory process governing the CDM. The CDM Executive Board is moving on a comprehensive work plan of strategic reforms which aim to improve the efficiency of the CDM process while always ensuring that only quality reductions and removals get credited.

Key expectations for this work include streamlining the project procedures, allowing for appeals against the Board's rulings on projects, consolidating the Board's guidance, strengthening the performance of the certifying Designated Operational Entities active in the market, enhancing the objectivity of project baselines, and instituting loans for developing projects in countries under-represented in the CDM.

At the same time, the Parties to the Kyoto Protocol are considering possible wider-ranging changes in the scope of the activities that may be undertaken through the CDM. These include the possible inclusion of new activities such as additional forestry types, carbon capture and storage, and nuclear facilities.

The JI project-based mechanism allows for similar projects as the CDM, except that the projects take place in developed countries and may be approved either by the host countries ("track 1") or under the UN ("track 2"). JI began operation later than the CDM and addresses a smaller number of countries. Nevertheless, 17 projects have now been finalized under track 2 and about 170 further projects have entered the pipeline (with a potential reduction in emissions in the order of 300 million tonnes CO_2 equivalent from 2008 to 2012). In addition, it is estimated that a further 170 projects have been approved under the track 1 rules.

Going Voluntary

> The role of the voluntary carbon market is often neglected in policy-making circles. Its emergence demonstrates the private sector's will to address climate change, even without a legal obligation to do so, although its lack of regulation remains the main stumbling block on the way to greater credibility and scale.

The motivation to voluntarily offset emissions is partly to show environmental responsibility and partly to gain carbon market experience, especially with further regulatory trading systems on the horizon. The size of the voluntary market remains small, accounting for around 1% of carbon market transactions in 2009, with a value of US$387 million (down from US$728 million in 2008)[3]. Much activity is based in the US where the prospect of state and federal trading systems has been present for several years.

Where the voluntary market stands out is as a testing ground for new ideas. New standards, registries and project types can be innovated and put through their paces, with a mix of criteria stemming from the need to prove environmental integrity (i.e. to obtain market value) and ensure business practicality. Although many initiatives have eventually sought rigour and environmental integrity by drawing on methods from the CDM and JI, some innovations from voluntary schemes may well find their way into future cap-and-trade systems, in the US and perhaps elsewhere.

Future Directions

Where does this all leave us today? The last decade has seen enormous growth and learning in the carbon market, among policy makers as well as the makers of business decisions. In Europe and some other regions, the institutions and service industries for emissions trading are maturing and carbon prices are being seriously factored into investment and other commercial choices.

Concerns and challenges nevertheless remain. Firstly, in practice there is not a global carbon market, but rather a fragmented set of activities and policy frameworks. The fragments will perhaps grow and consolidate over time but it is increasingly likely that this will only occur incrementally as the major drivers in the design of new market instruments remain oriented towards domestic interests.

Secondly, many governments in the developing world are questioning whether market approaches are able to deliver on the needs they have for sustainable development. There have been improvements in the numbers of CDM projects emerging in Africa and the least developed countries, but it has proven difficult for the mechanism to overcome long-standing hindrances and barriers to investment in some countries.

Thirdly, the carbon market's lifeline is the will of governments to reduce emissions and the extent to which they pass on these priorities to business in the form of targets. Current indications, especially in the midst of the current economic downturn, point to targets that can be relatively easily met and an offset market that is approaching saturation point. Moreover, the concept of offsetting emissions remains controversial and its acceptance depends on whether the targeted levels of emission cuts are sufficient to balance offsets with an assurance that sufficient mitigation action will be taken at home.

How deep the emission cuts should be is the subject of ongoing negotiations among governments on how the international framework of climate action should evolve after 2012. After an inconclusive summit in Copenhagen last year, attention has now shifted to what may be decided by governments when they meet in Cancun, Mexico, this coming December.

The discussions have not become easier since Copenhagen and it is unlikely that a full and specific package will emerge from Cancun. What is apparent however, is that holding the planet to a maximum temperature rise of 2°C, or less, above pre-industrial levels will require enormous levels of support – finance, technology, capacity-building – to be provided to developing countries to assist with their mitigation actions.

While much of this will need to be provided by developed country governments from public sources, it is inevitable that significant additional amounts will be needed from the private sector. Effective tools are needed to channel private sector investments into developing countries in ways that support development along green paths rather than brown. New market instruments have been proposed that would operate at scales much larger – for example at a sector level – than the current focus of most CDM projects. Many of the ideas are still young and in need of more elaboration, and perhaps some on-the-ground piloting.

Emissions from international aviation must also factor into the international community's fight against climate change. Despite the sector's unique challenges in determining how to distribute the effort and responsibility, the need to address these emissions is recognized by both governments and industry worldwide.

Technical opportunities for improving the carbon efficiency of international aviation are known, but what remains unclear is what additional policy measures can be drawn upon to accelerate their implementation. The EU has taken some steps to incorporate international aviation into its emissions trading system, and other proposals have been made for various forms of cap-and-trade on aviation. Ultimately, one of the issues to explore is whether emissions trading and offset approaches may have potential, not only to promote cost-effective reductions in emissions, but also to offer solutions to the difficult issue of how the effort for reducing international transport emissions may be distributed.

The carbon market is maturing in an uncertain world. Only time will tell what policy environment will be put in place and what directions the market will take within it. ■

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Introduction to Carbon Markets and the Clean Development Mechanism

By ***Holly Krambeck,*** *World Bank*

Holly Krambeck *is a Carbon Finance Specialist in the World Bank's dedicated Carbon Finance Unit, where she works on expanding transport sector access to climate-based finance. Her responsibilities include developing tools for estimating greenhouse gas emission reductions associated with different types of transport investment programs, as well as Clean Development Mechanism project review and management.*

Prior to joining the Bank, Holly worked as an infrastructure economics and finance specialist with Parsons Brinckerhoff, Inc., where she was task lead and project manager for infrastructure projects and climate-based initiatives in the US and abroad. Holly has a Master of Science in Transportation and a Master in City Planning, both from the Massachusetts Institute of Technology.

At the ICAO Colloquium on Aviation and Climate Change, held in May 2010, participants expressed an urgent need to develop long term, collaborative strategies for achieving sector-wide energy efficiency improvements, as well as low carbon growth. Further, to sustain these strategies, participants expressed a need to identify means to finance low carbon and energy efficient investments, especially in developing countries, where the financial barriers to implementing green technologies and strategies may be particularly high.

One financing option discussed during the Colloquium was the leveraging of carbon finance, and to help facilitate this discussion, the World Bank provided an overview of carbon markets – what they are, how they work, and how they may help ICAO member States reach their greenhouse gas (GHG) mitigation goals. Following is a slightly elaborated version of the presentation given during the Colloquium.

Overview of Carbon Markets

Carbon markets come in many shapes and sizes. There are compliance allowance trading schemes, offset schemes, and voluntary programs. To sort through these different markets and understand how these markets function and relate to each other, the following sections describe two key distinctions between different carbon market mechanisms: allowance trading versus offset schemes, and compliance versus voluntary markets.

Allowance Trading Versus Offset Schemes

There are two types of tradable commodities supported by carbon markets – allowances and offsets.

Allowance Trading Schemes

In allowance trading schemes, such as the European Union Emissions Trading Scheme (EU ETS), a regulatory body, such as a national government, establishes an annual greenhouse gas emissions cap for specific activities, such as power generation or purchase of mobile-source fuels. GHG emitters from regulated sectors are allocated a set of emissions allowance certificates, which represent their maximum allowable CO_2e (carbon-equivalent, which includes all six Kyoto greenhouse gases) emissions over a pre-determined compliance period.

For example, a firm that is allowed to emit 10,000 tons of CO_2e per year would be required to own 10,000 tons-worth of emissions allowance certificates. Some entities will emit more than their regulated cap and run out of allowance certificates, while others will emit below their cap (because of decreased production, improved technology, etc.) and have excess certificates. An allowance trading scheme brings these entities together, so that demand for additional allowances is met by surplus allowances held by less energy-intensive entities.

Offset Trading Schemes
Offset schemes enable firms and entities that are not regulated by caps, such as those based in developing countries, to participate in emissions trading. Entities that voluntarily engage in activities that mitigate greenhouse gas emissions in a measurable way may register these emissions reductions under an offset crediting scheme, such as the Clean Development Mechanism (CDM). Upon registration, these offset credits may be sold to entities that are seeking to reduce emissions, such as entities participating in allowance trading schemes.

To illustrate how allowance trading and offset schemes may complement each other, consider a firm participating in the EU ETS, which will exceed its allocation of allowance before the end of the current compliance period (2008 - 2012). This entity would have three options: a) purchase leftover allowances from another firm; b) purchase offsets generated through the CDM; or c) pay a penalty.

Compliance versus Voluntary Markets

In addition to the distinction between allowance and offset markets, there is also a distinction between voluntary and compliance trading schemes.

Compliance Trading Schemes
Under compliance trading schemes, such as EU ETS and the Regional Greenhouse Gas Initiative (RGGI) in the US, entities motivated by strictly-enforced emissions regulations trade in tightly monitored allowance and offset schemes. Participating entities that exceed emissions caps and do not take corrective action through trade in allowances or offsets are legally required to pay penalties levied by the regulatory body.

Voluntary Trading Schemes
On the other hand, participants in voluntary schemes, such as the Chicago Climate Exchange (CCX), are not assigned externally defined emissions reduction targets – rather, participants may voluntarily establish their own legally-binding caps. Participants in voluntary markets tend to cap themselves out of a sense of moral obligation or corporate social responsibility. For example, firms that wish to participate in the Chicago Climate Exchange will first determine an emissions reduction target and sign a legally-binding agreement with the Exchange, holding the firm accountable to meeting that target either through emissions reductions or through trades on the exchange.

Unlike the heavily regulated and monitored compliance trading markets, the commodities of the voluntary markets are not standardized and therefore not typically tradable across different markets. Today, there are simultaneous initiatives throughout the world to develop a unified standard for verifiable voluntary emissions reduction allowance credits and offsets, though, the results of these initiatives may not be realized for a few more years.

The Clean Development Mechanism

CDM is an offset generation program, which enables entities in developing countries to generate offset credits from select activities that mitigate greenhouse gas emissions. These credits may be sold to entities seeking to reduce emissions under either voluntary or compliance carbon markets. Revenues from the sale of CDM credits, in turn, may be used to support the green project investments.

Eligible Aviation Activities and Investments

The United Nations Framework Convention on Climate Change (UNFCCC) places strict guidelines for the registration and issuance of CDM credits and only a select number of activities are eligible. It maintains a list of approved "methodologies" that provide all of the relevant applicability conditions as well as modeling, data collection, and monitoring procedures for different approved project types. The following table lists approved CDM methodologies that may be applied to the aviation sector:

CDM ID#	Methodology	*Aviation Applications*
Operations		
AMS III.T	BioDiesel	*Alternative fuels**
AMS III.C	Low emissions vehicles	*Aircraft technology*; airside vehicles*
AMS III.S	Low emissions vehicles (fixed route)	*Aircraft technology**
AMS III.AA	Vehicle retrofits	*Aircraft technology*, airside vehicles*
Infrastructure		
AMS II.C	Energy efficient equipment	*Airport facilities and terminals*
AMS II.E	Building efficiency and fuel switching	*Airport facilities and terminals*
AMS I.D	Renewable energy generation	*Power generation*
AMS II.B	Renewable energy generation (grid)	*Power generation*

* *Domestic use only*

Table 1: *Clean Development Mechanisms (CDM) applicable to aviation.*

In general, most emissions trading schemes – either current or planned – will accept offsets developed using CDM-approved methodologies and procedures.

Applying for Clean Development Mechanism Registration

Following is a summary of the steps involved in the CDM registration process:

1) Project sponsor submits a completed template to the UNFCCC Executive Board and the UNFCCC-approved Designated National Authority (DNA), indicating its intention to pursue CDM registration.

2) Project sponsor completes a Project Design Document (PDD) template, which includes sections for presenting a project description, compliance with CDM and UNFCCC guidelines, emissions reduction calculations, and implementation and monitoring procedures.

3) Project sponsor then hires an independent, accredited Designated Operational Entity (DOE) to validate the PDD and supporting documentation.

4) During the validation period, the DNA issues a Letter of Approval, which indicates whether the proposed project activity supports national sustainable development goals.

5) Upon completion of the validation, the DOE submits a final validation report, as well as all project documentation and completed CDM templates, to the UNFCCC Executive Board for completeness check and review.

6) Finally, upon Executive Board approval, the project sponsor is notified of registration and may commence with generation of creditable emissions reductions and preparation of issuance procedures.

Given current delays associated with the CDM registration and issuance process, CDM procedures are expected to undergo a major overhaul following the end of the current Kyoto Compliance period in 2012, although, not much is known at this time about what specific changes to the system will be made.

There has been a growing trend towards supporting programmatic activities (i.e., a series of similar, replicable investments, rather than single, isolated projects) and Nationally Appropriate Mitigation Actions (NAMAs), a somewhat generic term used in support of sectoral schemes, where governments in developing countries may be financially rewarded for compliance with self-established greenhouse gas mitigation goals, by sector.

Whatever shape the future CDM market takes, it is almost certain CDM projects registered today will be able to continue generating saleable credits after 2012.

Looking Forward

Following is a list of options ICAO and its Member States may consider for leveraging carbon markets to support energy efficiency and low carbon growth investments through carbon markets:

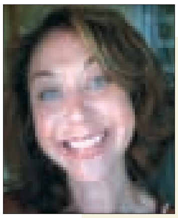
- Develop a green fund for the purpose of purchasing certified offsets from aviation-related industries, through schemes such as the CDM.
- Generate certified offsets, through schemes such as the CDM (would apply to domestic aviation in developing countries, only).
- Work with the UNFCCC (in collaboration with the International Maritime Organization, which faces similar challenges as ICAO) on developing a CDM-like offset scheme for the international aviation sector as a whole, which would enable participation from developed and developing countries.
- Develop an internal compliance or voluntary allowance trading scheme within the global international aviation sector (with linkages to external offset markets).

While each of these options presents a distinct advantage to ICAO Member States, they also pose challenges, which should be carefully considered in any follow-up work or initiatives.

For information on the World Bank's carbon finance activities, please visit the website: **www.carbonfinance.org**

Designing an Emissions Cap and Trade Program

*By **Katie Sullivan**, International Emissions Trading Association (IETA)*



__Katie Sullivan__ recently joined the International Emissions Trading Association (IETA) as its new Canadian Director. In this role, Katie leads IETA's efforts in further enhancing its Canadian members' ability to engage in constructive climate policy dialogue at federal, provincial and territorial levels, while also contributing to IETA's growing international policy work on economic instruments to combat climate change. Prior to joining IETA, Katie worked as a consultant for ICF International, where she provided strategic climate change advisory services and specialized in greenhouse gas policy and carbon market developments in North America. Katie holds a Masters in Environment, Development and Policy from the University of Sussex, and an Honours Bachelor of Public Affairs & Policy Management from Carleton University.

The broad and complex nature of the climate change challenge calls for decision-makers at all levels, and across all regions, to employ a suite of greenhouse gas and energy policies to achieve deep emission reductions over the long-term. Key instruments in these climate policy toolkits are known as market-based measures, whereby carbon pricing becomes integrated into the economic decision-making processes of market participants. These measures are designed to foster cleaner technology/investment choices and the overall de-carbonization of economies at the lowest cost to society. Although some developed regions of the world have recently slowed down climate policy action in the face of fierce political opposition, carbon pricing, in general, and emissions trading in particular, remain the weapons of choice in government policy arsenals to cost-effectively fight climate change.

General Types of Emissions Trading

In the field of emissions trading, two broad program design categories exist: cap and trade programs; and baseline and credit programs. Where a cap and trade mechanism uses an absolute emissions reduction framework (i.e., a permit/allowance or credit must be redeemed for every unit of emissions produced), a rate-based baseline and credit mechanism uses a relative framework, whereby entities must account only for deviations from their performance-standard baseline. To date, experience with emissions trading suggests that a cap and trade approach may prove more environmentally and economically beneficial than a strict baseline and credit trading system.

Cap and Trade

At the highest-level, and in the simplest of terms, the development of an emissions cap and trade system can be divided into several overarching steps. At the outset, a legally-binding economy-wide or sector-wide aggregate emissions limit (cap) is established. Second, this cap is divided into emissions permits (allowances), which are then allocated to eligible participants (covered or regulated entities) under the trading system. Third, participating entities are required to retain allowances to cover their emissions and allowed to trade (buy or sell) their permits in the market. Through trade, the permit purchaser essentially pays a charge for polluting, whereas the permit seller is financially rewarded for having successfully reduced emissions. Finally, on a pre-determined basis (e.g., annually), entities are required to submit allowances to the program authority to cover their facility, corporate, or entity-level emissions. Allowance price, set by fundamental market activity, will reflect the underlying cost of reducing emissions to comply with the regulatory cap; the more stringent the cap, the higher the allowance price. In principle, regulated entities that can reduce emissions through their least-cost option will do so and thereby achieve air pollution reduction goals at the lowest cost to society.

A number of regions around the world are developing or proposing emissions trading programs to meet climate policy goals. Many of these schemes allow for design adjustments, based on new information and lessons learned. As decision-makers must account for country or region-specific circumstances when designing policy initiatives, emissions trading programs and plans generally differ in target, scope, size, and allowance allocation method, among numerous other things. The largest emissions trading market in the world today is the EU Emissions Trading Scheme (EU ETS).

In January 2005, the EU ETS was implemented to cap carbon dioxide emissions from heavy industry. This program, that covers nearly half of the EU, became the cornerstone of the region's climate change policy towards meeting reduction commitments under the Kyoto Protocol. Assigning value to reductions in carbon dioxide emissions, established through trade in emission allowances, formed a market with an asset value worth tens of billions of dollars annually. Through linkages to emission credits generated under Kyoto Mechanisms (CDM/JI), establishing this price of carbon has been an international feat.

Despite some challenges that have faced the market, the EU continues to take a leadership role in using market-based mechanisms to address the climate challenge and remains fully committed to cap and trade and, in principle, the use of tradable offset credits and the linkage of existing/proposed programs. More popular criticisms of cap and trade will point to the existing EU ETS as an example of how a greenhouse gas trading program failed to reduce actual emissions while hindering the European economy. However, when one looks at the facts, this becomes a false argument.

Since its 2005 launch, the EU ETS has reduced emissions by 50-100 million metric tons of carbon dioxide a year, while adding more than 1.5 million new jobs in low-carbon technologies, all while adding some US$87 billion to the European economy. Today, the trading program represents the largest emissions market in the world, and Europe's carbon price undeniably represents the global benchmark. The lesson to draw from the European experience, to inform today's worldwide emissions trading debates, is that pricing carbon through cap and trade can enhance economies and improve productivity while achieving environmental objectives.

Key Cap & Trade Design Elements and Considerations

Determining the optimal scope of a cap and trade scheme requires a balancing of competing objectives. In general, a cap and trade system covering the highest percentage of an economy's emissions, as is practicable, has become a favored approach in policy design circles. This broad coverage of sectors, each with varying marginal (i.e. additional) abatement costs, enables the market to achieve high levels of cost savings. The differing marginal abatement costs of regulated entities under the program covered thereby allows them to sell emission rights (permits) to others whose internal control costs are higher, thereby creating a win-win situation for all involved. For those selling allowances, this new revenue stream provides an incentive to direct investment into emission reduction technologies and practices. For those purchasing allowances, the system creates incentives for better cost control. This beneficial market dynamic, between buyers and sellers, will continue to increase, as the system expands to cover the highest percentage of emissions.

Cap and Trade Design Elements

In developing a cap and trade program, four fundamental design elements can be identified:

1. **The cap** can be defined as the mandatory upper limit on the total emissions that can be released in a given period from covered sources. The stringency of a cap and trade program will depend on the level of the cap (e.g. a cap set below current emission levels will be more challenging to meet than one that allows for continued growth in emissions about current levels).

2. **Emission allowances** are permits that entitle the holder to emit a specified quantity of the pollutant, that is being regulated, during a given time period. For programs that target greenhouse gas emissions, allowances are typically equal to one metric ton of carbon dioxide equivalent emissions. The total number of allowances issued is determined at the cap level. For example, if the cap were set at 100 metric tons, a total of 100 allowances would be made available to the market in some fashion, either through free allocations or through an auction.
3. **Trading** allows for emitters to buy and sell allowances from other entities. Typically, a facility will buy additional allowances (entitling it to additional emissions), if the market price of allowances is less than what it would cost the facility – at the margin – to bring emissions down to the level implied by its initial allowance holdings. Similarly, a facility will sell allowances, if the allowance price is higher than it would cost to achieve the additional reductions made necessary by the sale of allowances. Every allowance purchased by one entity corresponds to an equal reduction in the allowances held by the selling entity. Therefore, allowance trades do not affect total allowable emissions, because they do not alter the number of allowances in circulation. Trading ensures that emissions are reduced at least cost and allowances go to the highest value applications.
4. **Monitoring and enforcement** rules help to assure accountability, heighten program integrity, and sustain confidence in the emissions trading market. At the end of each compliance period, entities regulated under a cap and trade system are required to submit allowances equivalent to the level of their greenhouse gas emissions. To assure compliance, the cap and trade program must include financial penalties for entities that do not hold a sufficient quantity of allowances to cover their emissions. The regulatory authority must track emissions to ensure that: **a)** emissions match allowances at particular sources, and **b)** overall emissions match overall allowances.

In addition to the core elements listed above, a cap and trade system can include other important design features or compliance mechanisms aimed at reducing/containing program costs and enhancing compliance flexibility, such as: the banking/borrowing of permits, use of international and domestic offsets, crediting for early action, and, of course, domestic and international offset use/access.

Other Considerations

Credits derived from greenhouse gas emissions reduction activities that take place outside of the capped sectors are called **offsets**, which can be purchased by regulated entities to cost-effectively meet their obligations under a carbon cap. It is particularly important that any offset design feature: ensure the environmental integrity of offset projects, obtain emission reductions from unregulated sectors of the economy, drive innovation in unregulated sectors, and provide a model for other programs.

There is no perfect design for an emissions trading scheme; if one existed, it would have universal application. There are a variety of design features that can be used, and each could either favor or penalize different participants. For example, some design issues that have proven challenging or contentious in policy debates, and will likely continue to, include: intensity-based versus absolute targets, choice of competitiveness provisions, inclusion or exclusion of hard/soft price collars, allowance auction versus free allocation (or a combination), treatment of new entrants, design/scope/access to offsets, and choice of denominator for intensity based schemes.

One of the more challenging and contentious issues related to cap and trade development is finalizing an approach to **allowance allocation**. Allocations (i.e., distribution rights, holding a monetary value, to pollute) can be designed to achieve or support "traditional" policy aims, such as program cost-effectiveness and compensation to emitters, or other sets of goals, such as preventing "leakage" of emissions, or production outside the program boundaries. Generally speaking, there are three main categories of allowance allocation approaches: grandfathering, benchmarking, and auctioning.

1. **Grandfathering** is an approach that provides participating facilities with a free allocation of allowances based on historical emissions; typically calculated as an average over recent years.

2. **Benchmarking** is a method whereby allowances are allocated based on an industry standard. For instance, once the total allocation for the electricity sector has been set, allowances can be based on the average greenhouse gas intensity of electricity production. Benchmark emission intensities may be based on technical assessments of technology or top-down calculations of outputs and allocations.
3. **Auctions** allow a program authority to choose to sell allowances to market participants through an auction process. While this method does not require historical information or benchmarking calculations, the administrative requirements and auctioning system may be complex and the political appetite for auctioning can sometimes prove hard to muster.

In 2007, IETA published a study, *Complexities of Allocation Choices in a Greenhouse Gas Emissions Trading Program*, which attempted to clarify some challenges and correct some misconceptions associated with the initial allocation of allowances under cap and trade schemes. Among other things, the report found that "…under 'idealized' conditions, the decision to adopt one of the three major allocation approaches (listed above) would affect neither the cost savings from an emissions trading nor the ability of the program to cap emissions from program participants; under these conditions, the allocation of allowances is assumed to become 'just' a distributional issue".

A number of jurisdictions around the world are currently in the process of designing, implementing, or at the very least, debating, cap and trade legislation. Through program harmonization and eventual "linking" of carbon markets, these existing/planned programs could potentially lead to deeper economic cost savings and much wider environmental benefits.

Conclusions

Pricing carbon through the trading of emissions forms the cornerstone of a system that restricts the aggregate allowable amount of a pollutant and allows market forces to continually move the allowed emissions to the highest value uses. Although not all emissions trading schemes are similarly designed, the underlying theme of each program or plan remains the same — the need for economies to provide business with the flexibility to determine the most economic means to reduce their emissions.

In designing a workable emissions trading program, an economy can make tangible strides towards recognizing that climate change is a problem requiring a host of tools to achieve reductions, while accommodating a diverse range of participating sectors and countries. Further, if openings for program linkages are built into market design (e.g. complementary compliance mechanism design), it will become possible to deepen, as well as maintain, existing levels of global participation and contribution while also achieving environmental benefits at the lowest cost to society and business.

Note by Secretariat: *ICAO developed guidance for use by States to incorporate emissions from international aviation into their emissions trading systems (Doc 9885) published in 2008, as well as a study report on issues related to linking open emissions trading systems involving international aviation in 2010 (see Economic Instruments article, Chapter 4 of this report).* ■

A Taxing Question ...

By ***Tim Johnson,*** *International Coalition for Sustainable Aviation (ICSA)*

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Taxation of the aviation industry always generates debate and controversy, but it is rarely far from policy-makers' minds, especially these days in the context of environmental protection.

ICAO defines a tax as "a levy that is designed to raise national or local government revenues which are generally not applied to civil aviation in their entirety or on a cost-specific basis". As it is often perceived that taxation takes money out of the industry, ICAO's Council recommended, as far back as 1996[1], that any levies be in the form of charges[2] rather than taxes, and that the funds collected should be applied in the first instance to mitigating the environmental impact of aircraft engine emissions. This principle is still recognised in the current Assembly Resolution[3]. Furthermore, ICAO policies recommend the reciprocal exemption from all taxes levied on fuel uplifted in connection with international aviation, and calls on states "to the fullest practicable extent to reduce or eliminate taxes related to the sale or use of international air transport".

Despite this stance, ICAO's Committee on Aviation Environmental Protection (CAEP) did look briefly at the cost-effectiveness of taxes alongside other possible market-based instruments, as a means of addressing greenhouse gas emissions. CAEP/5 (1998-2001) focused on a fuel (or en route emissions) tax, concluding that it raised significant legal concerns in relation to compatibility with existing bilateral agreements, as well as the potential for tankering (the practice of avoiding refuelling at an airport by carrying additional fuel on board, uplifted from an airport where the tax is not applied). With the CAEP modelling results suggesting higher cost-benefit ratios compared to charges and emissions trading, the approach has not been revisited.

In contrast, many governments still talk about taxation of the sector, either as a global aspiration, or in a national context. Recently, Germany announced its intention to introduce a ticket tax in 2011, while a similar tax on tickets is also being discussed as a possible means of generating revenues to fund climate adaptation and mitigation. And, based on media reports, there is a raft of other potential taxes in the pipeline or being considered. So why do politicians still view aviation taxes as a solution?

There are several possible answers. Certainly increased understanding of aviation's impact on the upper atmosphere makes it very visible in the public eye. And the absence of duty on fuel for international aviation, when so many other carbon-intensive sectors are subject to energy taxes, draws obvious comparisons about equity of treatment.

From an economic standpoint, any tax introduced for environmental purposes is consistent with the idea of internalising costs by getting the polluter to pay. Putting a price on carbon for example, sends a price signal to further improve efficiencies and, properly labelled, helps educate and raise awareness amongst the public. Sir Nicholas Stern[4] sums it up very well: "*Putting an appropriate price on carbon – explicitly through tax or trading, or implicitly through regulation – means that people are faced with the full social cost of their actions. This will lead individuals and businesses to switch away from high-carbon goods and services, and to* *invest in low-carbon alternatives. Economic efficiency points to the advantages of a common global carbon price: emissions reductions will then take place wherever they are cheapest*".

While Stern highlights both taxes and trading as possible approaches, taxes do offer some advantages over emissions trading schemes despite being generally regarded as less cost-effective. They are administratively simple and can be introduced quickly. In comparison to the monitoring, reporting and verification requirements associated with trading schemes, taxes will undoubtedly have lower transaction costs (often utilising existing sales systems). But perhaps their biggest political attraction is the ability to generate revenues.

Within the United Nations Framework Convention on Climate Change (UNFCCC) negotiations, international aviation has often been cited as a possible source of revenue to raise money for adaptation. Two years ago, the Maldives, on behalf of the block of nations representing the Least Developed Countries (LDCs) proposed a levy on tickets for international flights. At a rate of $6 for an economy class ticket and $62 for premium class tickets, the levy, it was estimated, could raise $8-10 billion annually. For LDCs that rely on tourism, it seemed a bold move, but the rates were in fact proposed at a level that was unlikely to have a significant affect on demand. Although this proposal has not been adopted, the sector is still seen by many as providing a valuable, reliable and equitable source of finance. And with the UNFCCC's High-level Group on Climate Finance currently looking at ways to raise $100 billion annually to help developing countries with the costs of climate adaptation, consideration of a levy for aviation will probably be high on the agenda.

There is a need for caution with this approach: while it may appear that there is growing momentum in some quarters for aviation taxes, if applied in isolation, they may not be the perfect solution especially if the focus is on raising finance rather than specifically reducing aviation emissions. For example, a flat-rate levy on tickets may raise substantial funds but would do little to influence airline behaviour or stimulate further efficiency improvements. Furthermore, it could give rise, potentially, to the argument that aviation is playing a role and does not need to take further action, making it difficult to get a political consensus on the need for additional measures.

Raising revenue for developing countries must be part of the solution, and is widely supported by non-governmental organisations, but it should not be at the expense of effective measures to tackle aviation's growing emissions. Viewed as part of an overall strategy to reduce aviation emissions it certainly deserves further attention, but additional measures, and most importantly an emissions reduction target, are equally vital ingredients.

This pitfall could be overcome, at least in part, if taxes (or charges) were made proportional to efficiency parameters, in effect a levy on fuel consumption. For many in the environmental sector, fuel taxes still appear the most straightforward and rational way to put a price on carbon and encourage further operational and technological improvements. Notwithstanding the current legal difficulties of reconciling this aim with bilateral air service agreements, many hope that this option will be open to policy-makers in the future.

Either way, there is strong support for a well-designed, effective global trading scheme, or other global market-based solutions for addressing aviation emissions. Any delays in agreeing and introducing such a scheme are likely to see increased pressure to consider the potential role of taxes, at least as an interim measure. ■

REFERENCES

1 *Council Resolution of 9 December 1996.*

2 *A charge being defined as a levy that is designed and applied specifically to recover the costs of providing facilities and services for civil aviation.*

3 *Resolution A36-22 Appendix L.*

4 *Stern Review: the economics of climate change (October 2006),* ***http://webarchive.nationalarchives.gov.uk/+/http:/www.hmtreasury.gov.uk/independent_reviews/stern_review_economics_climate_change/stern_review_report.cfm***

Market Based Measures Task Force

Overview of Reports from CAEP/8

By ***Trond Kråkenes*** *and* ***Kalle Keldusild***

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He has been co-rapporteur both of the ICAO Emissions Trading Task Force (ETTF) and the ICAO Market Based Measures Task Force (MBMTF).

Since 1998, the Committee on Aviation Environmental Protection (CAEP) has undertaken the development of policies, guidance material and technical and economic studies on various market-based measures to address GHG emissions from international aviation, including emissions trading, emission-related levies, and emissions offsetting. With a view to further developing information on market-based measures for aviation, CAEP/7 in February 2007 established a Market-based Measures Task Force (MBMTF) to develop the following three reports:

I. Report on Scoping Study of Issues related to Linking Open Emissions Trading Systems involving International Aviation;

II. Report on Offsetting Emissions from the Aviation Sector; and

III. Updated Report on Voluntary Emissions Trading for Aviation.

These reports were approved by CAEP/8 in February 2010 and by the Council in June 2010, and a summary of these reports is provided below.

I. Study of Issues related to Linking Open Emissions Trading Systems Involving International Aviation

1. Introduction and Scope

The use of market-based measures, and in particular open emissions trading, is considered by a large part of the aviation industry and many States as a cost-effective tool to support the achievement of "carbon neutral growth" for the aviation sector in the medium term. If aviation is going to stabilize its emissions, the view is that emissions trading can close the gap between the emissions from the anticipated growth of the sector and the emissions reductions that can be achieved through technical and operational means.

Discussions in ICAO and in other forums such as the United Nations Framework Convention on Climate Change (UNFCCC) have however demonstrated that an agreement to set up one global system including aviation might not be an easy topic. A more probable outcome in the short and medium term is a more widespread development of national and regional emissions trading systems, which could be linked together.

The linking of regional and local emissions trading systems might be one way forward on the road to an international wide-ranging carbon market, but so far there is limited experience of linking emissions trading systems.

The purpose of this report is to provide an overview of the issues related to linking emissions trading systems (ETS) that involve international aviation. In that context, the scheme that results from linking shall be global as it will geographically cover more than one country or region and open in the sense that aviation should be able to use for compliance, units that are created outside the aviation sector. According to previous CAEP analyses, a closed system, i.e. where compliance units could be created and used within the aviation sector only, is not regarded as cost effective.

2. Different Kinds of Linking of Emissions Trading Systems

An emission trading system establishes a **direct link** with another system when participants in one or both of the systems can use tradable units issued by the administrator of the other system to meet domestic compliance obligations. In other words, the direct linking makes the tradable units of the two systems equivalent for compliance use. The forms and variations of linking can be unilateral, bilateral and multilateral.

The administrators of two systems can establish a bilateral link if each accepts tradable units issued by the other system. Thus with a bilateral link, there can be two-way trade of units that are equally valid for compliance purposes in either system. A bilateral link requires that the systems be "compatible", and thus some form of agreement is needed.

The administrator of a trading system can establish a unilateral link with another system by agreeing to accept tradable units issued by the other system for compliance purposes, but not vice versa. A unilateral link could be easy to implement. It does not require that the two systems be "compatible" or that a bilateral agreement be completed, but it does require that the user system has access to compliance units in the supplier system. However, in practice it might be difficult to establish a unilateral link on a larger scale without the consent of the supplier system.

A system that establishes a unilateral or bilateral link with another system also establishes an **indirect link** with any other system to which the partner system is linked. The indirect link occurs without any formal or informal agreement between systems.

3. Benefits of Linking

The potential benefits of linking different trading systems include:

- Lower net cost of meeting the emissions cap across the two systems as a result of the flexibility to implement the lowest cost emission reduction measures across all participants;
- Increased financial incentives for entities to reduce emissions in systems where scarcity and price are increased due to linking;
- Reduced price volatility due to the creation of a larger, more liquid market for the tradable units of the linked systems; and
- Reduced competitiveness concerns due to the convergence of tradable unit prices in the linked systems, as well as a reduced likelihood of increase in emissions outside the scope of a trading system (carbon leakage).

Competitiveness issues are important in relation to the use of emissions trading involving international aviation. In the absence of a global system, the possibility of linking systems in different regions may considerably reduce competitive distortion if a significant proportion of international aviation emissions are captured by such linking arrangements. The risk of double counting of emissions will also be reduced by linking of systems.

4. Obstacles and Issues related To Linking Aviation Trading Systems

General Obstacles

The net benefits of linking trading systems will rarely be evenly distributed. Linking generates a convergence of prices and thus leads to a higher market price in the supplier system (as the supply of tradable units in that system decreases), and a lower price in the buyer system. In practise, the effect of linking on the convergence of prices of tradable units would depend on a combination of factors including: the relative price difference for achieving reductions in the two systems, the size of the market, and the additional reductions or commitments undertaken (if any), when the market is broadened through linking.

Linking could compromise the environmental integrity of the system with the stronger requirements. If tradable units from a system with weak monitoring, reporting and verification requirements did not achieve the intended reductions, but were nevertheless used for compliance purposes in the stronger system, the environmental integrity of the stronger system would be compromised. Furthermore, if the financial penalties are set at different levels, and there is no requirement to submit tradable units equal to the shortfall, effectively the lower penalty acts as a price cap for the entire system. Similarly, price caps or price interference, when present, could also be obstacles to linking.

In addition, there could be an incentive for one or both systems to make smaller reductions to its cap over time so that its participants could remain or become exporters of tradable units in the linked system.

These obstacles, including the possibility of higher total emissions, could be reduced or avoided by harmonizing the relevant provisions enough to make the linked systems "compatible". Much of the literature on linking trading systems focuses on the question of the "compatibility" of the systems that could be linked. Clearly, a level of compatibility will be a necessary prerequisite for any bilateral link to be established, and this compatibility would need to be sustained despite economic, technological and administrative developments over time. Sustaining the compatibility of the linked systems would, among other things, require a process for agreeing on revisions to the requirements of the linked systems.

Specific Issues Related To International Aviation

Aviation emissions have other climate change impacts than those caused by CO_2 emissions. However, it would be difficult to include the non-CO_2 effects such as NO_x, contrails and water vapour, in a trading system as there are many scientific uncertainties related to these effects, their duration, and their variability over time and location. On the other hand, aviation tradable units for CO_2 emissions might be regarded as permitting a larger climate change impact than from CO_2 only. Other emission trading systems might be reluctant to link with a system that includes international aviation because of the difference in the climate change impacts associated with their respective tradable units.

Many emissions trading systems for greenhouse gases are intended to help the country meet a national emissions limitation commitment under the Kyoto Protocol. Tradable units to be allocated to international aviation are not backed by Kyoto units for the time being, unless there was an agreement under the UNFCCC. The report discusses different risks and possible solutions when unique tradable units are used for compliance purposes for emissions from international aviation.

There are two ways for international aviation to be involved in an "open" emissions trading:

- some/all international aviation emissions are included in an existing national or regional emissions trading system that covers emissions from other sectors; or
- a specific emissions trading system is set up for some/all international aviation emissions and subsequently linked to one or more emissions trading systems that involve emissions from other sectors. It is noted that a system covering international aviation exclusively (closed system) would only be created with the precondition that it will be linked to one or more emissions trading systems involving other sectors.

The inclusion or the linking of international aviation with other systems raise some key issues, such as:

- Bilateral versus unilateral linking;
- Indirect linking;
- Willingness to link;
- Quality of tradable units and barriers to transfers of tradable units;
- Size of systems; and
- Double counting, registration and cancellation of allowances.

The report points out that, at present, only the EU Emissions Trading System (in combination with the Clean Development Mechanism) would likely be large enough to provide for the projected demand for external tradable units by a trading system for international aviation emissions. However, a national trading system established in the U.S. or links with a number of smaller systems may also be sufficient to meet the projected demand.

5. Harmonization Issues

From a technical perspective, harmonization of system designs to enable a bilateral link may be essential for only a relatively small number of provisions, such as a price cap. However, for political reasons, harmonization of several other provisions, such as the method for allocating tradable units and the use of offsets, is desirable and possibly essential. This is because a bilateral link effectively allows participants in one system access to many provisions of the other system.

A number of design elements are discussed in the report that should be considered in order to avoid the situation whereby linking leads to higher total emissions:

- cost containment measures such as price caps;
- non-compliance penalties and enforcement;
- borrowing and banking restrictions (as regards the use of tradable units);
- compliance period and life of tradable units;
- form of the emissions limit; and
- measures to address leakage (increased output and emissions by sources outside the trading system).

Other harmonization issues discussed are:

- coverage of the system (emissions sources and thresholds for participation);
- emissions constraints;
- distribution of tradable units;
- use of offsets;
- monitoring, reporting, and verification requirements;
- gateways; and
- government intervention.

A bilateral link requires that the designs of the two trading systems be harmonized enough to make them "compatible". Although a unilateral link does not require the same level of compatibility, in practice it will be important that certain elements of the systems are harmonized. Thus all the issues above should be assessed when considering any form of linking.

II. Offsetting Emissions From the Aviation Sector

1. Introduction

Offsetting can potentially be an important tool to mitigate the effects of aviation emissions on global climate, however, aviation-related offsetting has been rather limited so far. In addition, offsetting of emissions from aviation today is passenger-based only, and on a voluntary basis, although the biggest potential lies in using offsetting in a regulatory context.

2. Offsetting Defined

In general terms, an offset is a "compensating equivalent". As an activity, offsetting is the "cancelling out" or "neutralizing" of emissions from a sector like aviation with emissions reductions achieved in a different activity or location that have been rigorously quantified and verified. It is only when credits are acquired from outside the emissions trading scheme or linked schemes and used to meet commitments/obligations under the scheme that the activity is referred to as offsetting.

It is important to distinguish between the activity of "offsetting" and the creation of an "offset credit" used for offsetting emissions, because the term 'offset' has been used to refer to both. For the purposes of this article, "offsetting" is used to describe the action to compensate for greenhouse gas emissions. On the other hand, the term "offset credit" or "credit" is used to describe the product from reducing emissions in a different activity or location that is used in the activity of offsetting. For example, the Certified Emissions Reduction credits, generated by a Clean Development Mechanism (CDM) project under the Kyoto Protocol are offset credits.

Offsetting must also be distinguished from emission trading. If for example, a regulated emitter acquires emission credits or emission allowances from another regulated emitter within the same emission trading scheme, or from a linked scheme, this is referred to as emission trading. These credits or allowances could be used to achieve compliance with a regulatory obligation or could be banked for future use (compliance or trading). It is only when credits are acquired from outside the emission trading scheme, or linked schemes, and used from compliance that the activity is referred to as offsetting.

Both regulated emitters (or entities) and unregulated emitters may choose to offset their emissions. A regulated entity could use offsetting as one means to comply with an emission commitment, for example under an emissions trading scheme. An unregulated entity's motive for offsetting is to meet its own voluntary goals. In both cases, the emitters need to acquire offset credits that can be used for offsetting their emissions. However, the regulated entity can only use credits that are approved by a regulatory authority, whereas the unregulated entity can choose freely among all the credits that are available for offsetting.

Thus, offsetting can take place in both regulated and unregulated contexts. Offset credits that are accepted for offsetting are created according to different rules or standards. The following sections explain in more detail how credits available for offsetting are created, the standards that could be used to ensure their quality, how offsetting could take place, and finally, the effects of offsetting.

3. Assessment of Current Aviation Offsetting Activities

A web-based review of sixteen airline offsetting schemes was conducted by the MBMTF during 2008. The airlines chosen for this study were mainly European, North American or Australian, ranging from big companies with large global market shares to low fare airlines or smaller operations focused on a few destinations. The companies in the study use a range of business models and offset providers to offer this service. Some companies buy credits directly from a project partner, while others work with offset providers such as Carbon Neutral Company or myclimate. For example, two major airlines in Australia have reported that in 2008, 10-12 percent of their passengers had taken up the voluntary offset option.

Several concerns related to offsetting are discussed in the report. Some of the most important are related to: difficulties that airline passengers have in navigating websites, limited passenger participation, and lack of transparency about the credits being offered, including the general absence of rigorous verification requirements.

On the positive side, buying offsets mitigates greenhouse gas emissions and airline consumers are being educated about the effects of air travel on climate change. Furthermore, the development of carbon markets is encouraged, and the need for improved standards and verification requirements for the generation of offset credits is becoming more accepted.

4. Offsetting In the Future

Despite the rapid ongoing growth of voluntary offsetting by air passengers, the potential for this type of voluntary approach for mitigating the effects of aviations emissions on the global climate is likely limited. Despite what appears to be widespread support, the willingness to actually purchase credits on a voluntary basis has been weak.

Nevertheless, steps might be taken to increase demand and quality of non-regulatory offsetting. For example, ensuring offset credits meet internationally accepted rigorous standards for quantification and verification, and improving systems for tracking credits to ensure they are used only once, should both be pursued.

Offsetting in a regulatory context may be an important tool in the future. If there is a decision to regulate emissions from aviation that allows for emission trading and emission sources not covered by a regulated system, that can reduce emissions at a cost less than reducing emissions from aviation itself, an offsetting mechanism is likely to be part of the scheme.

The report concludes with a discussion of opportunities to use offsetting in the future. At the passenger level, it is possible to draw on the voluntary experience to date. If the current shortcomings are adequately addressed, support of voluntary passenger offsetting is likely to increase. However, a more comprehensive coverage of emissions could be achieved if the initiative or responsibility to voluntarily offset emissions is transferred from the passenger to the airline.

There is also the possibility of using offsetting at a global sectoral level, either in a regulated emission trading system, or through an emission charge. Emission trading offers an option for managing emissions from the aviation sector by means of a regulated cap on emissions that allows for emission trading, including the use of offset credits.

As regulatory emission trading systems can be administratively complex, a hybrid approach can be considered which could achieve specific environmental outcomes. The approach would involve imposing a charge on fuel uplifted by international flights departing a state/region and using the revenue generated to fund the purchase of offset credits that meet agreed criteria.

III. Voluntary Emissions Trading for Aviation

1. Introduction

To provide information on the various voluntary emissions trading being undertaken, CAEP/7 in 2007 developed a Report on Voluntary Emissions Trading for aviation (see ICAO Environmental Report 2007 pp.152 - 153), and CAEP/8 in February 2010 has made an update of the report.

2. Ongoing Schemes

This report provides updated information related to voluntary emission trading schemes covered by the earlier report, as well as information on new schemes.

It describes the general nature of various types of voluntary emissions trading schemes, presents and summarizes a number of practical experiences currently implemented throughout the world, and discusses the possible future development of such schemes involving aviation.

Ongoing schemes presented in both reports are: United Kingdom Emission Trading Scheme; Japan's Voluntary Emissions Trading Scheme; and Chicago Climate Exchange. Recent schemes introduced in the CAEP/8 report are Trial Voluntary Emissions Trading Scheme in Japan (2008-2012); Switzerland's Voluntary Emissions Trading Scheme; Asia Carbon Exchange; and Australian Climate Exchange.

3. Aviation Participation

Voluntary emissions trading schemes are becoming established in a number of countries including two of the largest economies in the world, the United States and Japan. However, aviation participation has been confined so far to the UK Emissions Trading Scheme and the Trial Voluntary Emissions Trading Scheme in Japan (2008-2012), even where only domestic aviation services have been involved.

Conclusions

ICAO has been developing policies, guidance material and technical and economic studies on various market-based measures for international aviation, inluding the study reports developed by CAEP/8 (see Figure 1), to help States develop and implementt these measures and to facilitate the highest degree of harmonization and cooperation among States, as part of global solutions to address GHG emissions from international aviation. ■

- *ICAO 36th Assembly Resolution (A36-22 Appendix L)*
- *ICAO's Policies on Charges for Airports and Air Navigation Services (Doc 9082)*
- *ICAO's Policies on Taxation in the Field of International Air Transport (Doc 8632)*
- *Council Resolution on Environmental Charges and Taxes (9 December 1996)*
- *ICAO Guidance on the use of Emissions Trading for Aviation (Doc 9885)*
- *CAEP/8 – Collected Information on Voluntary Measures*
- *CAEP/8 – Report on on Scoping Study of Issues related to Linking Open Emissions Trading Systems involving International Aviation*
- *CAEP/8 – Report on Offsetting Emissions from the Aviation Sector*
- *CAEP/8 – Updated Report on Voluntary Emissions Trading for Aviation*

Figure 1: *ICAO Policies, Guidance Material and Studies on Climate Change.*

Voluntary Measures to Address Aviation Greenhouse Gas Emissions From Aviation

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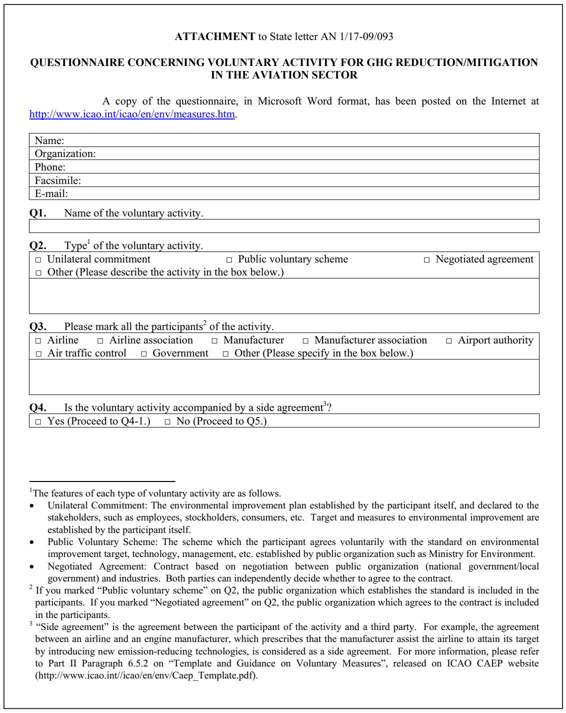
Background

In 2004, the Committee on Aviation Environmental Protection (CAEP) acknowledged the importance of collecting information on voluntary activities that have been implemented to reduce climate impact caused by greenhouse gasses (GHG) emitted from aviation. It was recognized that providing such information to the aviation community would encourage the implementation of more such activities.

As a first step, CAEP members and observers were invited by the Focal Point on Voluntary Measures (FPVM) to provide information on voluntary activities. Information on five activities was collected and CAEP recognized that it was important to invite more information from various stakeholders. In October 2006, the Secretariat requested information[1] from all 190 States on voluntary emission reduction activities that have been undertaken by States and stakeholders such as airlines, airport authorities, etc., and responses were reported to CAEP/7 in February 2007. Noting the importance of collecting and sharing such information, CAEP/7 recommended that ICAO continue to request the information periodically and to share the collected information through the ICAO website. This information resulted in a very rich source of practical and concrete measures taken to reduce aviation emissions impacts.



ATTACHMENT to State letter AN 1/17-09/093

QUESTIONNAIRE CONCERNING VOLUNTARY ACTIVITY FOR GHG REDUCTION/MITIGATION IN THE AVIATION SECTOR

A copy of the questionnaire, in Microsoft Word format, has been posted on the Internet at http://www.icao.int/icao/en/env/measures.htm.

Name:
Organization:
Phone:
Facsimile:
E-mail:

Q1. Name of the voluntary activity.

Q2. Type[1] of the voluntary activity.
□ Unilateral commitment □ Public voluntary scheme □ Negotiated agreement
□ Other (Please describe the activity in the box below.)

Q3. Please mark all the participants[2] of the activity.
□ Airline □ Airline association □ Manufacturer □ Manufacturer association □ Airport authority
□ Air traffic control □ Government □ Other (Please specify in the box below.)

Q4. Is the voluntary activity accompanied by a side agreement[3]?
□ Yes (Proceed to Q4-1.) □ No (Proceed to Q5.)

[1] The features of each type of voluntary activity are as follows.
- Unilateral Commitment: The environmental improvement plan established by the participant itself, and declared to the stakeholders, such as employees, stockholders, consumers, etc. Target and measures to environmental improvement are established by the participant itself.
- Public Voluntary Scheme: The scheme which the participant agrees voluntarily with the standard on environmental improvement target, technology, management, etc. established by public organization such as Ministry for Environment.
- Negotiated Agreement: Contract based on negotiation between public organization (national government/local government) and industries. Both parties can independently decide whether to agree to the contract.

[2] If you marked "Public voluntary scheme" on Q2, the public organization which establishes the standard is included in the participants. If you marked "Negotiated agreement" on Q2, the public organization which agrees to the contract is included in the participants.

[3] "Side agreement" is the agreement between the participant of the activity and a third party. For example, the agreement between an airline and an engine manufacturer, which prescribes that the manufacturer assist the airline to attain its target by introducing new emission-reducing technologies, is considered as a side agreement. For more information, please refer to Part II Paragraph 6.5.2 on "Template and Guidance on Voluntary Measures", released on ICAO CAEP website (http://www.icao.int//icao/en/env/Caep_Template.pdf).

Figure 1: *Questionnaire for reporting voluntary GHG mitigation activities.*

Recent Activities

In December 2009, the Secretariat requested further information[2], and 50 replies were received from 24 States and regions as of June 2010.

Table 1 shows the number of voluntary measures taken by various stakeholders. It is recognized that the recent increase in interest on climate change has contributed to this wide variety of stakeholders and the increase in the number of measures implemented and reported.

Organization	Number
Airline	37
Airline Association	7
Manufacturer	4
Airport Authority	15
Air Traffic Control	15
Government	13
Other	7

Table 1: *Number of voluntary measures taken by various stakeholders – by June 2010.*

Example of Measures that can be Taken

Typical operational measures taken by air traffic control include the introduction of fuel efficient procedures, such as CDO and improvement of ATM. Some airport authorities cooperate with airlines to promote the use of GPU, in addition to their own measures such as the use of renewable energy and LEDs for aeronautical lights. Typical measures taken by airlines to improve aircraft fuel efficiency include the renewal of aircraft, improvement of aerodynamics, fuel efficient flight planning, reduction of aircraft weight, use of GPU instead of APU, washing engines and training using flight simulator. Carbon offsetting is also introduced by some airlines.

Voluntary Agreements

Voluntary measures can take various forms. Thirty of the measures reported were classified as Unilateral Commitment, nine were classified as Public Voluntary Scheme, meaning that participants agree voluntarily with the standard established by the public organization, and five were classified as Negotiated Agreement between public organization and industries. By their nature, these agreements are not legally enforceable, however, partners are assumed to undertake good faith efforts to comply with the terms and conditions. If one or more partners are unable to comply with the agreement, the agreement can be terminated and alternative methods for reducing emissions can be pursued.

Examples of Voluntary Agreements

- ***Asia and Pacific Initiative to Reduce Emissions (ASPIRE)*** *which involves airlines, air traffic control, airport authorities and governments in a voluntary agreed measure to work together to reduce aircraft fuel burn and* CO_2 *emissions through efficiency improvements on key Asia and Pacific routes.*
- ***Memorandum of Understanding between Transport Canada and the Air Transport Association of Canada*** *to limit or reduce GHG emissions from aviation in Canada. The Agreement sets out a GHG emissions reduction goal for members of the Air Transport Association of Canada and covers both domestic and international air transport.*
- ***A negotiated agreement in Romania involving airlines, air traffic control, government and manufacturers****, which involves: Direct routes; Continuous Descent Approach at Henri Coanda International Airport, and Non-standard arrival trajectories (direct arrivals) at airports which provide approach services.*

Figure 2: *ICAO Voluntary Measures Web page.*

In February 2010, the ICAO Secretariat reconstructed its website to disseminate information on voluntary measures in a user-friendly manner (Figure 2). All information received is available at: **www.icao.int/icao/en/env/Measures/VM_Results_2010.htm.**

Moving Forward

Collecting and disseminating information on various voluntary activities to the aviation community will help and encourage the further implementation of such activities. ICAO welcomes additional submissions and updated voluntary activities, in order to ensure timely dissemination of a wide range of information. The questionnaire in MS-Word format is available at: **http://www.icao.int/icao/en/env/measures.htm.** ■

REFERENCES

1 State Letter AN 1/17-06/77.

2 State Letter AN 1/17-09/093.

IATA's Carbon Offset Program

By ***Paul Steele***

Paul Steele *is Executive Director of the Air Transport Action Group (ATAG), the only global association that represents all sectors of the air transport industry. Its mission is to promote aviation's sustainable growth for the benefit of global society.*

Paul is also Director Aviation Environment of the International Air Transport Association (IATA), with the responsibility for guiding and implementing IATA's environment strategy worldwide. Before joining IATA in December 2007, Paul was CEO of WWF International. Paul also has over 20 years' senior management experience with major international companies, including The Virgin Trading Company, Hilton Hotel Group and Pepsi Cola International.

IATA is an international trade body, created over 60 years ago by a group of airlines. Today, IATA represents some 230 airlines comprising 93% of scheduled international air traffic. The organization also represents, leads and serves the airline industry in general.

IATA is committed to demanding targets related to climate change. By 2020 its members will cap its net emissions with carbon neutral growth. By 2050 they will cut net aviation emissions in half, compared with 2005.

To achieve this, IATA actively promotes a four pillar strategy that involves: investment in technology, more effective operations, more efficient infrastructure, and positive economic measures. All four pillars are critical. In line with this strategy, in 2009, IATA launched an industry standard carbon offset program.

Carbon Offsetting Explained

Carbon offsetting is simply a way for individuals or organizations, in this case airline passengers and corporate customers, to "neutralize" (i.e. offset) their proportion of an aircraft's carbon emissions on a particular journey by investing in carbon reduction projects. (see Figure 1)

Carbon offsetting has proven popular, with the voluntary offsetting market currently worth US$ 338 million (2009). Anecdotal evidence indicates that a significant proportion of this market volume is associated with offsetting emissions from aviation. However, with no information-sharing among airlines and third party offset providers the "real" balance of aviation emissions on a global basis cannot be determined. In addition, the wide variety of carbon calculators, carbon prices, project types, and credit types has caused confusion and scepticism.

More than 30 IATA member airlines have introduced offset programs, either integrated into their sales websites, or as a "click-away" to a third party offset provider; to varying degrees of success. IATA's offset program brings both standardization to the process and makes it possible for airlines of any size to easily introduce a credible and independently validated offset program. TAP Air Portugal went live in June 2009 as the first partner airline in the project, and 15 more airlines are due to launch in 2010.

How The Program Works

Phase I of IATAs carbon offset program provides management services to participating airlines that offer carbon offsets to passengers through their internet-based sales sites. During the implementation process, IATA provides advice on modifying an airline's internet site and on how to integrate applications such as: Carbon Calculator Tool, project information, and Web interface. The IATA programme ensures that passengers can complete their purchase of carbon credits within the same transaction as paying for their ticket. This avoids the link and transfer to a third party and the need for a double transaction that has proven to be a major barrier to passenger purchases of offsets.

The core element of the program is the Carbon Calculator, which is based on the ICAO Carbon Emissions Calculator methodology (see *The ICAO Carbon Emissions Calculator* article, Chapter 1 of this report), enhanced with independently verified airline data. The Calculator allows airlines to enter data on fuel burn, load factor and passenger/freight weight on a city-pair basis, and to calculate emissions for each passenger by seat class (kg/CO_2). (see Figure 3)

During the flight booking process, passengers are given the option to offset these emissions with certified carbon credits by investing in UN-certified carbon reduction projects. These carbon credits are purchased from projects generating Certified Emission Reductions (CERs) issued through the Clean Development Mechanism (CDM) and approved under the United Nations Framework Convention for Climate Change (UNFCCC). Unique ticketing codes allows an airline to offer up to three different carbon offset projects; offset tracking is facilitated through code-share partners and interlining. Airlines are encouraged to select projects from locations which have a regional or cultural connection with the airline's passengers.

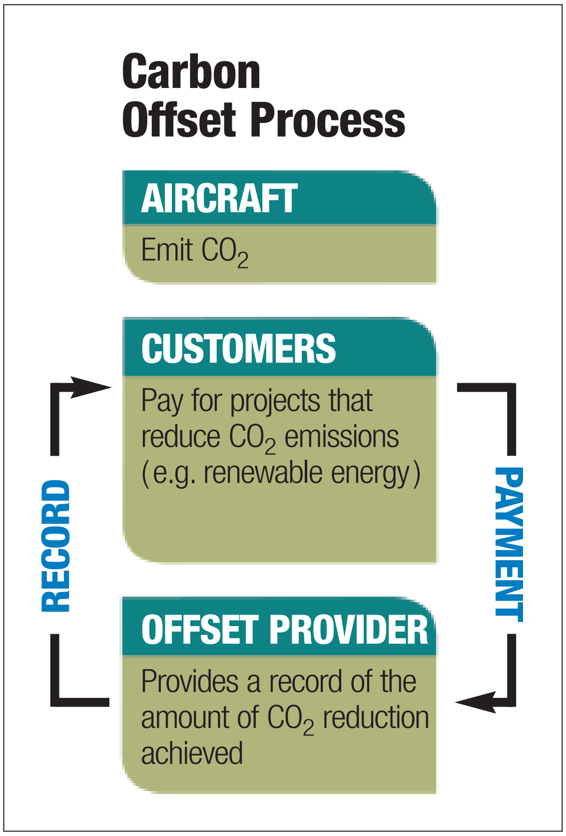


Figure 1: *IATA carbon offset process.*

> *"IATA's carbon offset programme offers best practice in the structure and implementation of carbon offsetting. Offsets are carefully selected and accounted for, and the issue of carbon calculation has been resolved by committing to the ICAO methodology supplemented with actual airline carbon data." Paul Steele, IATA Director Aviation Environment.*

The IATA Offset Program has been independently verified by the UK Government's Quality Assurance (QA) Scheme for Carbon Offsetting, allowing participating airlines to carry the QA scheme's logo (Figure 2) as a seal of approval.

The QA scheme validates the carbon data, website information, carbon credit purchasing, and registration details.

direct.gov.uk/offsetting

Figure 2: *Official seal, UK Government's Quality Assurance (QA) Scheme for Carbon Offsetting.*

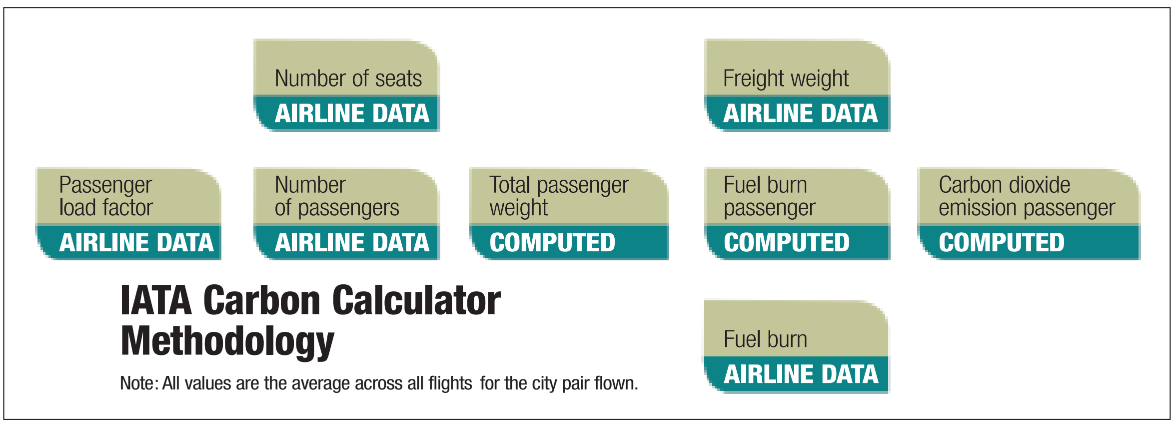


Figure 3: *IATA Carbon Calculator methodology.*

Next Steps

Phase II of IATA's Carbon Offset Program will expand the range of participating organizations to include other segments of the aviation business such as: global distribution systems, frequent flyer programs, and over-the counter sales. Aside from enabling the airline industry to present a coherent message to the global environmental community, this program also provides airlines with carbon market experience. It gives airlines assistance in driving towards internal sustainability and corporate responsibility goals. By unifying the industry approach, it strengthens the industry call for a global framework for addressing aviation emissions. The program provides the opportunity that the industry gets credited with the offsets purchased while it only pays once for its emissions. ■

REFERENCES

1 *IATA (2010)*
http://www.iata.org/WHATWEDO/ENVIRONMENT/Pages/index.aspx

2 *UK Government Quality Assurance Scheme for Carbon Offsetting Approval requirements and procedures for offset providers (2009)*
http://offsetting.decc.gov.uk.

CASE STUDY:

TAP Portugal Wins Award

TAP Portugal *was a launch customer of the IATA carbon offset program. Such have been its efforts that is was recently given the* ***Planet Earth Award 2010*** *in the* ***Most Innovative Sustainable Product category*** *by UNESCO and the International Union of Geological Sciences.*

"The Board of the International Year of Planet Earth (IYPE), that assessed and evaluated TAP's Offset Program, recognized it as being an innovative project representing a great advance to aviation sustainability," says Luisa Sousa Otto UNESCO's Project Manager for IYPE.

TAP purchases carbon credits from a hydropower plant in Brazil, which is registered under the UNFCCC Clean Development Mechanism. And its environmental work doesn't stop there. The Eco Act project extends company-wide, and promotes practical day-to-day solutions for environmental mitigation.

"The air transport industry has, in recent times, taken significant steps to protect environment," adds Fernando Pinto, CEO TAP. "That proves the industry's concern for environmental issues through the launch of sound projects, and by taking effective measures to help protect the environment in a sustainable way."

Chapter 5

ALTERNATIVE FUELS

Sustainable Alternative Fuels for Aviation

Overview

By ***ICAO Secretariat***

Background

Engineering improvements, technology enhancements, and advanced operations (including efficiency improvements in air traffic management) all have a role to play in reducing aviation fuel consumption and associated carbon emissions. Significant progress has been made in establishing technology goals for reducing aircraft greenhouse gas (GHG) emissions. On a per-flight basis, efficiency is expected to improve continuously through the year 2050 and beyond (see *Climate Change Outlook,* Aviation Outlook of this report).

ICAO is spearheading efforts to promote and harmonize worldwide initiatives for operational practices that result in reducing aviation's contributions to human produced emissions. However, even under the most aggressive technology forecast scenarios, the anticipated gain in efficiency from technological and operational measures does not offset the overall emissions that are forecast to be generated by the expected growth in traffic. To achieve the sustainability of air transport, other strategies will be needed to compensate for the emissions growth not achieved through efficiency improvements.

A promising approach toward closing this GHG emissions mitigation gap is the development and use of sustainable alternative fuels for aviation. Although such fuels already exist, they are not yet available in sufficient quantities to meet the overall fuel demand for commercial aviation.

Drop-in fuels are substitutes for conventional jet fuel that are completely interchangeable and compatible with conventional jet fuel. The reduction in GHG emissions from the use of drop-in fuels developed from renewable, sustainable sources is the result of lower GHG emissions from the extraction, production and combustion of the fuel. Sustainable drop-in alternative fuels produced from biomass or renewable oils offer the potential to reduce life-cycle greenhouse gas emissions and therefore reduce aviation's contribution to global climate change. (see article *Estimating Life Cycle Greenhouse Gas Emissions from Alternative Jet Fuels*, Chapter 5 of this report).

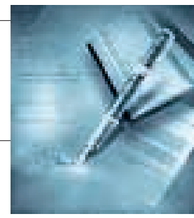
Over the short and medium-term horizon, aviation will be heavily dependent on drop-in liquid fuels (see article *Long Term Potential of Hydrogen as Aviation Fuel,* Chapter 5 of this report) and the development and use of sustainable alternative fuels will play an active role in improving the overall security of supply, and will stabilize fuel prices.

The Situation Today

Worldwide interest continues to grow in the development of more sustainable energy sources that could help face the challenge of climate change. For some time now, sustainable alternative fuels for aviation have been the focus of the aviation industry. Today, various consortia for the development of such fuels have been established, as shown in Table 1, and new initiatives are underway. Prospects for the use of sustainable fuels on a commercial scale are now being measured in years, not decades. (see article *Sustainable Aviation Fuel Research*, Chapter 5 of this report).

A broad range of stakeholders from around the world are collaborating to bring new, sustainable, fuels to the market. Of course, safety is paramount, and all aviation fuels must meet the required specifications. (see article *A Global Fuel Readiness Level Protocol*, Chapter 5 of this report).

During the past year, the qualification of some types of fuels was completed, and currently the qualification of others is well advanced. Of particular importance is the ASTM D-7566 Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons that was approved on 1 September 2009, since it was the first new jet fuel approval in 20 years! (see article *Proposal to Adopt a Global Fuel Qualification and Certification Protocol*, Chapter 5 of this report).

	Consortia and Research Initiatives
2006	Commercial Aviation Alternative Fuels Initiative (**CAAFI**) formed to promote development of alternative jet fuel options that offer safety, cost, and environmental improvement and energy supply security for aviation
2009	Sustainable Way for Alternative Fuels and Energy for Aviation (**SWAFEA**) is a study for the European Commission's Directorate General for Transport and Energy to investigate feasibility and impact from use of aviation alternative fuels
2010	Sustainable Bioenergy Research Project (**SBRP**) launched to demonstrate the commercial viability of using integrated saltwater agriculture to provide biofuels for aviation
2010	Brazilian Alliance for Aviation Biofuels (Aliança Brasileira para Biocombustíveis de Aviação – **ABRABA**) formed to promote public and private initiatives to develop and certify sustainable biofuels for aviation
2010	Sustainable Aviation Fuels Northwest formed to promote aviation biofuel development in the Pacific Northwest of the United States
	Policies, Methods and Processes
23 April 2009	**EU** requires lifecycle greenhouse gas emission savings from use of biofuels be at least 35% (Renewable Energy Directive 2009/28/EC)
7-9 October 2009	**ICAO** High-Level Meeting on Aviation and Climate Change
14 November 2009	Roundtable on Sustainable Biofuels (**RSB**) published Principles and Criteria for Sustainable Biofuel Production (v.1)
18 November 2009	**CAAF 2009** announces conclusions and recommendations: environmental sustainability/interdependencies, technological feasibility/economic reasonableness, development/use support, and production/infrastructure 
18 December 2009	**CAAF 2009** Declaration and Global Framework in conjunction with High-Level Meeting on International Aviation and Climate Change (**HLM-ENV**) outcomes presented as ICAO input to COP15
19 March 2010	US DOD's Defense Energy Support Center (**DESC**) and Air Transport Association of America (**ATA**) sign agreement to combine purchasing power to encourage development/deployment of alternative aviation fuels
	Fuel Certification/Qualification
1 September 2009	**ASTM D-7566 (Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons) approved as first new jet fuel spec in 20 years**
	Tests and Demonstrations
1 February 2008	**Airbus** flew A380 test aircraft with one engine running on 40/60% blend of Gas To Liquid (GTL) synfuel and conventional jet fuel
23 February 2008	**Virgin Atlantic** flew B747-400 with one engine operating on 20/80% blend of babassu oil/coconut oil biofuel with conventional jet fuel
30 December 2008	**Air New Zealand** flew B747-400 with one engine running on 50/50% blend of jatropha derived biofuel and conventional jet fuel
7 January 2009	**Continental Airlines** flew B737-800 with one engine using 50/50% blend of algae and jatropha biofuel mix with conventional jet fuel
30 January 2009	**JAL** flew B747-300 with one engine running 50/50% blend of camelina, jatropha and algae biofuel mix with conventional jet fuel
12 October 2009	**Qatar Airways** flew first revenue flight (London to Doha) on A340-600 with four engines operating on 48.5/51.5% blend of GTL synfuel with conventional jet fuel
23 November 2009	**KLM** flew B747-400 with one engine running on 50/50% blend of camelina biofuel with conventional jet fuel
22 April 2010	**United Airlines** flew A319 with one engine using 40/60% blend of natural gas F-T fuel jet fuel with conventional fuel

See **www.icao.int/AltFuels** for additional accomplishments

Table 1: *Sustainable Alternative Fuels for Aviation Accomplishments.*

It is now an indisputable fact that drop-in alternative fuels are a technically sound solution that will not require changes to the aircraft or fuel delivery infrastructure.

In November 2009, ICAO held a Conference on Aviation and Alternative Fuels (CAAF) to showcase the state-of-the-art in aviation alternative fuels. The Conference also addressed the key issues of sustainability, feasibility, economics, production, and infrastructure. At the Conference, States agreed to develop, deploy and use sustainable alternative fuels to reduce aviation emissions. To facilitate, on a global basis, the promotion and harmonization of initiatives that encourage and support the development of sustainable alternative fuels for aviation, the Conference established an ICAO Global Framework for Aviation Alternative Fuels. It is a web-based living document (www.icao.int/AltFuels). Information about new alternative fuel initiatives and tests to support qualifications appears almost daily.

Current Challenges

Today, sustainable alternative fuels offer the potential to reduce aviation environmental impacts, but are not yet available in quantities sufficient to meet the overall demand by commercial aviation. The cost and availability of sustainable alternative fuels for aviation remain key barriers to their large scale adoption (see article *From Alternative Fuels to Additional Fuels: Overcoming the Challenges to Commercial Deployment*, Chapter 5 of this report).

The testing of new fuels and the establishment of new production facilities require significant capital investment. In addition, since aviation represents less than 5% of the world's liquid fuel consumption, it is possible that fuel producers may initially target larger markets. If the use of alternative fuels is to be part of a comprehensive strategy for minimizing the effects of aviation on the global climate, regulatory and financial frameworks need to be established to ensure that sufficient quantities of alternative fuels are made available to aviation.

As requested by CAAF, ICAO has entered into preliminary discussions with the World Bank and Inter-American Development Bank to facilitate a framework for financing infrastructure development projects dedicated to aviation alternative fuels and incentives to overcome initial market hurdles. Furthermore, the adoption of alternative fuels by aviation might be simpler than for other sectors due to the relatively small number of fuelling locations and vehicles.

The definition of sustainability criteria will determine the types of feedstocks and processes that will be used to produce alternative fuels in the future (see article on *Sustainable Biofuel Raw Material Production for the Aviation Industry*, Chapter 5 of this report). Currently, there is no set of internationally accepted sustainability criteria; however, this issue is not exclusive to aviation.

ICAO's Role in Sustainable Alternative Fuels for Aviation

ICAO has been facilitating, on a global basis, the promotion and harmonization of initiatives that encourage and support the development of sustainable alternative fuels for international aviation. The Organization is actively engaged in the following activities to carry out this facilitation role:

- **a)** Providing fora for education and outreach on sustainable alternative fuels for aviation.
- **b)** Providing fora for facilitating the exchange of information on financing and incentives for sustainable alternative fuels for aviation programmes working with the relevant UN and regional financial entities.
- **c)** Facilitating the establishment of a regulatory framework that assures sufficient quantities of sustainable alternative fuels are made available to aviation.
- **d)** Facilitating development of standardized definitions, methodologies and processes to support the development of sustainable alternative fuels for aviation, taking into consideration the work that has been done so far in this area.
- **e)** Supporting a platform for access to research, roadmaps and programmes.

Conclusions

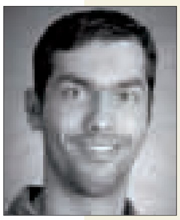
Sustainable alternative fuels for aviation offer a win-win solution for all stakeholders involved in their development, production, deployment and use. Air carriers will benefit from stabilized fuel prices and supply security. Both developing and developed States will benefit alike from the ability to produce feedstocks and fuels from locations that did not historically produce conventional fuels. Most importantly, the planet will benefit from lower net emissions of greenhouse gasses being released into the atmosphere.

Sustainable Aviation Fuel Research

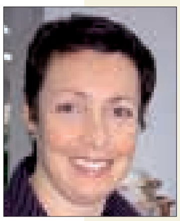
Masdar's Sustainable Bioenergy Research Project

By **Darrin Morgan, Sgouris Sgouridis, Linden Coppell, James Rekoske**

***Darrin Morgan** leads strategy development and execution for the Boeing Commercial Airplanes Sustainable Aviation Fuels Program. He is a co-founder of the Sustainable Aviation Fuel Users Group, that accounts for more than 15 % of global jet fuel demand and whose goal is to diversify aviation's fuel supply and reduce lifecycle greenhouse gas emissions.*



***Sgouris Sgouridis** is an Assistant Professor in Masdar Institute of Science and Technology. His current research interests focus on sociotechnical systems modeling including sustainable transportation systems and sustainable energy systems management. Dr. Sgouridis is co-PI in on projects related to aviation under carbon-constraints and is co-leading the development of the Sustainable Bioresource Research Project.*



***Linden Coppell** joined Etihad Airways in 2009 with responsibility for developing an overall strategy for environmental management. In particular she is ensuring compliance with environmental regulations and developing and implementing programmes for key areas such as carbon and emissions management.*

***James Rekoske** is Vice President and General Manager of the Renewable Energy and Chemicals business unit at Honeywell's UOP, a leading developer and licensor of technologies for the production of high-quality green fuels. Prior to this, Jim served as Senior Manager of Catalysis Research and Development for UOP and Technical Director for Petrochemical Catalysts. He was also the Director of Technology for Universal Pharma Technologies, a former UOP joint venture focused on technology and services in pharmaceutical chemistry.*

Introduction

While the benefits of aviation are well known, the aviation industry currently contributes approximately 2-3% of global anthropogenic greenhouse gas emissions. The industry is increasingly aware of the important role it must play in reducing greenhouse emissions and is already taking decisive action. Although, new aircraft technology, fuel conservation and improved airspace management offer the most immediate ways to reduce aviation's environmental impact in the longer term, these advances alone are not sufficient to offset the projected growth in air travel and the associated emissions.

The demand for air transport has increased steadily over the years, with passenger travel, growing by 45% over the last decade, and doubling since the mid 1980s. Sustainable aviation fuels offer the most promising opportunity for reducing aviation greenhouse gas emissions without impinging upon the positive contribution that aviation makes to the global economy. Proven technology has already been developed that converts bio-derived materials into synthetic paraffinic kerosene (SPK). Recent test flights indicate that SPK, when blended with petroleum-based jet fuel in a 50% mixture, meets or exceeds traditional Jet-A1 performance specifications without any modification to the engine or the airframe.

The major challenges now are around agronomy, scale, commercial viability and environmental sustainability. Around the world, emission trading schemes are being developed to reduce greenhouse gas emissions. Under some of these trading schemes, biofuels are 'zero-rated' meaning that they have no carbon liability for the fuel user. While this increases the incentive to develop "drop-in" biofuel solutions that generate lower carbon emissions over the "life cycle", such mechanisms alone are not enough to accelerate the development of a sustainable aviation fuel industry.

This article focuses on the efforts of the Masdar Institute and its partners to develop sustainable aviation fuels through its Sustainable Bioenergy Research Project.

Background

The aviation industry, led by the aircraft manufacturers, airlines and technology companies have proactively sought to undertake initiatives and measures to enable the commercial aviation sector to reduce its carbon footprint.

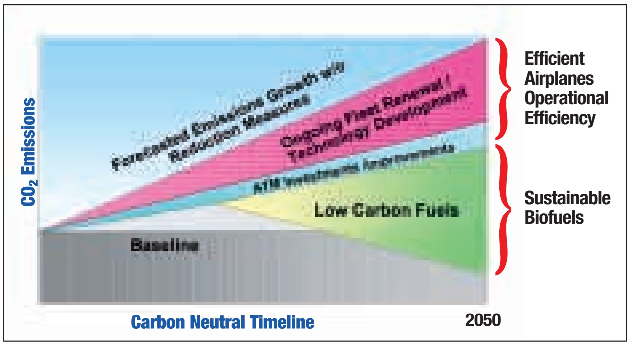


Figure 1: *Aviation industry timeline for carbon neutrality by the year 2050 (Source: Boeing/ICAO).*

Figure 1 depicts the various measures that the aviation sector will need to deploy to enable carbon neutral and/or negative carbon growth over the next few decades. The key point to note is that transitioning to low carbon sustainable aviation fuels is an imperative over and above more efficient aircraft and increased operational efficiencies.

Masdar Institute

In April 2006, the government of Abu Dhabi announced plans to establish an entirely new economic sector centered around the development of a zero carbon city, Masdar. The Masdar Institute of Science and Technology is the centerpiece of that initiative, dedicated to the development and promotion of alternative and sustainable energy. A key initiative of the Institute will be to develop sustainable aviation fuels and biomass-based electricity, working with various partners.

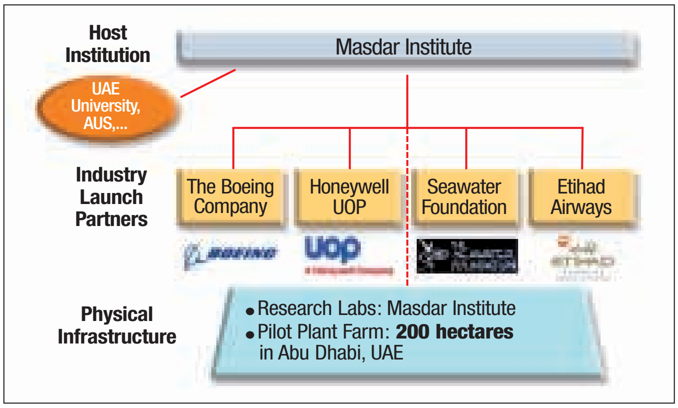


Figure 2: *Masdar Institute, industry partners and infrastructure for Sustainable Bioenergy Research Project.*

The principal activities of the Institute are to:

- Demonstrate and enhance the commercial viability of sustainable biofuel production in arid desert environments using an environmentally sustainable low CO_2 life cycle seawater farming system.
- Dialogue to refine model and attract secondary industry partners over time.
- Conduct research focused on feedstock development and commercial viability.

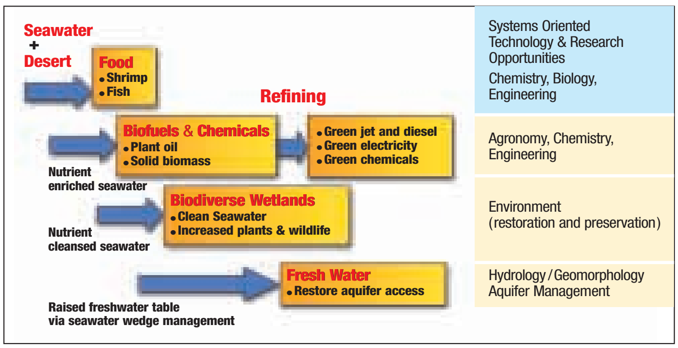


Figure 3: *Sustainable Bioenergy Research Project – conceptual activities model (Source: Boeing).*

Salicornia as Biofuel Source

Salicornia bigelovii, is an annual saltwater tolerant halophyte identified in the 1970's as a potential food and oil producing crop that can thrive on non-arable desert land with only seawater and minimal nutrient inputs. Salicornia's adaptation to salt water irrigation, coupled with crop yields that can equal or exceed freshwater crops such as soybean and rapeseed, make it an ideal crop to reclaim coastal deserts and other degraded coastal land.

Description	Jet A-1 Specs	Jatropha Derived HRJ	Camelina Derived HRJ	Jatropha/ Algae Derived HRJ
Flash Point, °C	Min 38	46.5	42.0	41.0
Freezing Point, °C	Max -47	-57.0	-63.5	-54.5
JFTOT@300°C				
Filter dP, mmHg	Max 25	0.0	0.0	0.2
Tube Deposit Less Than	< 3	1.0	< 1	1.0
Net heat of combustion, MJ/kg	Min 42.8	44.3	44.0	44.2
Viscosity, -20 deg C, mm^2/sec	Max 8.0	3.66	3.33	3.51
Sulfur, ppm	Max 15	< 0.0	< 0.0	< 0.0

Table 1: *Key Properties of Green Jet Fuel* (Source: Honeywell-UOP).

An Integrated Seawater Agriculture System (ISAS) uses aquaculture effluent to provide a majority of the nutrient content to the salicornia fields, with the leftover effluent being treated by a mangrove wetland. Salicornia has the potential to sequester carbon and have a positive land use impact primarily because the desert land it is grown on has minimal stored carbon and organic matter. Such a process shows very strong potential as a sustainable biomass resource without competing with traditional food crops, but instead providing additional food resources in the form of aquaculture products and protein meal to supplement animal fodder.

The Role of Honeywell's UOP

Honeywell's UOP, as a founding and funding member of the Sustainable Bioenergy Research Project, will provide process technology for the conversion of natural oils from the salicornia plants to Honeywell Green Diesel™ and Honeywell Green Jet Fuel,™ as well as process technology for the conversation of waste biomass from these plants to renewable power. UOP will also support the techno-economic analysis of the integrated seawater model and the evaluation of potential co-products along the chemicals value chain.

As an initial step in the project, an assessment, using Roundtable on Sustainable Biofuels Version One principles and criteria to determine sustainability is being sponsored by Boeing and Honeywell with the support of the Michigan Institute of Technology and Yale University.

Honeywell Green Jet Fuel has already been demonstrated using a variety of biological feedstocks including inedible oils such as camelina, jatropha and algae. Activity to date clearly shows that Green Jet Fuel properties meet, and in some cases exceed, specifications for commercial and military aviation fuels.

Green Jet Fuel has already been successfully demonstrated on several commercial airline and US Military test flights. Abu Dhabi's Etihad Airways has publicly announced its intention to be the leader of green aviation in the Middle East.

Etihad Airways and Boeing Roles

As major founding partners of the Masdar Institute, Etihad Airways and The Boeing Company will play the following leadership roles:

- UAE stakeholder engagement leadership.
- Integration of efforts towards global aviation frameworks via Sustainable Aviation Fuel Users Group **(www.safug.org)** and Roundtable on Sustainable Biofuels **(www.rsb.org)**.
- Commercial and strategic expertise on sustainability metrics and market requirements.
- Founding and funding members of the Project.

Summary

The Sustainable Bioenergy Research Project will lay the foundation for arid-land and saltwater based sustainable aviation fuels to reduce emissions cost effectively and mitigate exposure to future regulations and carbon costs. The project will also develop an important source of biomass-based electricity for arid land and saltwater accessible locations and, the participants believe, act as a model for other whole value-chain partnerships in the emerging sustainable aviation fuels industry.

Long Term Potential of Hydrogen As Aviation Fuel

By ***Keiichi Okai***

Keiichi Okai *is an associate senior researcher at Space Research and Development Directorate (ARD), Japan Aerospace Exploration Agency (JAXA).*

He received his B. S. (1996), M.S. (1998) and Dr. (Eng.) (2001) degrees in aeronautics and astronautics from the University of Tokyo. He joined the National Aerospace Laboratory (now JAXA) in April 2001. From October 2006 to September 2007, he was a visiting scientist at the German Aerospace Center (DLR), Cologne Germany.

His research topics are hydrogen and potential alternative aviation fuels, fundamental combustion and aero-engine system concepts. He is an American Institute for Aeronautics and Astronautics (AIAA) technical committee member and participate as expert in ICAO CAEP WG3 activities.

He was awarded the 18th Japan Society for Aeronautical and Space Sciences (JSASS) Award (best paper award) in 2009.

Introduction

To accomplish a significant reduction in CO_2 emissions, drastic efforts to introduce low carbon fuels are necessary. This article highlights hydrogen as a promising alternative fuel based on an assumption of the rapid realization of a hydrogen and fuel cell compatible society, and presents discussion of its technological potential and recommended research activities.

For ground and other transportation industries, R&D activities related to hydrogen and fuel cells are being pursued. Fuel cell technology has been attracting attention in the More Electric Aircraft (MEA) framework. This article examines the potential of hydrogen-fuelled subsonic commercial transport.

Hydrogen as Aviation Fuel

Research into hydrogen-fuelled aircraft has been conducted for many years[1].

In comparison with jet fuels, the merits and drawbacks as well as concerns of hydrogen as aviation fuel are summarized below:

Merits

- Higher energy content per unit weight (3 x)
- Zero (CO_2) emission
- Potential for lower NOx emission
- Easy handling as a combustible gas

Drawbacks

- Lower energy content per volume (1/4 x)
- Difficulty handling in storage and supply (cryogenic fuel)
- Material property (brittleness)

Additional Concerns

- Sustainable supply (with environmental compatibility)
- Infrastructure (airport)
- Impact of water vapor emissions (>2 x) on atmosphere
- Public acceptance of the fuel

As an aviation fuel, hydrogen clearly has strengths and weaknesses. The projected configuration of a hydrogen-fuelled subsonic aircraft is therefore invariably a compromise of the characteristics of hydrogen fuel. For aviation, hydrogen fuel storage during flight should be done in a liquid state due to the fuselage volume constraint.

Several recent feasibility studies show that the LH_2 subsonic transport aircraft is realistic, although some uncertainties such as fuel storage and fuel supply systems remain[1,2,3].

In actuality, hydrogen-fuelled flight operation of small aircraft (take off to landing) and of medium size aircraft during the cruising phase have been demonstrated already. Furthermore, small aircraft powered with fuel cells and hydrogen fuel, have already been demonstrated (2008, 2009)[4,5]. These facts attest that hydrogen-fuelled jet propelled aircraft and hydrogen-fuelled fuel cell powered aircraft are currently operable on a small scale. However, the realization of large-scale, long-haul hydrogen-powered aircraft remains a challenge.

From this standpoint, the three major technological challenges for LH_2-fuelled (subsonic) transport are the following:

1. Fuel supply management
2. Tank structure (fuel storage system)
3. Evaluation of effects of water vapor emission on the environment

Depending on the pace of R&D on hydrogen and fuel cells for ground-based transport and related industries, a potential scenario can be drawn up for aircraft as presented in Figure 1. Under this scenario, hydrogen-fuelled aircraft would be developed to meet the requirement to reduce CO_2 emissions and to move away from fossil fuel consumption when the hydrogen fuel management and its storage system technologies are mature enough for aviation purposes.

Current Challenges

Merits of Introduction of Hydrogen to Aviation -Historical and Social Perspective

One concern related to a full hydrogen society is the handling of fuel. In this sense, the aviation industry is ideal to demonstrate the functioning of a hydrogen-fuelled transport society because it has trained experts in restricted areas at airports to supply and manage the fuel.

The aerospace industry has some experience working with hydrogen[1], and valuable experience with hydrogen-related technologies can be gained from the careful development of rocket propulsion over time.

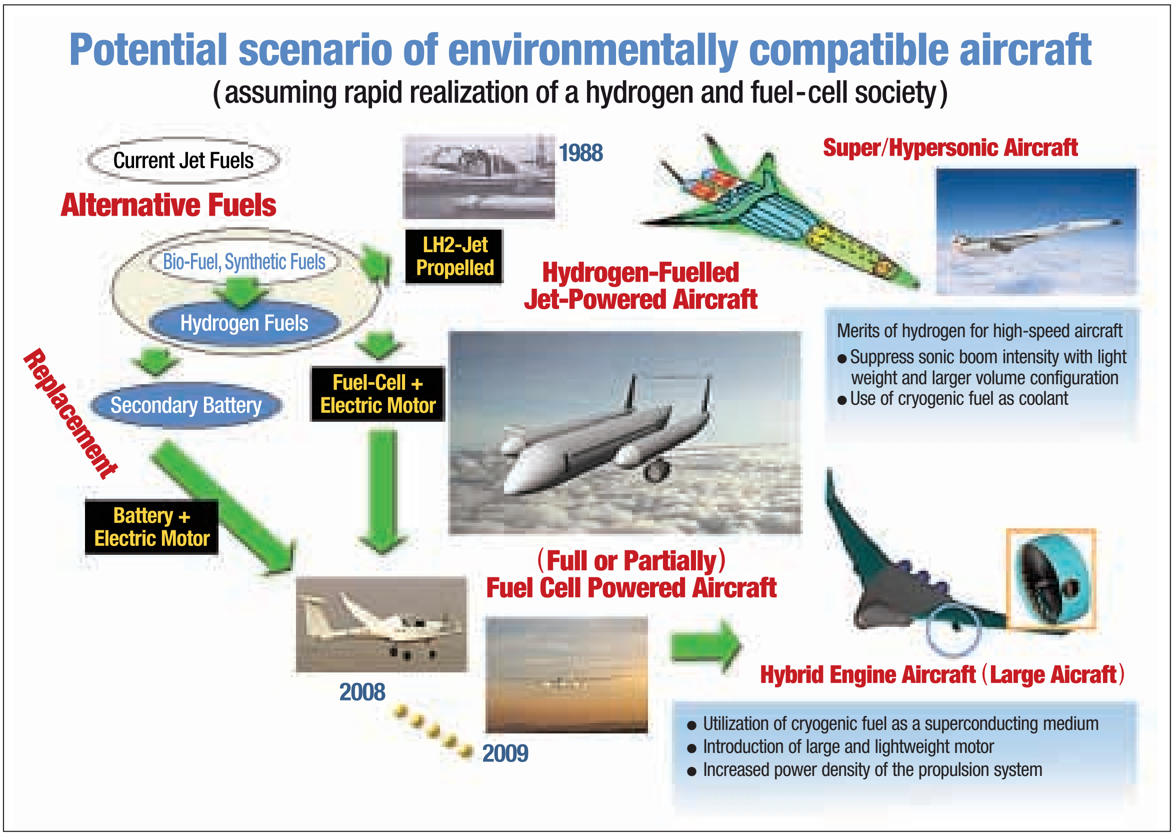


Figure 1: *Potential scenario for environmentally compatible aircraft. Photos from refs.*[1,4,5,6,7,8], courtesy Prof. K. Rinoie (University of Tokyo).

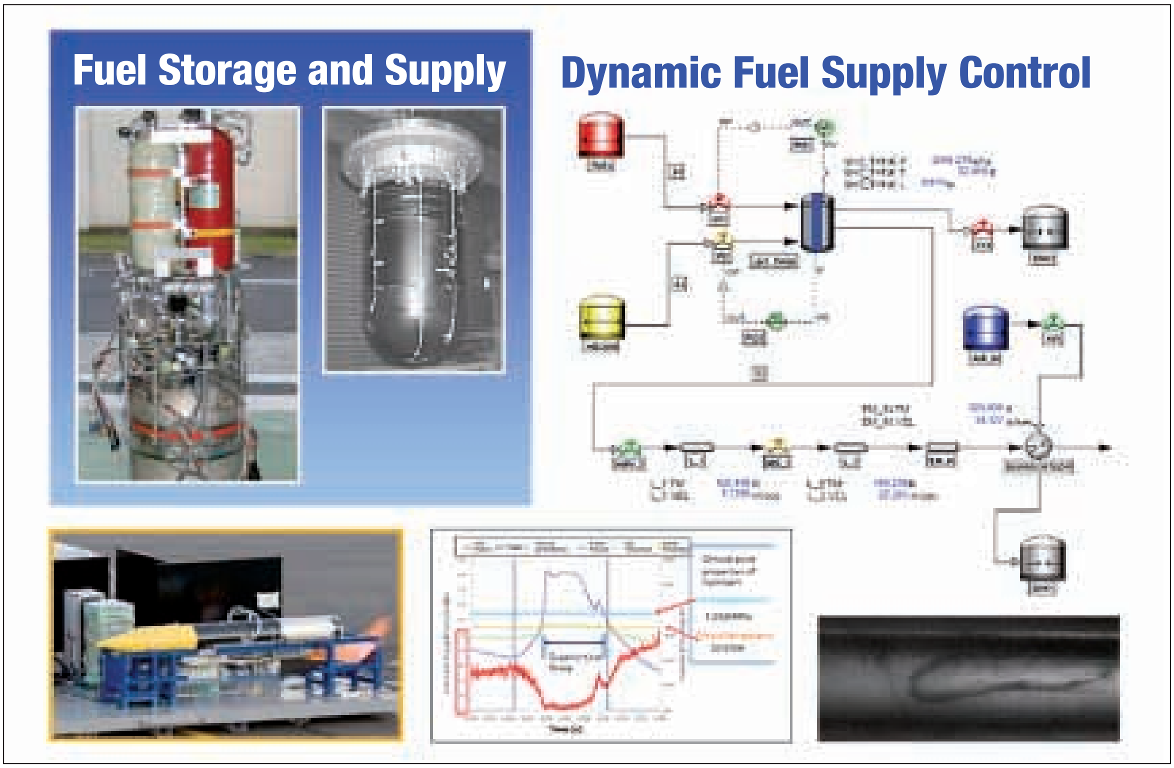


Figure 2: *Hydrogen system management approach* [7,9].

Hydrogen Management Systems Approach

Among the major challenges, fuel supply management and tank storage are two important aspects of handling hydrogen fuel. In order to realize hydrogen fueled commercial aircraft, accumulated experience related to hydrogen fuel management at the systems level is essential. An example of this is presented in Figure 2. A LH_2-fuelled hypersonic turbojet engine scale model was fabricated and an independent unit including the fuel tank, fuel supply, management system, and engine were tested without connection to a ground facility[7]. Through the firing tests, dynamic simulation and operation schemes on multiphase flow were developed[9]. The most recent systems approaches (development of an unmanned long-duration high-altitude aircraft) can be found by consulting reference[11].

Additional Goals to Pursue

Some merits exist to introducing liquid hydrogen as a fuel for hypersonic vehicles. The fuel's high energy density and cooling capabilities are its primary merits. This is a case in which an apparent disadvantage of the fuel can become a merit for a specified purpose.

Furthermore, the inevitable large fuel tank would become beneficial for achieving a low-sonic boom design for large supersonic transport aircraft (SST)[6], which might make supersonic over-land flight feasible.

Another important thing to note is that the introduction of hydrogen fuel would further promote the conversion of power sources from the conventional gas-turbines (or heat engines) to fuel cells. With hydrogen as the fuel, a fuel cell or fuel-cell and gas-turbine combination (hybrid) engine would provide higher efficiency and higher environmental compatibility than a gas-turbine engine. To be used as the sole propulsion power source, however, the power density of the fuel cell needs to be increased by two orders of magnitude.

For use in commercial aircraft, other electrical devices such as electric motors to drive fans should be kept light in weight while being of very large-scale. Present electric motor technology does not meet the requirement, so some innovation is necessary. Several conceptual proposals have been reported for hydrogen-fuelled subsonic transport with electric motors as a propulsion device[8,10].

The rapid increase of electric power demand for modern commercial aircraft make a power demand and supply mismatch quite undesirable. There are several R&D projects currently underway that are related to fuel cells for auxiliary power units (APUs), but most use reform-type fuel cells using current jet fuel. Recent activity includes study of the possible use of hydrogen as the fuel for a fuel cell onboard power supply [12,13].

An R&D project is being conducted on regenerative fuel cells with hydrogen as the fuel to be used to supply onboard electrical power[13]. The regenerative fuel cell is a mutual transformation device (i.e. chargeable fuel cell) between hydrogen energy and electricity. The high energy density capability of fuel cells and this mutual transformation capability present great benefits for the onboard power supply needs. These capabilities can meet the demands of optimized power management.

Combined with the most recent activities of a hydrogen-fuel management approach on the engine system and total airframe system, these near-term R&D efforts would bring us closer to realization of hydrogen-fuelled commercial (or medium/large scale) aircraft.

Conclusions

Based on the foregoing discussion, the following conclusions can be made about the use of hydrogen as alternative fuel for aviation:

- Hydrogen has long been considered a "new" promising alternative fuel.
- Recent activity towards the development of a hydrogen-based society is a good context for the accelerated development of hydrogen-fuelled aircraft.
  Hydrogen fuelled aircraft would be made possible technologically by the 2030's. However, since their availability on the market depends greatly on hydrogen fuel price, oil market status and the general public's knowledge on low environmental impact, as well as the arrival of the hydrogen-based social systems, the timing of their practical availability remains unpredictable.
- A systems verification approach would be promising because storage and handling of the fuel are important issues.
- Hydrogen-fuelled aviation would provide a good demonstration case for the introduction of a hydrogen society because handling of aviation fuel can be done by trained people and in restricted areas.
- Introduction of hydrogen as an aviation fuel would further encourage the development of fuel-cell powered aircraft.

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Sustainable Biofuel Raw Material Production for the Aviation Industry

By ***Yuri Herreras, Victor Stern, Anibal Capuano***

Yuri Herreras Yambanis *is an Industrial Engineer from Universidad Politécnica de Madrid, holds a Master in Nuclear Science and Technology from the same university and is currently developing his PhD in Sustainable raw materials for the bioenergy industry. Apart from his academic role, where he has published several articles, he has participated in international congresses and has developed several consulting projects in the renewable energies area.*

From September 2009 he has been managing BIOEca (Bioenergy and Agroenergetic Crops S.L.), a company that specializes in the implementation of integral agroenergetic projects aimed at supplying the biofuel industry with sustainable, competitive, non-food feedstock raw materials.

Victor Stern*, Austrian, born in 1968, is a Chemical with more than 20 years experience in Agriculture technology development and international business management. He has been Executive Vice-president of large agricultural commodity trading companies and entrepreneur. During the last decade he has been developing and implementing state-of-the-art technology applications towards crop yield improvement, soil and water management, with emphasis in biotechnology, nanotechnology, robotics, neural networks and agricultural monitoring networks. He developed overall technology integration in large agriculture deployments to increase agricultural production sustainability, productivity and economical viability. Currently is one of Managing Directors of BIOECA.*

Anibal Capuano*, Argentinean born in 1978, is an Agricultural Engineer specialized in technology applications for agricultural operations. He has been technical and project manager implementing large agricultural projects in Argentina, Brazil, Dominican Republic and Spain for companies in Food and Bio fuel sectors. During the last 4 years he has been full time researching about the issues around implementation of new energy feedstock crops. He is currently Agronomy Director at BIOECA in Spain.*

Raw Materials For the Aviation Industry

Bio-jet fuel Value Chain

Large scale bio-jet fuel production presents a variety of critical challenges that will need to be solved to ensure that the final product is viable, profitable, and sustainable. As shown in Figure 1, throughout the value chain there are important milestones that need to be reached to consolidate bio-jet fuel production in the domains of raw material supply, production technology, and biofuel certification.

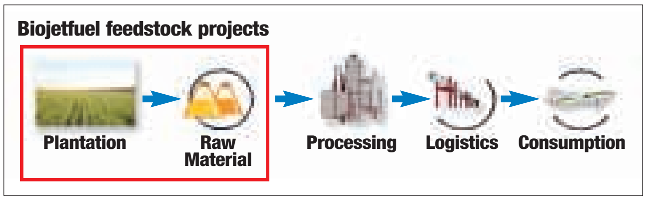

Figure 1: *Bio-jet fuel value chain.*

Aviation Raw Material Requirements

New biofuels for aviation will have to improve their GHG emissions balances throughout the entire life cycle and will have to guarantee that a number of criteria related to indirect effects and basic environmental issues are met. These include such factors as food security, land use, ecosystem interaction, and soil and water uses. Specifically, biofuels made from second generation feedstock crops should comply with the following main characteristics:

- Do not interfere with the food sector.
- Are produced on land not used for food production, or marginal land.
- Do not damage scarce natural ecosystems and are produced so that soil and water will not be contaminated or over-utilized.

- Do not require excessive agricultural inputs.
- Provide a net carbon footprint reduction compared to conventional jet fuel.
- Produce equal or higher energy content than jet fuel.
- Are not threatening to biodiversity.
- Provide socio-economic value to local communities.

Selected Second Generation Feedstocks

Alternative, sustainable aviation fuels can be produced using an ample variety of raw materials. Currently, four main crops are seen to be the primary candidate raw materials to be used, as shown in Table 1.

SHORT-TERM FEEDSTOCKS	LONG-TERM FEEDSTOCKS
CAMELINA	**ALGAE**
Rotational crop	High growth rate
Minimal inputs	Very high production yield
Grown in marginal land	Grown in barren land
Meal approved as animal feedstock	
JATROPHA	**HALOPHYTES**
Perennial high oil yield	Saline habitat
Non food feedstock	Grown in barren land
Grown in marginal land	
Social benefits	

Table 1: *Potential aviation feedstock classification and attributes – short-term and long-term.*

Camelina: Camelina is an annual flowering plant that grows well in low temperate climates. Some varieties of camelina contain 38-40% oil. Camelina can be produced on land not suited for other crops or where other large scale crops are not productive enough, requiring minimal water and fertilizer use. Similar to soy meal, camelina meal contains 35%-47% protein, 10%-11% fiber, and is rich in Omega-3 fatty acids and has been approved as raw material for animal feed. The fact that it is a high-quality animal feed significantly enhances the economics of the crop.

Jatropha: Jatropha is a perennial drought resistant and non-food oilseed crop that grows in tropical and subtropical climates. The plant, adapted to marginal land, does not grow in cold regions. Although very promising, jatropha projects are characterized by the manual harvest requirement, variable yields, and the meal has no clear economic value like camelina sativa.

Algae: Algae are cellular organisms with the ability to perform photosynthesis, thriving off carbon dioxide. They are characterized by their rapid growth rate and high oil production yields, and they can be grown on barren land. Land requirements to quantities of oil produced ratios are significantly lower than for short-term feedstocks. Although algae is potentially the most promising feedstock for the production of large quantities of sustainable aviation biofuel harvesting, processing and infrastructure issues have to be solved before reaching commercial viability for algae in the short term.

Halophytes: These are salt marsh grasses and other saline habitat species that can grow either in salt water or in areas affected by sea spray. To date, there is limited experience with halophytes plantations, although this may be a promising option for arid regions.[1,2]

Large Scale Raw Material Production - Short Term

Sustainability Issues

There are several issues to be tackled in order to ensure the sustainability of the bio-jet fuel project, including: economic viability, environmental respect, and social commitment, as summarized in Figure 2.

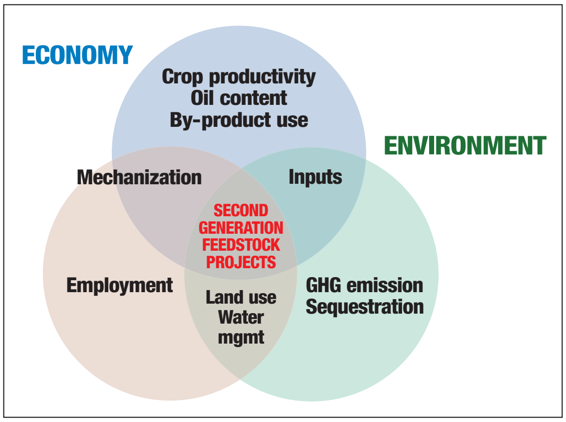

Figure 2: *Bio-jet fuel feedstock projects - main sustainability issues.*

Some of the issues being considered have more repercussions on the economic viability and sustainability of the project. These are: utilization and added value of the by-products (especially meal) from a purely economic point of view; integral crop mechanization (social perspective); and quantity and quality of the agricultural inputs being used (environmental perspective).

Response and Solutions

Guaranteeing the sustainability of large scale bio-jet fuel feedstock projects depends mainly on four primary issues, each of which must be considered and resolved:

A. Feedstock crop;
B. Production areas;
C. Agricultural inputs;
D. Plantation management.

A. Feedstock Crop

The raw materials produced from agroenergetic crops for aviation biofuels must be non food-feedstock items in order to guarantee that they do not compete with the food production industry.

The main technical criteria required for developing viable second generation crops in the short term for the production of bio-jet fuel feedstock are shown in Table 2.

TECHNICAL CRITERIA	REQUIREMENT
HARDINESS	Low agricultural inputs
TERM	Annual crop
CYCLE	Short
RISK	Extensive crop know-how
TECHNOLOGY	Mechanized crop
INVESTMENT	Low implantation investment
LAND	Rotational crops
EMISSIONS	Significant GHG emission reduction

Table 2: *Technical criteria for developing viable crops in the short-term.*

B. Production Areas

Using robust, annual, short-cycle crops, there are mainly three different types of production areas that can be used for bio-jet fuel feedstock production:

Marginal land: Robust crops can be grown, with minimal water requirements, and adapted to harsh climate conditions, on land where food crops are not viable.

Rotational/Fallow land: Can be planted with annual second generation crops, increasing the productivity of following crops and preventing soil erosion.

Double crop land: Areas where robust, annual and short-cycle crops can be grown within the same growing season using a double cropping scheme, thus preventing soil erosion.

C. Agricultural Inputs

A key issue related to the implementation of a sustainable feedstock project is minimizing the agricultural inputs required – mainly chemical fertilizers and pesticides - which directly affect the crop yield and quality. The main factors that affect crop yield and product quality are shown in Figure 3.

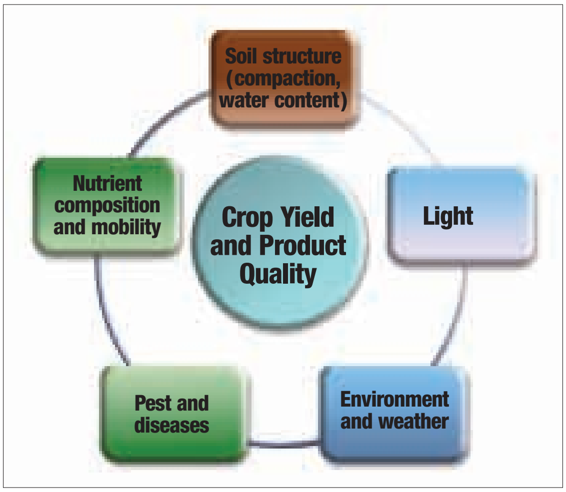

Figure 3: *Biofuel feedstock projects - main factors affecting crop yield and product quality.*

A key sustainable issue is to use technologies to close the biomass loop and nutrients cycles, allowing the improvement of soil - instead of its degradation - as well as increasing efficiency of plant metabolism. All of these technologies are proven and available while the key is to put them together as a single technology package for agricultural implementation.

The cost implementation structure of a biofuel crop is mainly driven by the amount of fertilizer used for its growth. In this sense, reducing the amount and cost of the fertilization program directly implies a lower seed production cost, and thus a cheaper vegetable oil.

One of the main factors related to GHG emissions during the crop's life cycle is nitrogen oxide (N_2O) emissions. Simulations conducted using rapeseed in Europe[3] show that CO_2

and N_2O emissions level reductions - including direct and indirect N_2O emissions due to leaching and volatilization - are of the same magnitude. Thus, any emission reductions achieved through chemical fertilization will have a significant positive impact On the global GHG emissions reduction balance of the crop.

Another key factor is the phosphorous cycle and the future crisis of phosphorous depletion in agriculture[4]. This potential problem for such large projects can be solved by biotechnology, since phosphorous can be recovered from organic waste without depleting scarce mineral reserves further. This is not a problem that cannot be solved, but it does require awareness and technology integration.

D. **Plantation Management**

Another requirement, that complements the application of bio-fertilization protocols and nutrient cycle and soil management, involves the implementation of plantation management systems and agricultural monitoring networks to ensure efficient use of agricultural inputs. Managing the plantations in a highly efficient manner implies integrating different production technologies and advanced management systems that minimize agricultural inputs, secure production goals, and maximize crop productivity.

Conclusions

In light of the foregoing, the following conclusions are made with respect to the implementation of bio-feedstock projects as an alternative source for aviation fuel:

- The aviation sector needs to use newly developed low carbon biofuels to achieve real GHG emission reductions. To achieve the aviation industry goals for 2020, it is necessary to develop a new industry for the production of sustainable bio-jet fuel in the short term.
- Success of this new industry will depend on the achievement and development of certain milestones along its value chain, chiefly among them: processing or conversion technology, new bio-jet fuel certification, and procurement of stable supply of feedstock for bio-jet fuel production.
- Currently, there are proven technologies for bio-jet fuel production. The challenge for the new bio-jet fuel industry is to find ways to develop a sustainable supply of bio-jet fuel feedstocks in regular quantities, at stable prices.
- To achieve such an objective, it is necessary to implement large scale raw material production projects in the short term. Analysis of the main critical factors that would guarantee the viability and sustainability of such projects indicates that, currently, both the appropriate crops and the agricultural technology exist to begin large-scale production of renewable and sustainable raw materials as aviation fuel feedstocks.
- Raw material biofuel production projects for the aviation industry should be initiated with second generation crops – such as camelina – where sufficient agricultural know-how exists and there is proven profitability.
- An important success factor for this initiative is that it allows for the recovery of fallow land, recycling it into prime agricultural land for later use by food-crops production since when third generation feedstocks like algae or halophytes become commercially viable the land area to produce equivalent amounts of fuels will be substantially reduced.

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A Global Fuel Readiness Level Protocol

By **Rich Altman, Nate Brown, Kristin Lewis** and **Lourdes Maurice**

Rich Altman *serves as Executive Director of the Commercial Aviation Alternative Fuels Initiative (CAAFI). Rich co-founded CAAFI in 2006 with U.S. Airline, Manufacturer, Airport and FAA Sponsors. The CAAFI coalition now includes over 350 sponsors and stakeholders worldwide. CAAFI sets an aviation focus for 50 energy suppliers, serving as a catalyst to accelerate technology development and deployment across the aviation supply chain. In addition to his CAAFI role Rich has authored the Transportation Research Board, Aviation Environment committee's critical issues papers on Alternative Fuel and Technology Deployment. Rich presently serves as a consultant to the EU alternative fuel initiative program SWAFEA.*

Nate Brown *is Alternative Fuel Project Manager in the FAA's Office of Environment and Energy, the office with principal responsibility for U.S. aviation environmental policy, research and development. At FAA, Nate focuses on energy, climate change and aviation alternative fuels issues. He is Deputy Executive Director of the Commercial Aviation Alternative Fuels Initiative (CAAFI), a public-private partnership for advancing alternative jet fuels for environmental sustainability and energy security. Nate has also worked for the U.S. Department of Transportation's Research and Innovative Technologies Administration (RITA) and on international climate change initiatives at the U.S. Department of State's Office of Global change.*

Kristin C. Lewis *is an Environmental Biologist with the Volpe National Transportation Systems Center, part of the Research and Innovative Technology Administration of the Department of Transportation. Dr. Lewis serves as the Deputy Executive Director (Technical and Research) for the Commercial Aviation Alternative Fuels Initiative (CAAFI). In addition, Dr. Lewis participates in research on aviation impacts in the National Parks and the development of noise and emissions models for aviation.*

Dr. Lewis holds a B.S. in Chemistry and Studies in the Environment from Yale University and a Ph.D. in Organismic and Evolutionary Biology from Harvard University.

Lourdes Q. Maurice *is the Chief Scientific and Technical Advisor for Environment in the Federal Aviation Administration's Office of Environment and Energy. She leads FAA's environmental research and advanced technology development programs. She has recently served as Acting Deputy Assistant Administrator for Policy, Planning and Environment and Acting Director of the Office of Environment and Energy. She received her B.Sc. in Chemical Engineering and M.Sc. in Aerospace Engineering from the University of Dayton and her Ph.D. in Mechanical Engineering from the University of London's Imperial College at London. Lourdes has served as a Lead Author for the Intergovernmental Panel on Climate Change.*

The quest for sustainable alternative fuels for aviation involves the consideration of multiple production processes and many different feedstocks using those processes. Synthetic Paraffinic Kerosenes (SPK) from a wide range of feedstocks have now been certified. Fuels from processes such as pyrolysis, fermentation and catalysis are in their infancy for aviation use. This article summarizes the latest developments in this area in terms of risk management considerations and fuel readiness levels for use in aviation.

Background

Aviation and aerospace projects are characterized by the use of risk management tools to govern the creation of high technology products that embody uncompromising levels of safety and efficiency and also create an acceptable environmental footprint. Because of the high cost of managing risk in the complex aviation and aerospace technical and production sector, and in accordance with Systems Engineering principles, a gated approach to risk management through the use of Technology Readiness Level (TRL) criteria has evolved.

Risk Management In Aviation Using Technology Readiness Level

The technology readiness scale initially used by the United States Air Force and National Aeronautics and Space Administration in the U.S., and subsequently by the commercial sector, has been in use for decades for the development of new aircraft, engines and space systems. This technology readiness scale is growing in use in Europe by aircraft and engine manufacturers for risk management purposes but is not incorporated into any European standards.

Together, these risk management tools are a proven means of:

- Characterizing conceptual research from the creation phase throughout the development of sub-elements and components to allow researchers to identify what phase a project is in, as well as identifying potential sources of funds for that research.
- Ensuring that manufacturing is scalable to levels needed for production levels that are both economically viable and environmentally acceptable at pilot plant levels, once proven at the subscale and component level.
- Supporting the certification for air worthiness.
- Supporting deployment across the entire industry in a manner that provides a sustainable business model.

Transition From Technology Readiness Levels To Fuel Readiness Levels

In the case of alternative jet fuels, in contrast to equipment production, the risk resides in separate arenas of both the chemistry of the fuel itself and its compatibility with the aircraft product and fuelling infrastructure. For this reason, use of the existing TRL process was not deemed adequate or appropriate to address this new challenge facing the industry. This led to discussions by various groups and agencies about the feasibility of developing a new readiness level standard that would apply separately to aviation fuel.

In January of 2009 at a meeting of the Commercial Aviation Alternative Fuel Initiative (CAAFI), a research and development initiative involving participants from Europe and the U.S., it was agreed that the U.S. Air Force efforts and an Airbus proposal could be brought together as a single Fuel Readiness Level (FRL). **Figure 1** presents the proposed FRL scale that was put forward for adoption:

FRL	Description	Toll Gate	Fuel Quantity+
1	Basic Principles Observed and Reported	Feedstock /process *principles* identified.	
2	Technology Concept Formulated	Feedstock / *complete* process identified.	
3	Proof of Concept	Lab scale fuel sample produced from realistic production feedstock. Energy balance analysis executed for initial environmental assessment. Basic fuel properties validated.	0.13 US gallons (500 ml)
4.1 4.2	Preliminary Technical Evaluation	System performance and integration studies entry criteria/specification properties evaluated (MSDS/D1655/MIL 83133)	10 US gallons (37.8 litres)
5	Process Validation	Sequential scaling from laboratory to pilot plant	80 US gallons (302.8 litres) to 225,000 US gallons (851,718 litres)
6	Full-Scale Technical Evaluation	Fitness, fuel properties, rig testing, and engine testing	80 US gallons (302.8 litres) to 225,000 US gallons (851,718 litres)
7	Fuel Approval	Fuel class/type listed in international fuel standards	
8	Commercialization Validated	Business model validated for production airline/military purchase agreements – Facility specific GHG assessment conducted to internationally accepted independent methodology	
9	Production Capability Established	Full scale plant operational	

Figure 1: *Proposed Fuel Readiness Level scale.*

Potential Uses of Fuel Readiness Level Scale

In addition to its use as a risk management tool, FRL has other potential uses such as:

a) A communications tool to help policy makers establish if and when the use of fuels currently in the R&D phase can be envisioned as true production options.

b) A mechanism by which government agencies, laboratories, or universities can determine if and how they can participate, given their organizations' role in R&D.

c) A tool for private and public investment sources to identify whether and where they should invest in deployment among all available options.

Conclusions

The above Fuel Readiness Level scale was developed by CAAFI sponsors and modified in consultation with a key energy supplier, an Original Equipment Manufacturer (OEM) stakeholder, and a fuel process technology developer. It provides a gated process to govern communication of technology maturity leading to qualification, production and, deployment readiness. The FRL was recognized by the ICAO Conference on Aviation Alternative Fuels in November 2009 as a best practice. The FRL continues to be updated and improved by CAAFI with the development and inclusion of detailed Pass/Fail criteria for each of the FRL level "Toll Gates" in order to improve its usability.

The FRL is appropriate for:

- Managing and communicating research status and development needs for R&D Investors.
- Managing and communicating the readiness level to airworthiness authorities and determining the appropriate timing for complementary and required environmental assessments.
- Managing and communicating the practicality of deploying fuels for use in production aircraft, engines and aviation infrastructure.
- Used as a process for aviation fuel development and deployment risk mitigation.

Estimating Life Cycle Greenhouse Gas Emissions From Alternative Jet Fuels

By **Nate Brown, Warren Gillette, Jim Hileman** and **Lourdes Maurice**

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Alternative jet fuels produced from renewable sources have the potential to reduce aviation's impact on global climate change. However, a full accounting of the life cycle greenhouse gas (GHG) emissions, which extends from the well, field, or mine to the wake behind the aircraft, is necessary to determine whether a biofuel, or any other alternative fuel, will cause an overall environmental benefit or detriment. This article presents background information on the use of life cycle analysis for estimating GHG emissions.

Synthetic Paraffinic Kerosene (SPK) are a class of drop-in fuels, which can be created via Fischer-Tropsch (F-T) synthesis or the hydroprocessing of renewable oils to a Hydroprocessed Renewable Jet (HRJ), and have similar molecular composition to conventional jet fuel. The combustion of SPK fuels can results in somewhat lower CO_2 emissions (per unit mass of fuel) as compared to conventional jet fuel due primarily to higher hydrogen to carbon ratios.

Depending on the feedstock that is used in the fuel production and the details of extraction and production, the life cycle GHG emissions from an SPK fuel can vary by two orders of magnitude. If waste products are exclusively used to create the fuel and to power the fuel production process, then the emissions could be as little as a tenth of those from conventional jet fuel; however, if the extraction and production of the fuel results in the conversion of lands with high carbon stocks, then the emissions could be eight times higher than conventional jet fuel.

This article summarizes the key issues regarding the use of life cycle analysis for estimating GHG emissions from alternative jet fuels while highlighting ongoing research being conducted in the United States and Europe to estimate the life cycle GHG emissions from alternative jet fuels.

Estimating GHG Emissions From Alternative Jet Fuels – The Process

A Life Cycle Assessment (LCA) estimate is a compilation and evaluation of inputs, outputs and potential environmental impacts of a production system throughout its life cycle. A LCA of alternative jet fuels involves an evaluation of the environmental impacts of resource extraction, fuel production and fuel combustion on air and water quality as well as global climate change; the focus here is on the creation of an inventory of "well-to-wake" life cycle GHG emissions.

Life cycle GHG emissions include those created from the extraction of raw materials through the combustion of the processed fuel by the aircraft. This can be described with a set of five life cycle stages:

1) *Raw Material Acquisition,*
2) *Raw Material Transport,*
3) *Fuel Production from Raw Materials,*
4) *Fuel Transport and Aircraft Fueling,* and
5) *Aircraft Operation*.

The emissions inventory is generally given in terms of the emissions, or the impact of the emissions, relative to some unit of productivity delivered by the fuel. To allow for an equitable comparison of SPK and conventional jet fuels, which have different energy content on both a unit mass and a unit volume basis, the emissions are given on the basis of a unit of energy delivered to the aircraft tank. To allow for an equitable comparison of carbon dioxide with other GHG emissions such as N_2O and CH_4 that may result from fuel production, Global Warming Potentials (GWP) are generally used to sum emissions into units of carbon dioxide equivalent, CO_2e. As such, life cycle GHG emissions are often given in terms of grams carbon dioxide equivalent per megajoule (gCO_2e/MJ).

Metrics using GWP have major limitations in terms of examining the impact of non-CO_2 combustion emissions from aviation. As such, while non-CO_2 combustion emissions should be estimated as part of a life cycle GHG emissions inventory, an appropriate means of combining these emissions with those from life cycle stages 1 through 4 (from well-to-tank) and the CO_2 emissions from life cycle stage 5 (tank-to-wake) has not yet been defined.

Three areas meriting special consideration in regards to estimating a life cycle GHG emissions inventory, (1) *System Boundary Definition,* (2) *Emissions Allocation among Co-Products,* and (3) *Data Quality and Uncertainty,* are discussed further in the following sections.

System Boundary Definition

Based on the International Organization for Standardization (ISO) guidelines, a life cycle GHG emissions inventory should include a full accounting of the GHG emissions that result from the creation of all materials, energy, and activities that are related to the fuel production; not only those within the processes of the primary production chains, but also those supporting necessary input to the primary production chain. The system boundary therefore needs to be defined such that it captures all of the processes used in jet fuel creation.

If sufficient quantities of agricultural products were redirected from the production of food to the production of biofuels, then indirect land use changes would need to be accounted for in the LCA. For example, complete domestic use of an existing agricultural product as a fuel feedstock would reduce exports of that crop, resulting in compensatory land use change elsewhere. The resulting land use change could lead to considerable GHG emissions, especially if the converted land is from high carbon sequestration systems such as rainforest or peat lands. However, efforts to develop sustainable fuels for aviation are seeking to avoid these sorts of impacts. For example, use of fallow domestic agricultural land or excess production of existing crops would incur no such GHG emissions.

The accurate estimation of GHG emissions from indirect land use change requires the use of sophisticated economic models that capture the agriculture and energy sectors of the global economy. An estimation of the life cycle GHG from soy-based HRJ, which extended the results from such an economic analysis, indicates that the indirect land use change emissions from a large-scale diversion of soy oil to biofuel production could lead to a doubling of GHG emissions relative to conventional jet fuel. This is comparable to the emissions from coal-to-liquids from F-T synthesis if no carbon capture and sequestration were being used.

Emissions Allocation Among Co-Products

Some processes within a fuel production pathway result in multiple outputs. For example, a refinery outputs gasoline and diesel fuel in addition to jet fuel. Another example, exhibited by many biofuels, is the creation of meal in addition to the renewable oil that is then processed to HRJ. The emissions that are created upstream of such processes must be divided, or allocated, among the products.

ISO recommends that emissions be allocated to co-products using the following methods in the following order:

1) *process disaggregation* in which the unit process is divided into two or more sub-processes,

2) *system expansion* wherein the system boundaries are expanded to include the additional functions related to the co-products, and

3) *allocation* by physical properties (e.g., mass, volume, energy content) or market value.

In the case of biofuel production, the life cycle estimate may need to include emissions from biomass creation based on the relative mass, energy content, or market value of the oil and the meal that remains after oil extraction. This is because the system cannot be disaggregated further and system expansion may require a model for the entire agriculture industry. The selection of allocation strategy can significantly affect the GHG emissions from a fuel, including the potential for unrealistic emissions, which indicates the importance of this parameter.

Data Quality and Uncertainty

Data quality and uncertainty depend on time-frame and scale. For example, it is easier to obtain high quality data for an existing product, (e.g., conventional jet fuel from crude oil), than from an emerging or non-existent industry, (e.g., algal HRJ). High quality data are required to develop life cycle GHG inventories that can be used to inform decisions regarding alternative aviation fuels.

Scenario dependent analyses have also been used to bracket emissions from fuel pathways, providing a means of evaluating uncertainty. The underlying data and assumptions were varied to provide three scenarios that provide a mean and an anticipated range of low to high values.

Ongoing Life Cycle Analysis Efforts

Multiple research efforts are ongoing in the U.S. and Europe to estimate the life cycle GHG emissions from conventional and alternative jet fuels. These are in addition to the considerable, similar efforts to estimate the life cycle GHG emissions from ground transportation fuels.

In the U.S., the National Energy Technology Laboratory examined the GHG emissions from U.S. transportation fuels, including jet fuel, derived from conventional petroleum while Partnership for Air Transportation Noise and Emissions Research (PARTNER) researchers have examined a wide range of alternative jet fuel pathways and have recently released a report (available at http://web.mit.edu/aeroastro/partner/reports/proj28/partner-proj28-2010-001.pdf). Boeing is sponsoring research on jatropha based jet fuels at Yale University and algae based jet fuels at University of Washington and Washington State University.

In Europe, Cambridge University in the U.K. examined algal jet fuels as part of the OMEGA consortium while ONERA in France are currently leading an evaluation of a wide range of fuel options as part of SWAFEA (Sustainable Way for Alternative Fuel and Energy in Aviation).

Conclusions

Based on the work done to date estimating life cycle greenhouse gas emissions from alternative jet fuels, the points in the following paragraphs can be concluded.

The ability to compare the life cycle GHG emissions from alternative aviation fuels is an essential element of a global assessment of GHG emissions from international aviation and any other sector that is considering the use of a new fuel. It is the appropriate means for comparing the relative GHG emissions from alternative jet fuels with conventional jet fuel.

The assessment of the life cycle requires a careful definition of the system boundary among other key factors. This definition will allow the analysis to determine if GHG emissions associated with both direct and indirect land-use change will result from the production of the alternative jet fuel.

There are multiple research efforts are underway in the U.S., Europe and other States to estimate the life cycle GHG emissions from conventional and alternative jet fuels, as well as from ground transportation fuels.

Life cycle analysis is the appropriate means for comparing the relative GHG emissions from alternative jet fuels with conventional jet fuel. This recommendation was adopted by the ICAO CAAF in Rio de Janeiro, Brazil in late 2009.

Proposal To Adopt
A Global Fuel Qualification and Certification Protocol

By ***Mark Rumizen, Nate Brown, Rich Altman*** *and* ***Lourdes Maurice***

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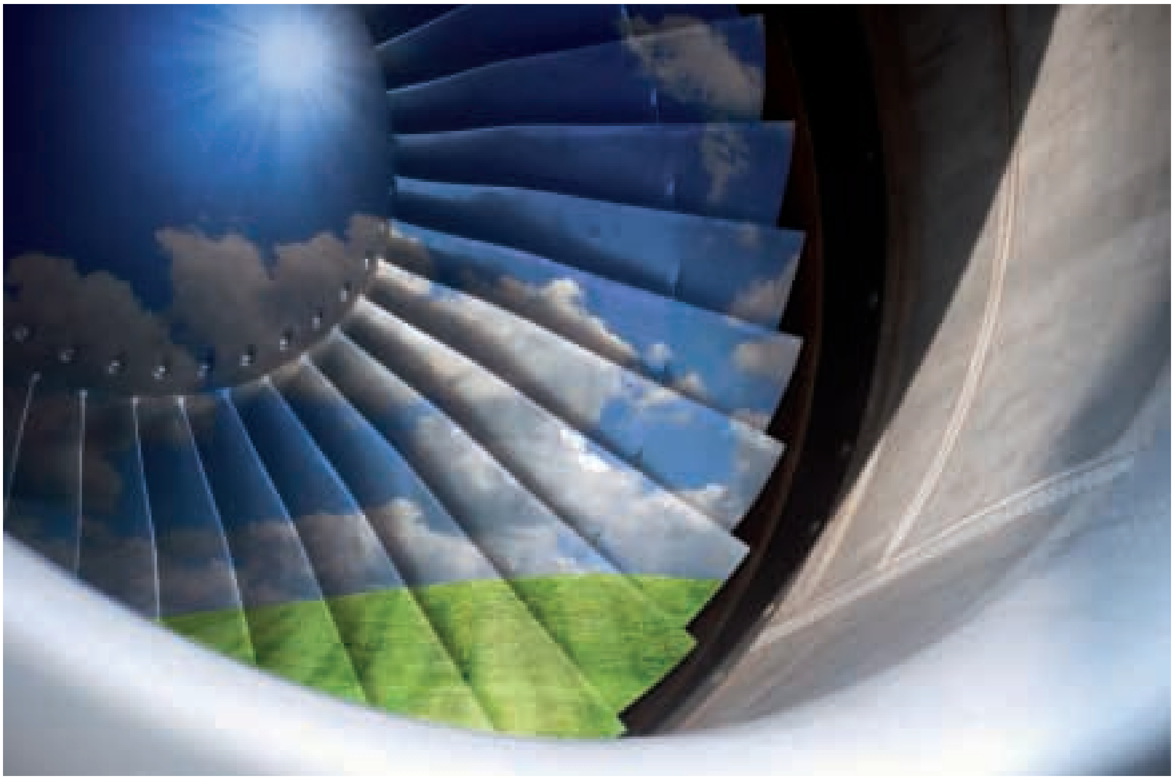
Industry fuel specifications such as D1655 and DEF STAN 91-91 are used by the aviation fuel industry stakeholders to standardize and control the properties and quality of aviation fuel as it travels through the distribution system. Civil airworthiness authorities (CAAs) also rely on fuel specifications to ensure the safety of aircraft operations. The aviation fuel community has developed qualification and certification concepts and procedures to approve an alternative fuel for operation on the existing fleet. This article summarizes the process being developed by the aviation industry in the United States to qualify and certify new classes of aviation fuels.

Introduction

Early turbine engines were designed to operate on kerosene fuels due to the wide availability, low cost, and desirable performance properties of those fuels. Over the decades since the introduction of the first turbine engines, demands for improved performance and safety resulted in aviation fuel specifications defining tightly controlled versions of kerosene. These specifications established tighter controls on the fuel properties necessary to accommodate technical advances in turbine engine design. Two aviation turbine fuel specifications used in many areas of the world are ASTM International Standard D1655 and Defence Standard 91-91 issued by the United Kingdom's Ministry of Defence.

Aviation fuel is transported in bulk and frequently changes ownership as it moves from its origination at the refinery to its final destination at the airplane. Industry fuel specifications such as D1655 and DEF STAN 91-91 are used by the aviation fuel industry stakeholders to standardize and control the properties and quality of aviation fuel as it travels



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through the distribution system. The producers must formulate the fuel to meet the specification properties, fuel handlers in the distribution system such as pipeline companies must certify that the fuel meets the specification when delivering fuel, aircraft engine designers must design their engines to operate over the range of fuel properties in the specification, and aircraft operators such as airlines must ensure that the fuel loaded on to their airplanes meets the criteria of the specification.

Civil airworthiness authorities (CAAs) also rely on fuel specifications to ensure the safety of aircraft operations. Airworthiness regulations issued for aircraft and engines require that operating limitations be established for each certificated design. These operating limitations typically specify the industry, military or company aviation fuel specifications that the aviation fuel must meet for use on the specified aircraft and engine.

The existing fleet of turbine-engine-powered aircraft has been designed to operate on conventional aviation turbine fuel (jet fuel) that meets the major industry specifications described above. However, due to recent environmental, supply stability, and cost issues related to conventional petroleum-derived jet fuel, approvals have been requested to use new, alternative fuels derived from nonconventional feedstocks on the existing fleet of turbine engine powered aircraft. In response to these requests, the aviation fuel community has developed qualification and certification concepts and procedures to approve an alternative fuel for operation on the existing fleet.

This article describes the process being developed by the aviation fuels industry and the Federal Aviation Administration (FAA) to qualify and certify new classes of aviation fuels. It is believed that the concepts presented here should be applicable to other CAAs and fuel specification-writing organizations.

Aviation Fuel Qualification and Certification

As mentioned above, fuel specifications are an integral element of the aviation fuel infrastructure. Consequently, a new specification needs to be developed, or an existing specification needs to be revised, to enable the use of any new alternative aviation fuel in this infrastructure. Qualification processes are used by specification-writing organizations, such as ASTM International, to develop new fuel specifications, or to revise existing specifications, in order to add a new alternative fuel. These qualification processes include a technical evaluation of the fuel, followed by development of the specification requirements and criteria. A description of the ASTM aviation fuel qualification process is described later in this article.

If the alternative fuel is found to have essentially the same performance properties as conventional jet fuel, then it is considered a drop-in fuel. Conversely, if substantive differences exist between the performance properties of the new alternative aviation fuel and conventional jet fuel, then the fuel is considered a non-drop-in fuel.

Drop-in fuels may be incorporated into the existing jet fuel specifications, and will therefore meet the established operating limitations for the existing fleet of turbine engine powered aircraft. For these, amended airworthiness certification of the existing aircraft and engines is not required.

Non-drop-in fuels will require a new specification, and therefore will not meet the established operating limitations for the existing fleet of turbine engine powered aircraft. In these cases, amended airworthiness certification of the existing aircraft and engines is required to incorporate new operating limitations.

Industry Aviation Fuel Qualification Process

The process that ASTM International uses to approve a new fuel consists of a test phase to evaluate the fuel or additive, followed by an approval phase that includes ASTM International balloting on the new specification, or revision to an existing specification, for the fuel.

Test Phase

In general, the fuel must undergo sufficient testing and development to show that, under the conditions in which it will be used in an aircraft, it is compatible with typical engine and aircraft materials. The fuel must comply with the specification properties that are necessary to meet the performance and durability requirements of the airplane, rotorcraft, or engine. The data should address compatibility with other fuels, lubricants, and additives that are approved for engines and aircraft. Fuels must be shown to be capable of being mixed with other approved fuels or additives at all anticipated temperatures. The fuel must be shown to maintain its properties at limiting operating temperatures to prevent blocking of fuel lines and filters.

The test phase includes investigations of the effect of the candidate fuel on fuel specification properties, fit-for-purpose properties, materials compatibility, component rig tests, or engine tests. The extent of the test phase depends on the chemistry of the new fuel or additive, similarity to approved fuels and additives, and engine manufacturer experience. Departure from engine manufacturer experience would require more rigorous testing. The results of the test phase will be documented in a research report prepared by the fuel formulator with oversight by the aircraft equipment manufacturers. The research report provides the data and information necessary for review of the ASTM International members who participate in the balloting process.

Approval Phase

Upon completion of the test phase, the research report is reviewed by engine manufacturer representatives on the ASTM International Aviation Fuels subcommittee. If approved by the engine manufacturers, a draft specification with appropriate language and criteria is developed. This draft specification and the research report are submitted to the entire subcommittee for review and balloting. The specification and research report may go through several revisions before a final version of the specification is approved by the membership. The subcommittee ballot is followed by a committee level ballot before final approval by ASTM International and publication of the specification.

ASTM International is considered a voluntary consensus standards organization. These organizations are characterized by a balanced membership of stakeholders, each with an equal voice that participates in a well-defined process to create industry standards or specifications. Because the specifications produced by these organizations go through a rigorous technical vetting process, they are considered to provide very robust control of quality and performance. Consequently, CAAs such as the FAA utilize these standards and specifications in their regulatory oversight of aviation.

FAA Airworthiness Certification for New Alternative Fuels

The airworthiness certification process of the U.S. Federal Aviation Administration (FAA) relies on the development and oversight of specifications and standards by voluntary consensus standards bodies such as ASTM International.

These specifications are used to define the operating limitations that must be established by the aircraft and engine manufacturers to gain type certification of their product.

For new aircraft and engine designs, no additional fuel-related testing will typically be required beyond that required for the product certification program. This is because the new aircraft or engine is undergoing a complete certification compliance program using either existing jet fuel or the new alternative jet fuel. The certification of a new airplane or engine requires a comprehensive compliance plan that should encompass all of the airworthiness standards applicable to fuels and should cover the complete range of operating conditions to which the fuel is exposed. Additional materials compatibility testing is required only if the new airplane or engine design contains new or unusual materials that the fuel would come in contact with that were not evaluated during the industry qualification process described earlier.

However, for previously certified aircraft and engines, the extent of fuel-related certification testing will be based on whether the fuel is a drop-in fuel or non-drop-in fuel.

Drop-in Fuels

As described above, drop-in fuels must meet the existing operating limitations of certificated aircraft and engines. Typically, the operating limitations will be specified as "Jet A/A-1 Fuel", or "Jet A/A-1 Fuel meeting ASTM D1655". Because the drop-in alternative fuel will be incorporated into the existing jet fuel specifications, there will be no change required to these operating limitations and no associated certification testing. In effect, the alternative fuel seamlessly enters the fuel distribution infrastructure and requires no special treatment or identification, and is co-mingled with conventional jet fuel. From the perspective of the certificated aircraft and engine, conventional fuel and the drop-in alternative fuel provide identical performance and safety.

Non-Drop-in Fuels

The certificated operating limitations for a previously certified aircraft or engine will need to be revised to add the specification reference for the new alternative fuel. In addition, modifications to the design of the aircraft or engine may need to be incorporated to accommodate the new alternative fuel. This will require an amendment of the type certificate or a supplemental type certificate (STC) (if the applicant is not the original equipment designer). In either case, the fuel-related regulatory requirements must be re-validated by testing of aircraft and engine. In most cases, certification approval of an engine to operate with the new alternative fuel will need to be followed by certification approval of the aircraft on which the engine is installed.

Conclusions

The following conclusions can be made with respect to adopting a global fuel qualification and certification protocol:

- The concepts presented here should be applicable to other CAAs and fuel specification-writing organizations.
- There are benefits and advantages to be gained by cooperating with other CAAs and voluntary consensus standards organizations to facilitate the approval of new alternative fuels.
- The current industry qualification and global certification processes are the appropriate means for approving a new alternative jet fuel.

REFERENCES

1 *ASTM International Standard **D1655**, "Standard Specification for Aviation Turbine Fuels."*

2 *ASTM International Standard Practice **D4054**, "Guideline for the Qualification and Approval of New Aviation Turbine Fuels and Fuel Additives."*

3 *ASTM International Standard **D7566**, "Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons."*

4 *Defence Standard 91-91: "Turbine Fuel, Aviation Kerosine Type, Jet A-1 NATO Code: F-35 Joint Service Designation: AVTUR."*

From "Alternative" Fuels to "Additional" Fuels: Overcoming the Challenges to Commercial Deployment

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In commenting on the tremendous progress made in the development of alternative aviation fuels, a participant at the May 2010 ICAO Colloquium on Aviation and Climate Change offered a keen observation: we may want to start referring to the fuels as "additional" fuels, rather than as "alternative" fuels. There was resounding agreement in the Colloquium that aviation is striving for that very target, but that challenges remain. In this article we identify the key challenges to deployment of aviation "alternative fuels" at a scale to warrant the fuels being considered "additional." Perhaps more importantly, we note the work that is being undertaken by industry, governments, researchers, would-be feedstock and fuel suppliers, ICAO and others to overcome those challenges.

The Desire for Alternatives

There can be no question that the world's airlines are dedicated to the development and deployment of sustainable alternative aviation fuels. A quick review of the industry's commitments bears this out. In April 2008, the Air Transport Association of America (ATA) issued an alternative aviation fuels commitment stating that its members "are dedicated to the development and deployment of safe, environmentally friendly, reliable and economically feasible alternatives to conventional petroleum-based jet fuel."[1] Members of the Sustainable Aviation Fuel Users Group (SAFUG) later pledged to "advance the development, certification and commercial use of drop-in sustainable aviation fuels."[2] And the International Air Transport Association (IATA) has expressed is continuing commitment to sustainable alternatives to petroleum-based fuel as a critical means to reduce the industry's carbon footprint, break the "tyranny of oil" and "drive economic development in all parts of the world."[3]

The airlines are certainly not alone in their quest. In early 2006, ATA, the U.S. Federal Aviation Administration (FAA), the Aerospace Industries Association (AIA) and the Airports Council International-North America (ACI-NA) banded together to form the Commercial Aviation Alternative Fuels Initiative (CAAFI). As a coalition of airlines, aircraft and engine manufacturers, airports, energy producers, universities, international participants and government agencies, CAAFI aims to promote the development of alternative jet fuel options that offer equivalent levels of safety and compare favourably with petroleum-based fuels on cost and environmental bases. Work of the various stakeholders over the past few years has proven that alternative fuels to power commercial aircraft in flight are real. Indeed, since 2008 there has been a string of successful test flights of commercial aircraft utilizing an array of biofuel and synthetic fuel alternatives,[4] in addition to countless rig tests and analyses.

In light of all of this activity, a question posed by the Chairman, President and Chief Executive Officer of United Airlines, Glenn F. Tilton, comes to mind: "If the airlines need alternative fuels, want alternative fuels, and we've flown aircraft with them, why then, don't we have them?"[5] While noting there is no simple answer to this question, Mr. Tilton observed, in sum, that we need to overcome the obstacles to commercial application of these fuels. Indeed, from an airline point of view, before any alternative fuel can have commercial application in aviation it must be demonstrated to be (1) as safe as petroleum-based fuels for powering aircraft; (2) capable of being produced so as to provide reliable, cost-competitive supply; and (3) more environmentally friendly than today's fuels.[6] We outline each of these challenges below, along with the steps being taken to address them.

Safety

Safety is the airlines, airframe and engine manufacturers' number-one commitment. To ensure safety, commercial jet fuel must meet precise technical and operational specifications, and jet engines are designed to work with jet fuel having these specific characteristics. This is the first and most critical challenge for alternative aviation fuels. Significantly, the aviation community has established processes for meeting this challenge.

Any alternative jet fuel must satisfy the regulatory and standards-making organization specification requirements for jet fuel. In the United States and much of the world, the recognized jet fuel specification is set by ASTM International.[7] Until very recently, ASTM D1655, "Standard Specification for Aviation Turbine Fuels," was the only ASTM jet fuel specification. Based on a process forwarded by CAAFI and other supporters, in August 2009, after completing its rigorous review process, ASTM approved D7566, "Aviation Turbine Fuel Containing Synthesized Hydrocarbons." This specification allows for alternatives that demonstrate that they are safe, effective and otherwise meet the specification and fit-for-purpose requirements to be deployed as jet fuels, on a par with fuels under ASTM D1655.

The initial issue of D7566 enables use of fuels from the Fischer-Tropsch (FT) process in up to a 50 percent blend with conventional jet fuel. FT fuels can be generated from a variety of feedstocks, including biomass (biomass to liquid) and natural gas to liquid, in addition to coal to liquid and combinations thereof. Most critically, however, the ASTM D7566 specification is structured, via annexes, to accommodate different classes of alternative fuels when it is demonstrated that they meet the relevant requirements. An annex is currently under consideration for hydrotreated renewable jet (HRJ) blends (also referred to as bio-derived synthetic paraffinic kerosene, or "Bio-SPK"), which is expected to be approved by 2011, with other alternatives (e.g., hydrolysis/fermentation, lignocellulosic bioconversion, pyrolysis/liquefaction) to follow as data from technical evaluations is obtained.

By meeting the rigorous jet fuel specification and fit-for-purpose requirements, sustainable alternative aviation fuels are demonstrated to be "drop-in" fuels, completely compatible with existing airport fuel storage and distribution methods and airplane fuel systems. Accordingly, they do not carry any added infrastructure costs for airlines, fuel distributors or airport authorities, adding to their commercial viability.

While much of the leading work on alternative aviation fuels is occurring in the United States, the global nature of the aviation industry and its overall regulatory framework allow for international deployment. Despite the existence of jet fuel specifications separate from the ASTM specification, such as the United Kingdom's Defence Standard (Def-Stan) 91-91,[8] collaborative processes are in place to allow for data exchange to harmonize the specifications as data and conditions warrant. Further, ICAO, as the United Nations (UN) body charged with setting standards and recommended practices for international aviation, is providing a forum for further information exchange and international policy development on sustainable aviation alternative fuels.[9]

Supply Reliability and Cost Competitiveness

Fuel costs are a significant portion of an airline's operating costs – in many cases, the greatest portion. Given that airlines typically generate razor-thin profit margins even in good years – and incur substantial losses in bad years – any fuel used by the airlines must be competitively priced and reliably provided.

As noted by Bill Harrison, Technical Advisor for Fuels and Energy at the U.S. Air Force Research Laboratory, scaling up supply and making alternative aviation fuels cost-competitive may well be the most significant challenge to their commercial deployment.[10] Due to the nascent nature of the enterprises, in most instances, feedstock production for alternative fuels – particularly for biofuels – is still in the early stages of development, requiring investments to construct commercial-scale processing facilities. Refinery facilities can require significant upfront capital, which can be challenging to obtain in current market conditions. Also, with feedstocks representing up to 80 percent of the cost of alternative fuel, appropriate incentives are essential to develop the feedstock base. Absent that, even if financing is adequate to construct alternative jet fuel facilities, the resultant fuel may nonetheless be unaffordable to the consumer. Long-term contracts between alternative-fuel suppliers and consumers must be predicated on the fuel being cost-competitive. Further, in the case of bio-feedstocks, it is imperative to develop an appropriately incentivized agricultural base that yields adequate energy content but does not compete with existing food crops.

As United Airlines' CEO has pointed out, airlines generally are not in a position to finance alternative fuel companies in light of the financial challenges the airlines have faced for many years. They are, however, sending the "market signals" that they are prepared to purchase alternative aviation fuels that are safe, reliable, cost-competitive and environmentally beneficial. In addition to general statements in this regard, several pre-purchase agreements announced to date bear this out. Further, aviation is an attractive buyer, with airports representing ready-made nodes in a network of concentrated demand. Indeed, in the United States, four airports – Los Angeles (LAX), New York-Kennedy (JFK), Chicago O'Hare (ORD) and Atlanta (ATL) – each support uplift of more than one billion gallons of jet fuel annually. The 10 largest airports account for approximately half of all U.S. commercial jet fuel uplift, with the 40 largest locations accounting for an estimated 90 percent. And demand for alternative jet fuel increases further when factoring in military requirements, as through the "Strategic Alliance for Alternative Fuels"[11] signed in March 2010 by ATA and the U.S. Defense Energy Support Center (DESC), the procuring arm for the U.S. military.

While concentrated demand prevails, as recognized in ICAO's Declaration of the Conference on Aviation Alternative Fuels, additional funding is needed from governments and the private sector.[12] CAAFI is among the groups working to promote such funding. Governments should be encouraged to do more. As spelled out in its Global Framework for Aviation Alternative Fuels,[13] the ICAO task to provide "fora for facilitating the exchange of information on financing and incentives for sustainable alternative fuels for aviation programmes working with the relevant UN and regional financial entities" should be helpful.

Environmental Benefit

A significant driver for the deployment of alternative aviation fuels is the benefit they may bring in reducing emissions from aviation, whether associated with local air quality or global climate change. In terms of local air quality, for example, alternative fuels tend to have much lower sulphur content than petroleum-based fuel, and hence lower particulate matter emissions. As carbon is fundamental to powering aircraft engines, this and the carbon dioxide generated upon combustion cannot be eliminated from drop-in jet fuels, but they can be reduced, either through increasing the per-unit energy provided in the fuel, reducing carbon somewhere along the "lifecycle" of the fuel, or some combination thereof. Indeed, there can be emissions all along the "life" of the fuel – from growing or extracting the feedstock, transporting that raw material, refining it, transporting the finished fuel product and using it. By examining the emissions generated at each point in the lifecycle, one can ensure that the emissions benefits that are sought are in fact real and do not create emissions "dis-benefits" along the way.

CAAFI, SAFUG, the European Sustainable Ways for Alternative Fuels and Energy in Aviation (SWAFEA) and other groups have made significant progress in confirming the methodologies for lifecycle analysis of alternative aviation fuels[14] and in supporting or performing case studies that use these methodologies.[15] While the emissions aspect of this work is most central, these groups also are focused on ensuring that alternative fuels ultimately are sustainable under all relevant environmental criteria, including land use, water management and the like. However, rational and supportive standards and/or regulations for documenting and crediting the environmental performance of the fuels will need to be put in place.

From a fuel-user perspective, there are at least three elements necessary to the alternative fuels environmental regulatory structure to support commercial viability. First, any demonstrated environmental benefit relative to traditional jet fuel should be credited. Of concern in this regard are regulatory proposals that seek to require alternative fuels to achieve benefits of several orders of magnitude over traditional fuels before any environmental credit is given. Second, the regulatory provisions need to recognize that airlines typically commingle the fuel they purchase in common-carrier multi-product pipelines and airport fuel storage facilities, such that the purchasing airline might not actually fly with the exact fuel it purchases. For commercial viability, part of which requires avoiding duplicative storage and distribution infrastructure, the regulatory structure will need to accord the environmental credit to the airline that purchases the more environmentally beneficial fuel, even if that airline does not fly with it. Finally, aviation is a global business. For airlines to be able to fully employ alternative fuels, the environmental criteria for alternative aviation fuels in international aviation ultimately will need to be made compatible worldwide. ICAO has a unique and most important facilitating role to play in this regard.

Conclusion

The aviation community is dedicated to the development and deployment of environmentally friendly alternative aviation fuels. These fuels are real – we know how to fly them. Now we must make them commercially viable so they are not only "alternative fuels," but "additional fuels." Groups like CAAFI are critical to this desired outcome. So, too, are ICAO and its 190 Member States. ■

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Chapter 6

ADAPTATION

ICAO
ENVIRONMENTAL
REPORT 2010

Aviation and Adaptation to Climate Change

Overview

By ***ICAO Secretariat***

Climate change is considered to be one of the most serious environmental threats to sustainable development, with adverse impacts expected on human health, food security, economic activity, natural resources and physical infrastructure. There is solid scientific evidence to suggest that despite the technology improvements as well as other operational and economic measures to reduce greenhouse gas (GHG) emissions, the climate could continue to change, and the potential consequences might be significant.

The likely impacts of climate change (storms, heat waves, etc.) were initially assessed by the Intergovernmental Panel on Climate Change (IPCC) in 1999 and these assessments have since been updated, the most recent one being IPCC's Fourth Assessment Report issued in 2007. According to the latest IPCC assessments, the impacts of climate change will be felt worldwide (see article *Adaptation to Climate Change – Challenges Facing Civil Aviation Stakeholders*, Chapter 6 of this report). The need to address the adverse effects of climate change either by mitigation or by adaptation is becoming more pressing.

The articles in Chapter 6 of this report focus on how the changes in climate could affect aviation and the possible areas where aviation might need to adapt its ground and flight operations.

Adaptation - An International Concern

The Bali Action Plan adopted in 2007 at the thirteenth Conference of the Parties (COP13) of the United Nations Framework Convention on Climate Change (UNFCCC), identified "adaptation" as one of the four building blocks (along with mitigation, finance and technology) required for a strengthened future response to climate change. These building blocks are meant to enable the full, effective and sustained implementation of the UNFCCC through long-term cooperative action, from now to beyond 2012.

Most recently, in 2009 at COP15 held in Copenhagen, the UNFCCC Parties stressed the need to establish a comprehensive adaptation programme. It was agreed that enhanced action and international cooperation on adaptation is urgently required and that the developed countries should provide adequate, predictable and sustainable financial resources, technology, and capacity-building to support the implementation of adaptation actions in developing countries[1]. Adaptation to the effects of climate change is now acknowledged as necessary for responding effectively and equitably to the impacts of climate change.

Adaptation versus Mitigation

The terms "adaptation" and "mitigation" describe two actions that are essential in the climate change area. From its beginning, the international climate effort has focused primarily on "mitigation" — reducing GHG emissions to address climate change. However, in recent years, more attention is being given to "adaptation" – adjusting to and dealing with the impacts of climate change. The inset box provides more formal definitions of climate mitigation and adaptation. While mitigation addresses the causes of climate change, adaptation addresses the effects of the consequences. Obviously, better mitigation, because of its proactive nature, reduces risks at an early stage and therefore lessens the need for adaptation. Similarly, early recognition of climate change and anticipation of its impacts will be essential for adjustments in the future. This early preparation will reduce the impacts to any given degree of climate change.

__Climate mitigation__ can be defined as actions taken to stabilize or reduce GHG concentrations in the atmosphere. The IPCC defines mitigation as "an anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases" [2]*.*
An example of a typical mitigation measure for aviation would be optimizing the air traffic management systems to enable more direct routings and therefore reducing GHG emissions.

__Climate adaptation__ refers to the ability of a system to adjust to climate change to moderate potential consequences or to manage the consequences of those impacts that cannot be avoided [3]*.*
The IPCC defines adaptation as "adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderate harm or exploits beneficial opportunities" [4]*. Successful adaptation can reduce vulnerability by strengthening existing strategies. A typical case of adaptation for aviation would be improvements in coastal area airports' defences against sea level rise.*

Adaptation and Aviation

While drastic reductions in emissions through mitigation measures could stabilize atmospheric GHG concentrations at low levels, it is expected that they will be above the current levels in a few years. With higher concentrations, new phenomena will be observable such as a rise in temperatures and sea level, changes in precipitation, and more extreme weather as shown in Figure 1 (see article *Adaptation to Climate Change – Challenges Facing Civil Aviation Stakeholders*, Chapter 6 of this report).

IPCC predicts a rise in mean sea level between 0.6 feet to 1.9 feet by 2100.

Anticipation of and adaptation to these impacts are vital to ensure a reduction in the magnitude of consequences of climate change. The impact of temperature and precipitation changes could increase the demand for cooling for buildings or increase the drainage requirements for runways. These are only some potential effects among others (see article *Adapting to Climate Change at Airports*, Chapter 6 of this report). Some limitations for ground and flight operations have

	Level of Uncertainty	Probability of Occurence
Sea level rise	Virtually certain	≥99%
Temperature changes		
Decreases in very cold days	Virtually certain	≥99%
Increases in Arctic temperatures	Virtually certain	≥99%
Later onset of seasonal freeze, earlier onset of seasonal thaw	Virtually certain	≥99%
Increases in very hot days and heat waves	Very likely	≥90%
Precipitation		
Increases in intense precipitation events	Very likely	≥90%
Increases in drought conditions for some regions	Likely	≥66%
Changes in seasonal precipitation and flooding patterns	Likely	≥66%
Storms		
Increases in hurricane intensity	Likely	≥66%
Increased intensity of cold-season storms, with increases in winds, waves and storm surges	Likely	≥66%

Less certainty

IPCC 2007. Summary for Policymakers. In climate Change 2007: The Physical Science Basis.
Contribution of Working Group 1 to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

Figure 1: *Potential likelihood of need for adaptation measures (IPCC 2007 Summary for Policymakers in Climate Change 2007).*

already been noticed in Europe. These include high wind events, freezing rain, heavy precipitation and lightning strikes (mainly in summer) that can threaten buildings, facilities, and aircraft. Similarly, in winter, there are challenges associated with snow prediction and removal (see article *European ATM and Climate Adaptation - A Scoping Study*, Chapter 6 of this report).

The impacts of climate change will be more visible in low lying coastal areas in terms of sea levels and storm activities. Infrastructure such as runways and buildings at some airports could be impacted because of rising sea levels (see article *Adapting to Climate Change at Airports*, Chapter 6 of this report). According to a preliminary review of an OECD Report[5], 64 airports have been identified as likely to be affected by the predicted rise in sea levels. In view of the risks to major coastal cities, as indicated in the IPCC report[6], flooding and storm activities could impact movement of aircraft and travellers adversely. In addition, possible damage to infrastructure on the air and land side of the airports should be considered. Even though there are some uncertainties about the potential impacts of climate change on aviation operations and related infrastructure, clearly there are challenges that will need to be addressed.

Conclusions

Adaptation to climate risks may take the form of specific actions or projects, for example, construction of a sea wall to protect areas from rising sea levels, or establishment of an early warning system for potential flooding or heat waves. These solutions will require significant investments. States are becoming increasingly aware of the potential risks associated with climate change and will have to incorporate these risks into their future planning, such as for airport development, and design their adaptation strategies accordingly.

While ICAO has shepherded improved aviation environmental protection since the 1960s through development of standards and recommended practices, it is aware that additional ambitious mitigation efforts are still needed. The Organization recognized the need to also consider adaptation since the consequences of climate change need to be anticipated and effectively addressed. ■

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6 *IPCC Fourth Assessment Report*

Adaptation to Climate Change

Challenges Facing Civil Aviation Stakeholders

By **Herbert Puempel**

Herbert Puempel *is currently the Acting Director of the Meteorology Branch, Weather and Disaster Risk Reduction Services (WDS) Department at the World Meteorological Organization (WMO), and has been Chief of the WMO's Aeronautical Meteorology Division since 2006. In addition, Dr. Puempel has been a member of the Commission for Aeronautical Meteorology since 1991, and the WMO Observer to the ICAO Committee on Aviation Environmental Protection (CAEP) since 2000.*

Dr. Puempel obtained his PhD in Meteorology and Physics from the University of Innsbruck in 1978, undertaking his studies in the fields of theoretical physics, dynamic meteorology and Spanish translation.

Introduction

Climate change and variability are subjects of intense study and discussion, not only in the scientific community but also in different sectors of the economy. The issue poses major challenges to political and economic bodies and decision-makers. Through its various programmes, the World Meteorological Organization (WMO), which represents 189 Member countries and territories, has addressed these questions since the emergence of observational and theoretical evidence. Most recently, the WMO hosted the third World Climate Conference in September 2009 in Geneva, which involved participation of scientists, major economic bodies, and high-level decision-makers from national governments and international organizations.

The Conference culminated in the creation of a Global Framework for Climate Services with the aim to contribute to the assessment and reduction of climate and weather related risks to all societal sectors, including transportation. The scientific community is now realizing the need to investigate possible ways to adapt to climate change and it is understood that this issue is no longer fundamentally in question. Nevertheless, it is recognized that some remaining issues such as the effects of contrails and cirrus, and possible avoidance and trade-offs, still require major research and operational efforts (see Figure 1).

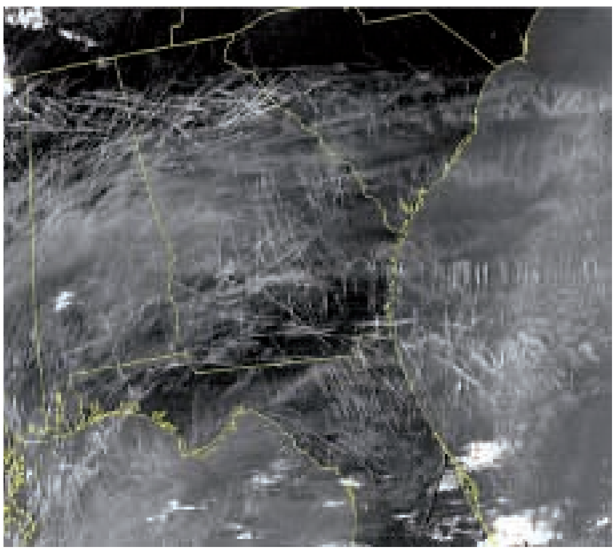


Figure 1: *Satellite imagery of contrails over Eastern North America.*

The implementation of a range of new climate-related services will be essential if those building and operating transport systems are to make the best decisions. Furthermore, decisions made at one particular time, on the basis of the best available information at the time, will need to be constantly re-evaluated. In essence, an adaptive management approach, underpinned by a Global Framework of Climate Services (GFCS), will need to be:

- Accessible to all parties; since climate variability has a potential impact on economic decisions, this information must be openly available.
- Driven by ongoing research, and building on existing collaboration between the meteorological and transport communities dealing with chronic risks.
- Continuously improving forecasts, in particular for specific regions and locations, and expressed in a clearly understandable way to decision-makers.
- Improving the range, availability and accessibility of information through exchange of data between research and operational agencies for the Earth, atmospheric and oceanic systems.
- Creating information that facilitates accessibility and mobility options that are robust in terms of climate variability and that considers mitigation, including travel related to tourism.

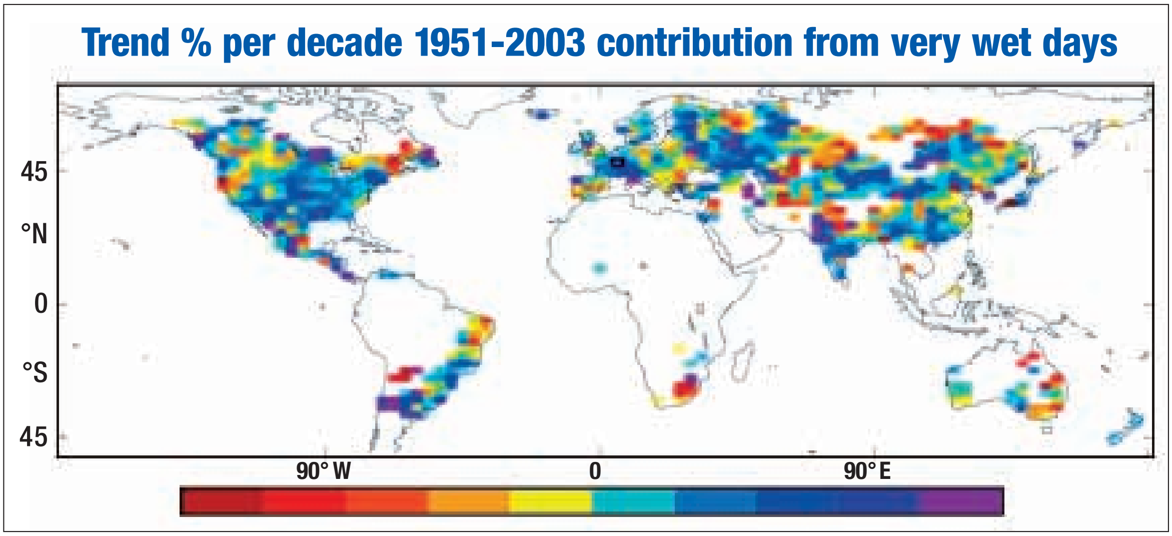
Climate Change and Variability – A Scientific Challenge

While the 4th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) provided a fairly robust global trend for surface temperatures, and to some extent also precipitation, specific scenarios on a regional and local basis will require considerable further efforts before they can be translated directly into critical information for decision-makers.

Far from a uniform shift to higher temperatures and changed annual rainfall amounts, observational evidence and results of higher resolution model runs and downscaling exercises appear to indicate that extremes of temperature, wind and precipitation are likely to become more frequent. Also indicated is that the duration of significant events (i.e. heat waves, droughts, etc.) may see noticeable changes. In some regions such as the Mediterranean and the southern European area, the contribution of strong and extreme rainfall events to the annual precipitation total has been seen to increase over recent decades.

Analysis of Figure 2 reveals the following: **Upper:** Observed trends (%) per decade for 1951–2003 for the contribution to total annual precipitation from very wet days corresponding to the 95th percentile.

Middle: Anomalies of the global annual time series of very wet days (with respect to 1961–90) defined as the percentage change from the base period average (22.5%). The orange



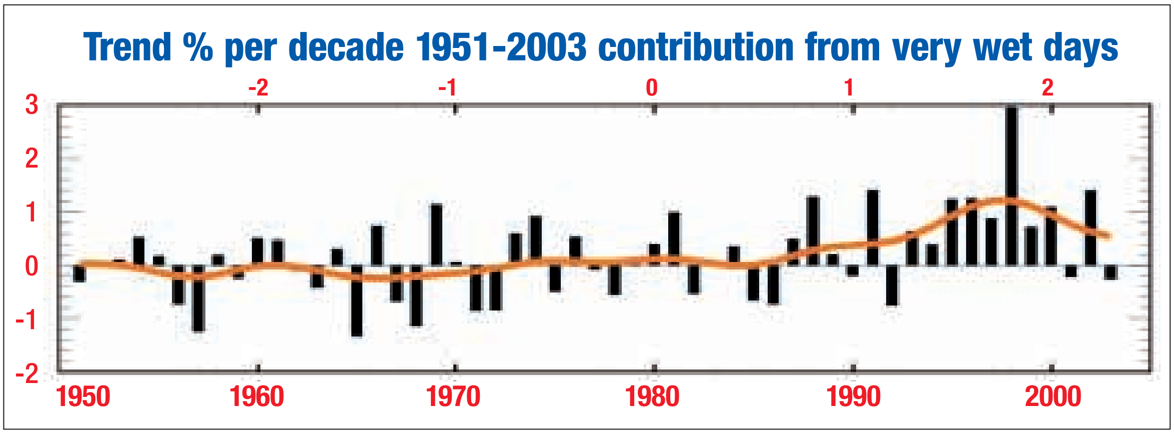


Figure 2: *Worldwide precipitation trends, by decade, 1951 to 2003 (Technical Summary IPCC WG1 Fourth Assessment Report).*

line shows decadal variations. **Lower:** Regions where disproportionate changes in heavy and very heavy precipitation during the past decades were documented compared to the change in the annual and/or seasonal precipitation. Thresholds used to define "heavy" and "very heavy" precipitation vary by season and region.

While it may be tempting to assume a general trend toward higher temperatures, and that problems related to snowfall and low temperatures may become rare and less disruptive to transport systems, it appears that high variability will be the more likely scenario. Several winters with short periods of snow cover and milder temperatures are often countered by very severe and long-lasting events.

Operational Challenges of Weather and Climate Extremes

The current relevant publication from WMO on detecting significant changes is WMO Technical Document No. 1500: "Guidance on Analysis of Extremes In A Changing Climate In Support of Informed Decisions For Adaptation". It highlights the difficulties faced by operational meteorological and climatological services in providing the required information, as follows: "For the moment, it remains difficult to detect significant changes in many types of extremes because of the limited amount of available observational information. This is because extreme events are rare by definition, and because observational records, where available, are often not long enough. It should be noted that a failure to detect a significant trend indicates there is insufficient information to reliably identify change, but this does not necessarily mean that there is no change or that the likelihood of a given type of extreme event has not been affected by other changes that have been observed in the climate system."

Considering the need to incorporate climate information and trends into planning and operation of vital transport infrastructure, experts in climate and transport have recommended the following principles and approaches:

Climate resilience: Planning and design of transport infrastructure needs to account for climate uncertainties to enable more resilient responses to climate change. Typical examples would include adaptation of runway construction and airport infrastructure to anticipated temperature changes (important for the density altitude[1] and thus required take-off length). Issues will include: the anticipation of sea level rises and storm surges for coastal airports, anticipated possible changes in the severity and frequency of severe storms (in particular tropical storms), and anticipated changes in maximum wind speeds and gusts. As another example, the changes to permafrost soils may need to be assessed and incorporated into the design of runways in polar and arctic regions.

Multi-disciplinary cooperation: Information sharing and cooperation among professionals in meteorology, hydrology, engineering, statistics, ecology, biology, economics and financial management, and the wider community as well.

Whole-of-life approach: Typical transport infrastructure has a planned lifecycle of several decades to a century, over which a realistic appreciation of expected climate conditions is necessary to protect the users, the infrastructure and the investment.

Risk assessments: Potential risks and cost-benefit analyses of adaptive and mitigation strategies need to be updated regularly in light of emerging evidence of change.

Extreme events: Strengthen emergency response planning and management to respond to extreme events.

Special Vulnerability Considerations of Complex Systems

Global economies are becoming increasingly dependent upon reliable transportation systems. In many cases, fast and efficient transport of goods can replace the traditional storage necessity for such commodities as parts, primary material for manufacturing, food and other essential goods such as medication, IT components, as well as intermediate products. Accordingly, the dependability and resilience of transport is becoming key to uninterrupted essential production and supply chains.

Multi-modal transport systems, where individual sub-modes are no longer able to compensate for a breakdown in one transport mode, suffer from a complex vulnerability to extreme events. A timely example of this is the eruption of the Eyjafjall Volcano in Iceland, which led to a complete shutdown of the European Air Transport System for up to 5 days in April 2010, followed by several shorter and more localized episodes of related traffic disruption. During that outage, it became clear that the remaining modes of transport did not have enough spare capacity to make up for the lack of air transport, which resulted in extremely wide-ranging economic consequences.

As some meteorological, climatological or hydrological phenomena are likely to affect several modes of transport simultaneously, such as major floods or widespread heavy snow or freezing rain, the challenge to the meteorological and climatological community will be to provide a seamless, user-oriented service that supports vital decisions by industry, infrastructure maintenance units and traffic authorities. The decision-making information required by those authorities will range from the tactical (i.e. required in minutes to hours), to strategic (i.e. required in days to weeks), to that needed for long-term planning purposes, which can range from seasonal to multi-decadal time frames.

Specific Considerations - Aviation Operations In A Changing Climate Regime

As mentioned earlier, the detailed effects of climate change on different weather regimes continues to pose a serious challenge to climate science. The atmospheric phenomena with the highest impact on aviation tend to be caused by the smallest scales of motion[2] in the atmosphere. Large-scale changes, such as a slow pole-ward drift of the mid-latitude jet streams, can be fairly easy to accommodate in the short term by adjusting route planning and frequency. However, severe critical events such as microbursts due to severe convection, or runway flooding in similar events, will probably be affected by a large degree of uncertainty for some time to come.

Similarly, climate-change related variations in boundary-layer effects such as fog and low ceilings, as well as questions of local air quality may require significant further study to be fully included in adaptation planning processes. Questions about air quality may re-emerge in some densely populated areas following studies now planned to examine the effects of the complete air traffic shut-down that took place during the recent volcanic ash crisis in Europe. ■

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1 ***Density Altitude*** *is a term used by ICAO and WMO to represent the altitude where the observed air density, vital for calculating the necessary take-off distance, would be in the Standard Atmosphere. It increases with every degree Celsius measured at the runway level.*

2 *Small motions such as turbulence, microbursts, wake turbulence which happen at a scale of tens to hundreds of meters, etc.*

European ATM and Climate Adaptation
A Scoping Study

By ***Alan Melrose***

Alan Melrose *has 38 years experience in environmental management in a wide range of private and public sector organisations. Establishing Manchester Airport's Environmental Control Department in 1988, he was actively involved in delivering Manchester's Second Runway and helped to secure several 'world firsts' in environmental management.*

Alan joined EUROCONTROL 9 years ago and leads projects including the Continuous Descent implementation initiative, Collaborative Environmental Management roll-out and environmental training. Alan supports various ICAO activities including the development of CDO guidance and is a task leader in CAEP Working Group 2 including chairing the Independent Expert Operational Goals Group.

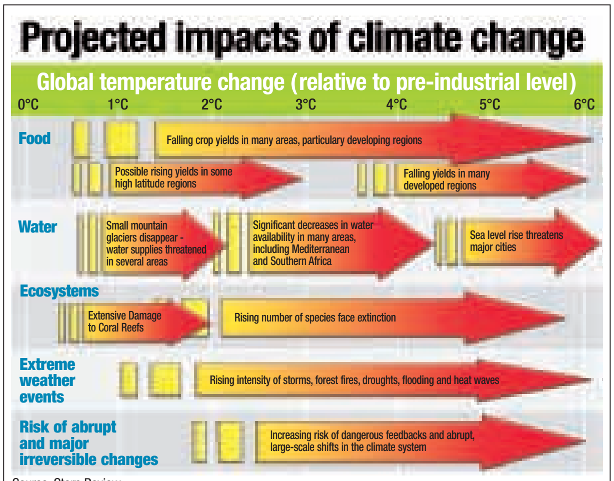
This article is based on a study undertaken for EUROCONTROL jointly by the UK MET Office, The OMEGA Project, and Manchester Metropolitan University. The complete study will soon be available for free download at ***www.eurocontrol.int.***

Background

It is currently estimated that aviation produces about 3% of human-produced emissions. While it is important that the aviation industry does everything it can to reduce greenhouse gas emissions, the rate of climate change is unlikely to be significantly influenced by aviation's efforts alone. Many scientists are now predicting some level of global warming, even if society stopped emitting tomorrow, which is unlikely. Some climate change impacts are being felt by society now (e.g. eco-system changes) and other impacts (e.g. flood damage) could manifest within the asset-life of recent and future major infrastructure development.

This consideration of how the climate may affect economies, business, and society, and how these sectors should respond, is known as "climate adaptation". The anticipated effects of climate change relating to temperature increase are shown in Figure 1 taken from the UK Government funded *Stern Review*.

The critical temperature change threshold seems to be between 2-4 degrees Celsius, warming much above 2 degrees Celsius may trigger other natural climate changes and conditions that society cannot control. Some scientists are now predicting that climate change from humans' historical emissions could be around 1-3 degrees Celsius, without factoring in any present or subsequent emissions. In fact, a 4 degree Celsius temperature rise is now regarded by some climate scientists as being the most likely future scenario. Figure 1 indicates that this outcome is likely to lead to some dramatic impacts on human activities, including aviation.



Source: Stern Review

Figure 1: *Projected impacts of global temperature change.*

Operationally, aviation is one of the most climate/weather sensitive industries. It is affected by changes to visibility, storminess, temperature, icing events, flooding events, and the operational effects of these such as changing demand patterns, availability of runways, etc. So far there has been limited research into the potential impacts of climate change on aviation operations. One exception to this is a national study undertaken by Norway (all sectors) that includes a section on the potential impacts of climate change on the Norwegian air transport system (NTP (2007): "Nasjonal transportplan 2010-2019. Virkninger av klimaendringer for Transportsektoren").

It is important to note that Air Transport Management is an integrated system, and as such, an impact in one part of the system can affect all other parts of the system. We have all recently witnessed the system wide effects of the Icelandic volcanic ash event. But such events are not new; Figure 4 shows the European Civil Aviation Conference (ECAC) effects of a temporary unplanned runway restriction at one airport.

EUROCONTROL Climate Adaptation Study Overview

In 2008, EUROCONTROL updated its Challenges of Growth (CoG) study as it does every few years. That study identifies and quantifies the main risks to the European ATM system's ability to accommodate forecast growth in demand and is widely used to inform industry forecasts and development plans. The CoG report includes a section on environment that was previously centred around environmental constraints on airports. In this most recent update however, the additional question was asked – *'what happens if the climate changes despite efforts to control emissions as some scientists are predicting?'*

Since interest in this topic has grown rapidly, the ICAO Colloquium on Aviation and Climate Change allocated an entire session to Climate Adaptation.

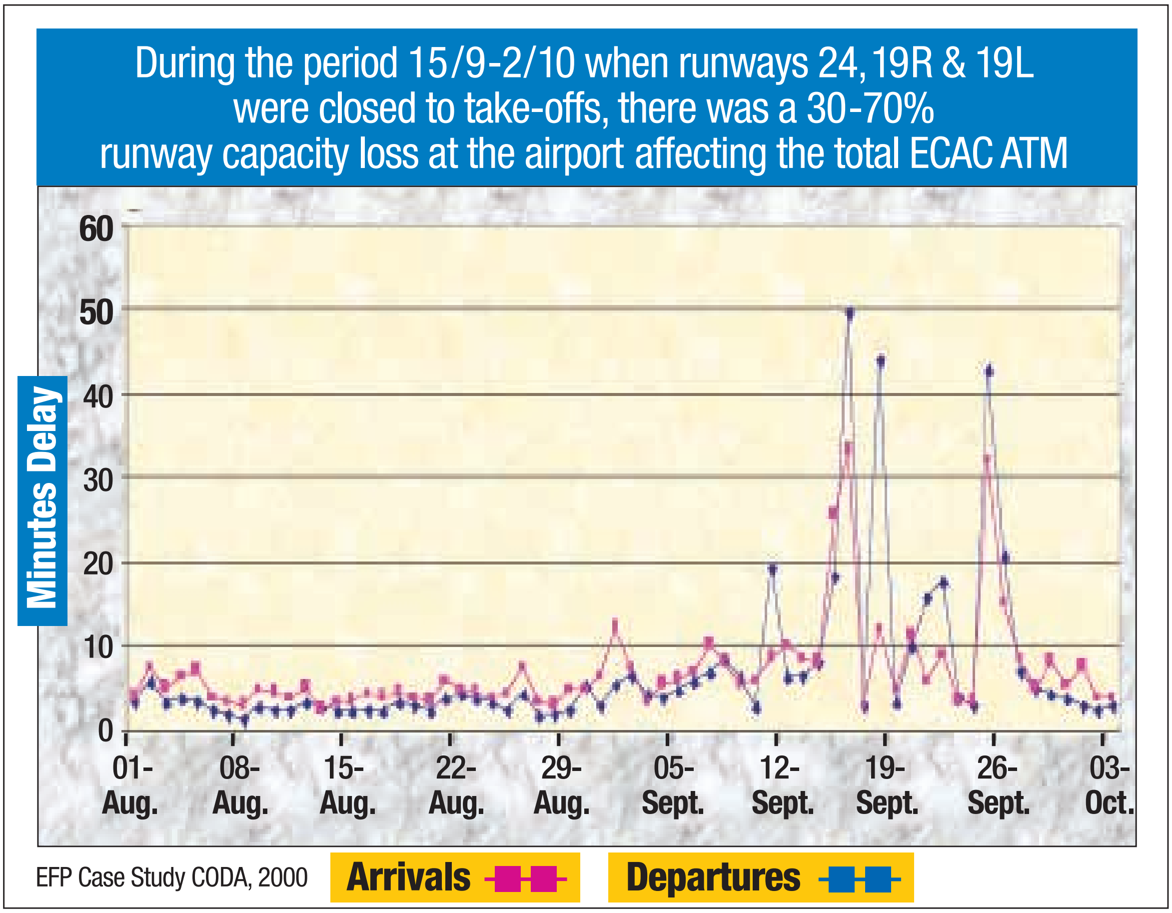


Figure 4: *Effect of some runway closures on entire ECAC ATM system.*

Potential Effect	Primary Climate Change Effects	Confidence / Likelihood	Possible ATM Impacts
Temperature change	• Higher mean temperatures, especially in winter for N. Europe and summer for S. Europe. • Higher, colder tropopause	**High:** Long observational record of temperature increases, all studies considered concur on further increases and in patterns of regional and seasonal change.	• Demand re-distribution (geographical) • Demand peak redistribution (seasonal) • Airport and runway demand mismatch • Airspace capacity and demand mismatch • Optimal cruise altitude changes • Airspace design changes • Traffic flow management issues • Aircraft performance changes • Possible runway length issues • Possible fuel load/yield and range issues • Possible increase in noise contours due to reduced climb performance
Snow & frozen ground	• Fewer days of snow/frost (especially Alpine, Scandinavia, N. Baltic).	**High – Medium:** All regional models considered showed same broad level response, but are driven by the same global model. Regional model projections concur with independent studies.	• Demand re-distribution (e.g. winter sports) • Reduced de-icing and snow clearance requirements • Increased de-icing and snow clearing requirements due to loss of 'white runways'
Precipitation and water supply	• Increased precipitation in N. Europe: winter flooding • Decreased precipitation in S. Europe: summer water shortages	**High – Medium:** All studies considered agree on large scale regional and seasonal patterns of precipitation change but not on exact magnitude. All studies considered indicate future increases in intensity and frequency of droughts for Southern Europe. Exact magnitude of change remains uncertain due to concerns over soil parameterization in regional climate models.	• Demand re-distribution • Demand re-distribution (geographical) • Demand peak redistribution (seasonal) • Airport and runway demand mismatch • Airspace capacity and demand mismatch • Loss of Airport availability and hence perturbation and delay
Sea level	• Increased mean sea level • Increased impacts of storm surges and flooding	**High – Medium:** All studies considered concur that European sea levels will continue to rise. Questions remain over exact local extent of sea level rise due to regional influences such as El Niño. Confidence in changes to extreme water levels is lower than that for sea level projections due to fewer studies and the dependence on changes in the storm track, which are uncertain.	• Demand re-distribution • Loss of Airport availability (over 30 potentially at risk in ECAC) • Loss of ground access to airports • Major economic costs from events and from providing protection • May require public economic support for ground transport infrastructure protection • Delay and perturbation • Some airports may become less viable • Knock-on impacts for diversion airports
General	• The summation of the above	**Medium:** Some high impact risks have medium high confidence in their probability. Timing however is perhaps less certain.	• Borrowing capability • Business case certainty • Route development issues • The appropriateness of major plans as presently designed (e.g. SESAR) - planned ATM performance improvements may already be aligned with this challenge?
Jet stream	• Jet stream changes: movement poleward and upward	**Medium – Low:** 11 of the 15 models considered agree on continued pole-ward movement of storm tracks. Exact changes in storm frequency and intensity remain uncertain due to uncertainties in the detailed model physics needed to represent these changes accurately.	• Changes to storm tracks and hence location of possible weather disruption • Wind strength and direction changes at surface • Possible flow management and airspace design changes
Convective weather	• Increased intensity of precipitation events, lightning, hail and thunderstorms	**Medium – Low:** Severe convection results derived from changes in occurrence of related phenomena, such as intense precipitation events. Uncertainty surrounding modelling of convection and a limited number of studies give low confidence in exact magnitude of change.	• Increased convective weather disruption and delay • Potential safety issues if storminess number and severity increase or predictability reduces
Visibility	• Decrease in winter days affected by fog	**Low:** Fog and haze are boundary layer features not well represented by climate models due to their coarse resolution. There are no studies outside those of the Met Office Hadley Centre so although results from a single model study are plausible they are not necessarily reliable and should not be generalised.	• Fewer capacity restrictions due to reduced visibility • Reduced business case for low-visibility related technologies

Table 1: *Potential climate change effects and their possible impacts on ATM operations.*

Main Findings

As with any new challenge to the aviation industry, stakeholders have legitimate concerns about how this risk is presented. It is important not to raise unnecessary fears or trigger responses that are unnecessary or out of proportion to the risk involved. Until the risks are clarified, any response to this challenge must be considered as speculative. The likelihood, timing, and impact of climate change on the European ATM system will depend on the extent of temperature change as well as on society's ability to reduce emissions of greenhouse gases. Although still uncertain, some scientists believe that certain aspects of climate change are already affecting us. The potential climate effects on air transport are summarized in Table 1, which has been synthesised from the EUROCONTROL report, and in light of subsequent discussions on this topic.

Government Responses To-Date

Climate adaptation is already on the political agenda for some Governments. For example the Nordic States have considered climate impact risk (including aviation) for the last 10 years. In the UK, the Government enacted its first Climate Change Act into law. So there is aviation and transport related climate adaptation related information out there but it is typically on a State by State basis. Information of an ATM system-wide nature however is less mature; ICAO's recent study on the safety implications of Climate Change being a notable exception (http://atwonline.com/eco-aviation/article/climate-change-may-impact-aviation-safety-icao-warns-0517).

Conclusions

Based on the information uncovered for the EUROCONTROL climate adaptation study the author of this report concludes:

- Some level of climate change now seems to be inevitable despite efforts to minimize emissions. As a weather and climate sensitive industry, this could have significant operational and planning implications for air transport in the medium-longer term – and not just for safety.
- Currently, this issue sits in the environmental domain because of its cause - and yet this is really a social, business, economic risk and critically an operational issue - it is therefore a true sustainability issue that cuts across all aviation domains and should not be considered to be primarily an 'environmental' issue.
- Aviation is perhaps lagging behind other industry sectors in understanding and responding to this issue. Banks and insurance companies could potentially raise this issue on the air transport industry agenda at any time. It may therefore be prudent for aviation to develop sufficient knowledge to allow a meaningful dialogue when major planning or investment decisions are being made.
- A new focus on climate adaptation however does not diminish the need to mitigate the aviation industry's climate related emissions or fuel costs.

It is possible that ATM system-wide aviation performance planning is already fully aligned with the potential operational risks from climate change, and that nothing more needs to be done. The truth is however, we just don't know. We must therefore continue to closely monitor all developments related to the issue of the impact of climate change on aviation reacting in a timely and appropriate fashion. Indeed since climate change related impacts form a potential risk to global mobility, crucially including aviation, perhaps society should proactively seek to understand this further – and perhaps governments should fund appropriate global aviation research, with the aviation sector itself playing a central and supporting role.

Adapting to Climate Change at Airports

By ***Xavier Oh*** and ***Olav Mosvold Larsen***

Xavier Oh *has been the Environment Manager at ACI since September 2005 and is based in the ACI Montreal Bureau, located near ICAO Headquarters.*

As an industry association, ACI is an official Observer at ICAO's Committee on Aviation Environmental Protection (CAEP). Xavier is the ACI representative.

As the Secretary of ACI's World Environment Standing Committee, one of his main tasks is developing, coordinating and implementing policy on all issues relating to the environment and airports.

Noise and gaseous aircraft emissions are the main global issues, but local issues such as air and water quality, energy efficiency and land management also have global significance.

Olav Mosvold Larsen *holds a Cand. Polit degree (MA equivalent) in Political Science from the University in Oslo (UiO). He previously held a position as researcher at the Program for Research and Documentation for a Sustainable Society (ProSus) at UiO, working mainly on issues related to Environmental Policy Integration (EPI) and sustainable production and consumption. Mr Larsen joined Avinor – the Norwegian airport operator and air navigation service provider – in 2007 as senior executive adviser on issues related to sustainable development and transport and climate change.*

Adaptation Versus Mitigation

Discussions on aviation and climate change have been dominated by questions related to mitigation measures. What actions can States and the aviation industry take to reduce emissions from aircraft? What are the roles of aircraft technology, system efficiency, alternative fuels, and market-based measures? All of these issues are directed towards reducing the contribution of aviation emissions to climate change.

In the case of airports, adaptation considerations need to address the changes that must be made to operations and infrastructure in response to changes in the climate and weather patterns. There are two fundamental issues that this discussion needs to address:

- Planning for the continued operation of airports with the changed climate conditions.
- Planning for the continued operation of airports under changed business conditions.

IPCC Expectations

In 2007, the Intergovernmental Panel on Climate Change (IPCC) published its fourth assessment report which included indications of the expected changes in climate over the coming decades and the likelihood of each outcome. Starting with the most likely, the following issues were highlighted: sea level rise considered as virtually certain, temperature increases almost virtually certain, precipitation increases as very likely, and storm activity as likely.

It is important to note that while the above are the expected trends in global average terms, local conditions and changes are expected to vary significantly.

The next four sections look at each of the above issues separately and examine the potential impacts on airports and their operation.

Sea Level Rise

The various numerical models used by the IPCC predict an average sea level rise ranging from 0.2 to 0.5 metres by the year 2100 (based on the medium emissions growth scenario.) Different local effects mean that the actual sea level rises at different airports will vary.

The effects on coastal areas could be significant and could include permanent or regular flooding, storm surge flooding, coastal erosion, and land-subsidence. According to the ICAO airport database there are more than 40 airports on all continents with a recorded elevation above sea level of 3 m (8 ft) or less. There would be many more airports with some of their property lower than this elevation. In many low lying countries such as the Netherlands, the Maldives, and Bangladesh, inundation threatens the entire country rather than just the airports.

This issue poses a major long-term risk to infrastructure located at coastal airports. Runways and taxiways might be unusable at high tide, or even permanently. Terminal buildings, apron areas, access roads and rail links could be impacted. Because the design life of terminal buildings is normally around 50 years, and the design life of runways typically exceeds 100 years, the risks of impacts from climate related events to existing and currently planned infrastructure likely within the next 50 to 100 years need to be assessed.

Possible solutions to minimize these risks are likely to require substantial capital investment: levees and seawalls may be required to prevent flooding, and improved drainage to pump low-lying water from airport areas will be required. Some structures may need to be built higher than current practice. For the lowest and most exposed airports, relocation of the entire airport may need to be considered. Nevertheless, if possible climate change effects are addressed in the planning, design and construction of all new infrastructure projects at airports, the additional costs could be significantly reduced.

Temperature Changes

The IPCC predictions of average temperature increases for the 3rd and 10th decades of the century are shown in Figure 1.

The effects on weather at airports will include decreases in the number of cold days, increases in the number of hot or very hot days, which could, combined with changes in precipitation, have a profound impact on airport operations.

Fluctuations in daily temperature extremes will be higher. Temperature increases will not be uniform and the northern latitudes will experience the greatest rises, resulting in significant impact on winter operations. Other consequences are likely to include changing seasonal demand for passenger and cargo traffic, degradation of local air quality, and melting permafrost under high-latitude airports.

The impacts of temperature changes on airport operations and planning could include such considerations as: aircraft

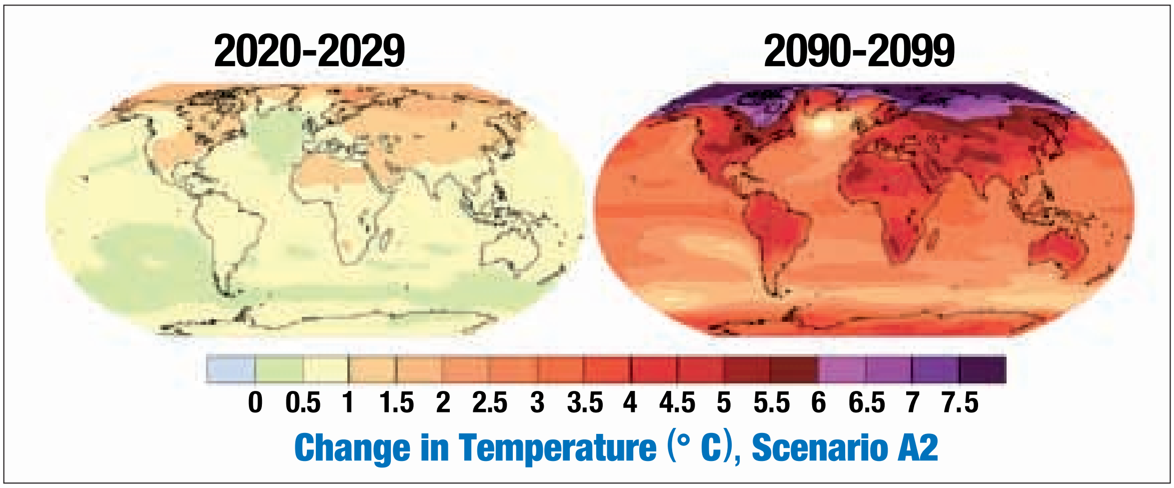


Figure 1: *IPCC Temperature change predictions for the decades 2020-2029 and 2090-2099.*

payload limitations in hot weather, longer runway requirements for long haul flights, slow climb rates that will adversely affect noise levels and airspace usage, diversion of incoming traffic if the temperature is too high, increased demand for cooling of terminals and aircraft, and more stringent local air quality emissions mitigation measures.

Precipitation Changes

The IPCC predicts that precipitation will generally decrease in the tropics and increase in higher latitudes as shown in Figure 2. The climate models also foresee more intense precipitation in many regions.

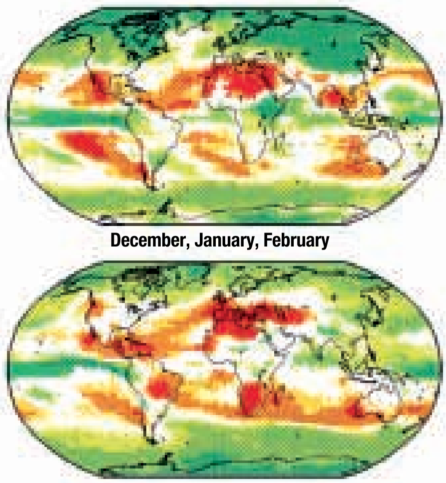


Figure 2: *IPCC worldwide precipitation predictions (2090-2099 relative to 1980-1999).*

These forecast precipitation levels will have profound effects on several regions of the world. For airports, the anticipated effects will include: increased flooding causing runway closures and requirements for improved drainage, water damage causing erosion and landslides, and an increased for storm-water run-off management measures to avoid ground and surface water contamination. In addition, in areas with less precipitation, airports and regions that rely on rainwater for their water supply are expected to experience water shortages and there will be an increase in disruptions from dust storms.

Storm Activity Increases

Storm activity is predicted to increase in both the frequency of events and their intensity. This will be accompanied by increases in wind speed, wave size, and storm surges. The images show storm damage in Norway and measures taken to reinforce coastal defences at airports. Communication equipment, mobile phone masts, RWY and TWY lighting could also be at risk during storms.

Changing Business Conditions

Issues not directly related to weather can also be expected as a result of climate change. For example, business conditions will be impacted by both the actual changes in climate and by efforts to reduce the impacts. Related items that will require risk assessment analysis will include: effects of climate on seasonal passenger demand, effects of climate on the quality and quantity of tourist destinations, cost of additional infrastructure such as sea defences, building stability measures, and increased cooling capacity, potential decrease in airport asset values, shortages of water, power, fuel and land, new storage and delivery infrastructure required for non-drop-in alternative fuels, regulations limiting the growth of aviation, and conducting aviation operations within an aviation emissions cap.

Future Challenges

Clearly, there are substantial challenges that will need to be addressed in the medium and longer terms, including the effects of changing business conditions. It is envisaged that airports will keep their current focus on mitigation, but will also recognize the longevity of airport infrastructure and the need to consider future climate impacts.

In the shorter term, airports should be up-to-date on the latest science on the effects of climate change, and should start the process to better evaluate the risks facing individual airports. Airports should then start addressing some of the uncertainties of climate change outcomes, especially with respect to local effects. This could include planning for new infrastructure with climate change impacts in mind such as considering the criteria for drainage, erosion protection, wind loads for critical infrastructure, and the possible effects on surface access to the airport.

If the predicted changes actually do occur, the possible effects of climate change have the potential to profoundly affect, and possibly devastate, airports and aviation operations in general. All stakeholders need to begin the process by considering the issues involved and assessing the extent of the risks posed.

Chapter 7

FINANCING

Aviation and Financing of Emissions Reduction Measures

Overview

By ***ICAO Secretariat***

Climate financing is one of the key elements of the international discussions addressing climate change in the medium and long term. The scale and size of the challenge that is associated with sustained reductions of greenhouse gas (GHG) emissions on a global scale requires rigorous solutions and robust financing mechanisms that will be needed to develop and deploy mitigation technologies and to adapt to the impacts of climate change. In particular, significant financial and human resources will be required to ensure that developing countries are able to meet the challenge of climate change while growing their own economies in a sustainable manner.

Background

According to the United Nations Framework Convention on Climate Change (UNFCCC), the current levels of funding available for climate change-related initiatives will be insufficient to address the future financial flows estimated to be required for adaptation and mitigation measures under a strengthened future climate change agreement, post-2012[1]. Developing countries currently receive only 20 to 25% of the investment they need for climate change mitigation and adaptation, which only represents approximately 46% of the total that will be required by 2030.

While several States have been able to undertake initial actions to combat climate change using their own financial resources (as a result of their own economic growth), the energy demand in developing countries is projected to increase immensely, which will require additional resources. Nonetheless, the resulting emissions reductions expected to be achieved by developing States by 2030 is estimated to be about 68% of global emission reductions (see article *Climate Finance – Challenges and Responses: World Bank Perspective*, Chapter 7 of this report).

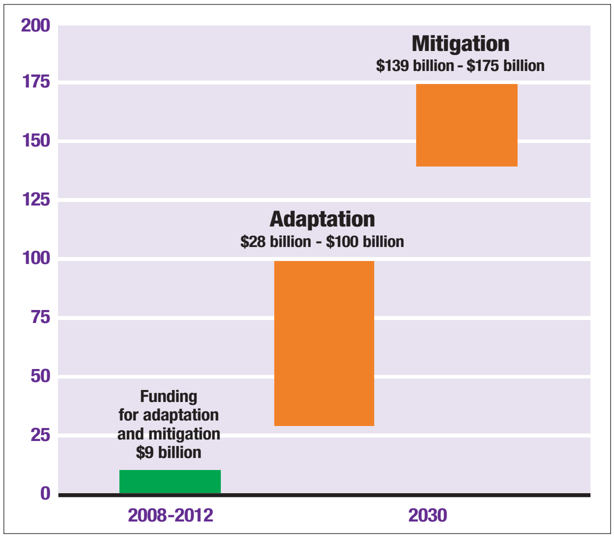


Figure 1: *Additional investment needs in developing countries, by 2030 (World Bank presentation at the ICAO Colloquium on Aviation and Climate Change, Montreal, May 2010).*

Climate Change Financing Mechanisms

Several financial mechanisms to address climate change are currently in place, including the following:

Global Environment Facility (GEF[2]) was established by UNFCCC to operate the financial mechanism under the Convention on an on-going basis, subject to review every four years to provide funds to developing countries.

Special Climate Change Fund (SCCF[3]) was created in 2001 to complement other funding mechanisms to finance projects relating to:

- Capacity-building[4];
- Adaptation (for more information on adaption please see Chapter 6 of the report);
- Technology transfer;
- Climate change mitigation and economic diversification for countries highly dependent on income from fossil fuels.

Least Developed Countries Fund (LDCF) is intended to support a special work programme to assist the LDCs.

Clean Development Mechanism (CDM[5]) allows a developed country with an emission-reduction or emission-limitation commitment under the Kyoto Protocol to implement an emission-reduction project in developing countries. Such projects can earn saleable certified emission reduction (CER) credits, each equivalent to one tonne of CO_2, which can be counted towards meeting Kyoto targets.

Adaptation Fund became operational with the first commitment period of the Kyoto Protocol in 2008 to finance practical adaptation projects and programmes in developing countries and support capacity-building activities. It is funded from an adaptation levy of 2% on CDM projects.

Climate Investment Fund (CIF[6]) was established in 2008 by several multilateral development banks. The CIF has balanced and equitable governance with equal representation from developed and developing countries. The objective is to influence climate investments in the following areas:

- **Clean Technology Fund**: Finances demonstration, deployment, and transfer of low carbon technologies.
- **Strategic Climate Fund**: Targeted programs to pilot new approaches and improvements.

Community Development Carbon Fund provides carbon reduction financing to small scale projects in the poorer rural areas of the developing world. The Fund, a public/private initiative designed in cooperation with the International Emissions Trading Association and the UNFCCC, became operational in March 2003.[7]

The World Bank and the International Finance Corporation have also developed carbon funds with (co-)funding by States (see article *Climate Finance – Challenges and Responses: World Bank perspective*, Chapter 7 of this report). Similar carbon-financing initiatives are currently being developed by various other international financial institutions. The World Bank and regional development banks provide financing for investment in mitigation and adaptation measures to developing countries. This includes loans to support projects and initiatives in the transport sector (see article *The African Development Bank and Climate Change Mitigation in Africa and article Financing Biofuels in Latin America and the Caribbean*, Chapter 7 of this report).

A number of nationally-based financing instruments also exist, including: the Carbon Trust in the United Kingdom, the Green Financing in the Netherlands, and the Energy for Rural Transformation in Uganda. It is notable that the World Bank Group has developed various instruments to trade greenhouse gas (GHG) emission rights among States (see article *Climate Finance – Challenges and Responses: World Bank Perspective*, Chapter 7 of this report). These financing models and financing instruments have been specifically designed for climate change projects. Other funds are also available or currently under development. For instance, the United Nations Environment Programme (UNEP) is working to create a policy and economic framework in which sustainable energy can increasingly meet the global energy challenge.

Recently, the Secretary General of the United Nations established the High-Level Advisory Group on Climate Change Financing (AGF) to study potential sources of revenue for financing mitigation and adaptation activities in developing countries. This funding is expected to tap into a wide variety of sources. In relation to international aviation, the AGF will also consider options relating to fiscal instruments that could apply to this sector.

Financing Mechanisms for Aviation

International aviation currently has no dedicated financial mechanism related to climate change. Because international aviation is not covered by the Kyoto Protocol, it has no access to any of the Kyoto flexible financing instruments such as CIF or CDM. The absence of a structured mechanism does not mean that there are no initiatives or specific examples of financial contributions to support aviation climate change actions.

In the context of the current debate on the possible inclusion of international aviation in a future UNFCCC international agreement, ICAO is actively investigating the appropriate market-based measures and hence mechanisms to meet the goals associated with the aviation sector (see the articles *The African Development Bank and Climate Change Mitigation in Africa* and *Financing Biofuels in Latin America and the Caribbean*, Chapter 7 of this report).

Although international aviation is prepared to implement measures for reducing its climate change impact, it should not be singled out or treated in a discriminatory manner. Any aviation financing mechanism should primarily serve the interests of the sector. This would ensure equity and non-discrimination since international aviation would be responsible for its real impact on climate change.

The ICAO High-level Meeting on International Aviation and Climate Change in October 2009 agreed on, "further elaboration on measures to assist developing States and to facilitate access to financial resources, technology transfer and capacity building". ICAO is the appropriate institution to deal with aviation financing, as it can adapt the financial instruments to aviation specific goals and at the same time assist developing countries, not only financially, but also through technology transfer and capacity building. ■

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www.unfccc.int

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Climate Finance

Challenges and Responses: World Bank perspective

By ***Ari Huhtala***, *World Bank*

***Ari Huhtala** is coordinating and reporting on activities related to climate finance, including work on tracking and monitoring financial flows, cooperating with the UN, OECD and other organizations, and developing a UNFCCC/UNDP/WBG climate finance knowledge platform. He joined the World Bank in 2009 and before that he spent most of his life in development work, first in the field of industrial development and technology/investment promotion and then specializing in environmental financing issues. His experience includes UNDP in Hanoi and Dhaka, UNIDO headquarters in Vienna in charge of programs in Asian LDCs, UNIDO Representative in Bangkok, manager for cleaner production financing at UNEP Paris, environmental advisor to the Finnish Foreign Ministry and Team Leader for a KfW environmental credit line in Indonesia. Ari holds a Masters of Economics from Finland.*

Needs

Additional needs in developing countries to limit global mean temperature rise to +2ºC above pre-industrial levels will grow over the next decades and could, according to the recent World Development Report, reach US$139 to 175 billion per year by 2030. These numbers are estimates of net additional costs of low-carbon interventions over their lifetime, capturing in particular their future benefits (such as fuel savings, local health benefits, etc.). Upfront incremental investment needs at the same time are much higher, ranging from US$265 to 565 billion per year (more than 1% of Gross Domestic Product (GDP) in major emerging economies and other developing countries), and may act as a barrier to climate action given financing constraints. As a reminder, today about 1.6 billion people lack access to electricity. Universal electricity access could be achieved with additional power-sector investment of US$35 billion (International Energy Agency 2009[1]) per year in 2008-2030.

In addition, about US$75 to 100 billion (Economics of Adaptation to Climate Change study, world Bank 2009) could be required annually over the next 40 years to support adaptation to the inevitable impacts of climate change in developing countries. These estimates correspond to the costs to cope with future climate change impacts, over and above the development baseline. One should also consider financing needs for research, development, demonstration and deployment of new technologies as well as capacity building and facilitation of enabling policies, regulatory frameworks, institutions and markets in support of adaptation and mitigation.

The following table summarizes the challenges and possible resources and instruments related to financing mitigation action:

Barriers	Resources and Instruments
Low awareness, capacity and experience of climate risks, of costs and benefits of low-carbon opportunities and adaptation options, of access to climate finance resources and instruments.	**Building an enabling environment** Global Environment Facility (GEF)[2] Trust funds Bilateral Donor Funds Development policy operations
Misaligned, weak or absent regulation and incentives, e.g. absence of an adequate, long-term and predictable price for carbon; counter-incentive subsidies; lack of regulatory framework for renewable energy expansion...	
Chronic lack of long-term funding, e.g. high cost of capital or low liquidity in domestic financial markets.	**Addressing additional costs and risks and leveraging other sources of finance** GEF Least Developed Country Fund (LDCF)[3] and Special Climate Change Fund (SCCF)[4] Adaptation Fund
High (perceived) risks, such as strategic, country, commodity price, technology, or operation risk…	Climate Investment Fund (CIF)[5] Carbon Finance (revenue enhancement) CIF (partial risk guarantees) World Bank Group (WBG)[6] guarantees and structured finance International Finance Cooperation (IFC)[7]

***Table 1:** Examples of Resources and Instruments to Overcome Barriers to Climate Action.*

Response

Developing countries are already taking action by using their own resources. With currently available climate financing covering only 5% of the needs, the political commitment in Copenhagen from developed countries to provide a "new and additional" $30 billion by 2012, and mobilize $100 billion per year by 2020, is a welcome step. These resources must be delivered in full. Combating climate change will require tremendous efforts and ingenuity to mobilize resources at scale, to coordinate their delivery through a combination of policy and finance instruments, and to maximize their leverage on much larger amounts of public and private investments to catalyze a shift towards climate-smart development.

Given the size of the resource gap and the diversity of needs, both public finance (from domestic and international sources) and market instruments (particularly carbon markets) will play an important role. Both will help address the additional costs and risks of climate action, making low-carbon and climate-resilient options more attractive and accelerating transformation of development pathways. In addition, public finance will help build momentum for climate action by piloting innovation and generating experience, and by creating an enabling environment and building capacity.

Drawing on its experience in economy-wide support to governments on sustainable development and policy reforms and in emerging climate finance instruments, the World Bank Group (WBG) has responded to a growing demand from developing client countries in climate-smart investments as well as institutional and policy measures. This includes in particular:

- Strategic policy support including contributing to creating an enabling environment for climate-friendly action;
- Investing in climate resilience and low carbon growth;
- Mobilizing, and facilitating access to, the resources of climate finance;
- Pursuing innovation in carbon finance for larger impact on sustainable development;
- Exploring innovative application and combination of instruments to maximize the leverage of both development and climate finance; and
- Strengthening knowledge and capacity base.

Instruments

Recognizing that transformative changes in the way development interacts with climate would require resources at a larger scale and greater flexibility, several multilateral development banks worked together to establish the **Climate Investment Funds (CIF)** in 2008. The idea was to **leverage climate smart investments at a scale** that has not been possible before.

Designed through extensive consultations, the CIF is governed by a balanced representation of contributing and recipient countries, with the involvement of UN agencies, GEF, the Adaptation Fund, bilateral development agencies, the private sector, and civil society. Thirteen investment plans have already been endorsed under the CIF's Clean Technology Fund (CTF[8]) resulting in a total financing envelope of about $40 billion, leveraging the CTF contribution nine-fold, of which one-third is private sector resources. The other CIF component, the Strategic Climate Fund, comprises the Pilot Program for Climate Resilience (PPCR[9]) and the two newest programs: the Forest Investment Program and the Scaling up Renewable Energy Program for low-income countries.

Given the size of the resource gap and the diversity of needs, both public finance and **market instruments** will play an important role. Having pioneered the carbon market and managing US$2.5 billion in **carbon funds**, the World Bank Group continues to test innovative approaches. The Forest Carbon Partnership Facility (FCPF[10]) assists with country readiness and provides incentives for reduced emissions from deforestation and forest degradation (REDD[11]). Much of the focus in our carbon finance work is on equity and facilitating access by poorer countries: while Africa accounts for only 2-3% of all Clean Development Mechanism (CDM[12]) projects in the world, it represents 20% of projects in the World Bank's carbon finance portfolio. The Carbon Partnership Facility (CPF[13]) that was launched in Copenhagen last December is designed to support programmatic and sector-wide interventions and broaden the impact of carbon finance on climate-friendly investment choices.

In addition to dedicated financing, **risk-mitigation tools** can help mobilize additional long-term capital and lower borrowing cost. This is by increasing investor and lender confidence. The International Finance Corporation (IFC), the private-sector arm of the World Bank Group, facilitates investments in clean technologies through several risk-sharing products, as well as via an integrated investment-advisory platform.

It is vital to share lessons of successful innovations for wider replication adjusting to national and sectoral circumstances. The **Climate Finance Knowledge Platform**, currently being developed jointly by UNDP[14] and WBG, in close collaboration with the UNFCCC[15] Secretariat, is such an example: the platform seeks to provide comprehensive information, knowledge and guidance to investment planners and project managers in developing countries on enabling policies, examples of successful combination of different instruments, information on such funds and tools to improve the quality of decisions.

Conclusion

Whatever future climate finance structure emerges, it should **support recipient country priorities**. It should channel resources quickly and efficiently, tailor financial products to project needs, and maximize synergies between development and climate finance. Dedicated climate funds are not the full solution to the problem of financing climate change mitigation, but an important way of filling gaps, supporting the overall development efforts of developing countries towards lower emission paths and catalyzing finance from public and private sources.

Increasingly, reliable, comprehensive and transparent **reporting** is needed to demonstrate that new climate finance instruments are not introduced at the expense of those targeting other objectives. Exact and comparable figures on additional contributions to fund incremental expenses will probably not be possible, but there is scope in developing and improving the OECD DAC Rio[16] Markers and portfolio monitoring tools in Multilateral Development Banks. The World Bank is currently developing a system to monitor adaptation and mitigation co-benefits in its portfolio.

The Secretary General of the United Nations has established a High-Level Advisory Group on Climate Change Financing (AGF[17]) which is currently reviewing a wide variety of options (including possible indirect taxes on international aviation and maritime activities) for further consideration by the Parties in future climate negotiations, with a view to finding sustainable **international climate finance architecture**. In this process, the experience by the multilateral development banks in delivering and leveraging finance and supporting implementation is worth looking at to clarify what works, when, and why. ■

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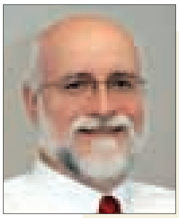
Financing Biofuels in Latin America and the Caribbean

By ***Arnaldo Vieira de Carvalho***



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Introduction

Latin America and the Caribbean (LAC) region has one of the cleanest energy matrices in the world. The region relies on renewable energy for 30% of its total primary energy demand, compared with a figure of 13% for the world and 7% for the OECD countries[1]. Renewable energy is responsible for 70% of the region's total net electricity generation, compared with 18% for the rest of the world and 15% for the OECD.

The Inter-American Development Bank (IDB) is the oldest regional development bank and the main source of funds for the LAC region. Over the last 50 years the IDB has contributed more than US$26 billion in loans and guarantees for the energy sector across the region, including biofuels, which amounts to about 14% of IDB's total lending for all sectors. Financing of hydroelectric projects makes up the bulk of its cumulative energy loans portfolio, accounting for about one third of IDB's total energy lending.

Nevertheless, there is still plenty of room for a much improved renewable energy scenario for the region, motivated by climate change pressures combined with the abundance of competitive renewable energy sources, including biofuels. To support these kinds of projects, the IDB has several funding mechanisms available that can be used; in particular, it has loans and guarantees (US$15.5 billion in 2009, for all sectors), as well as its non-reimbursable technical assistance program (US$530 million in grants in 2009, for all sectors).

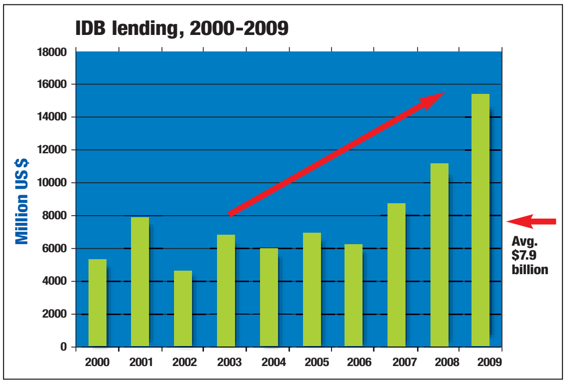

Figure 1: *IDB Historical Lending to LAC – 2000 to 2009.*

The IDB's Sustainable Energy and Climate Change Initiative fund (SECCI) has dedicated one of its four pillars exclusively to biofuels. This has been extremely useful in promoting the development and use of biofuels in LAC, for both private and public sector clients.

Biofuels Use In LAC

Brazil's ethanol program is world renowned for displacing more than half of the gasoline consumption in that country. In addition, Colombia, Peru, Paraguay, Costa Rica, El Salvador and Jamaica are among the countries that are implementing ambitious plans to expand biofuel production and domestic consumption in the near term.

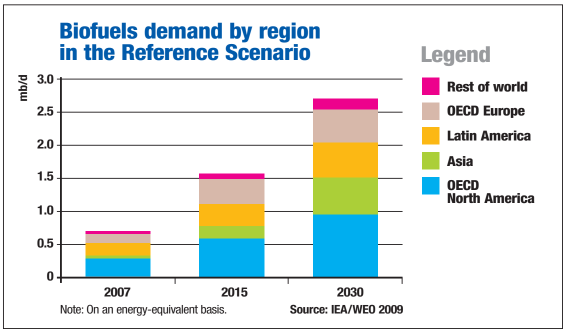

Figure 2: *Future relevance of biofuels in LAC, compared with rest of world – 2015 to 2030.*

In the longer term, LAC will continue to play a major role in the biofuels world arena, as shown in Figure 2, as published originally by IEA WEO-2009.

Supporting Biofuels in LAC - Lessons Learned

In addition to financing the private sector in building the biofuels production infrastructure — such as the Brazilian CNAA ethanol plants project illustrated in Figure 3 — it is also necessary to support the public sector with grant-financing to help access specialized advisory services. This is especially important for the energy and agriculture ministries of the various countries so that they can make informed decisions about the preparation and implementation of their sustainable biofuels programs.

Inter-American Development Bank-IDB

Press Release

July 23, 2008

IDB lends US$269 million for three Brazilian ethanol plants

The Inter-American Development Bank will lend $269 million for three new ethanol plants in south-central Brazil, in the **largest biofuel investment ever made by a development bank.** The Board of the Bank unanimously approved the financing today.

The three plants are being developed by Companhia Nacional de Açúcar e Álcool (CNAA), a joint venture formed by Brazilian sugar producer **Santelisa** Vale, U.S. private equity firms and **Global Foods**, a holding company registered in the Netherlands Antilles.

The three **new plants** are being built in the states of **Minas Gerais and Goiás**, far from the Amazon or any protected areas. Instead of purchasing land outright, CNAA will lease it from owners of medium to small-sized plots who decide they can earn a better return from sugar cane than they can from low-intensity pasture—the area's predominant land use at present.

The new plants will use **mechanized harvesting** for more than 90 percent of their acreage, and they will provide some 4500 high-quality permanent jobs. The plants will produce up to **420 million liters of ethanol** for the domestic market each year, and will generate their own electricity by burning bagasse (**56 MW each**).

Figure 3: *Press release – IDB funding of three Brazilian ethanol plants.*

When deciding whether to fund biofuel projects, the issue is not whether the biofuels are good or bad, but whether they are sustainable. The IDB is committed to ensuring that biofuel production is socially and environmentally sustainable. To determine this, in addition to its stringent environmental and social safeguard criteria, IDB applies its *Biofuels Sustainability Scorecard*, which was developed in close collaboration with major public and private sector players in the biofuels market (see **www.iadb.org/biofuelsscorecard**).

When produced in a sustainable way, biofuels are an economic alternative to gasoline and diesel fuel. They are an effective means to: reduce emissions of pollutants and greenhouse gases, create jobs and reduce rural poverty. Consequently, the development, production and use of sustainable biofuels is an excellent way to contribute to the LAC's social and economic sustainable development.

For that reason, the IDB is working with more than half of its borrowing Member Countries, (i.e. Argentina, Brazil, México, Colombia, Chile, El Salvador, Honduras, Guatemala, Dominican Republic, Haiti, Guyana, Suriname and Paraguay), to help them make informed decisions about their biofuel programs. They are advised by experts financed by IDB on the most effective ways to: attract investments, identify alternatives that generate new jobs, reduce poverty and improve quality of life in rural areas, while contributing to the reduction of greenhouse gases emissions.

In parallel, the IDB collaborates closely with the US and Brazil on their Biofuels Initiative for third countries program, which specifically benefits Haiti, Honduras, Guatemala, El Salvador and the Dominican Republic. The development of information such as that indicated in Figure 4 was funded by IDB to guide the decisions of participating countries on where to grow different biofuel energy crops.

Next-generation Biofuels

In addition to supporting activities to develop first-generation biofuels with long-term prospects, the IDB has started promoting next-generation biofuels initiatives as well. Grant-financing is being used to support ForEnergy S.A., a public-private partnership of ENAP Refinerías S.A. and Consorcio Maderero S.A. from Chile. In association with a local R&D institution, they have put together the Biocomsa Consortium to build a facility for producing hydrogen and steam from woodchips and biomass residues via gasification.

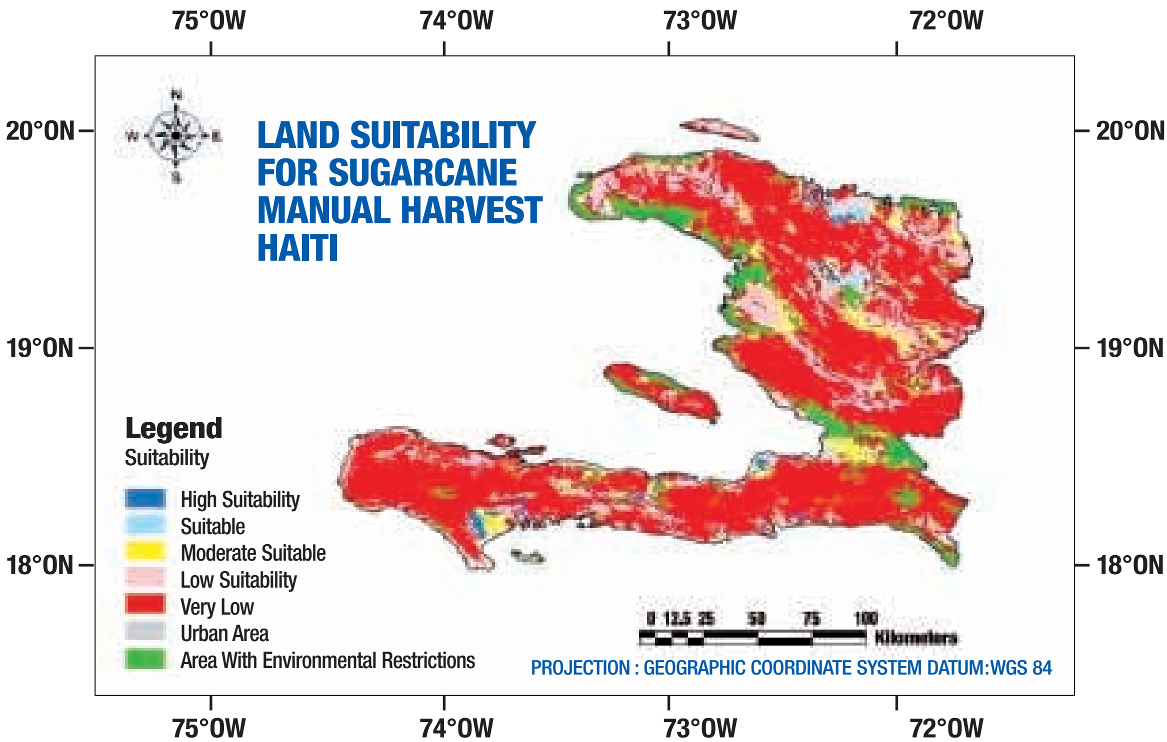

Figure 4: *Land suitability map for biofuel crop development. (ref. Fundação Getulio Vargas - FGV).*

Eventually, the hydrogen produced by this project will be converted into a variety of biofuels using the Fischer-Tropsch process. If the pilot project is successful, Biocomsa will scale-up its plant as the second phase of the project.

The Renewable Jet Fuel Market

The new biofuels aviation fuel niche market will offer an excellent opportunity for LAC to play a leading role in the near future.

One of the options for airlines to meet the CO_2 reduction targets established by ICAO is to develop alternative fuels that would also help the industry be more competitive by reducing jet fuel price volatility. The aviation industry has established groups such as the Commercial Aviation Alternative Fuels Initiative (CAAFI) to promote the development of greener aviation fuels (see **www.caafi.org**).

This initiative provides LAC with an opportunity to develop competitive value-added products which will contribute to social and economic development and increase the numbers of local jobs. Because feedstock production accounts for about 80% of the total cost of producing alternative jet fuel, such costs will be lower in LAC countries compared with other parts of the world; particularly the OECD countries.

Most importantly, this new biofuel market niche appears to have a much better integrated and coordinated stakeholder support structure than the traditional gasoline and diesel sectors. With its strong environmental component, the biofuel sector is expected to encounter fewer barriers, making it a candidate for rapid development in LAC and elsewhere.

LAC Aviation Industry Is Motivated

LAC-based airlines are currently planning numerous biojet fuel demonstration/test flights for 2010, involving both cargo and passenger aircraft. The various market players are looking forward to these developments as a way to stimulate investment and provide sustainable development for LAC.

For more information on alternative fuels, please see **Chapter 5** of this report.

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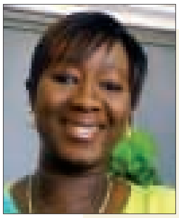
The African Development Bank and Climate Change Mitigation in Africa

*By **Nogoye Thiam** and **Balgis Osman-Elasha,** African Development Bank (AfDB)*



***Nogoye THIAM** is a Climate Change Mitigation Expert at the African Development Bank. She has wide experience in climate change and energy field. Dr. THIAM has contributed to the IPCC 4th Assessment Report WG III (Mitigation of climate change). Among her major publications in the energy sector is: **Towards a Sustainable Energy System for Africa**- in "Facing Global Environmental Change, Environmental, Human, Energy, Food, Health and Water Security Concepts", Springer 2009.*

***Balgis Osman-Elasha** is a Climate Change Adaptation Expert at the African Development Bank. In addition to her doctorate in forestry science; she has more than 10 years of professional knowledge and experience in climate change issues. She was one of the lead authors for the "4th Assessment Report WG II (Vulnerability & Adaptation Assessment)". Dr. Osman-Elasha also functioned as a coordinating lead author collating the "International Assessment of Agricultural Science and Technology for Development (IAASTD).*

Introduction

Africa is responsible for the production of about 4 per cent of the world's greenhouse gases, but it is expected to bear the biggest share of the climate change impacts. The continent's diverse climates and ecological systems have already been altered by global warming and will continue to face more damaging impacts in the years ahead.

In the process of development, Africa will increasingly need energy and under a business as usual scenario, with high reliance on fossil fuels, this will result in the generation of more GHG emissions. Without proper and timely mitigation measures this situation could put Africa among the major future GHG emitters. On the other hand, Africa has a good opportunity to be part of the solution to climate change through following a more sustainable development path leading to the reduction of global GHG emissions.

The transition to a low-carbon future can bring major economic gains and huge benefits beyond climate change impacts for Africa which may be seen in the short as well as the long term. For example, energy efficiency can open up new sources of growth and jobs. Renewable energy sources can free countries from a dependence on imported fossil fuels and cleaner transport means less pollution and better health.

AfDB's efforts to combat climate change

Strategies and action plans

The African Development Bank (AfDB) is currently supporting African governments in integrating climate issues into economic planning and management at both the national and regional levels, not least through high-level inter-ministerial coordination. The response measures by the Bank include inter alia the development of a number of climate change action plans and strategies such as:

- The **Climate Risk Management and Adaptation (CRMA)** strategy, which aims at achieving climate proofed initiatives by developing policy, legal and regulatory reforms; knowledge generation and capacity building.

- The **Climate Change Action Plan**, which guides the implementation of the Bank's climate change related strategies. It will also act as a road map for the Bank's actions related to climate change at different levels from policy and advocacy development to on-the-ground projects in key sectors such as: agriculture, water, energy and transport.
- The Bank is also promoting investment in clean energy projects and therefore, it has developed a **Clean Energy Investment Framework (CEIF)**. The Framework guides the Bank's investments in expanding energy access in Africa, particularly for the poor, and creates a shift in energy investments favoring low-carbon development paths.
- The Bank is in the process of developing a **Green Growth Strategy**, which aims at supporting and promoting low carbon, climate change-resilient investment in African countries. With appropriate financial and technical support, a low carbon growth path could offer great opportunities for Africa to make use of its comparative advantages, such as in forest resources, hydro and solar potential, bio-energy, and improved land use systems

Sustainable transport

According to the Intergovernmental Panel Climate Change (IPCC)[1], the transport sector, in 2004, was responsible for 23% of world energy-related GHG emissions with about three quarters coming from road vehicles. The increase in population and housing growth in the suburbs have contributed significantly to longer journeys for many people and have led to more energy use resulting in further increase in greenhouse gas emissions which contributes to climate change. This phenomenon is also true in Africa, where economic prosperity and population growth have led to an increase in transport activity and car ownership.

To tackle this situation and to help African countries to go low-carbon, several AfDB-financed projects and initiatives in the transport sector have been developed. In addition, the bank is supporting the development of bio-fuels projects as substitutes for fossil fuels which are increasingly leading to financial and environmental insecurity.

Specific interventions for reducing pollution and greenhouse gases from the transport sector

Local rail services are vital for creating sustainable communities, as they help boost long term economic prosperity while managing demand for car travel, and hence carbon emissions. The bank supports several regional rail projects (e.g. Dar Es Salam- Isaka-Kigali/Keza-Musongati railway project, Nairobi Metropolitan Transit System, High Speed railway project Tanger-Kenitra etc.).

Increasingly, airport projects at the Bank are accompanied by the implementation of electrical installations powered by renewable sources of energy, largely by solar energy. This is the case in Morocco where renewable energy from solar panels powers the main parts of the airport. In the Democratic Republic of Congo solar panels have been installed to feed the aviation navigation equipment.

The Bank is aware that the aviation sub-sector is a big contributor to carbon emissions and subsequent climate change and therefore, it has put in place a carbon offsetting program to mitigate the negative impacts on the climate. The program presents an excellent tool to raise awareness of the climate change impacts of aviation, and at the same time to help mitigate its impact by supporting other low carbon activity. To this end, the Bank offsets its carbon emissions from most of its recent meetings and conferences (e.g. Bank's annual meetings, participation in Copenhagen COP 15 meeting etc.). During the last annual meeting held in Abidjan, Côte d'Ivoire, the Bank saved 5665 CO_2-eq greenhouse gas emissions. The offsetting payments are invested in supporting projects that encourage low carbon emissions, such as an efficient fuel-wood stoves project in Nigeria, where in certain regions the irrational use of firewood has led to severe deforestation and desertification.

Experience with biofuels

Some African regions have comparative advantages for bio-energy development. The Bank has already received several requests from a number of African countries, particularly from the private sector, for project financing and is working to respond rapidly to these. However, the Bank recognizes that what works in some countries may not work for another, which is why it emphasizes the need for policies and regulations to control the production of biofuels, and the Bank should take into consideration:

- Undertaking an assessment of each bio-mass resource based on its merits and demerits as a fuel source.
- Understanding implications of the deployment in the large scale of biofuels for land use and deforestation and also for food security, biodiversity and water resources, and assessing the social risks.
- Establishment of an internationally certified environmental and social safeguards systems and practices to facilitate access to international markets.

In light of these concerns, some projects in Africa are under preparation for Bank financing, such as the Addax bio-energy project in Sierra Leone and, the Markala sugar project in Mali.

The Addax project is developed as an integrated bioenergy project near Makeni in Sierra Leone. The first phase of the project aims at establishing a 10,000 ha sugarcane plantation with an 800 ha outgrower scheme. The plantation is expected to generate roughly 800,000 tons of sugarcane per year that will be used to produce: (i) 100,000 m^3 of fuel ethanol for export; and (ii) roughly 20 MW of electricity from biomass, of which 15 MW will be available for sale to the domestic market.

Though Markala is a sugar project, it has an additional component for biofuel production. The project involves establishing a 14,132 ha irrigated cane estate, 275 km northeast of Bamako. The project will have a sugar mill with a cane crushing capacity of 8,000 tons per day, producing 190,000 tons of sugar per annum. It will further produce 15 million liters of ethanol per annum and co-generate 30 MW of electricity.

Conclusion

There is a growing global awareness to this reality, and a good understanding by Africans of the importance of following a sustainable development path with a low-carbon economy. The AfDB is leading Africa's effort in this respect and is increasingly involved in issues related to mitigation of GHG emissions.

The Bank is supporting the development of green projects in Africa as a means to offset and carbon neutralize its emissions resulting from staff's participation in international conferences, and in emissions from big meetings and conferences organized by the Bank.

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Chapter 8

ACT GLOBAL

UNITING AVIATION ON CLIMATE CHANGE

ICAO ENVIRONMENTAL REPORT 2010

Act Global

*By **ICAO secretariat***

International aviation, as a global sector that connects people and businesses across the world, has traditionally relied on the development of global solutions to deal with the challenges it has encountered. To facilitate this, ICAO is the recognized and accepted forum for dealing with all international aviation matters, including environment related issues.

As discussed in various parts of this report, any solution to address international aviation's greenhouse gas emissions will need to include technological innovations, operational improvements, and market based measures, as well as innovative new solutions such as alternative fuels. The trans-boundary nature of climate change and international aviation calls for worldwide cooperation of governments, industry and society to come up with the most appropriate approaches to all of these solutions in order to effectively address the global challenges of mitigating climate change and adapting to its effects.

ICAO does not act alone in its work. As part of the broader United Nations family, it actively seeks to cooperate with all other relevant agencies and bodies (e.g. United Nations Framework Convention on Climate Change (UNFCCC), Intergovernmental Panel on Climate Change (IPCC), United Nations Environmental Programme (UNEP), and the International Maritime Organization (IMO), to name a few) that address work areas that are important for accomplishing the objectives of the Organization. Furthermore, as an active member of the UN Chief Executives Board (CEB), ICAO is committed to ensuring that the UN "delivers as one" through coherent and coordinated efforts in the area of international aviation and climate change. It is also committed to reducing the carbon footprint of the operations of the Organization itself and is currently taking concrete steps toward estimating its contribution to greenhouse gas emissions and is initiating measures to reduce them.

As governments move closer toward the development of a new global agreement to address climate change under the UNFCCC, ICAO has already demonstrated its readiness to contribute to those efforts. Through the first ever agreement by a sector on its greenhouse gas emissions and by setting up a framework for further elaborating targets and approaches, ICAO is leading the way toward the sustainable growth of aviation.

This chapter of the report provides information on: the ongoing efforts of the UN to deliver on climate change as one unified body; the work of the UNFCCC toward the development of a future global agreement on climate change; and the work of the UN and ICAO to lead by example by reducing the environmental impact of their internal operations and moving toward climate neutrality. ■

Liaison With Other UN Bodies

UN System Delivering As One

By ***ICAO Secretariat***

Within the United Nations, climate change has been recognized as a development issue, as well as an environmental one, particularly because it can have a significant impact on the economic growth and poverty alleviation efforts of countries, and the achievement of the United Nations Millennium Development Goals.

The cross-cutting character of climate change underlines the importance of a system-wide response. Addressing climate change has been a major priority of the UN Secretary-General Ban Ki-moon since the beginning of his tenure. Through his efforts, and with the assistance of the United Nations System Chief Executives Board for Coordination (CEB), acting on climate change has become one of the key issues on which the UN delivers a united response.

Since 2007, the CEB has embarked on a major effort to align the strengths of the UN system organizations to achieve a coordinated, action-oriented approach to the global and multifaceted challenge of climate change. In December 2008, the CEB Climate Change Action Framework was presented during the 14th Conference of the Parties (COP14) to the United Nations Framework Convention on Climate Change (UNFCCC) in Poznan, Poland with the publication "Acting on Climate Change: The UN System Delivering as One." The Framework includes five focus points and four cross-cutting areas for collaborative UN system action, reflecting the issues that are being discussed in the UNFCCC setting, with corresponding convening agencies. In addition, information sharing has been enhanced through the facilitation of online knowledge-sharing and the provision of public information tools. More recently, at COP15 in December 2009 held in Copenhagen, Denmark, the CEB reaffirmed the strengths of a joint UN system-wide effort on climate change by presenting a CEB Statement of Purpose and Policy Brief on UN system adaptation efforts to deal with climate change.

In addition to supporting member States to more effectively address the impacts of climate change, the CEB initiative is seen as a "thematic pilot" for the UN system "delivering as one" in response to major global challenges. It also addresses the need to project a coherent and effective institutional framework that can serve the international community in a credible manner.

The ICAO is an integral part of the CEB and has been recognized as the competent specialized agency to set standards and recommended practices for GHG emissions from aircraft. In this role, ICAO has been actively pursuing cooperation with all other organizations involved in work on how to address international aviation and climate change. Examples of such cooperation are given in Table 1.

ICAO is committed to continued contribution to the work of the CEB to ensure that the UN "delivers as one" through coherent and coordinated efforts in this very important area of work. ■

Negotiations On A Future Global Climate Change Agreement

In May 1992, the international community agreed on a framework for addressing climate change through the adoption of the United Nations Framework Convention on Climate Change (UNFCCC). The Convention covers a broad spectrum of issues including reducing greenhouse gas (GHG) emissions from human activities and efforts to adapt to, and cope with, the effects of climate change. Almost two decades later, 193 countries have ratified the Convention, making it a nearly universal instrument.

UN Body	Related Activities
United Nations Framework Convention on Climate Change (UNFCCC)	• Implementation of the Convention and its Kyoto Protocol. • Post-2012 negotiation on climate change. • Kyoto Mechanisms (domestic aviation projects). • Aviation emissions data and methodological issues. • Regular updates to governments on the work of ICAO on climate change, including statements to SBI, SBSTA, AWG-LCA, AWG-KP, CDM Board.
Intergovernmental Panel on Climate Change (IPCC)	• IPCC Assessment Reports. • Special Report on Aviation and the Global Atmosphere (1999). • NGGIP – National Greenhouse Gas Inventory Programme. • Guidelines for National Greenhouse Gas Inventories. • Current information on impacts of international aviation.
United Nations Environmental Programme (UNEP)	• EMG/IMG – Carbon Neutral UN Initiative. • EMG/IMG – Green Economy. • EMG/IMG – Sustainability Management. • Sustainable UN (SUN).
UN World Meteorological Organization (WMO)	• Adaptation. • Data collection. • CAEP technical input.
UN Chief Executives Board for Coordination (UN CEB)	• Coordination of UN efforts on climate change. • Participation in high level meetings. • Statements on climate change mitigation.
UN Commission on Sustainable Development (UN CSD)	• Agenda 21 and further developments. • Rio+12.
UN World Health Organization (WHO)	• Health impacts from aviation.
International Maritime Organization (IMO)	• Addressing GHG emissions from international maritime transport. • Coordination on implementation of Kyoto Protocol Art. 2.2. • Post-2012 negotiation on climate change. • Market-based Measures for international bunkers emissions.
UN World Tourism Organization (UNWTO)	• Aviation environmental policies and tourism.
UN Economic Commission for Europe (UNECE)	• Conferences on transport and environment.
UNECE Convention on Long-Range Transboundary Pollution (CLRTAP)	• Protocols on substances – NOx, Volatile organic compounds (VOCs).
Ozone Secretariat (Montreal Protocol)	• Updates/guidance regarding Montreal Protocol for the depletion of Ozone. • Scientific Assessment Panel. • Aviation's use of halons for fire fighting.

Table 1: *UN cooperation on aviation and climate change.*

Kyoto Sets the Tone

The Kyoto Protocol to the UNFCCC, which was adopted in 1997, shares the Convention's objective, principles and institutions and constitutes a first attempt to set legally-binding greenhouse gas emission reduction and limitation targets for 37 industrialized countries and the European community. The resulting emissions reductions amount to an average of five per cent below 1990 levels over the five-year period 2008-2012.

The Kyoto Protocol commitments can be met through the implementation of national measures and the use of three market-based mechanisms (emissions trading, clean development mechanism and joint implementation). These mechanisms help stimulate green investment and help industrialized countries meet their emission targets in a cost-effective way.

This system is complemented by reporting and review procedures, which aim to ensure the accuracy of the information provided on the efforts of countries, and a compliance system that ensures that countries are meeting their commitments.

Building on the Convention and the Kyoto Protocol

Since 2005, the work under the Convention and the Kyoto Protocol has focused on long-term cooperative action to address climate change over the coming decades addressing five key elements: mitigation, adaptation, financing, technology transfer, and capacity building. It is anticipated that the outcome of this process will be a new global agreement on climate change that will ensure the sustainable development of our societies.

At the UN Climate Change Conference in 2005, Parties to the Kyoto Protocol initiated a process to consider further commitments of developed countries for the period beyond 2012. The resulting decision established the "Ad-hoc Working Group on further commitments for Annex I Parties under the Kyoto Protocol" (AWG-KP) to conduct this process and report annually on the status of this process.

The UN Climate Change Conference in December 2007 culminated in the adoption of the Bali Roadmap which consists of a number of forward-looking decisions that represent the various tracks that are essential to strengthen international action on climate change. Central to the Bali Roadmap is the establishment of a process to enable full, effective and sustained implementation of the Convention through long-term cooperative action up to and beyond 2012, known as the Bali Action Plan (BAP). It focuses on five key elements: a shared vision for long-term cooperative action, mitigation efforts by both developed and developing countries, adaptation efforts, investment and financial needs, and development, deployment, dissemination and transfer of technology. Discussions on these topics take place in the "Ad-hoc Working Group on Long-term Cooperative Action under the Convention" (AWG-LCA) negotiating group .

Addressing Aviation Emissions

Emissions from international aviation include over-flight of potentially multiple States and the high seas, making them difficult to assign to a particular State. Recognizing the complexity of how to address these emissions, the Convention and the Kyoto Protocol excluded them from countries' national totals and from the reduction/limitation commitments. Specifically for the Kyoto Protocol, Article 2.2 requires industrialized countries to pursue the limitation or reduction of GHG emissions from international civil aviation through ICAO.

The issue of how to address GHG emissions produced by international aviation has been on the agenda of the UNFCCC negotiation process both under the AWG-KP and AWG-LCA. During the negotiations, governments have debated how to reconcile the principle of non-discrimination under the Chicago Convention (which established ICAO) with the principles of common but differentiated responsibilities (CBDR) and respective capabilities under the UNFCCC and the Kyoto Protocol. In relation to setting emission reduction targets for international aviation, some countries favoured a negotiating process under the UNFCCC while others supported the coordination of all aspects of the work by ICAO.

Regarding implementation, the negotiations have centred on the possible use of cooperative sectoral approaches and sector specific actions for the international aviation sector, and the possible development of instruments for financing mitigation and adaptation activities using funds collected through fiscal policies (e.g. levies) for international aviation.

The political outcome of the 15th Conference of the Parties to the UNFCCC (COP15), which is reflected in the Copenhagen Accord, does not contain any references to how international aviation emissions could be treated. Given this situation, ICAO has the opportunity to make further progress on the recommendations of its High-level Meeting on International Aviation and Climate Change and Conference on Aviation and Alternative Fuels, in support of the negotiation process on a future climate change agreement. ■

Achim Steiner

- UNEP Executive Director, (United Nations Environment Programme)
- United Nations Under-Secretary General
- Director-General of the United Nations Office at Nairobi

The Green Economy Is It Time for Take Off?

The notion that Bertrand Piccard's Solar Impulse aircraft, which recently flew day and night using solar cells, could one day carry passengers and cargo around the globe in a new and environmentally-friendly way may seem ridiculous to some right now.

But one is reminded of the sketch by American comedian Bob Newhart that features an imaginary chat between an entrepreneur and the Wright Brothers about commercializing their new aeroplane more than a century ago. When told that the plane would have to touch down every few minutes, the promoter queries whether the inventors really think this will attract customers on proposed scheduled package flights to Florida!

Little could our fictional promoter have known about the way that aviation would rapidly evolve over the next 100 years. The challenges of the early 21st century have also evolved and are increasingly driving the aviation industry to find solutions to a wide range of environmental problems including climate change. Over the past two years, ICAO and UNEP have been increasingly collaborating on this issue, particularly in the area of the United Nations and its carbon footprint.

The UN's Environmental Management Group, at the request of the UN Secretary-General, has pinpointed that over 50 per cent of the organization's carbon footprint relates to travel, including air travel. Together our two agencies have worked closely on a carbon emissions calculator aimed at measuring and reducing the UN's emissions. The calculator may also be able to assist businesses and individual citizens become part of the climate solution too.

Some airlines and aircraft manufacturers are taking on this challenge as well. ICAO has a critical role to play in bringing together governments and the regulatory frameworks. Indeed, the signals sent out to the marketplace by policymakers are pivotal to bolstering the enthusiasm of industry and business to invest in transformational technologies, innovation, and research.

ICAO's work includes a programme of action that has set a two per cent annual improvement in fuel efficiency. Areas that are being examined for efficiencies include the management of air traffic and airports. Innovations such as the potential role of biofuels and other substances such as fluorinated gases are also coming rapidly into the picture. UNEP and ICAO are cooperating in all of these areas.

A future global economy needs to achieve a balance between growth and the legacy that growth leaves behind for the next generation. Aviation has a significant role to play in realizing that transition to a low carbon, resource efficient Green Economy.

Before the Wright Brothers, the idea of manned powered flight was nothing more than a fantasy. Today, the challenge is no longer manned powered flight, but rather, environmentally-friendly flight. With the right market signals stimulating investment and human ingenuity, the sky is the limit. Piccard's solar powered plane—and the other sun-powered aircraft that have taken to the air in recent years—may look like a fantasy today, but who knows. They once said the same of Orville and Wilbur's invention over a century ago.

International air transport and the global effort to address climate change

Christiana Figueres

Executive Secretary of the United Nations Framework Convention on Climate Change (UNFCCC)

Science has spoken clearly – drastic reductions of emissions of greenhouse gases (GHGs) are needed in all sectors to effectively address global climate change.

International aviation is an important global sector for trade and for the world's economy, and is a significant contributor to the emissions that cause climate change. If left unchecked, aviation's current and projected growth are very likely to have further impacts on climate.

ICAO was entrusted by governments which are Parties to the Convention and its Kyoto Protocol to work on limiting and reducing the greenhouse gas emissions from international aviation. In response, ICAO agreed on a global aspirational goal to improve the fuel efficiency of international civil aviation by two percent annually and its States endorsed a Programme of Action on International Aviation and Climate Change that is under implementation. Work has started on development of a carbon dioxide Standard for new aircraft engines.

Building upon the recommendations of the High-level Meeting and Alternative Fuels Conference held last year, ICAO continues its work to achieve further progress toward the 37th ICAO Assembly in September 2010 and beyond, in particular on three areas: exploration of more ambitious goals; development of a framework for market-based measures; and elaboration on measures to assist States.

The measures that the Assembly may consider — such as a medium-term goal on carbon-neutral growth, long-term goals on carbon emissions reductions and market-based measures operating across national borders - could reverse the trend of emissions from international aviation. The development of a global framework for market-based measures in international aviation would avoid the patchwork or duplication of such measures.

Under the United Nations Framework Convention on Climate Change (UNFCCC), governments are now developing a text on cooperative sectoral approaches and sector specific actions in international aviation and maritime transport that will continue to be the focus of discussions in the run-up to Cancun, where the next UN Climate Change Conference will be held at the end of the year. Government proposals build on the uniqueness of this sector, and include clarifying the principles that should guide this work, setting of sectoral targets and working through ICAO to achieve these targets, and defining the possible use of revenues generated by market-based measures.

One challenge that remains to be addressed is that ICAO is based on the principle of non-discrimination, while the United Nations Framework Convention on Climate Change (UNFCCC) is based on the principle of common but differentiated responsibilities. Innovative thinking and solutions are needed to reconcile these principles. Developed countries must lead in reducing emissions, while developing countries need support to engage in mitigation actions.

Market-based measures can reconcile the principles of ICAO and the UNFCCC by raising funds for adaptation and mitigation in developing countries through, for example, a global cap on aviation bunker fuels, as well as by deploying revenues from emissions rights auctions. A global cap on bunker fuels would be in line with the 'equal treatment' principle of ICAO, and using the revenues to assist developing countries in addressing climate change would be in line with the provisions of the UNFCCC.

ICAO has traditionally recognized the different circumstances among Member States' capacity to respond to climate change and the need to assist them either through technical and financial support or via differentiated timelines for the implementation of measures. To this end, possible areas to further explore include exemptions from market-based measures of small- or transitional rules for larger-size commercial air operators from developing countries and use of revenues for supporting the introduction of sustainable biofuels for aviation in developing countries.

Informing the Conference of the Parties on practical actions for regulating GHG emissions from international aviation would make a significant contribution towards a global climate change strategy for the sector and to a successful outcome in Cancun. Government representatives at the UNFCCC Conference are looking forward to receiving input from ICAO.

Greening the Blue:
Moving the UN Towards Climate Neutrality…

By ***Aniket Ghai and Niclas Svenningsen***

***Aniket Ghai**, a Kenyan national, works at UNEP's Environment Management Group secretariat, where he coordinates its work on a Green Economy and formerly coordinated the UN system's move towards climate neutrality. He has been employed by UNEP for the past eleven years, during which he set up and ran the Geneva Environment Network, led UNEP's first-ever assessment of the Palestinian environmental situation, and implemented a programme of environmental capacity building for Palestinians and Israeli-Palestinian environmental cooperation.*

***Niclas Svenningsen** is the head of the Sustainable United Nations (SUN) at the United Nations Environment Programme (UNEP), based in Paris, France. SUN is coordinating the implementation of the UN climate neutral strategy across the entire UN system. He is also responsible for UNEP's work on sustainable buildings and construction, as well as UNEP's urban program, and sustainable public procurement program. He has a background in civil engineering, environmental law and journalism. He has spent the past 20 years working on various sustainable development issues in the developing world both for the UN and as an independent consultant.*

Climate change is a key priority for the United Nations (UN) to address. In the mandates of different UN organizations – ranging from peace keeping, public health and emergency assistance, to biodiversity, poverty alleviation, economic development, and specialized agencies such as ICAO – climate change has significant importance. In other words, climate change is much more than a simple environmental issue for the UN and most of its affiliated organizations are currently working with different aspects of climate change in their various programmes and projects.

But the question arises, what is the UN doing about its own carbon footprint? How credible can the UN be in its programmes and activities if it does not practice what it preaches to others?

From Preaching To Practice

UN Secretary-General Ban Ki-moon has repeatedly emphasized the need for the UN to 'walk the talk', in particular, on key issues such as climate change. Following this call by the Secretary General, in October 2007 the UN Chief Executives Board adopted the UN Climate Neutral Strategy. This Strategy committed all UN agencies, programmes and funds to achieve three goals by the end of 2009:

1. Estimate the annual greenhouse gas emissions, consistent with accepted international standards.
2. Undertake efforts to reduce our greenhouse gas emissions.
3. Analyze the cost implications and explore budgetary modalities of purchasing carbon offsets to eventually reach climate neutrality.

The above were adopted in the context of greening the UN in general, and in particular, of improving the resource efficiency of UN organizations.

The implementation of the UN Climate Neutral Strategy is the responsibility of each UN organization but the Environment Management Group (EMG) was tasked to oversee and report on the implementation of the strategy. The EMG is an inter-agency group that facilitates coordination and cooperation among UN organizations on environmental matters. In order to support on-the-ground inter-agency cooperation, the Issue Management Group on Sustainability Management (IMG) was established under EMG with one representative from each UN organization assigned to assist in jointly developing tools and approaches needed to implement the climate neutral strategy.

The Sustainable UN (SUN) facility provides technical support to all UN organizations to identify and realize opportunities for emissions reductions. SUN also extends the same support to organizations outside the UN, in particular, to public organizations in developing countries. In this context, ICAO plays an important role in providing tools and training and in supporting approaches for calculating and reducing the UN's climate footprint from air travel.

Setting The Boundaries

One of the first challenges for the UN climate neutral strategy was to determine what activities should be included when calculating greenhouse gas emissions from the organization. UN organizations typically include a wide range of functions and activities, from office work and administration, to meetings, travel and transport, to field operations, emergency assistance, and peace keeping missions. It was decided by the EMG members that the UN would use the Greenhouse Gas Protocol (a widely used methodology, developed by the World Resources Institute and the World Business Council for Sustainable Development) to calculate emissions. This basically says that activities over which the UN has management (financial) control should be included in the organizations' greenhouse gas inventories.

This means that, for example, when UN organizations plan meetings they must include in their greenhouse gas inventories the emissions from travel to the meeting of all participants for whom the UN paid the travel. The climate footprint of participants who paid their own way to the meeting is not included. The air travel related part of the inventory is computed using the ICAO Carbon Emissions Calculator.

UN and the ICAO Carbon Emissions Calculator

For nearly every UN body, the emissions from air travel are the single largest source of their carbon footprint (usually more than 50%). As a result, it is important that the best possible estimate of these emissions be calculated as accurately as possible.

Since ICAO had developed an internationally approved Aviation Carbon Emissions Calculator, it was decided by the IMG to use the same calculator within the UN to estimate CO_2 emissions from air travel. Thus, UN organizations provided ICAO with sample sets of data taken from their travel booking systems, which were then used by ICAO to build a prototype interface to its aviation carbon calculator tailored to the needs of the UN officers involved in the preparation of carbon inventories. (for more information on the development of the ICAO Carbon Emissions calculator, see article *The ICAO Carbon Emissions Calculator,* Chapter 1 of this report *).*

Thanks to this coordinated approach, in December 2009 the UN released its first ever common greenhouse gas inventory. This inventory reported on emissions from 49 UN organizations, including ICAO, showing a total climate footprint of 1.7 million tons CO_2 equivalent in 2008 (see Figure 1). About 50% of this comes from travel, while the remaining parts are split mainly between operation of offices, electricity use, and fuel use by ground transport.

Many UN organizations have already begun to seek ways to reduce their emissions and IMG is now working to produce draft emission reduction plans for all UN organizations by the end of 2010, to be presented and hopefully adopted by their governing bodies in 2011.

From Sources To Causes

In tackling emissions, it is not enough to simply know the sources of greenhouse gases. It is also necessary to understand their causes. For example, the causes of emissions from heating an office may range from the performance of the heating system and insulation of the building envelope, to the choice of energy supply and the setting of indoor target temperature, to attitudes of staff, and the training of technicians. Opportunities for efficiency improvements and greenhouse gas emission reductions are often found in

Key figures 2008	
Total emissions	1'741'413 t CO_2eq
Emissions per staff member	8.4 t CO_2eq
Air travel per staff member	4.0 t CO_2
Number of staff	206'954

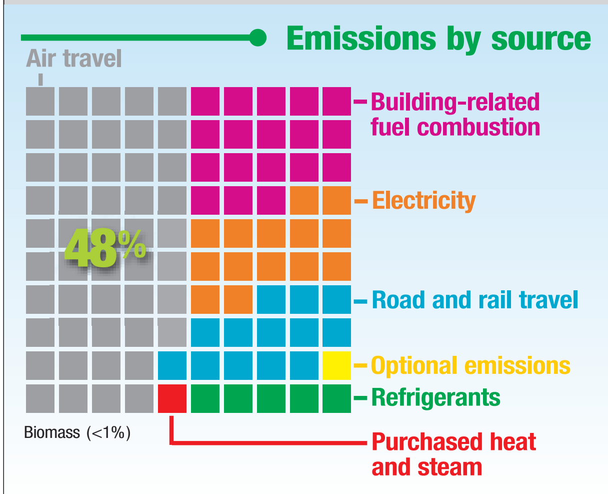

Figure 1: *Total GHG footprint and key performance indicators from UN system facilities, travels of officials, and peacekeeping operations.*

areas as diverse as: management systems, procurement, training, facilities management, travel policies etc. The bottom line is that one needs to know both the sources and the causes of emissions to be able to reduce them.

SUN and IMG are developing a range of tools and services to guide organizations in their climate neutral pursuit. All of these tools, along with more than 60 case studies about ongoing sustainability work throughout the UN system, tips, best practices, links, and other resources are now available on the UN's new common sustainability website "*Greening the Blue*" (**www.greeningtheblue.org**).

What's Next?

The first two years of implementation of the climate neutral strategy has demonstrated that climate neutrality is a realistic and attainable objective for the UN. Not only is it a chance to walk the talk on climate change, but it is also an opportunity to improve the efficiency of many aspects of the organization's work. However, to achieve the climate neutral goal also requires dedication and investment of time of staff and management alike.

Over the next year a number of initiatives will be undertaken, including: the second annual greenhouse gas inventory will be conducted, a first generation of emission reduction plans for all organizations will be prepared, and a blue print will be drawn up for how climate neutrality and sustainability may be integrated into the organization through a common approach to sustainability management systems. Greening the UN is off to a good start, but much more remains to be done before the organization can truly claim to walk the talk on climate change. ■

Moving ICAO Toward Carbon Neutrality

By ***ICAO Secretariat***

As described in the article *Greening the Blue – Moving UN Towards Climate Neutrality* (Chapter 8 of this report), the United Nations has adopted a climate neutral initiative (CNUN). As a UN agency, ICAO has supported this initiative from the beginning and is actively working to reduce its own climate footprint. This article provides an overview of ICAO's efforts to date towards its goal of eventually achieving climate neutrality through carbon neutrality.

ICAO's Approach To Climate Neutrality

Carbon neutrality is not a static condition but the result of an active and dynamic process, as described by the UN Issue Management Group (IMG) on sustainability management. As defined by the IMG, the UN system follows a systematic approach toward climate neutrality that includes the following three fundamental steps shown in Figure 1:

1. **Measure** the organization's footprint.
2. **Reduce** greenhouse gas emissions by developing targeted goals and strategies.
3. **Offset** the remaining annual emissions by purchasing offset credits certified to a transparent and consensus based standard.

To date, ICAO has focused its work on the first two steps of the process described above, while discussions continue throughout the UN on how best to implement the third step.

Step 1: Measure

In 2009, for the first time, the ICAO Secretariat estimated its total climate footprint.

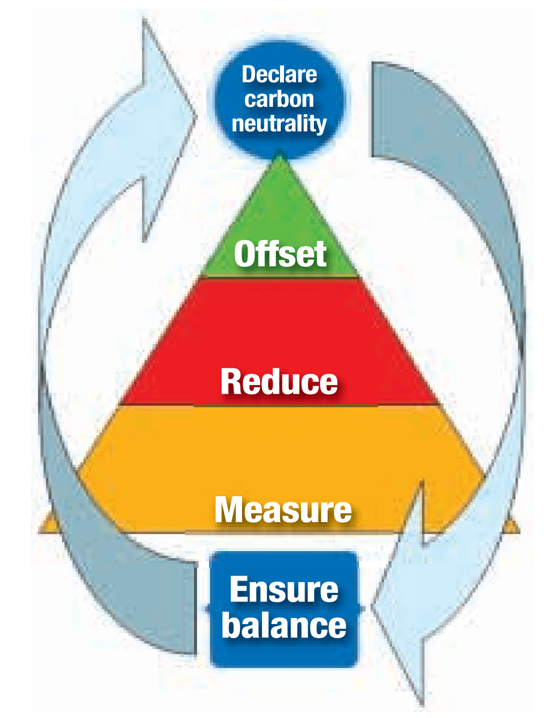

Figure 1: *Carbon management process to achieve climate neutrality.*

The calculation was accomplished by using the UN Greenhouse Gas Calculator that was developed by UNEP in order to produce consistent inventories of greenhouse gases arising from facilities, operations, and non-air travel emissions. For air travel, ICAO's Carbon Emissions Calculator for the aviation-related emissions was used.

ICAO's total GHG emissions and the relative amounts of different greenhouse gases are shown in Figure 2. Those numbers may change in the near future with improved data availability and refined methodologies. Consistent with other organizations, the activities accounting for the largest shares of emissions in ICAO's inventory are air travel and electricity usage.

Key figures

Total emissions	5'460.4t CO_2eq
Emissions per staff member	7.7 t CO_2eq
Air travel per staff member	3.1 t CO_2
Air travel per staff member	24'427 km
Office-related emissions per m^2	70 kg CO_2eq

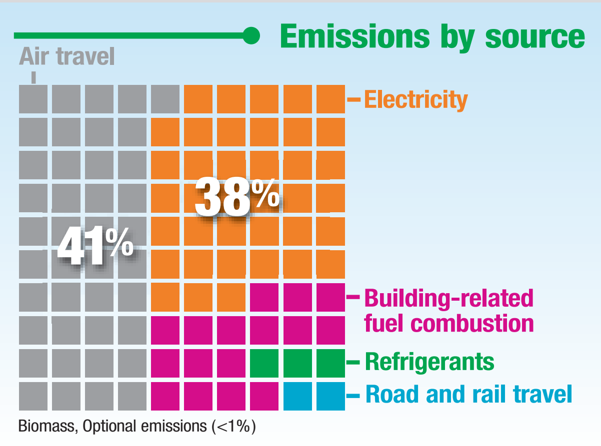

Figure 2: *ICAO`s total emissions, key GHG performance indicators, and emissions, by source.*

Step 2: Reduce

There has been much progress in recent years in greening ICAO. A major milestone was the achievement of Canada's first Leadership in Energy and Environmental Design for Existing Buildings (LEED-EB) Gold Certification that was awarded to ICAO Headquarters in Montréal. The ICAO Headquarters building required major work in order to meet LEED standards, which involved significant challenges as several modifications had to be made in terms of lighting, plumbing, ventilation, water use, recycling, and maintenance.

The achievement of this certification by the company that owns and leases the Organization`s Headquarters underscores ICAO's desire to integrate environmental considerations into its daily operations and building management.

Even before the CNUN initiative was launched, the ICAO Secretariat had implemented a series of environmentally-friendly practices such as: conducting paperless meetings, and using web-meeting services; as well as many other initiatives aimed to reduce energy consumption.

The challenge for the next few years is to formalize the isolated environmental initiatives into cohesive policies and staff regulations. As part of this effort, UN IMG organizations agreed to prepare their first Emission Reduction Plan (ERP) for 2011-2013, to achieve further emission reductions to be monitored against the inventory data already collected.

As the preparation of the ERP involves various aspects of ICAO operations, a Task Force with members from different offices was established. This Task Force will analyze achievable systematic improvements in ICAO operations, taking into consideration environmental benefits and cost-saving opportunities in the following priority areas:

1. Paper consumption – reduced paper consumption and enhanced recycling.
2. Telecommuting – reduced utilization of office space and related energy resources.
3. E-communication – enhanced IT platform and tools to support the first three action areas.
4. Sustainable procurement – procurement code modelled after overarching UN guidance.
5. Official travel – optimized official staff travel procedures.

Conclusions

ICAO continues to lead by example in support of the UN Climate Neutral Initiative with the successful quantification of its climate footprint and the implementation of active steps toward reducing it. Moreover, ICAO will continue to support the other UN organizations by providing the best available information and tools to support the accurate quantification of emissions from air travel.

ICAO is already benefitting from its reduced carbon footprint and improved operational sustainability through reduced exposure to increases in energy costs and future carbon prices and regulations. With formalized policies regarding its operations, the Organization will continue to work to further reduce the environmental impact of its in-house operations.

ICAO ENVIRONMENTAL REPORT

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The Greening of ATS Message Handling…

Transition from **AFTN** to **AMHS** Will Reduce Environmental Impact of Air Traffic Service Communications

As the international aviation world steps up its efforts to reduce and minimize the impact of aviation activity on global climate, **Radiocom Inc.** is doing everything possible to support these efforts.

It is well known that the transition from AFTN to **AMHS**, as the new ICAO supported standard for ATS message handling services, will result in numerous savings that will flow both directly and indirectly from more efficient aeronautical communications. System wide gains from more efficient communications systems will result in reduced time taken for operations including: clearances for taxiing and take-offs, flight durations, descents, etc. These incremental time savings will reduce fuel consumption during every phase of a flight, thus having a significant cumulative environmental impact by reducing greenhouse gas emissions on a global basis.

Radiocom's reduced bandwidth requirements are crucial to avoiding greater spectrum congestion, and allowing the re-use of existing communication infrastructures. This is critical for allowing developing countries with limited means to access this state-of-the-art technology, where other protocols that are not optimized for slow links (i.e. Internet), are costly and/or impractical.

As one of the pioneers of **AMHS** Extended Service with a fully integrated ATS communication system, **Radiocom** provides one of the best solutions for transitioning from AFTN to **AMHS**, helping to significantly reduce the environmental impact of aviation operations.

Radiocom's proprietary Comgate® gateway enables bidirectional translation between AFTN and **AMHS** messages, permitting both worlds to coexist, until the inevitable transition from AFTN to Extended **AMHS** takes place.

The Extended ATS Message Handling Service provides the following security services:

- Message origin authentication
- Content integrity
- Message sequence integrity

The general **AMHS** security policy is a common minimum that does not prevent specific Member State users from implementing more stringent security policies. These apply to:

- Communications between direct **AMHS** users supporting the Extended ATS Message Handling Service.
- Communications from direct **AMHS** users to AFTN/**AMHS** gateways supporting the Extended ATS Message Handling Service.

Other security provisions for Extended **AMHS** are:

- Login provisions defined at the ATS Message User Agent, for the ATS Message Server and for the AFTN & **AMHS** Gateway.
- Storage of management information about ATS Message Servers and AFTN & **AMHS** Gateways.

The security offered by **AMHS** is mostly due to the use of the X.400 protocol set, as specified by ITU-T (International Telecommunications Union - Telecommunication Standard Sector). These X.400 standards are an alternative to the more prevalent Internet e-mail Simple Mail Transfer Protocol (SMTP) which is a ”de facto” public standard.

Therefore, X.400-based applications offer more capabilities and can be tested more rigorously than SMTP implementations, and consequently are better for applications where safety, security and speed of messaging are paramount. There are a number of SEMS (Safe Electronic Messaging System) products that are based on X.400 implementations.

The advantages that make X.400 ideal for **AMHS** messaging are:

- Highly reliable;
- Clean protocol layering;
- Extensibility;
- High functionality;
- Per recipient information;
- Delivery reports;
- Unchanged content;
- Peer authentication;
- Priority;
- Security;
- Management and/or originator specified alternate recipient;
- Delivery time control;
- Performance and low bandwidth needs; from Server to User Agent.

X.400 offers many advanced capabilities not available using Internet SMTP messaging. In addition, X.400 is less costly to operate than HTTP, as it requires far less bandwidth.

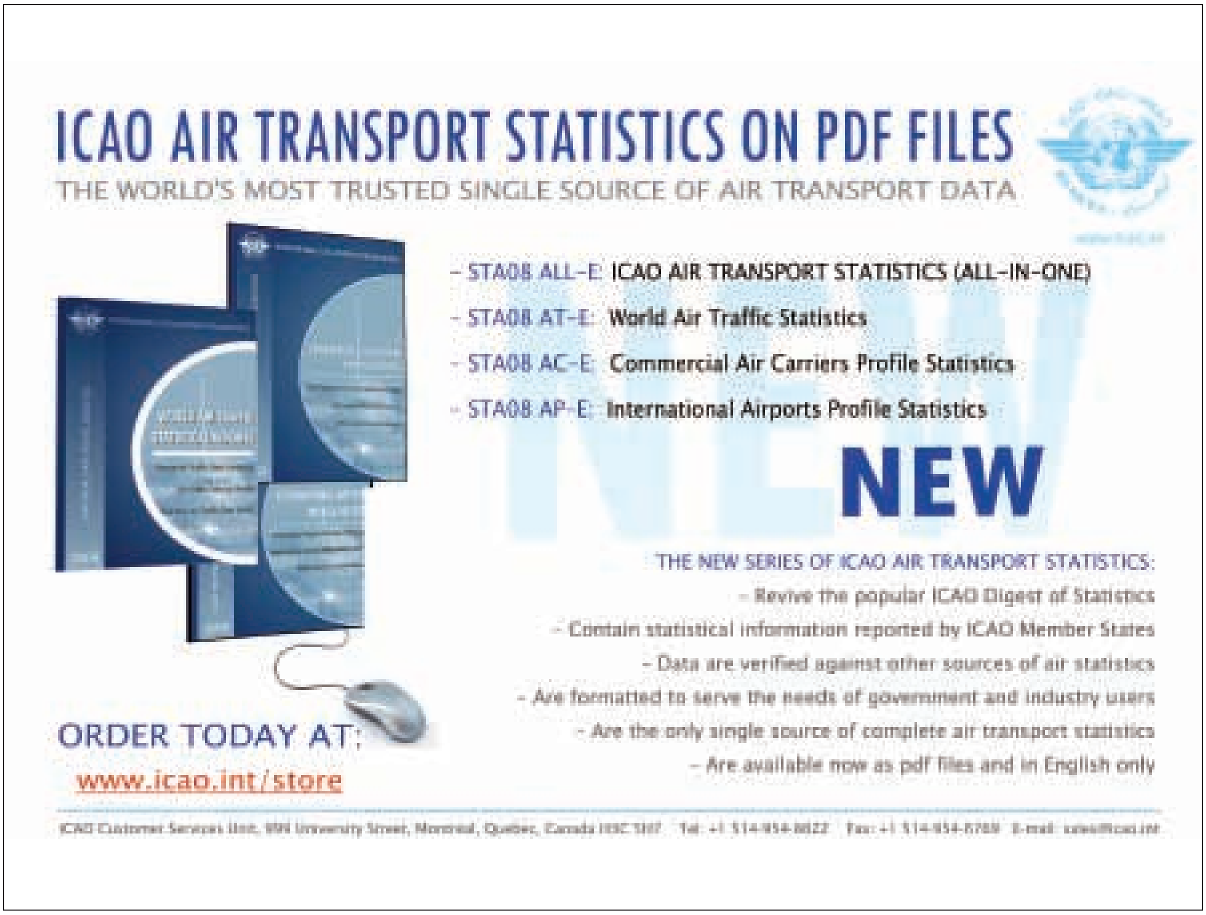
Radiocom's **AMHS** only requires a bandwidth of 9.6 kbps or less for communication between the main servers (MTA/MS) and User Agents.

This means that in locations where it is difficult or costly to implement networks of 64 kbps bandwidth (required for HTTP exchange), a lower bandwidth solution is available.

There is no doubt that **AMHS** is the way forward for aviation communications. The transition to **AMHS** worldwide is only a matter of time and as such, an investment in this solution should be sought right from the beginning. This will help avoid excessive and unnecessary transitional solutions costs, for all ICAO Member States.

In these days of concern about climate change impacts, the cumulative environmental efficiencies that will be gained through the implementation of **AMHS** make it the obvious “green solution” for ATS messaging services.

*ICAO Doc.9880-AN/466 used as reference for this article.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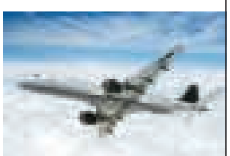

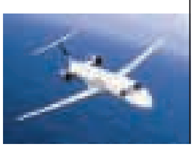

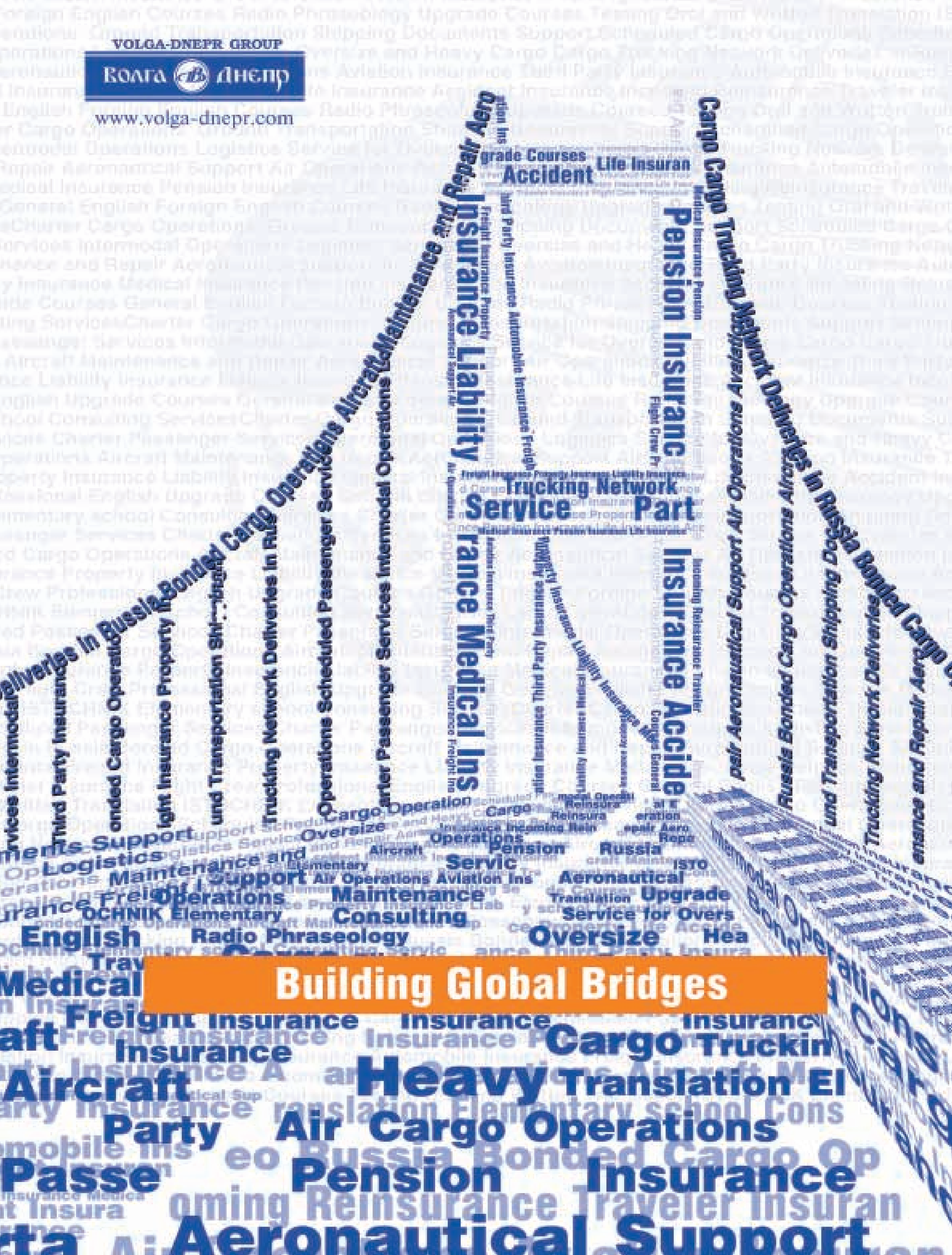
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Several policy options were activated to reduce aircraft emissions and protect aviation environment.
ON GOING EFFORTS BY NIGERIA
Acquisition of Modern aircraft using the Cape Town Convention and Aircraft Protocol;
Removal of ATC delays through the implementation of GNSS and PBN as well as runway improvement.
Massive improvement of airport facilities and infrastructure.
Adoption of Environmental Management Systems (EMS) by Airlines, Airports and Air Navigation Service providers.
The development of an alternative source of power supply at the airports (Solar and Wind Energy).
As a result of these measures and the expected improvement in technology including use of alternative fuel, Nigeria is inching towards total compliance of ICAO initiatives on Aviation Environmental Protection.
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