ICAO

ENVIRONMENT

2013 Environmental Report

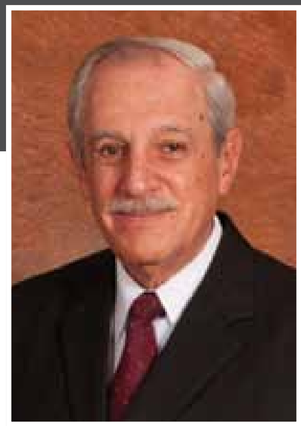
Destination Green


COOPERATION
MITIGATION
POLICIES
CLIMATE CHANGE
SYNERGIES
NOISE
INTERNATIONAL AVIATION
POLICIES
ICAO
FINANCING
ADAPTATION
AIRCRAFT
MARKET-BASED MEASURES
LOCAL AIR QUALITY
INTERNATIONAL ORGANIZATIONS
TECHNOLOGY
ALTERNATIVE FUELS
STATES' ACTION PLANS
GLOBAL EMISSIONS
ENVIRONMENT

ICAO ENVIRONMENTAL REPORT 2013

AVIATION AND CLIMATE CHANGE

Produced by the Environment Branch
of the International Civil Aviation Organization (ICAO).



MESSAGE FROM THE PRESIDENT OF THE COUNCIL OF ICAO

Roberto Kobeh González

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

ICAO and its Member States are taking concrete steps toward coordinated and comprehensive action to address the impact of international aviation on the environment. Our ultimate goal in this regard remains a sustainable future for international aviation.

Following the adoption of a global policy by the 37th Session of the ICAO Assembly, which invited ICAO Member States to voluntarily submit action plans on their CO_2 emission reduction activities, the Organization undertook intense capacity-building initiatives in consultation and cooperation with them. As a result, within just a few years, this programme has successfully facilitated the preparation and submission of State action plans representing approximately 80% of global international air traffic. This global coverage is expected to reach 90% by the end of 2013.

ICAO has continued to develop policies, standards, guidelines and tools to facilitate the development of a “basket” of measures which have helped Member States design and implement their action plans. Progress has been achieved on all related elements, including technical Standards, operational initiatives, sustainable alternative fuels, and market-based measures (MBMs).

Each element of the basket can be used to achieve ICAO’s collective global aspirational goals of improving annual fuel efficiency by 2%, while stabilizing global CO_2 emissions at 2020 levels.

The Organization is also focused on how to best support Member States that require assistance to implement the measures identified in their action plans. ICAO has been exploring partnerships with other international organizations and will continue to seek out new ways to facilitate access to financing.

The impressive amount of work undertaken by ICAO, its Member States, the aviation industry and other stakeholders being showcased by this 2013 edition of the ICAO Environmental Report can serve as a basis for discussions and decisions on how best to move ahead in a number of aviation and environment-related fields.

Continuous progress in all of these areas over the coming years will be paramount for achieving ICAO's environmental goals, and ultimately, the sustainable future of aviation. ■

MESSAGE FROM THE SECRETARY GENERAL

Raymond Benjamin

Secretary General of the International Civil Aviation Organization (ICAO)

This 2013 edition of the ICAO Environmental Report builds on the first and second editions published in 2007 and 2010 respectively. It showcases the progress achieved to date, bringing together a vast array of ideas and solutions and identifying important new challenges to help advance the global discussion on aviation and the environment.

The last Session of the ICAO Assembly, held in October 2010, clearly mandated ICAO to take bold and meaningful action that would help to lead the international aviation community toward an environmentally sustainable future. Together we are achieving steady progress, developing robust policies and global initiatives to encourage and facilitate the implementation of measures to reduce the impact of international civil aviation on the environment.

Besides the intense outreach and capacity-building we're presently engaged in to encourage and assist States in the preparation of national action plans on CO_2 emissions reduction, not to mention important recent advances achieved by ICAO's Committee on Aviation Environmental Protection (CAEP), ICAO continues to lead the development of environmental trends and tools to quantify the impacts of aviation operations and mitigation measures on the environment. Sound technical information and environmental data remain fundamental to well-informed and considered decisions.

Our sector has also recognized that the use of sustainable alternative fuels in commercial flights is now a reality. Airlines are using drop-in biofuels that do not require changes to aircraft design or fuel delivery systems, meaning that our next important challenge in this area will be facilitating the availability of these fuels at prices and quantities in line with the needs of operators.

Since the last ICAO Assembly, the Organization has sought to further progress its work on market-based measures (MBMs), including the development of a framework to guide the application of MBMs to international aviation and the feasibility of a single global scheme. Much work is needed, and ICAO will continue to expeditiously progress its efforts in this area.

Environmental protection is a global issue that requires collective, global solutions and ICAO is committed to meeting its responsibilities to bring about the sustainable future of international civil aviation. Doing so will require our sustained and global support for social and economic development objectives, while at the same time undertaking robust and effective measures to reduce the impact of international civil aviation on the environment. ■

TABLE OF CONTENTS

CHAPTER 4 – GLOBAL EMISSIONS

CHAPTER 5 – STATE ACTION PLANS

CHAPTER 6 – ASSISTANCE AND FINANCING

CHAPTER 7 – ADAPTATION

CHAPTER 8 – PARTNERSHIPS AND COOPERATION WITH OTHER ORGANIZATIONS

ACKNOWLEDGMENTS

ICAO ENVIRONMENTAL PROTECTION PROGRAMME

Boubacar Djibo

Director, Air Transport Bureau (ATB)

In 2010, the 37th Session of the ICAO Assembly reaffirmed the responsibility of ICAO and its Member States to achieve maximum compatibility between the safe and orderly development of civil aviation and the quality of the environment. It focused the Organization's efforts in this regard on three environmental goals:

- To limit or reduce the number of people affected by significant aircraft noise.
- To limit or reduce the impact of aviation emissions on local air quality.
- To limit or reduce the impact of aviation greenhouse gas (GHG) emissions on the global climate.

This mandate is carried out by ICAO's Air Transport Bureau, which oversees the activities of the Organization's Environment Branch and Committee on Aviation Environmental Protection (CAEP) – a recognized international forum of environmental experts from both the regulatory and industry sectors.

The ICAO Council reviews and adopts CAEP recommendations. It informs and provides recommendations to the ICAO Assembly, which meets every three years to establish policies on all aviation matters including aviation environmental protection. The Organization also produces complementary studies, reports, manuals, and circulars on the subject of aviation and the environment.

With respect to ICAO's work on aircraft noise, the ICAO Balanced Approach policy for noise management provides the framework under which States can address noise issues around their airports. In recent years the CAEP has been conducting a thorough review of new technologies available for the reduction of noise at source, undertaking substantial work on the environmental and economic impacts of adopting more stringent noise certification standards. This work culminated in consensus agreement during the CAEP/9 meeting in February 2013 to recommend a new Chapter 14 Noise Standard which is 7 EPNdB below ICAO's current limit.

On the issue of local air quality improvement, ICAO has already adopted regulatory Standards for the certification of nitrogen oxide (NO_x), carbon monoxide (CO), and hydrocarbons (HC). A great deal of new information is also now becoming available in the field of particulate matter (PM) and its impacts, which will potentially lead to the development of a new standard in this area.

Climate change was the main focus of the environment-related deliberations at the 37th Assembly and it was noted that, to reduce international aviation CO_2 emissions and promote sustainable aviation growth, a comprehensive approach would be necessary. This is where the Organization's efforts have been focused since 2010, progressing work on the development of a "basket" of measures which includes technological standards, operational measures, alternative fuels, and market-based measures. Very positive results have been achieved on all fronts.

I look forward to seeing how the 38th Assembly will respond to these outcomes, and especially to the new priorities and roadmap it will set for the international aviation community on all matters relating to aviation environmental protection. ■

REPORT OVERVIEW

Jane Hupe

Chief, Environment Branch, ATB

The ICAO Environmental Report 2013 provides an overview of the main developments related to aviation and the environment during the period 2011 to 2013. As in previous ICAO Environmental Reports (2007 and 2010), the goal was to consolidate into one single publication a comprehensive and reliable compendium of information on the work of ICAO and its Member States and other organizations involved in this area.

After the last ICAO Assembly in 2010, the Organization embarked on a very active work programme with special focus on climate change issues including: development of: a new CO_2 certification Standard; sustainable alternative fuels; market-based measures; State action plans; and assistance to States. Global debates on sustainability, in connection with the UNCSD conference (Rio+20), have brought new perspectives to the environmental sustainability of air transport. Discussions under the UNFCCC process on a future global climate deal and its new flexible mechanisms have implications for the discussions under the purview of ICAO, in particular on a global market-based measure for international aviation. The Organization closely followed these international developments, as well as the debates around the inclusion of international aviation in the EU-ETS, the EU decision to “stop the clock”, and the announcement by IATA to support a global offsetting scheme to achieve carbon neutral growth from 2020.

So much has happened during the last triennium amidst this dynamic and evolving scenario, that it was very difficult to select the material for inclusion in this Report. It was therefore decided to focus on the information that would be most relevant to support well-informed debates and decisions by ICAO Member States at the 2013 Assembly, and which would form an important basis for progressing the ICAO environmental work in the next triennium. This information was showcased during the ICAO Symposium on Aviation and Climate Change (May 2013), and it is now compiled within these pages for the reader's easy reference.

This Report consists of eight chapters. **Chapter 1** is an **Aviation and Environment Outlook**, including present and future trends in traffic, noise, and emissions. **Chapters 2**, **3**, and **4** are dedicated respectively to the mitigation of aviation's impact on **Aircraft Noise**, **Local Air Quality**, and **Global Emissions**. **Chapter 5** describes the initiatives of the Organization in support of the preparation and submission of **State Action Plans**. **Chapter 6** explores avenues for **Assistance and Financing**, and **Chapter 7** addresses **Adaptation**. Finally, **Chapter 8** describes **ICAO’s Partnerships and Cooperation with Other Organizations**. Written in accessible language, each chapter of the Report begins with a summary overview to familiarize readers with the subject being addressed, followed by subject-focused articles provided by various experts. Many of the featured articles summarize studies and reports by the foremost international experts and renowned scientists in their fields.

I sincerely hope that you enjoy reading this Report, and that it will stimulate productive and enlightened discussions on aviation and the environment, while at the same time, demystifying commonly-held misconceptions. Arriving at optimal solutions begins with clearly defining the challenges and this can only be achieved by providing the most recent valid information. This is especially true for climate change, which is one of the most pressing global issues of this early part of the 21st century and a top priority for the entire UN system.With the increasing engagement of its Member States, and close cooperation with the aviation industry and other stakeholders, ICAO is taking concrete actions and moving closer towards the "Future We Want": a future in which international air transport is sustainable.

ACKNOWLEDGEMENTS

ICAO wishes to thank the authors from various States and disciplines who have kindly shared their expertise, imagination and enthusiasm, along with the CAEP Working Group Rapporteurs and Experts. The Organization is truly grateful to them, and believes that their collective insights will stimulate dialogue and contribute to defining sustainable climate change solutions. ICAO looks forward to receiving comments and suggestions on how to improve future editions of the ICAO Environmental Report. ■

ABOUT ICAO AND THE ENVIRONMENT

ICAO is a specialized agency of the United Nations created in 1944, with the signing of the Convention on International Civil Aviation, to promote the safe and orderly development of international civil aviation throughout the world. It sets standards and regulations necessary for aviation safety, security, efficiency, capacity and environmental protection. The Organization serves as the forum for cooperation in all fields of civil aviation.

ICAO has been at the forefront of aviation environmental issues since the late 1960s. The Organization's work on the environment focuses primarily on those problems that benefit most from a common and coordinated approach on a worldwide basis, namely aircraft noise and engine emissions. Standards and Recommended Practices (SARPs) for the certification of aircraft noise and aircraft engine emissions are covered by Annex 16 of the Convention.

ICAO has a membership of 191Contracting States and works closely with other UN bodies and international organizations with an interest in aviation. ICAO has established three environmental goals:

1. To limit or reduce the number of people affected by significant aircraft noise.
2. To limit or reduce the adverse impact of aviation emissions on local air quality.
3. To limit or reduce the impact of aviation greenhouse gas emissions on the global climate.

The Environment Branch, of the ICAO Air Transport Bureau (ATB) is in charge of progressing the work of the Organization in this field. It is also responsible for providing support and managing the activities of the ICAO Committee on Aviation Environmental Protection (CAEP).

CAEP is a technical committee of the ICAO Council and undertakes most of the work of the Organization for the development of Standards and Recommended Practices (SARPs) in this area. It is an international forum that involves close to 400 experts for the study and development of measures to minimize the impact of aviation on the environment. Every technical proposal developed by CAEP is analysed according to four criteria: technical feasibility, environmental benefit, economic reasonableness, and the interrelationship among measures. The ninth meeting of CAEP (CAEP/9) was held from 4 to 15 February 2013.

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

TOWARDS ENVIRONMENTAL SUSTAINABILITY

BY **JANE HUPE**, CHIEF, ENVIRONMENT BRANCH OF ICAO

As this third edition of the ICAO Environmental Report is published, we find ourselves at an exciting time; it being one year after the United Nations Conference on Sustainable Development (Rio+20) and nearing the conclusion of the tremendous work programme on aviation environmental protection that was agreed by the 37th Session of the ICAO Assembly. It was at this Assembly that ICAO's 191 Member States made it unequivocally clear that the air transport sector is committed to meeting its responsibilities for sustainable development, maximizing its support for economic development, reducing its impact on the environment, and consolidating its social benefits.

Through the increased use of low-carbon technology, environmentally friendly materials, new aircraft systems, and sustainable energy sources, the air transport sector is making significant advances across a range of sustainability issues. It does so by making sure that its actions around the world are based on the economic, environmental, and social pillars of sustainable development.

This commitment has been illustrated by the complex and growing network of about 1,500 airlines that offered scheduled services connecting 3,850 commercial airports worldwide in 2011. They link both major and minor city pairs, facilitating the movement of people, goods, and services. From fresh fish to diamonds, aviation underpins nearly every aspect of modern life, carrying 35% of all goods by value, and supporting 3.5% of global GDP.

Other, less evident benefits that aviation offers are:

- critical transportation and logistical links to hinterlands, islands and remote communities;
- essential services, such as healthcare, mail, education;
- emergency aid and humanitarian assistance; and
- data collection for scientific research and meteorology.

Indeed, it would be difficult to imagine a world without aviation. Therefore, striking a balance among the three pillars of sustainability is crucial to enabling air transport to grow in an environmentally sustainable manner, while continuing to ensure the freedom to travel by air. This report is dedicated to describing the broad range of ways that international aviation subscribes to these objectives, and in particular to the environmental pillar of sustainability.

When considering the environmental sustainability of international aviation, it is important to examine not only what has been achieved thus far, but also the work that remains to be undertaken toward making future progress.

Over the past 50 years, aircraft have become 80% more energy efficient and 75% quieter. Aviation as a whole accounts for approximately 2% of global anthropogenic CO_2 emissions, with international aviation producing about 60% of those emissions. Many sectors of the global economy would be envious of such a track record. Yet, as the *Outlook* section of this report explains, by the year 2030 air traffic is expected to double, with continued growth to 2050. It is estimated that aircraft noise, and emissions that affect local air quality and global climate are expected to increase, but at a rate slower than aviation demand.

At the 37th Session of the ICAO Assembly, Member States adopted collective global aspirational goals for the international aviation sector to improve annual fuel efficiency by 2%, and to limit CO_2 emissions at 2020 levels. The Assembly also defined a basket of measures designed to help achieve these goals. This basket includes: technology improvements, operational changes, alternative fuels, and market-based measures.

In the last three years ICAO has seen continuous progress in every one of these elements, with some measures resulting in actual, concrete CO_2 reductions. It is important to keep track of these improvements. Studies undertaken by the Organization have shown that all elements of the basket of measures will be needed in order for international aviation to reach carbon neutral growth after 2020. The measures selected by States to contribute toward the achievement of the global aspirational goals are communicated to ICAO through the States action plans. An intense capacity-building programme was put in place by the Organization, including the provision of guidance material and training workshops in every ICAO Region, to assist State focal points in the preparation of action plans. ICAO has made tools available to States across a wide range of platforms to help them understand current and possible future aviation emissions. Support was also provided as required to assist the quantification of CO_2 emission reductions during the preparation of the plans. These successful initiatives resulted in more than 60 States, covering 80% of the global international traffic, submitting action plans to ICAO by mid-2013. This will facilitate the compilation of information on the collective progress towards achieving the aspirational goals.

PUSHING THE BOUNDARIES THROUGH TECHNOLOGY

***Figure 1:** The Golden Gate Bridge in the Bay Area During a Flight Test on April 24 2013, Before the Departure of the Solar Impulse Crossing. ©Solar Impulse/Revillard/Rezo.ch*

Innovative concepts provide us with a long-term vision for the development of zero-emission air transport vehicles. Some pioneering examples are listed below:

- *EADS' fully electric aircraft:* The VoltAir's next-generation electric batteries power highly efficient superconducting electric motors which drive counter-rotating, shrouded propellers. The propulsion system is combined with an innovative airframe made largely of composites which makes for incredible strength and significantly lighter weight. www.eads.com/eads/int/en/our-innovation/our-technologies/Advanced-Concepts/VoltAir-concept.html
- *The Honeywell and Safran EGTS green taxi system:* This system can significantly improve passenger aircraft operational efficiency by reducing fuel and other taxi related costs, as well as providing environmental benefits by slashing carbon and other emissions generated during taxi operations. www.greentaxiing.com
- *Solar Impulse:* The Solar Impulse demonstrated that a solar-powered airplane can fly day and night without fuel. It is a long-range solar powered aircraft developed by the Swiss Solar Impulse team in collaboration with several partners including the École Polytechnique Fédérale de Lausanne. It recently completed a crossing of the United States, from San Francisco to New York City, without a single drop of fuel. www.solarimpulse.com

The preparation of action plans and the implementation of the selected basket of measures by ICAO Member States often depend on the availability of assistance and financing. ICAO has proactively taken the necessary steps toward reaching cooperation agreements with the European Union and UNDP/GEF on concrete financial assistance programmes for capacity building and reduction of aviation CO_2 emissions though State Action Plans. In the coming years, the Organization will continue to pursue other avenues for financial assistance including external lines of "green funding" and the use of contributions to the ICAO Environment Voluntary Fund.

As the basket of measures to address the emissions that affect the global climate is implemented, consideration of the interdependencies between aircraft noise and other emissions that affect local air quality is needed to ensure that the improvement in one environmental area does not compromise the progress in another. The sustainability of aviation depends on the continuous and balanced reduction of its impacts on all of these areas. Therefore, the new "Chapter 14" Noise Certification Standard proposed by CAEP, which is more stringent than its predecessor, is most welcome.

Technological progress is key to achieving environmental sustainability. The aviation activity itself is the result of visionaries that dared to dream that a human could fly and then engaged in making it a reality. From the dawn of aviation it has been a technology oriented industry. Aircraft are increasingly more efficient, using very light composite materials, flying on sustainable alternative fuels, and research continues to seek further technological advances. In addition to this constant evolution, other new and revolutionary technologies are making their way into the market and may someday be the key to achieving air transport sustainability (see **Figure 1**).

In parallel, the need to adapt the global aviation system to climate change becomes critical to ensuring the continuity of vital air transportation links.

The collective will of ICAO's 191 Member States has made it clear that international aviation will contribute to global environmental sustainability. In pursuit of this mission, ICAO cooperates actively throughout the UN system both on matters of global sustainability, such as through Rio+20, and also in ensuring that the UN leads by example with the Climate Neutral UN initiative. Together, we will continue to work towards a safe, secure, economic, and environmentally sound international aviation industry, to ensure access to a sustainable aviation for generations to come.

COMMITTEE ON AVIATION ENVIRONMENTAL PROTECTION (CAEP)
Outcomes from CAEP/9

The Committee on Aviation Environmental Protection (CAEP) is a technical committee of the ICAO Council. Its mandate is to study and develop proposals to minimize aviation's effects on the environment. It was established in 1983, superseding the Committee on Aircraft Noise and the Committee on Aircraft Engine Emissions.

CAEP is composed of 23 Members from all regions of the world, and 16 Observers (see **Table 1**). Approximately 400 internationally-renowned experts are involved in CAEP activities and working groups (see **Figure 1**). All of its proposals are assessed on the basis of four criteria: technical feasibility; environmental benefit; economic reasonableness; and interdependencies, for example, among others, measures to minimize noise and emissions.

The ICAO Council reviews and adopts CAEP recommendations, including amendments to the Standards and Recommended Practices (SARPs) on aircraft noise (Annex 16, Volume I) and engine emissions (Annex 16, Volume II), and in turn reports to the ICAO Assembly where the main policies on environmental protection are ultimately defined.

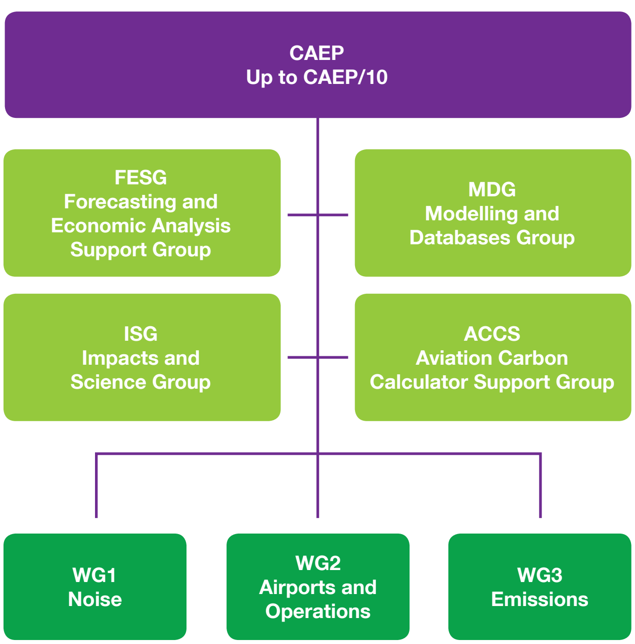


***Figure 1:** CAEP working groups and structure leading to CAEP/10 (2016).*

CAEP Member States (23)		
Argentina	Australia	Brazil
Canada	China	Egypt
France	Germany	India
Italy	Japan	Netherlands
Poland	Russia	Singapore
South Africa	Spain	Sweden
Switzerland	Tunisia	United Kingdom
Ukraine	United States	

Observers (16)		
Observers States		
Greece	Indonesia	New Zealand
Norway	Turkey	United Arab Emirates
Observers Organizations		
ACAC: Arab Commission of Civil Aviation		
ACI: Airports Council International		
CANSO: Civil Air Navigation Services Organisation		
EU: European Union		
IATA: International Air Transport Association		
IBAC: International Business Aviation Council		
ICCAIA: International Coordinating Council of Aerospace Industries Associations		
ICSA: International Coalition for Sustainable Aviation		
IFALPA: International Federation of Airline Pilots' Associations		
UNFCCC: United Nations Framework Convention on Climate Change		

***Table 1:** CAEP Member States and Observer States and Organizations.*

***Figure 2:** First CAEP Steering Group Meeting of the CAEP/9 cycle, Toulouse, France, 8 to 12 November 2010.*

CAEP/9 ACHIEVEMENTS

The ninth meeting of the Committee on Aviation Environmental Protection (CAEP/9) was held at ICAO headquarters in Montréal, Canada in February 2013. The meeting was attended by approximately 200 participants. This meeting marked the culmination of three years of intense activity by the CAEP working groups looking into aircraft noise, operations, and emissions. It involved more than 400 experts from different States and organizations around the world.

Based on the work of the Committee's technical experts, the CAEP/9 meeting agreed on a comprehensive set of 18 recommendations that will help ICAO fulfil its mandate on aviation environmental protection. Key areas of progress and focus during CAEP/9 included:

- an agreement on two new aircraft noise Standards;
- an updated set of technology goals for aircraft noise;
- a set of aspirational operational goals for fuel burn reduction;
- progress on development of the new ICAO Aircraft CO_2 Emissions Standard;
- progress on development of a new Particulate Matter Standard;
- tabling of updated traffic and fleet forecasts; and
- establishing priorities and work programmes for the CAEP/10 work cycle (2013-2016).

New Aircraft Noise Standards

CAEP recommended that Annex 16, Volume I be amended to include an increase in stringency of 7 EPNdB relative to the current Chapter 4 cumulative levels. This resulted in the recommendation of a new Chapter 14 Noise Standard, that will be applicable to new aircraft types submitted for certification on or after 31 December 2017, and on or after 31 December 2020 for aircraft less than 55 tonnes.

In addition, following extensive discussions and consultations, and in cooperation with airworthiness, operations and legal experts, CAEP recommended the amendment of Annex 16, Volume I, Chapter 13 to include a Noise Certification Standard for tilt-rotor aircraft. This also includes a recommendation for the consideration of tilt-rotor provisions in the ICAO Annexes on Personnel Licensing, Operations, Aircraft Registration, and Airworthiness, in Annexes 1, 6, 7, and 8 respectively (see Chapter 2, Aircraft Noise, in this report).

New Noise Technology Reduction Goals

During this CAEP cycle, a second review was undertaken by the Independent Expert Panel of novel aircraft noise technology and medium and long term noise reduction goals. CAEP/9 endorsed an updated set of mid-term (2020) and long-term (2030) technology goals for reducing jet and turboprop aircraft noise. CAEP agreed to publish this review and that the noise technology goals be used to inform and guide future ICAO noise activities (see Chapter 2, Aircraft Noise, in this report).

Operational Goals For Fuel Burn Reduction

CAEP recommended the publication of two documents: a new ICAO manual on operational opportunities to reduce fuel burn and emissions, which will replace ICAO Circular 303; and a new ICAO guidance document on environmental assessment of air traffic management operational changes. CAEP also considered the challenging aspirational operational environmental goals developed by the Independent Experts, which were included in the environmental trends presented in Chapter 1 in this report (see two articles *Two New ICAO Manuals on Reducing Emissions Using Enhanced Aircraft Operations*, Chapter 4 in this report, and *Environmental Trends in Aviation to 2050*, Chapter 1 in this report).

Development of an ICAO Aircraft CO_2 Emissions Standard

The work towards the development of an ICAO CO_2 Standard is focused on creating an aircraft-based Standard to reduce aircraft CO_2 emissions by encouraging the integration of fuel efficient technologies into aircraft design and development. CAEP reached significant milestones in this work by agreeing on the CO_2 metric system, which provides a measure of aeroplane CO_2 emissions, and which led to the agreement on a mature CO_2 Standard certification requirement. The Committee also agreed that the certification requirement should be published in an ICAO Circular. To move forward and to build on the significant progress made to date, CAEP has agreed on a comprehensive work plan with a late-2015 deliverable date to set a CO_2 Standard (see article *Development of an ICAO Aircraft CO_2 Emissions Standard*, Chapter 4 in this report).

Figure 3: *Second CAEP Steering Group Meeting of the CAEP/9 cycle, Beijing China, 12 to 16 September 2011.*

Figure 4: *Third CAEP Steering Group Meeting of the CAEP/9 cycle, St Petersburg, Russian Federation, 9 to 13 July 2012.*

Progress on a Particulate Matter Standard

Further work on developing a particulate matter (PM) Standard continued, as CAEP worked with SAE to demonstrate the non-volatile PM (nvPM) sampling system used to measure at the engine exhaust. As a result, a working draft of the document *Aerospace Recommended Practice* (ARP) is nearly complete. Measurement campaigns and finalization of the ARP will continue as a prelude to the nvPM emissions certification requirement and the new Standard (see article *Development of a Particulate Matter Standard for Aircraft Gas Turbine*, Chapter 4 in this report).

Updated Air Traffic and Fleet Forecasts

The CAEP Forecast and Economic Analysis Support Group (FESG) completed the development of new traffic and fleet forecasts. The forecasts were developed by route groups for both passenger and cargo services, over a forecast period of 2010 to 2040, with an extension to 2050. CAEP recommended that the forecast be used as the basis for all environmental analyses undertaken during the CAEP/10 cycle. Regarding the updated fuel trends for international aviation, work will include modelling fuel burn figures for 2006, 2010, 2020, 2030, 2040, with an extension to 2050 (see article *Environmental Trends in Aviation to 2050*, Chapter 1 in this report).

Priorities for CAEP/10

ICAO continues to work toward its environmental goals for international aviation which are targeted to reduce the number of people exposed to significant aircraft noise as well as reducing the impact of aviation emissions on global climate and local air quality. The results of the CAEP/9 meeting in 2013 represent further steps towards achieving these goals, and continue to demonstrate the strong determination of the international community to deliver comprehensive environmental solutions for the aviation sector.

During the CAEP/10 cycle (2013 to 2016) efforts will continue to be focused on emissions, noise, and operations, including the completion of the CO_2 Standard and the further development of a PM Standard. ■

CHAPTER 1

AVIATION AND ENVIRONMENT OUTLOOK

AIR TRAFFIC AND FLEET FORECASTS

BY ICAO SECRETARIAT

Commercial air traffic, both passenger and freight, as well as business aviation are expected to continue to grow for the foreseeable future, bringing about benefits to people and economies in both developed and developing nations. This growth will not come without challenges; these include the need for additional resources (financial, human, as well as natural resources), bigger aircraft fleet, increased airport and airspace capacity, better training, and more efficient air navigation systems. Yet, even with all of the technical and operational improvements expected over the forecast horizon, the environmental footprint of aviation is expected to increase.

The traffic and fleet forecasts developed by the Forecasting and Economic Analysis Support Group (FESG) of the ICAO Committee on Aviation Environmental Protection (CAEP) form the basis of various analyses conducted within CAEP. Such analyses include estimates of: engine and aircraft emissions, populations around the world living near airports affected by aircraft noise and local air quality issues, and the contribution of aviation to global greenhouse gas emissions and climate change. FESG also performs economic and financial assessments of potential policy options under consideration by CAEP that are designed to minimize the adverse effects of aviation operations on the environment.

The development of the CAEP forecasts is a collaborative process involving forecasting experts from Member States, observer organizations and ICAO. The CAEP forecast is developed in accordance with specific requirements identified by the CAEP Working Groups which are essential for the conduct of the analyses within CAEP.

The forecast covers a 30-year time horizon, and is developed for both passenger and freight services, for 32 route groups (*i.e.* 23 international and nine domestic routes) and at the global level. Three growth scenarios have been developed: Most Likely, High, and Low. The CAEP forecast is based on forecasts, inputs and models provided by Member States, observer organizations (*i.e.* aircraft and engine manufacturers, air navigation service providers, aviation safety agencies, etc.) and the ICAO Secretariat. All of the inputs, assumptions, and methodologies used (*i.e.* route groups, load factors, seat classes, traffic growth rate forecast, etc.) are defined and agreed through a consensus process among the stakeholders involved in the forecast development.

AIR TRAFFIC FORECASTS

The development of the Air Traffic Forecasts involves the production of individual sets of forecasts for passenger and freight, followed by merging the two to produce combined passenger and freight traffic forecasts and projections to the year 2050. The following paragraphs briefly summarize the results of that process.

Passenger Traffic Forecast

Under the Most Likely scenario (central forecast), the world passenger traffic, expressed in terms of revenue passenger-kilometres (RPKs), is expected to grow from five billion to more than 13 billion RPKs over the 2010-2030 period, at an average annual growth rate of 4.9%. Under that scenario, international traffic would grow at 5.1% cent per annum, while domestic traffic would grow at a slower rate of 4.4% per annum.

During the following ten years, 2030 to 2040, growth is expected to moderate to an average of 4.0% per annum, with international and domestic air traffic growing at the rates of 4.1% and 3.8% cent per annum, respectively.

As shown in **Figure 1**, international traffic's share of total traffic will increase from 64% in 2010 to about 68% in 2040.

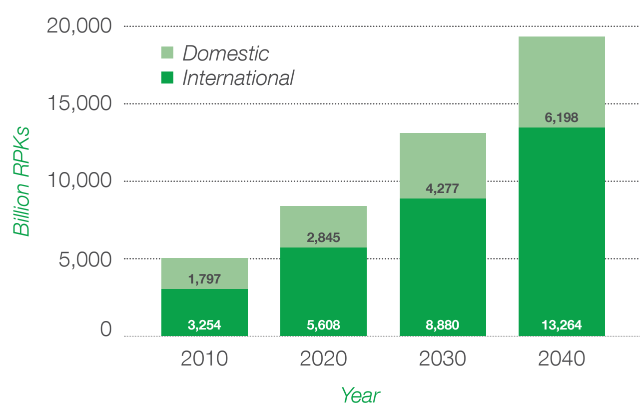


Figure 1: *CAEP/9 Passenger Traffic Forecast (Central).*

With reference to **Figure 2**, the 2010 top five route groups in terms of passenger traffic volumes, Domestic North America, Intra-Europe, North Atlantic, Intra-Asia/Pacific, and Domestic China/Mongolia, will remain at the top during the 2030 to 2040 period, although their relative rankings will change. The combined share of these route groups in total RPKs will decline from about 52.4% in 2010, to 47.7% and 46.4% in 2030 and 2040, respectively.

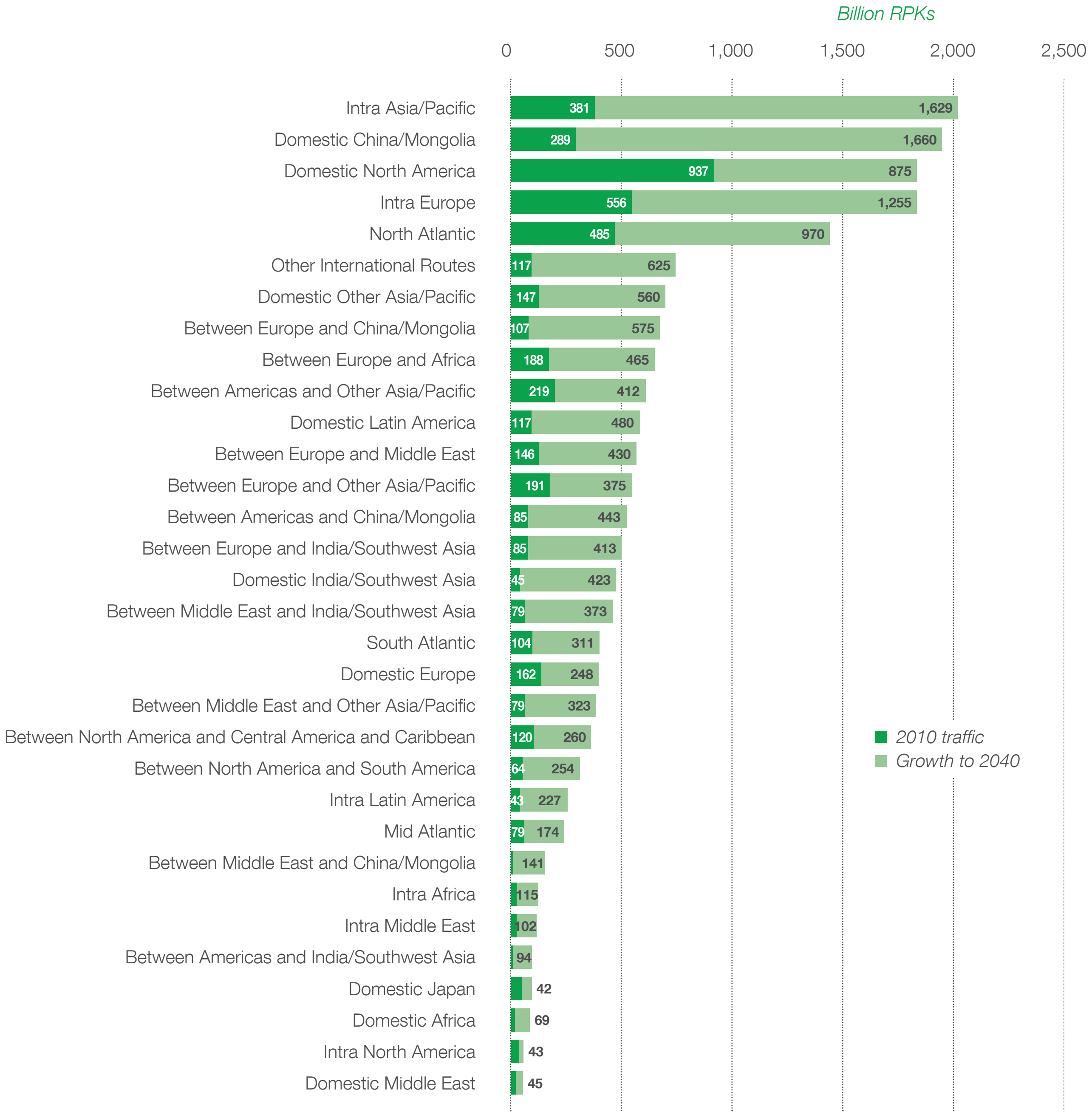


***Figure 2:** CAEP/9 Passenger Traffic Forecast (Central) by Route Group.*

Freight Traffic Forecast

Under the Most Likely scenario (central forecast), the world air freight traffic, expressed in terms of revenue tonne-kilometres (RTKs), is expected to grow at an average annual growth rate of 5.2% from 2010 to 2030, and at 4.6% between 2030 and 2040. As a result, under this scenario world air freight traffic will increase from 203.2 billion RTKs in 2010, to 562 and 885 billion RTKs in 2030 and 2040, respectively.

The largest increases in air freight traffic volumes over the forecast time horizon are expected to take place on

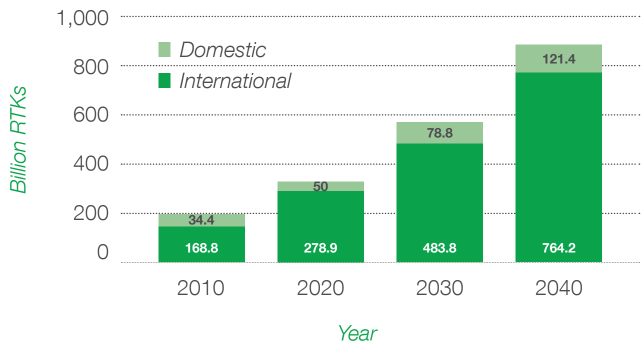


***Figure 3:** CAEP/9 Cargo Traffic Forecast (Central).*

Scenario/Sector	2010-2020	2020-2030	2030-2040	2040-2050	Actual 2010	CAEP/9 Forecast 2020	2030	2040	2050
High Scenario (Optimistic)	% Growth				Billion RTKs				
Total International	6.1	5.7	4.6	4.2	494	891	1,553	2,438	3,679
Total Domestic	5.0	5.2	4.5	4.1	214	349	578	899	1,345
Global [International + Domestic]	**5.8**	**5.6**	**4.6**	**4.2**	**708**	**1,240**	**2,131**	**3,336**	**5,024**
Most Likely Scenario (Central Forecast)									
Total International	5.4	5.0	4.3	3.7	494	840	1,372	2,091	3,013
Total Domestic	4.6	4.2	3.9	3.5	214	335	506	741	1,049
Global [International + Domestic]	**5.2**	**4.8**	**4.2**	**3.7**	**708**	**1,174**	**1,878**	**2,832**	**4,062**
Low Scenario (Pessimistic)									
Total International	4.8	4.1	3.8	3.4	494	793	1,188	1,733	2,414
Total Domestic	4.1	3.2	3.2	3.0	214	321	442	605	812
Global [International + Domestic]	**4.6**	**3.9**	**3.7**	**3.3**	**708**	**1,114**	**1,630**	**2,338**	**3,226**

[1] Average annual growth rate of revenue tonne-kilometres [RTK].

***Table 1:** CAEP/9 Combined Passenger and Freight Traffic Forecasts 1 (Including Projections to 2050) – Central Forecast and Sensitivity Analysis – Most likely, High and Low Scenarios.*

international route groups: Intra Asia/Pacific; Europe; Other Asia/Pacific (which includes Japan and Australia); Europe-China/Mongolia; and Americas-Other Asia/Pacific.

Combined Passenger and Freight Traffic Forecasts and Projections

The passenger and freight traffic forecasts were combined and projections to the year 2050 were developed. Those combined traffic forecasts, expressed in terms of average annual growth rates and RTKs, including the projections to 2050 are presented in **Table 1**.

AIRCRAFT FLEET FORECAST

Passenger Aircraft

The passenger aircraft fleet forecast was developed using the passenger traffic forecast, a classification of aircraft into 13 seat categories and agreed assumptions on load factors and aircraft utilization. The CAEP/9 passenger fleet forecast is provided in **Table 2**.

The future fleet composition was derived using an appropriately calibrated passenger aircraft retirement function. The results are illustrated in **Figure 4**. A total of about 56,000 new aircraft will be needed by 2040 to accommodate the predicted demand, 65% of which will be for growth, and the remainder will replace current aircraft.

Of those aircraft in service at year-end 2010, aircraft remaining in passenger service are expected to be 14,400 for 2020, 5,910 for 2030, and 620 for 2040.

Seat category	2010	2020	2030	2040
20-50	2,961	3,299	3,958	4,476
51-70	1,113	2,183	3,240	4,493
71-85	935	1,438	1,984	2,591
86-100	623	821	1,115	1,565
101-125	1,450	1,993	2,662	3,383
126-150	4,038	5,415	6,908	8,377
151-175	3,487	5,078	6,575	8,324
176-210	1,925	3,943	5,760	7,538
211-300	2,076	3,622	6,314	8,979
301-400	821	1,434	2,243	3,884
401-500	292	544	982	1,496
501-600	10	83	264	671
600+		19	238	762
Total	**19,732**	**29,872**	**42,242**	**56,537**

***Table 2:** CAEP/9 Passenger In-Service Fleet Forecast by Seat Category – Most Likely Scenario (Central Forecast).*

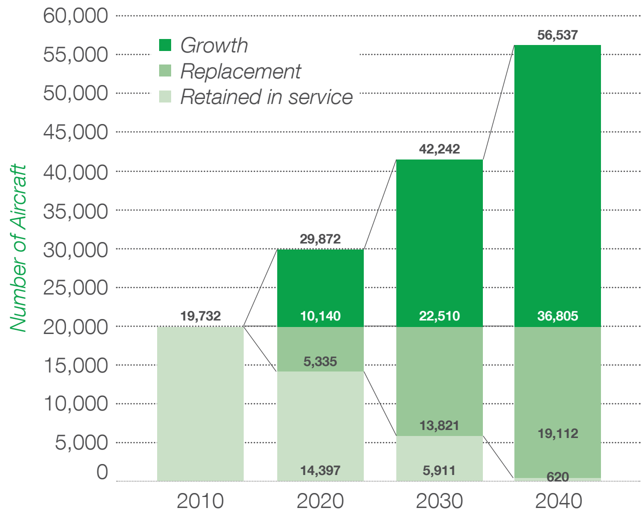


Figure 4: *Passenger Fleet Evolution – CAEP/9 Central Passenger Fleet Forecast.*

Freighter Aircraft
Similarly, the freighter aircraft fleet forecast was developed using the freight traffic forecast, and assumptions about load factors. The forecast was developed based on aircraft capacity and reallocated to the same seating categories (in terms of aircraft size) as the passenger forecast. The CAEP/9 freighter fleet forecast is provided in **Table 3**.

Seat category	2010	2020	2030	2040
20-50	765	819	891	973
51-70	133	113	115	117
71-85	2	29	35	37
86-100	70	71	79	86
101-125	225	36	39	49
126-150	44	130	354	539
151-175	59	245	395	606
176-210	192	460	484	701
211-300	583	633	913	1,342
301-400	227	342	698	1,044
401-500	60	33	11	11
501-600	295	329	300	437
600+	2	118	239	350
Total	**2,657**	**3,358**	**4,553**	**6,292**

Table 3: *CAEP/9 Freighter Fleet Forecast by Seat Category – Most Likely Scenario (Central Forecast).*

Business Aviation
A forecast for business jet aircraft with fewer than 20 seats was also developed for nine regions and three aircraft categories (light, medium, and large business jets), with assumptions on the number of flight hours and the average flight duration, per aircraft type, and by region. The fleet forecast for business jet aircraft is presented in **Table 4**.

Regions	2010	2020	2030	2040
Africa	320	545	965	1,641
Europe	2,180	3,975	6,650	10,831
Middle East	1,400	2,190	3,050	4,258
Latin America and Caribbean	380	745	1,435	2,593
North America	9,700	11,390	13,580	16,356
Asia Pacific				
China	150	1,070	2,450	4,936
India/Southwest Asia	155	470	1,365	3,092
North Asia	56	110	200	347
Pacific and South East Asia	249	486	881	1,525
Total (World)	**14,590**	**20,981**	**30,576**	**45,579**

Table 4: *CAEP/9 Forecast of In-Service Business Jet Aircraft Fleet (Aircraft with Fewer than 20 Seats).*

Forecast of Aircraft Operations (flights)
The forecast of total aircraft operations was developed by combining the individual forecasts for passenger, freighter, and business aviation aircraft. It is expected that the number of aircraft operations worldwide will triple by 2040. **Table 5** summarizes the aircraft operations forecast. ■

Type of operation	2010	2020	2030	2040
Passenger flights	28.5	43	60.9	82
Freight flights	1.6	2.3	3.2	4.4
Business aviation flights (< 20 seats)	2.6	3.7	5.3	7.9
Total (World)	**32.7**	**49**	**69.4**	**94.3**

Table 5: *CAEP/9 Forecast of Aircraft Operations (Millions).*

ENVIRONMENTAL TRENDS IN AVIATION TO 2050

BY GREGG FLEMING AND URS ZIEGLER

GREGG G. FLEMING

As Director of Environmental and Energy Systems at the U.S. DOT's Volpe Center, he has over 25 years of experience in all aspects of transportation-related acoustics, air quality, and climate issues. He has guided the work of numerous, multi-faceted teams on projects supporting all levels of Government, Industry, and Academia, including ICAO, the U.S. FAA, the National Aeronautics and Space Administration, the U.S. EPA, and the U.S. National Academy of Sciences. Along with Dr. Ziegler, Mr. Fleming is co-Rapporteur of CAEP's Modeling and Databases Group.

URS RENÉ FRITZ ZIEGLER

After having completed his studies in natural sciences he worked in the field of environmental protection for a civil engineering company as well as for more than 10 years for the Swiss Office for Environmental Protection. During this time he also acquired a masters degree in public administration. In early 2005 he joined the Swiss Federal Office of Civil Aviation as Head of the Office's Environmental Protection Unit. He is the Swiss CAEP member and is co-Rapporteur of CAEP's Modelling and Databases Group.

BACKGROUND

Each three-year work cycle, the ICAO Committee on Aviation Environmental Protection (CAEP) develops environmental trends in aviation to include:

- greenhouse gas (GHG) emissions;
- noise levels;
- local air quality (LAQ) emissions.

CAEP's Modelling and Databases Group (MDG) aims to use the latest input data and related assumptions to assess the present and future impact and trends of aircraft noise and aircraft engine emissions. During the last triennium, CAEP/MDG modelling focused on the improvement of trends related to global climate, particularly fuel burn and carbon dioxide (CO_2) emissions trends. Substantial improvement has been achieved in the method to produce these trends that now enables the assessment of the contribution of international aviation separately, along with the different measures available for reducing its associated fuel burn and CO_2 outputs. CAEP/MDG has produced fuel burn and CO_2 emission trends from international aviation, which are discussed herein.

This section presents a discussion of assumptions, models and databases, scenarios, and results for three categories: (1) fuel burn, demand uncertainty, CO_2 and alternative fuels, (2) effective perceived noise level in decibels (EPNdB), and (3) oxides of nitrogen (NO_x) and particulate matter (PM).

GREENHOUSE GAS TRENDS

The assessment of GHG trends is based on the CAEP central demand forecast using a base year of 2010. Forecast years included 2020 and 2030 with an extension to 2040, and results were further extrapolated to 2050. Data presented for 2005 and 2006 was reproduced from prior trend assessments.

Three models contributed results to the GHG trends assessment: US Federal Aviation Administration's (FAA) Aviation Environmental Design Tool (AEDT), EUROCONTROL's Advanced Emissions Model (AEM), and Manchester Metropolitan University's Future Civil Aviation Scenario Software Tool (FAST). Key databases utilized in this assessment included the AEDT Airports Database, Campbell-Hill and Growth and Replacement Fleet Database, and the Common Operations Database (COD). These are all proprietary MDG databases, with the exception of Campbell-Hill which is owned and maintained by Airlines for America.

Table 1 shows the nine full-flight fuel burn and CO_2 scenarios developed for the assessment of aircraft GHG trends.

Figure 1 depicts results for global full-flight fuel burn for international aviation from 2005 to 2040, and extrapolated to the year 2050. The fuel burn analysis considers three main factors: the contribution of aircraft technology, improved air traffic management, and infrastructure use to reduce fuel consumption. **Figure 1** also illustrates the fuel burn that would be expected if the 2% annual fuel efficiency aspirational goal was achieved.

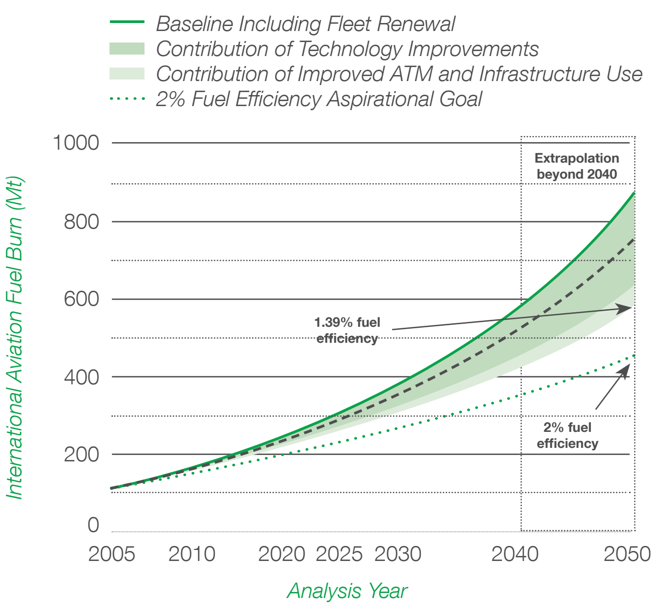
Figure 2 puts these contributions into context with the uncertainty associated with the forecast demand, which is notably larger than the range of potential contributions from technological and operational improvements.

The results presented in **Figures 1** and **2** are for international aviation only. In 2010, approximately 65% of global aviation fuel consumption was from international aviation. Based on CAEP/MDG's analysis, this proportion is expected to grow to nearly 70% by 2050.

Scenario	Name	Technology Improvement	Operational Improvement
1	Baseline Including Fleet Renewal	None	None
2	Low Aircraft Technology and Moderate Operational Improvement	0.96%/annum, 2010-2015 0.57%/annum, 2015-2050	CAEP/8 IE* Lower Bound
3	Moderate Aircraft Technology and Operational Improvement	0.96%/annum, 2010-2050	CAEP/8 IE* Lower Bound
4	Advanced Aircraft Technology and Operational Improvement	1.16%/annum, 2010-2050	CAEP/8 IE* Upper Bound
5	Optimistic Aircraft Technology and Advanced Operational Improvement	1.50%/annum, 2010-2050	CAEP/8 IE* Upper Bound
6	Low Aircraft Technology and CAEP/9 Independent Expert (IE) Operational Improvement	0.96%/annum, 2010-2015 0.57%/annum, 2015-2050	CAEP/9 IE*
7	Moderate Aircraft Technology and CAEP/9 IE Operational Improvement	0.96%/annum, 2010-2050	CAEP/9 IE*
8	Advanced Aircraft Technology and CAEP/9 IE Operational Improvement	1.16%/annum, 2010-2050	CAEP/9 IE*
9	Optimistic Aircraft Technology and CAEP/9 IE Operational Improvement	1.50%/annum, 2010-2050	CAEP/9 IE*

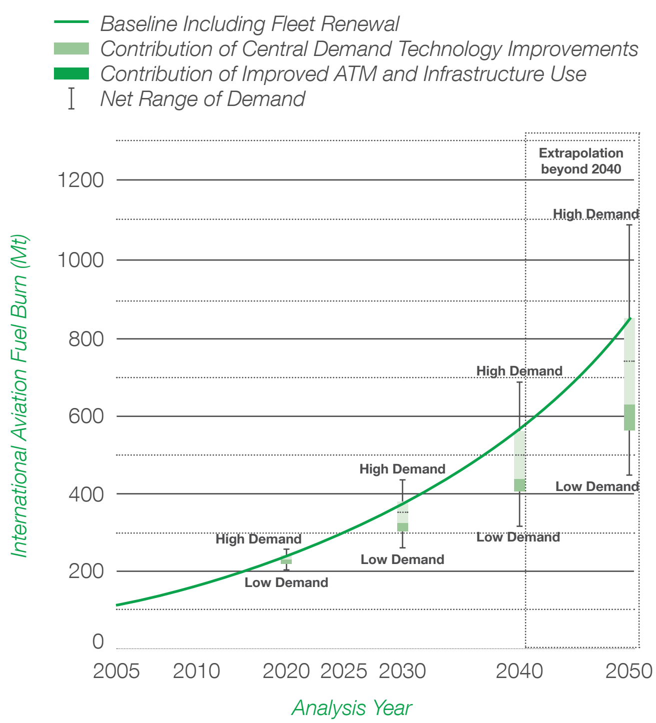
* Recommendations from the Independent Experts (IE) Operational Goals Group

***Table 1:** Full-flight fuel burn and CO_2 scenarios for the assessment of aircraft GHG trends.*



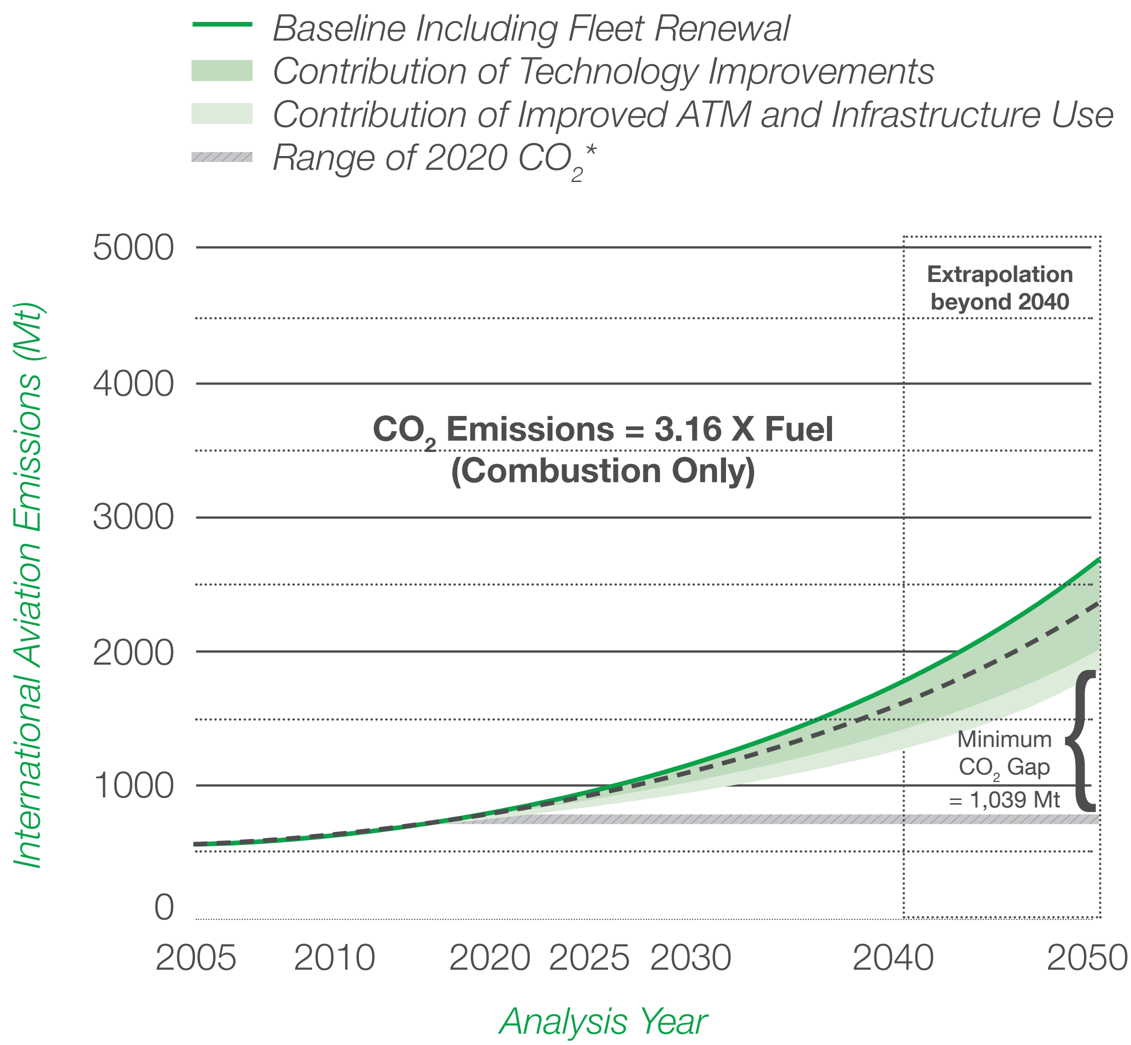
*Dashed line in technology contribution range represents the "Low Aircraft Technology Scenario".
Note: Results were modelled for 2005, 2006, 2010, 2020, 2025, 2030, and 2040 then extrapolated to 2050.

***Figure 1:** ICAO/CAEP Fuel Burn Trends from International Aviation, 2005 to 2050.*



Note: Fuel burn was only modelled for the central demand forecast. The effects of the high and low demand sensitives shown are based on the ratio of forecasted revenue passenger kilometres for high/low demand relative to central demand.

***Figure 2:** Range of Uncertainties Associated with Demand Forecast, 2005 to 2050.*



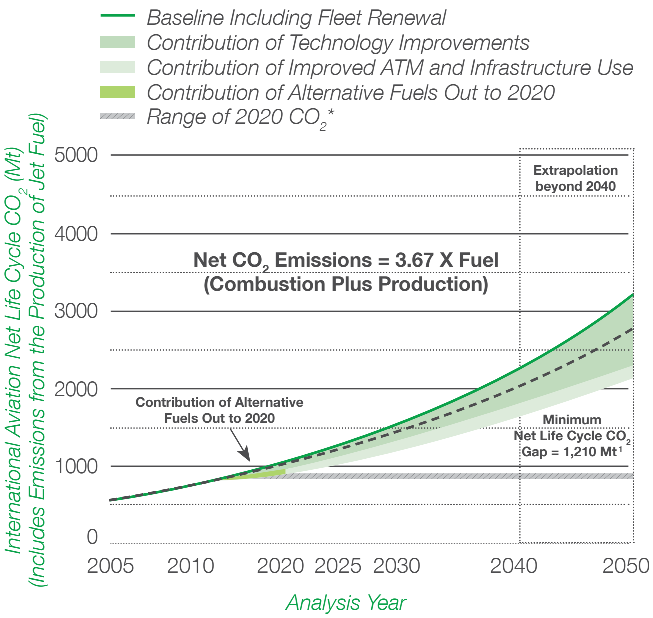
*Actual carbon neutral line is within this range. Dashed line in technology contribution range represents the “Low Aircraft Technology Scenario”.
Note: Results were modelled for 2005, 2006, 2010, 2020, 2025, 2030, and 2040 then extrapoled to 2050.

Figure 3: *CO_2 Emission Trends from International Aviation, 2005 to 2050.*

Figure 3 presents full-flight CO_2 emissions for international aviation from 2005 to 2040, and extrapolated to the year 2050. This figure covers the CO_2 emissions associated with the combustion of jet fuel, assuming that 1 kg of jet fuel burned generates 3.16 kg[1] of CO_2. As with the fuel burn analysis, this analysis considers: the contribution of aircraft technology, improved air traffic management, and infrastructure use. In addition, the range of possible CO_2 emissions for 2020 is displayed relative to the global aspirational goal of keeping the net CO_2 emissions at this level. Although not displayed separately, the demand uncertainty effect on the fuel burn calculations shown in **Figure 2** would be identical for CO_2, since CO_2 is a simple scalar on fuel burn.

CONTRIBUTION OF ALTERNATIVE FUELS TO GHG TRENDS ASSESSMENT

Member States and observer organizations have provided targets for alternative fuel production in the years 2020 and 2050. **Figure 4** illustrates the maximum potential for sustainable alternative fuels to contribute to international aviation net life cycle CO_2 reduction in 2050. Net life cycle emissions include those from both fuel creation and fuel combustion. Accordingly, the life cycle emissions of conventional jet fuel and of sustainable alternative fuels are both reflected in the figure. For the purposes of this analysis, it is assumed that the emissions created from the production of jet fuel from fossil sources are to be 0.51 times[2] the fuel amount, and from their combustion, 3.16 times the fuel amount.



[1] **Potential Alternative Fuels Contribution in 2050[2]**
State targets could close up to 25% of gap
Maximum potential contribution could close in excess of 100% of gap

[2] If all alternative fuels in 2050 were zero net carbon

*Actual carbon neutral line is within this range. Dashed line in technology contribution range represents the "Low Aircraft Technology Scenario."
Note: Results were modelled for 2005, 2006, 2010, 2020, 2025, 2030, and 2040 then extrapoled to 2050.

Figure 4: *Net Life Cycle CO_2 Emission Trends from International Aviation, 2005 to 2050.*

Figure 4 does not assume any allocation of responsibility, or a policy decision, or a recommendation for net life cycle emissions, since this approach, which was carried out by a Member State in support of CAEP, has not yet been fully vetted and endorsed by ICAO. In the absence of international agreement and specific ICAO guidance on life cycle analysis methodologies, for the purposes of this analysis, the contribution of alternative fuels are presented here assuming they have zero net life cycle CO_2 emissions.

GHG emissions are not reported to the United Nations Framework Convention on Climate Change (UNFCCC) on a life cycle basis. Instead, they are reported to UNFCCC as emissions based on "bunker fuels" sold to aircraft engaged in international transport. CO_2 emissions from international aviation are not included in national emission totals, and are reported separately using a value that is equal to 3.16 times the fuel amount, while jet fuel production emissions are reported in a separate category as national emissions. Similarly, the aircraft technology and operational improvements described in this section will not directly contribute to the reduction of jet fuel production emissions.

In order to improve future estimates of the contribution of sustainable alternative fuels toward reducing international aviation emissions, there may be a need to further develop methodologies to take into account aviation net life cycle emissions.

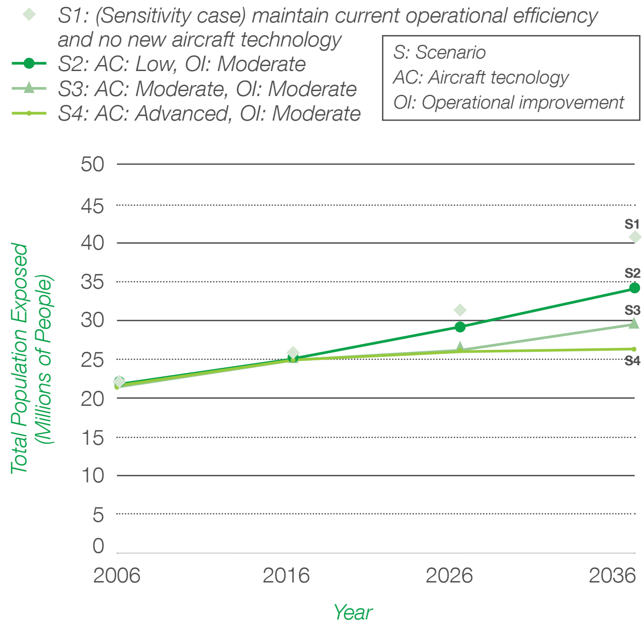
INTERPRETATION OF GREENHOUSE GAS TRENDS

In 2010, international aviation consumed approximately 142 million metric tonnes of fuel, resulting in an estimated 448 million metric tonnes (Mt, 1 kg x 10^9) of CO_2 emissions. Based on the GHG trend assessment assumptions described above, this equates to 522 million tonnes of net life cycle CO_2 emissions. It is projected that, by 2040 fuel consumption will have increased by between 2.8 and 3.9 times the 2010 value, while revenue tonne kilometres (RTK) are expected to increase 4.2 times under the central demand forecast. By extrapolating to the year 2050, it is estimated that fuel consumption will have increased four to six times the 2010 value, while revenue tonne kilometres are expected to increase seven times under the central demand forecast.

Under Scenario 9 in the GHG trends assessment scenarios described in **Table 1**, aviation fuel efficiency, expressed in terms of volume of fuel per RTK, is expected to improve at an average rate of 1.4% per annum to 2040, and at almost the identical rate when extrapolated to 2050. While in the near term (2010 to 2020), efficiency improvements from technology and improved ATM and infrastructure use are expected to level off, they are projected to accelerate in the medium term (*i.e.*, 2020 to 2030). During that latter period, fuel efficiency is expected to improve at an average rate of 1.76% per annum under Scenario 9. That magnitude of fuel efficiency improvements is not unexpected, given the 1.5% per annum technology improvement associated with Scenario 9, and the variability of the forecasted RTK. The analysis shows that additional technological and operational improvements beyond even those described in Scenario 9 will be required to achieve the global aspirational goal of 2% per annum fuel efficiency.

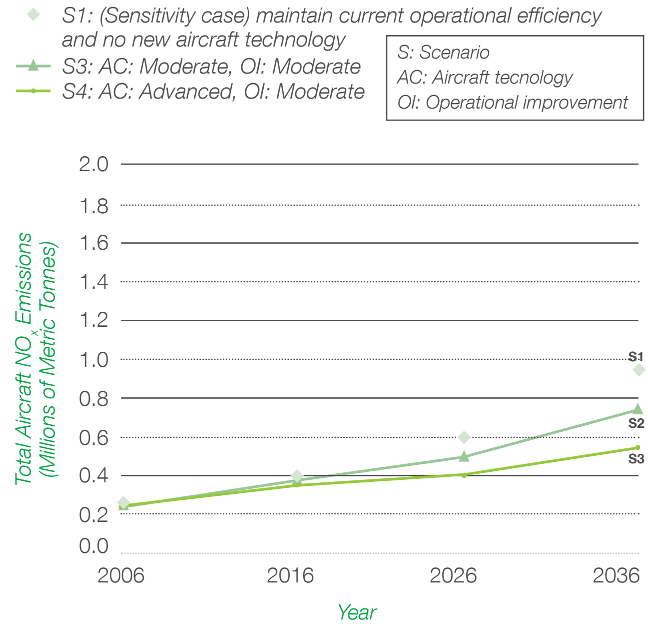
By the year 2020, it is expected that international aviation will consume between 216 and 239 Mt of fuel per annum, resulting in 682 to 755 Mt of CO_2 emissions. Based on the GHG trend assessment assumptions, this translates to between 794 and 879 Mt of net life cycle CO_2 emissions. Under the most likely scenario, it is estimated that approximately 3% of this fuel consumption could consist of sustainable alternative fuels by 2020. Based on the maximum anticipated fuel consumption in 2020 under Scenario 1, and the anticipated Scenario 9 fuel consumption in 2040, a minimum CO_2 emissions gap of 523 Mt is projected for 2040.

Extrapolating Scenario 9 to the year 2050 results in an estimated 1,039 Mt gap. Based on the GHG trend assessment assumptions described above, net life cycle CO_2 emissions gaps of 607 Mt in 2040 and 1,210 Mt in 2050 are projected. Significant uncertainties exist in predicting the contribution of sustainable alternative fuels in 2050. Nevertheless, based on



Note: Population exposed relative to 2006 baseline. Population levels are assumed constant from 2006 to 2036.

Figure 5: *Total Global Population Exposed to Aircraft Noise Above 55 DNL.*



Note: Population exposed relative to 2006 baseline. Population levels are assumed constant from 2006 to 2036.

Figure 6: *Total Global Aircraft NO_x Below 3,000 Feet AGL.*

targets established by ICAO Member States, it is possible that 25% of the gap could be closed by the year 2050 through the use of sustainable alternative fuels. Considering the maximum evaluated contribution from sustainable alternative fuels (based on potentially available feedstocks and land areas) with assumed net zero-carbon emissions relative to conventional jet fuel, it is possible that the gap could be completely closed.

NOISE TRENDS

A number of scenarios were developed for the assessment of aircraft noise trends, as shown in **Table 2**.

Scenario 1 is the "sensitivity case" that assumes the operational improvements necessary to maintain current operational efficiency, but it does not include any aircraft technology improvements beyond those available in 2006 production aircraft. Since Scenario 1 is not considered a likely outcome by the CAEP, it is purposely depicted in all graphics with no line connecting the modelled results for the years 2006, 2016, 2026 and 2036. The other scenarios all assume increased implementation of both operational and technological improvements. Scenarios 2, 3 and 4 are assumed to represent the range of most likely outcomes.

Scenario	Name	Technology Improvement	Operational Improvement
1	Sensitivity Case	None	None
2	Low Aircraft Technology and Moderate Operational Improvement	0.1 EPNdB/annum, 2013-2036	Moderate
3	Moderate Aircraft Technology and Operational Improvement	0.3 EPNdB/annum, 2013-2020 0.1 EPNdB/annum, 2020-2036	Moderate
4	Advanced Aircraft Technology and Moderate Operational Improvement	0.3 EPNdB/annum, 2013-2036	Moderate

Table 2: *Scenarios Developed for the Assessment of Aircraft Noise Trends.*

Scenario	Name	Technology Improvement	Operational Improvement
1	Sensitivity Case	None	None
2	Moderate Aircraft Technology and Operational Improvement	50% CAEP/7 NO_x Independent Expert goals for 2026, nothing thereafter	Moderate
3	Advanced Aircraft Technology and Operational Improvement	100% CAEP/7 NO_x Independent Expert goals for 2026, nothing thereafter	Advanced

Table 3: *Scenarios Developed for the Assessment of Aircraft LAQ Trends.*

Figure 5 shows results for the total global population exposed to aircraft noise above 55 DNL (day-night average sound level, in decibels) for the years 2006, 2016, 2026 and 2036. The 2006 baseline value is about 21.2 million people. In 2036, total population exposure ranges from about 26.6 million people with Scenario 4, to about 34.1 million people with Scenario 2, assuming constant 2006 population levels throughout the observation period.

LOCAL AIR QUALITY TRENDS

A number of scenarios have also been developed for the assessment of aircraft emission trends below and above 3,000 feet above ground level (AGL) that affect LAQ, with particular emphasis on oxides of nitrogen (NO_x), as shown in **Table 3**.

As with noise, Scenario 1 is the "sensitivity case" that assumes the operational improvements necessary to maintain current operational efficiency levels, but it does not include any aircraft technology improvements beyond those available in 2006 production aircraft. Scenarios 2 and 3 assume aircraft NO_x improvements based upon achieving 50% cent and 100% of the reduction from the current NO_x emission levels to the NO_x emissions levels set by the CAEP/7 NO_x Independent Expert goals review (about 60% of the current CAEP/6 NO_x standard for 2026.) Fleet-wide operational improvements by region were also included.

Figure 6 depicts results for global NO_x emissions below 3,000 feet AGL for the years 2006, 2016, 2026 and 2036. The 2006 baseline value is about 0.25 million metric tonnes (Mt, 1 kg x 109). For the year 2036, estimated total NO_x ranges from 0.52 Mt, with Scenario 3, to 0.72 Mt under Scenario 2.

The results for particulate matter (PM) emissions below 3,000 feet AGL follow the same trends as those for NO_x. The 2006 baseline PM value is 2,200 metric tonnes. For 2036, total global PM is projected to be about 5,800 metric tonnes under Scenario 2.

Estimated NO_x levels for the scenarios assessed for above 3,000 feet AGL are identical to those for NO_x below 3,000 feet AGL. The 2006 baseline value is about 2.5 Mt. For 2036, total NO_x estimates range from about 4.6 Mt under Scenario 3, to about 6.3 Mt with Scenario 2.

CONCLUSION

The CO_2 emissions that affect the earth's climate, as well as aircraft noise, and emissions that affect LAQ, are all expected to increase through the year 2050, but at a rate slower than the increase in aviation demand. However, it has to be kept in mind that the uncertainty associated with future aviation demand forecasts is larger than that for the range of contributions from technology and operational improvements.

International aviation fuel efficiency is expected to improve through 2050, but measures in addition to those considered in this analysis will be required to achieve the 2% annual fuel efficiency aspirational goal. Sustainable alternative fuels have the potential to make a significant contribution to achieving this goal, but sufficient data is not available to confidently predict their impact over the long term. Also, considering only aircraft technology and operational improvements, additional measures will be needed to achieve carbon neutral growth by the year 2020. ■

REFERENCES

1 [For 3.16] Conventional Aviation Kerosene Fuel to CO_2 Conversion Factor (2010). Committee for Aviation Environmental Protection, CAEP-WG3-(Emissions Technical) recommendation.

2 [For 0.51] Stratton, R. W., H. M. Wong, *et al.* (2010). Life Cycle Greenhouse Gas Emissions from Alternative Jet Fuel, Version 1.2. Cambridge, Massachusetts, PARTNER/MIT.

ENHANCING EUROPEAN MODELLING CAPABILITIES

BY ANDREW WATT

ANDREW WATT

He is Head of Environment at EUROCONTROL. In this role, Andrew is responsible for ensuring that the Eurocontrol Agency strongly supports the Air Traffic Management (ATM) sector's contribution to the long-term sustainability of the air transport industry. The scope of work covers ATM environmental initiatives related to airports and the pan-European airspace network, how best to manage environmental issues within ATM, support to policy making, support to R&D and to SESAR. He is also co-Rapporteur of CAEP's WG2 (Airports and Operations).

In support of ICAO's Committee on Aviation Environmental Protection (CAEP) studies, and to assist with environmental impact assessments in general, EUROCONTROL, with the support of the European Commission and EASA, has developed key environmental modelling tools and a historical world air traffic movement database, including:

- Advanced Emissions Model (AEM);
- System of Airport Noise Exposure Studies (STAPES) model;
- Airport Local Air Quality Studies (ALAQS) model;
- World Interconnected Sources Database of Operational Movements (WISDOM).

EUROCONTROL, EASA, and the European Commission have decided to enhance these models to better support future European and CAEP policy assessments. The spearhead of the new wave of European support is represented by an integrated noise and emissions assessment model called IMPACT, as well as a future aircraft fleet and movements forecast tool known as AAT.

LOCAL AIR QUALITY ASSESSMENTS

The airport emissions inventory and local air quality toolset, ALAQS – ArcView (ALAQS-AV), was developed by the EUROCONTROL Experimental Centre between 2002 and 2007. The ALAQS-AV tool is based on a Geographical Information System (GIS) that simplifies the process of defining the various airport elements (*i.e.* runways, taxiways, buildings, etc.), and allows the spatial distribution of emissions to be visualized. The tool provides a four-dimensional emissions inventory for an airport in which the emissions from the various fixed and mobile sources are aggregated and subsequently displayed for analysis. Once the emissions inventory has been established, dispersion modelling can be used to calculate pollutant concentrations at an airport and in the surrounding area throughout a day. The system is thus compatible with legislative requirements for 8-hour, 24-hour, and annual mean values of pollutant concentrations.

GLOBAL EMISSIONS ASSESSMENTS

EUROCONTROL's Advanced Emissions Model (AEM) can determine the amount of fuel burned by a specific aircraft type equipped with a specific type of engine, flying a specific 4D trajectory. As shown in **Figure 1**, it can also determine the specific by-products of that fuel burn, including:

- carbon dioxide (CO_2);
- water vapour (H_2O);
- the oxides of sulphur (SO_x);
- the oxides of nitrogen (NO_x)[1];
- (un-burnt) hydrocarbons (HC)[2];
- carbon monoxide (CO); and
- some volatile organic compounds[3] (VOCs) such as benzene and acetaldehyde.

The set of TOGs (total organic gases) is a subset of VOCs.

World Interconnected Sources Database of Operational Movements (WISDOM) is EUROCONTROL's version of the ICAO CAEP common operations database. FAA/VOLPE has a similar version known as the Aviation Environmental Design Tool (AEDT). Essentially, WISDOM contains information about global civil aviation traffic (see **Figure 2**). Radar-based trajectory data from North America and corrected flight-plan data from Europe are combined with scheduled flight data from "the rest of the world" to form a global resource of real flight data that can be used for environmental impact assessments. In addition to supporting the analysis of CAEP policy options, it can also be used, for example, to generate global inventories of civil aviation emissions by running the trajectories from WISDOM through AEM. Such data is also very useful to the scientific research community.

NOISE ASSESSMENTS

System of Airport Noise Exposure Studies (STAPES) is a multi-European airports noise model. The development of STAPES was initiated by EASA in January 2008, with joint EC-EUROCONTROL funding. This noise modelling capability aims to quantify, on a multi-airport basis, the impact of the

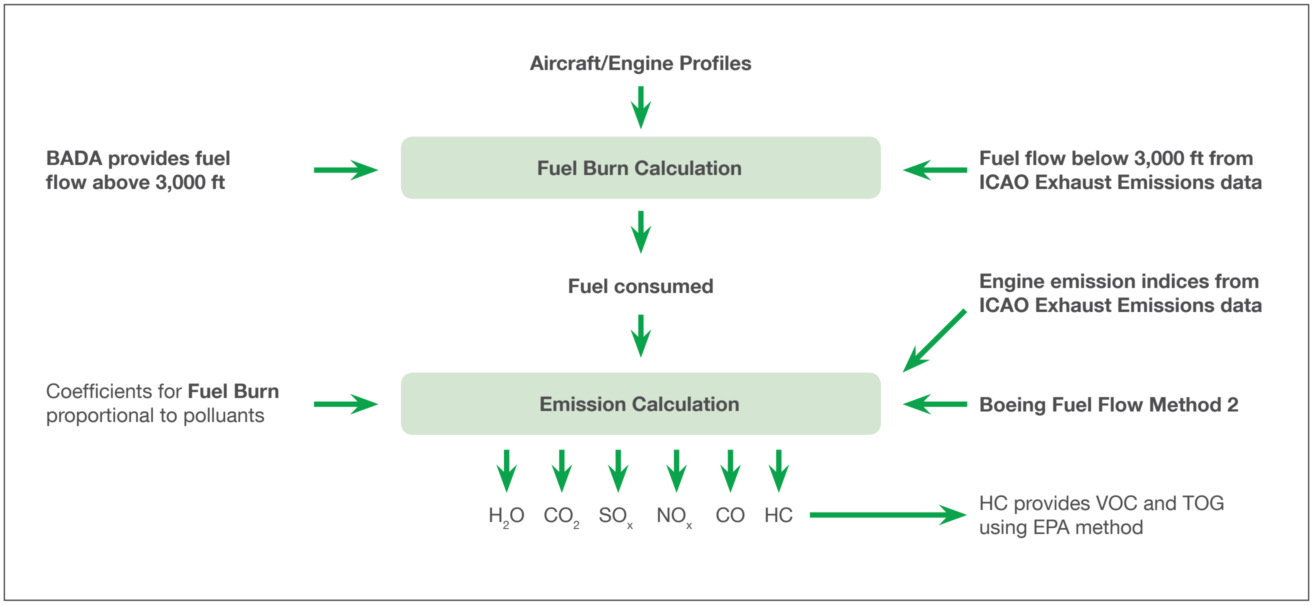


Figure 1: *AEM Fuel Burn and Emissions Calculation.*

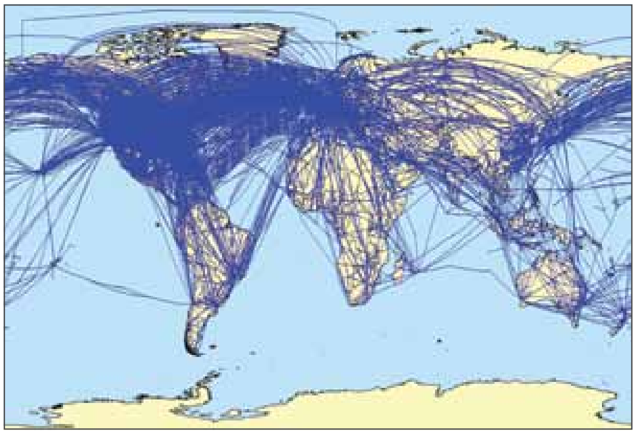


Figure 2: *WISDOM Coverage in Terms of Flight Movements.*

noise resulting from current traffic (the baseline) and future traffic scenarios, taking into account the ongoing evolution of air traffic and fleet mix. The impacts will be analysed in terms of potential policy options and new operational concepts. Noise impact is quantified in STAPES by estimating the overall number of people exposed to varying levels of noise.

In contrast to the "traditional" noise assessments for individual (specific) airports, this modelling system delivers, in a consistent way, an estimate of the overall noise impact that would result from implementing future noise policy options, noise abatement procedures, or other ATM-related operational concepts; each of which may have an effect on the distribution of traffic across different European airports. Its consistency comes from using a common modelling methodology and common datasets, based on internationally agreed modelling best practices.

The STAPES airport database currently includes 28 European airports. Soon, it will be extended to include up to 10 additional airports with the goal to cover about 90% of the European population that is exposed to significant noise levels (> 55 Lden).

LOOKING AHEAD

Integrating Noise and Emissions Assessments – IMPACT

Although AEM, ALAQS, and STAPES focus on different impacts on the environment (*i.e.* global emissions, local air quality, and noise), they all require similar flight operations and aircraft performance data as input. It therefore became obvious that it would be possible to develop an integrated model that would be highly valuable; this was how the idea for IMPACT was born.

As shown in **Figure 3**, IMPACT enables both the emissions (AEM) and the noise (STAPES) models to be run from the same modelling platform with access via a secure Web portal. In short, IMPACT puts AEM and STAPES "in the cloud". This new cloud modelling platform incorporates the notion of common input data, namely aircraft operations and trajectories, jointly used by the integrated noise and emissions models. IMPACT also includes a data warehouse that hosts all the reference and default data needed by the common input data processor and the STAPES and AEM models, such as BADA 4.0 and ANP v2.0.

Although IMPACT was developed in the context of the European SESAR programme, with the main objective being to develop and deliver a modelling system designed

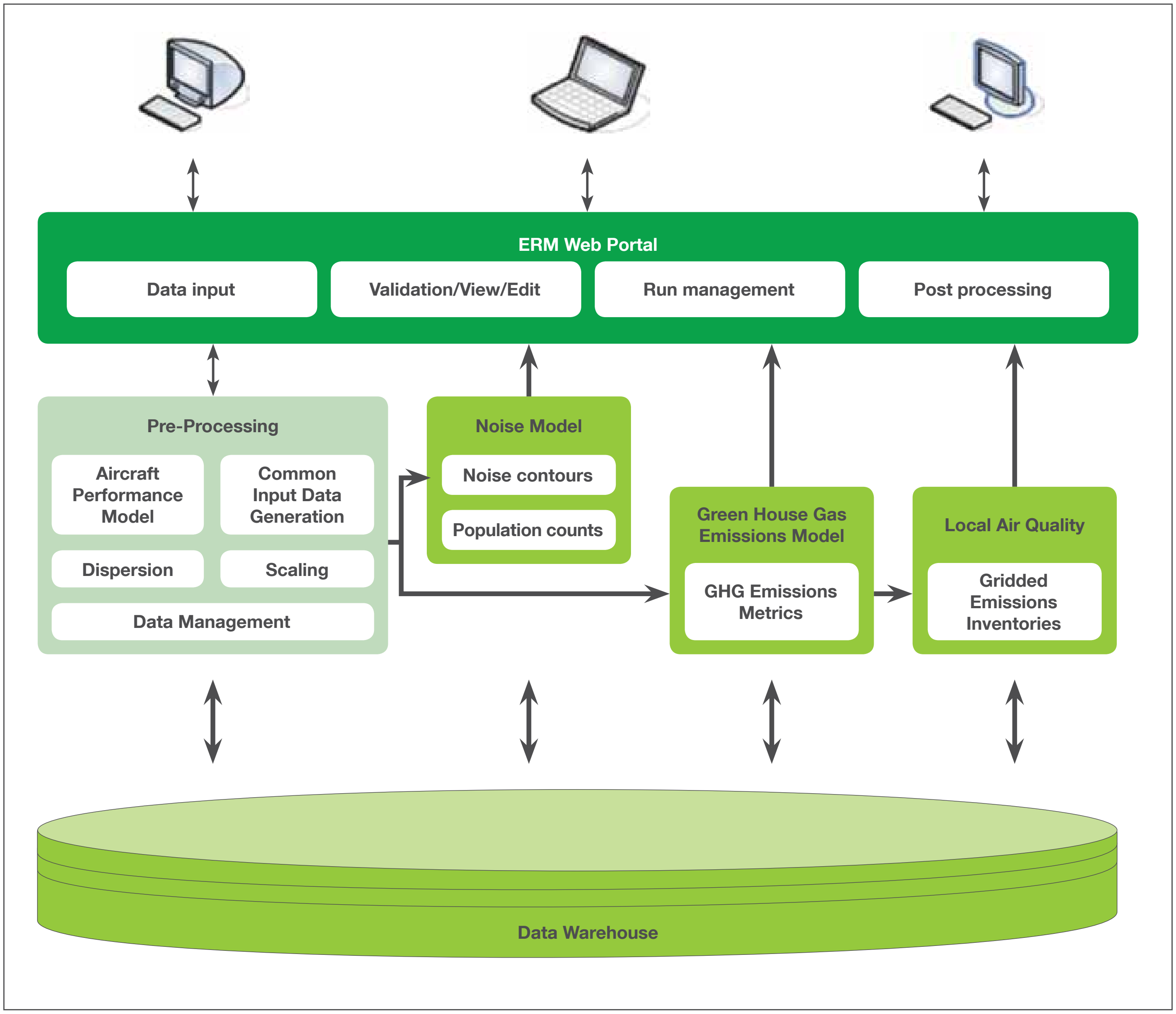


Figure 3: *Schematic Overview of the IMPACT Model.*

to support the assessment of the impacts of noise and emissions due to the SESAR operational improvements (OIs), its use is not limited to SESAR.

Because IMPACT relies on models that have already been CAEP stress-tested and used in CAEP assessments, EUROCONTROL, EASA and the European Commission are expecting that IMPACT will be available for use in the context of future ICAO environmental policy assessments beginning in 2014.

FUTURE FLEET AND MOCEMENTS FORECASTS

To meet both European needs, and as part of their support to ICAO/CAEP, the European Commission, EASA, and EUROCONTROL have initiated work to develop a fleet forecasting capability, which will be known as the Aircraft Assignment Tool (AAT).

The AAT is a generic modelling tool that converts a forecast of flights into a forecast of movements by particular aircraft types flying between specified pairs of airports. The output of the AAT can be used as input to models such as IMPACT. Such information can also be used to assess the evolution of the aircraft fleet for future planning and policy purposes and will be made available to ICAO CAEP purposes.

Figure 4 provides a schematic design of the AAT. It distinguishes the internal process of the AAT within the lightly-shaded outer box from the external inputs.

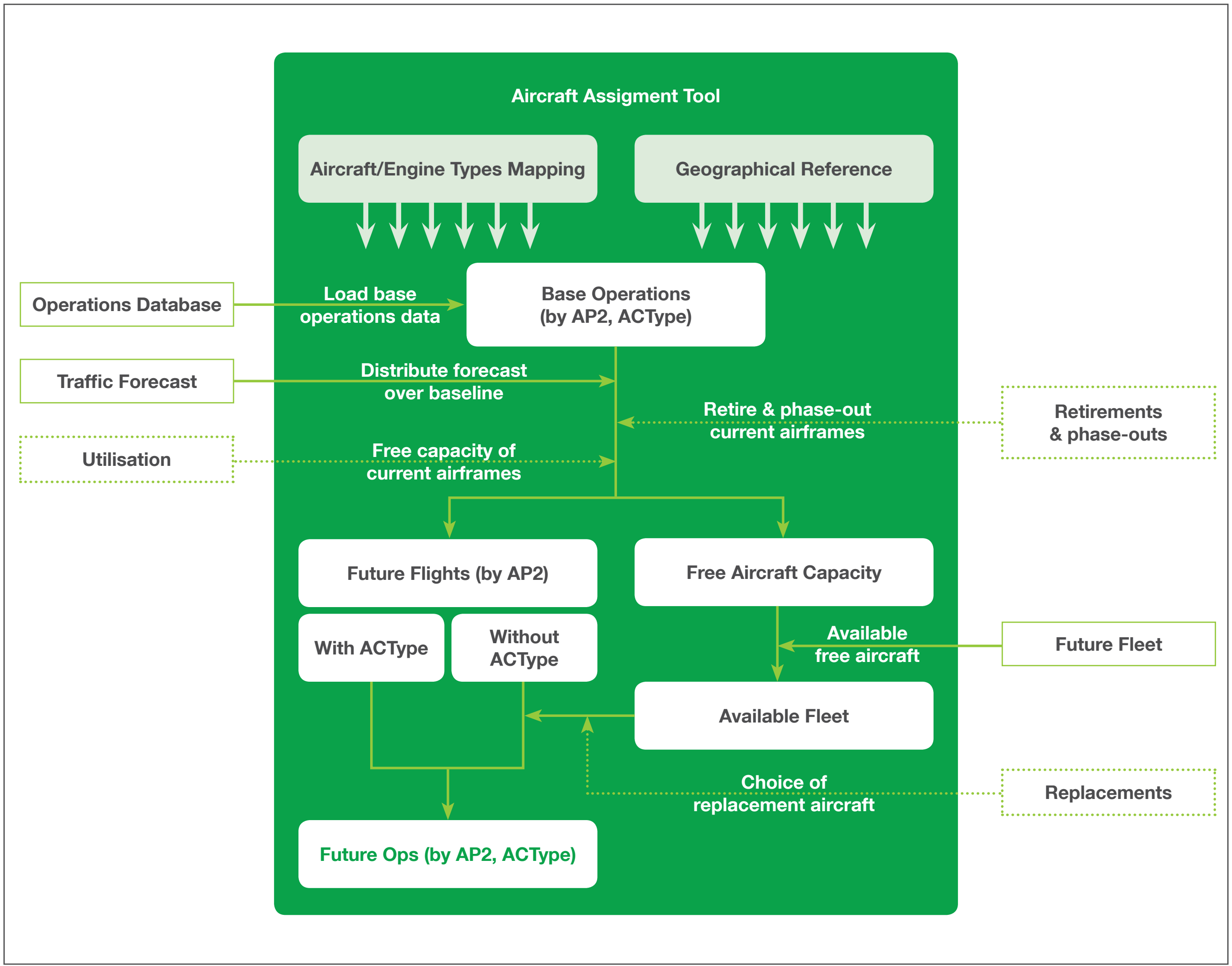


Figure 4: *Schematic of the Aircraft Assignment Tool (AAT) Design.*

A functional outline of the AAT has the following five steps:

1) Load base operations data: Loading and pre-processing the base operations data from the specified historical data.
2) Distribute forecast over baseline: The traffic forecasts are generally constructed at some higher level of aggregation than the base operations data.
3) Retirements and phase-outs: Some of the current aircraft will retire or be phased-out by the time of the forecast horizon.
4) Current fleet utilization.
5) Assignment of aircraft to operations: Operations with missing aircraft/engine type specifications resulting from previous steps (either from creating new operations by traffic growth or from retiring/phasing-out aircraft) are addressed.

With AEM, ALAQS, and WISDOM; EUROCONTROL, EASA and the European Commission continue to work together to make available the best suite of tools for European and CAEP policy and environmental impact assessments. IMPACT and AAT are the new flagships of European modelling capability. ■

REFERENCES

1 NO_x consists of nitric oxide [NO] and nitrogen dioxide [NO_2].

2 HC consists of hydrocarbon compounds of all classes and molecular weights (and so includes methane [CH_4]).

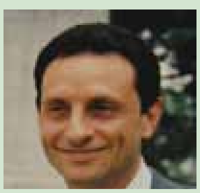
3 VOCs include all compounds of carbon except carbon monoxide [CO], carbon dioxide [CO_2], carbonic acid [H_2CO_3], metallic carbides and carbonates, and ammonium carbonate [$(NH_4)_2CO_3$].

THE AVIATION ENVIRONMENTAL DESIGN TOOL (AEDT)

BY **CHRISTOPHER ROOF** AND **FABIO GRANDI**

CHRISTOPHER J. ROOF

As Chief of the Environmental Measurement and Modeling Division at the US Department of Transportation's Volpe National Transportation Systems Center, he leads an interdisciplinary team of scientists, engineers and software developers on transportation-related environmental projects. His two decades of technical experience include measurement, modeling and analysis of noise, fuel burn and emissions for all modes of transportation. Mr. Roof supports the Federal Aviation Administration (FAA) in a number of areas including the development of the Aviation Environmental Design Tool (AEDT) and policy analyses such as those for ICAO. He regularly participates in numerous domestic and international technical organizations that address transportation environmental issues.



FABIO GRANDI

He has been a program manager in the Noise Division of the FAA's Office of Environment and Energy (AEE-100) since 2011 and his responsibilities include managing the Aviation Environmental Design Tool (AEDT) development program, system level analyses, and other research and support projects. He has 17 years of experience in the field of aviation modeling, software development, and database systems integration and has been a member of the AEDT design and development team since the inception of the program in 2003. Mr. Grandi has also been a member of the FAA team supporting ICAO/CAEP work since 1997 (CAEP/5) and was the designer and developer of the Model for Assessing Global Exposure to the Noise of Transport Aircraft (MAGENTA) and the Fleet and Operations Module (FOM), the tools that provided the analytical bases for the Chapter 4 noise standard.

BACKGROUND

CAEP has quantified environmental consequences and benefit/cost analyses of policies intended to further these efforts utilizing a number of analytical tools and methodologies contributed by ICAO members. Until recently, however, most of those tools focused primarily on a single aspect of the environment, namely noise, local air quality, and greenhouse gas emissions.

Almost a decade ago the US Federal Aviation Administration (FAA) recognized the need to support policy development with the capability to simultaneously analyze all environmental consequences in an interdependent manner, and using a common set of data and assumptions. Shortly thereafter, in collaboration with Transport Canada and the US National Aeronautics and Space Administration (NASA), the FAA began planning and implementing a suite of environmental modelling tools that would enable the interdependent analysis of aviation scenarios. Recognizing the significant challenges associated with such an undertaking, input and guidance was sought from numerous international stakeholders[1,2,3] before finalizing development plans. The FAA has produced development plans and multiple versions of AEDT to support CAEP throughout the last two CAEP cycles.

AEDT EXPLAINED

The core of the tools suite is the Aviation Environmental Design Tool (AEDT)[4]. This model utilizes scenario-based schedule and operational data to predict environmental consequences. Because it utilizes a single set of input data to model noise, local air quality, and greenhouse gas emissions, AEDT is by definition an interdependent tool. This tool may be used standalone, or integrated with one or more components of the tool suite. The other components include: the ability to define new types of aircraft (*i.e.* primarily the Environmental Design Space [EDS], but also other tools), analyze the use of alternative fuels, generate economically-driven operational scenarios (Aviation Environmental Portfolio Management Tool [APMT-E], and environmental impact analysis [APMT-I]). The individual components of the tool suite are built around a common set of assumptions and robust system databases. **Figure 1** shows an overview of this FAA tool suite.

AEDT uses relational system databases that enable data-driven analyses to be undertaken at a number of levels. The tool is scalable; from detailed, airport-specific analysis of runway configurations and other scenarios, up to full gate-to-gate domestic and global policy analysis to support organizations such as CAEP. The databases contain noise, emissions and full-flight performance information for over 1,200 airframe/engine combinations. They also define airport parameters for more than 20,000 airports worldwide. Aircraft movements are an important part of AEDT's input data. The tool is capable of importing a number of operations and trajectory data sources, including: the commercially available

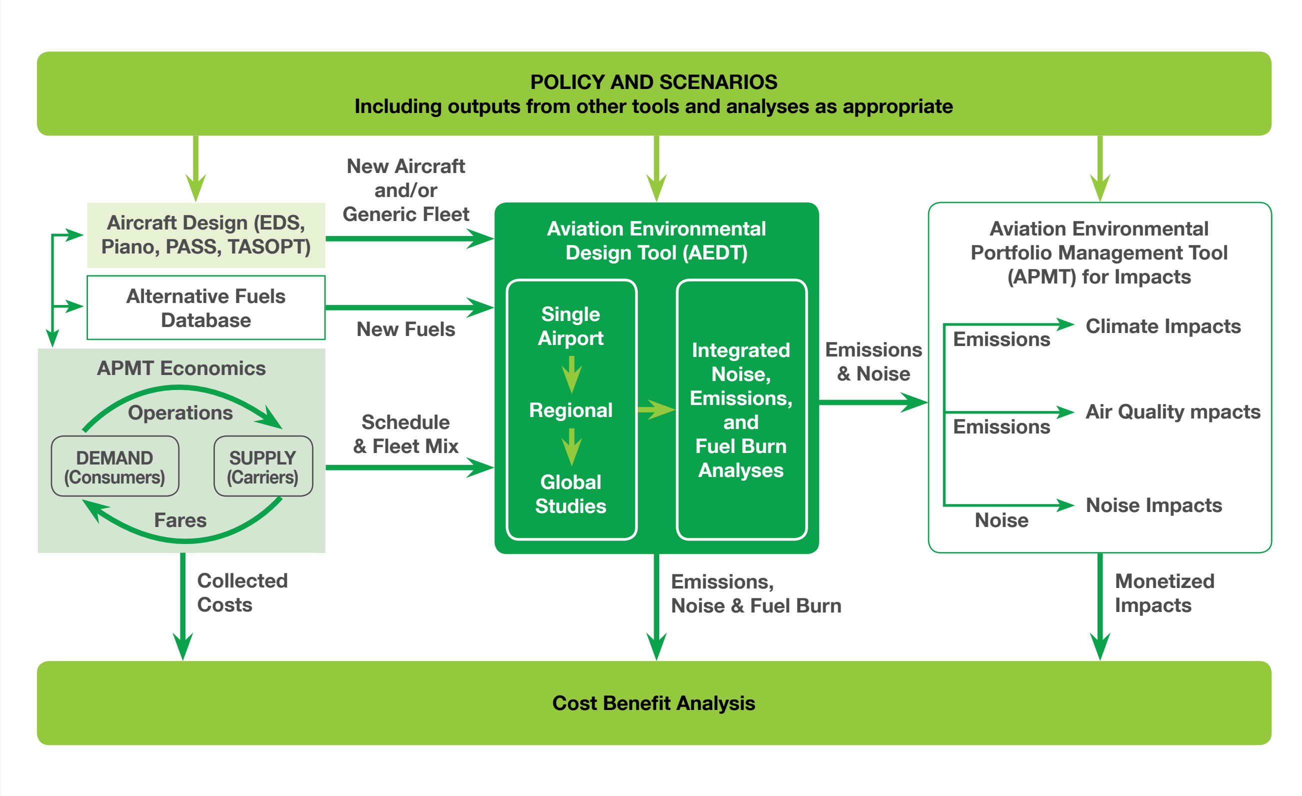


Figure 1: *Overview of the FAA Environmental Tool Suite.*

OAG Aviation and OAG Cargo, the FAA's Enhanced Traffic Management System (ETMS)[5], EUROCONTROL's Enhanced Tactical Flow Management System (ETFMS)[6], as well as more detailed information such as flight data recorder and ADS-B data. **Figure 2** depicts the approximate 300 unique airports utilized for the CAEP/9 noise stringency analysis from the 20,000+ available in the AEDT Airports Database[7].

Figure 2: *Global Airport Coverage for CAEP/9 Noise Stringency Analysis.*

Full-flight aircraft performance is modelled in AEDT utilizing multiple methodologies and data sources. A single module within the tool incorporates terminal area aircraft performance (generally up to 10,000 feet above field elevation, AFE) from the ICAO-endorsed international Aircraft Noise and Performance (ANP) database[8] It also uses the methodologies outlined in ICAO's *Recommended Method for Computing Noise Contours Around Airports* (Doc 9911)[9] as well as the European Civil Aviation Conference's (ECAC) *Report on Standard Method of Computing Noise Contours around Civil Airports*, Doc 29 (3rd Edition)[10]. These are merged internal to AEDT with EUROCONTROL's Base of Aircraft Data (BADA)[11], which provides data and algorithms to model aircraft performance above 10,000 feet as well as fuel flow for all modes of flight.

AEDT Version 2A was released publicly in 2012. With a focus on air traffic, airspace, and procedure actions, this tool officially replaces FAA's legacy Noise Integrated Routing System (NIRS). **Figure 3** illustrates a noise analysis undertaken using AEDT 2A for multiple airports in relatively close proximity to each other. In addition to enabling the assessment of environmental interdependencies, this also allows for the modelling of the interactions of airspace complexities where departure and arrival patterns at individual airports overlap. Version 2A is already in use for US domestic airspace actions, and has been procured for use in other countries, as well as by higher education institutions for inclusion in formal curricula.

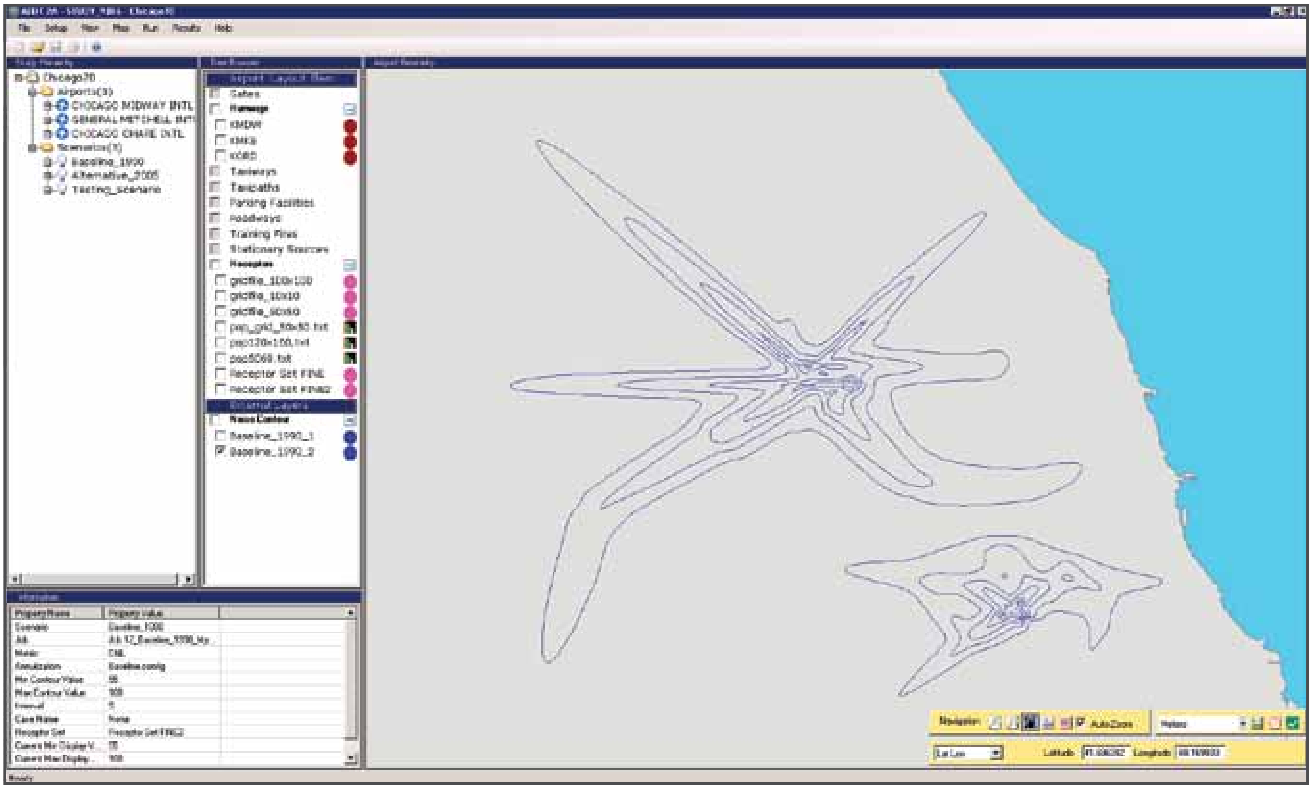
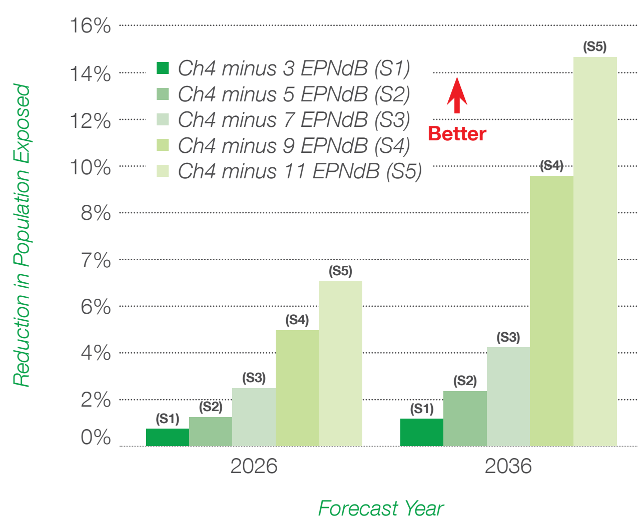


Figure 3: *Example Contour Analysis Using AEDT.*

VALIDATION AND VERIFICATION OF AEDT

Given the unprecedented nature of environmental interdependency analysis, AEDT has been subjected to a wide range of validation and verification processes over the last few years. These include initiatives at the software development level, as well as peer review and stakeholder outreach. At the development level, given that AEDT is in part based upon a number of legacy tools, baseline data sets and software implementations exist to which AEDT may be referenced. These legacy tools include: the above-mentioned NIRS, the Integrated Noise Model (INM)[12], the Emissions and Dispersion Modelling System (EDMS)[13], the System for assessing Aviation's Global Emissions (SAGE)[14], and the Model for Assessing Global Exposure to the Noise of Transport Aircraft (MAGENTA)[15]. In order to utilize the vast nature and history of these databases, more than 1,400 unit tests have been developed. These are run daily and/or weekly to ensure that existing and new code implementations meet all known requirements.

Peer review and stakeholder outreach has also been a key component of AEDT development. A Design Review Group (DRG) helped to refine requirements beyond those identified by the original National Academy of Science workshops. Throughout development, there has also been a core group of stakeholders who test beta versions of the software at mid-development phases. Further, ICAO CAEP's Modelling and Database Group (MDG) undertook a formal model evaluation process, including among other aspects, review of model capabilities, methodologies, transparency, and usability. Through that process AEDT was identified as an officially accepted ICAO tool[16].



Reduction with implementation by 31 December 2020

Figure 4: *Noise Stringency Scenario-based 65 dB DNL Per Cent Reductions.*

CAEP ANALYSIS

AEDT has already been utilized for a number of domestic and international policy analyses. Each time the tool is used, algorithmic and database enhancements are incorporated to account for additional or unexpected requirements. In support of ICAO, several scenarios were analysed for the CAEP/8 NO_x stringency initiative. This was one of the first of such analyses where a single tool and common database was utilized, thus enabling a robust understanding of all environmental considerations beyond NO_x, the primary pollutant of interest. In concert with APMT-E and APMT-I, which were developed for US domestic policy analysis, a full cost-effectiveness study was undertaken, based on common assumptions and input data.

Recently, AEDT was used for the CAEP/9 noise stringency analysis to understand the implications of tighter stringencies on global noise exposure. Multiple stringency options were investigated at population exposure levels of day-night average sound level (DNL) 55 dB and 65 dB. In keeping with the interdependency theme, in addition to quantifying the per cent reduction in population exposed to noise, relative to a baseline no stringency case, differences in fuel burn and emissions as a result of the stringencies were also quantified. **Figure 4** presents a summary of the stringency options analysed and the associated per cent reduction in population exposed to 65 dB DNL.

Looking ahead, AEDT is anticipated to be used to analyse the environmental considerations associated with a proposed CAEP/10 CO_2 emissions standard. Similar to the CAEP/9 noise stringency analysis, emissions besides CO_2 will be analysed, as well as fuel burn and population noise exposure. If it is decided that CAEP will analyse particulate matter (PM) during the CAEP/10 work program, AEDT will be able to predict those emissions, as well as related interdependencies.

SUMMARY

In summary, the Aviation Environmental Design Tool enables the thorough investigation of environmental scenarios by facilitating interdependent analysis of fuel burn, emissions, and noise exposure. This is done in a single environment using common input data and assumptions. When combined with other components of the FAA tool suite, detailed examination of new technology considerations, as well as cost-effectiveness, are facilitated. These capabilities provide policymakers with complete and consistent information for consideration. The scalability of the tool also provides a platform such that policies enacted at the international and domestic levels may be initiated and analyzed consistently at the local and regional levels. ■

REFERENCES

1 FAA Aviation Environmental Design Tool (AEDT) Workshop #1: http://onlinepubs.trb.org/onlinepubs/reports/aedt_nov_2004.pdf

2 FAA Aviation Environmental Design Tool (AEDT) Workshop #2: http://onlinepubs.trb.org/onlinepubs/reports/aedt_april_2005.pdf

3 FAA Aviation Environmental Design Tool (AEDT) Workshop #3: www.faa.gov/about/office_org/headquarters_offices/apl/research/models/history/media/workshop3_2005.pdf

4 AEDT User Guide: https://aedt.faa.gov/Documents/AEDT2a_UserGuide.pdf

5 www.fly.faa.gov/Products/Information/ETMS/etms.html

6 www.eurocontrol.int/network-operations/etfms

7 AEDT Technical Manual: https://aedt.faa.gov/Documents/AEDT2a_TechManual.pdf

8 International ANP Database: www.aircraftnoisemodel.org

9 ICAO Doc 9911, Recommended Method for Computing Noise Contours around Airports, ICAO Document No. 9911, First Edition, International Civil Aviation Organization Committee on Aviation Environmental Protection, 2008.

10 ECAC Doc 29, Report on Standard Method of Computing Noise Contours around Civil Airports, Third edition, European Civil Aviation Conference, 2005.

11 EUROCONTROL BADA Database: www.eurocontrol.int/services/bada

12 www.faa.gov/about/office_org/headquarters_offices/apl/research/models/inm_model

13 www.faa.gov/about/office_org/headquarters_offices/apl/research/models/edms_model

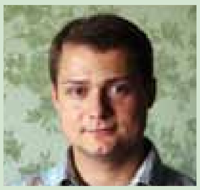
14 www.faa.gov/about/office_org/headquarters_offices/apl/research/models/sage

15 www.faa.gov/about/office_org/headquarters_offices/apl/research/models/magenta

16 ICAO Environmental Report 2010: www.icao.int/environmental-protection/Pages/EnvReport10.aspx

DEVELOPMENT OF NEW ENVIRONMENTAL SOFTWARE TOOLS PEGAS/PEGASUS FOR LAQ AND TURBOFAN EVALUATOR KEEPER

BY YURY MEDVEDEV



YURY V. MEDVEDEV

He is a researcher at the Central Aerohydrodynamics Institute (TsAGI, Russian Federation). His field of research includes aeroacoustics, aircraft emissions, ecology of aviation, numerical modeling and software development. Yury is completing his Ph.D. study in the numerical investigation of swirled flow evolution and stability. Yury is the author and developer of the PEGAS LAQ tool and the KEEPER environmental turbofan engine model. He is a member of the CAEP Modeling and Databases Group (MDG) and a liaison member of the SAE A-21 (noise modeling) and E-31 (engine emission) groups.

BACKGROUND

Over the last several years the issue of aviation environmental impact has gained a higher level of awareness and importance in the Russian Federation due to the steady growth of cities and local settlements around airports. Naturally, as these populations have grown, the number of people exposed to the negative effects of air traffic has increased, resulting in an increase in health-related complaints. This situation requires that appropriate and precise solutions for evaluating and understanding aircraft noise and emissions trends and forecasts be found. The models and methods previously developed did not provide an appropriate level of accuracy and functionality. For instance, the application of stationary source dispersion methods to aircraft pollutant emissions delivered low quality and inadequate results. Therefore, new methodologies and solutions were urgently needed.

INTRODUCTION

First the LAQ problem was considered. The analysis of the approaches and models developed in Russia and abroad allowed for the elaboration of a method that would satisfy the ICAO recommendations, while also being flexible and universal. The Gaussian (elliptical) distribution was chosen as the core physical model for the dispersion process. In addition, relationships for atmospheric stratification, assumptions for wind speed, and turbulence coefficients are considered by the dispersion model. The aircraft-related adjustments include: computational fluid dynamics (CFD) modeling of the jet exhaust that was used to develop a pollutant plume shift correction; an on-ground and in-air trajectory constructor; an emission calculator (pollutant and GHG inventory), and a basic performance module. **Figure 1** shows the general scope for the data related to the LAQ analysis.

This is how the Pollution Estimation from General Aviation Sources (PEGAS) solution was started. This LAQ tool was the first in a series of aviation environmental solutions. This new model was reviewed by CAEP in 2013. Before that, a validation

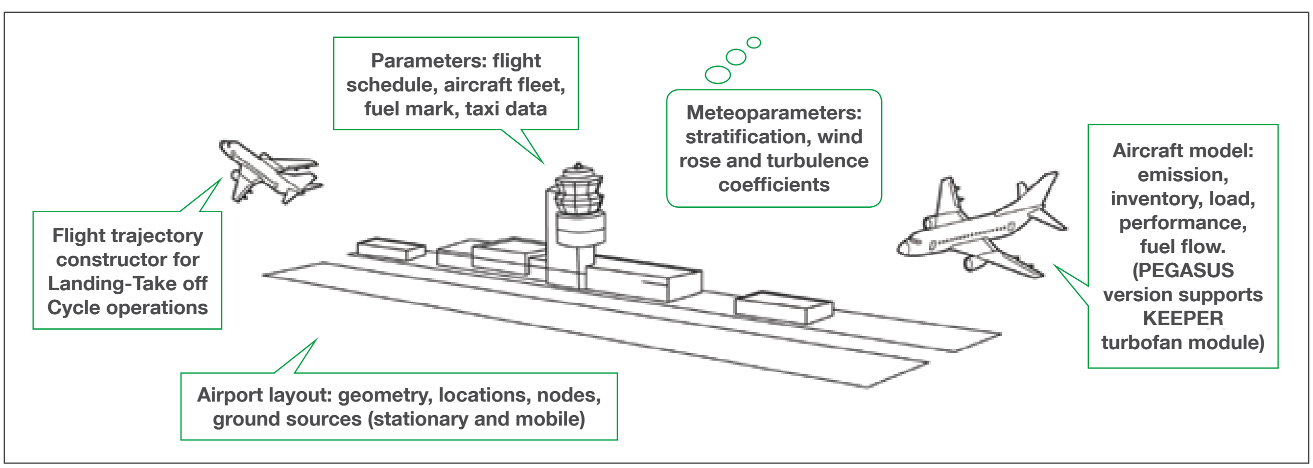


Figure 1: *The General Data Scope Required for LAQ Analysis.*

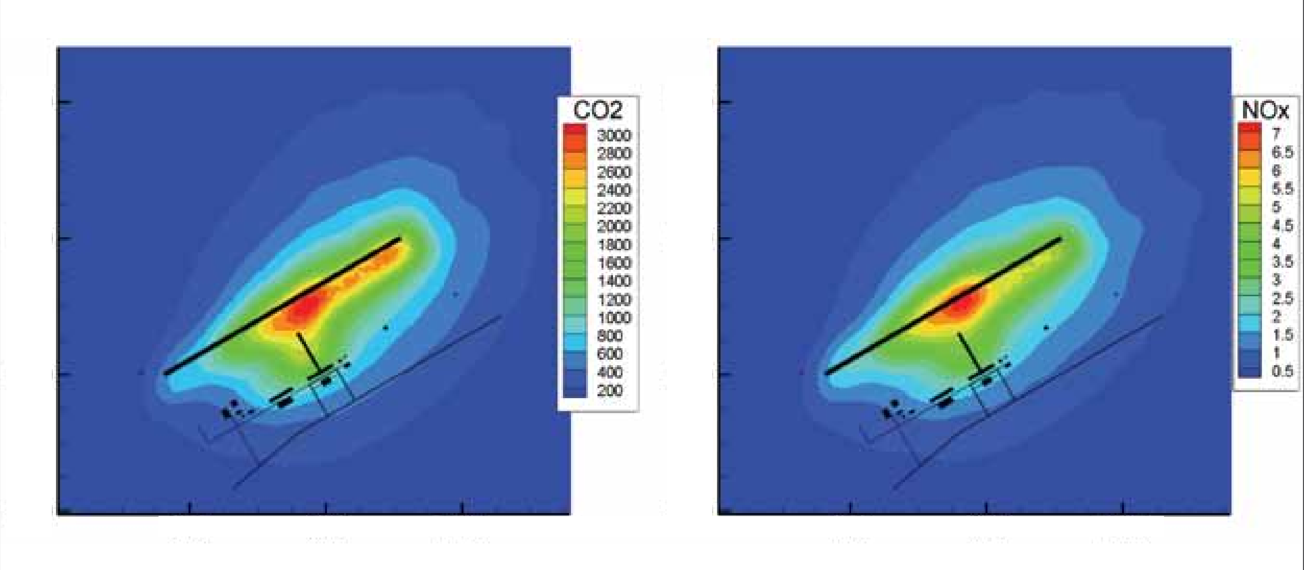


Figure 2: *CAEPort Annual CO_2 (left) and NO_x (right) Concentrations (µg/m³) for the Real LTO Cycle.*

and verification process in the CAEP Modeling and Database Group was initiated. The sample problem included the inventory for the NO_x stringency scenarios and the main test was the CAEPort LAQ model evaluation problem. This task includes the annual flight timetable and corresponding meteorological dataset with a one-hour measurement interval. Additionally, the taxiing times for each aircraft operation were included in the task. **Figure 2** depicts obtained pollutant concentration maps in the vicinity of the modeled airport. The PEGAS solution was found to be sufficiently robust, rigorous, transparent and appropriate for CAEP LAQ analyses. The evaluation process considered the tool's ability to support an emissions inventory and a dispersion analysis.

ADVANCED APPROACH

The PEGAS tool works within pre-defined emission parameters[1]. For the forecasting or parameter search tasks this was insufficient. Consequently, the Key Evaluator for Emission Parameters and Environmental Research (KEEPER) project was launched. This tool is designed to provide a wide-range data set covering aircraft bypass engines on the basis of the general engine information. The aims in developing the KEEPER solution were the following:

- to provide an accurate and rigorous dataset for estimating the emission indices (including Particulate Matter (PM)) and fuel flow rates for projected aircraft engines and corresponding aircraft types;
- to evaluate the possible ranges of engine parameters for random operation modes;
- to provide rigorous and verified datasets for projects made on SOPRANO software and TsAGI in-house approaches;
- to assist in the parametric investigation and optimization problems (LAQ, regional and global scale).

The KEEPER model is to be applied as the supplementary application to the environmental analysis of the aircraft types with the bypass engines installed. The KEEPER solution is one of the basic steps to the versatile environmental analyses performed by TsAGI. The important part of the procedure is the statistical analysis of the engine generations and other available datasets that were applied to provide data projections and scenarios modeling. This provides feedback to other aircraft industry units and optimization routines for the air traffic and environmental departments.

The automated application of KEEPER to LAQ problems required major software upgrades. Thus, PEGAS qualitatively evolved into Pollution Evaluator from General Airport Sources – Unified Solution (PEGASUS) which has already been applied to large projects (for example, the LAQ analysis for Haneda Tokyo International Airport, see **Figure 3**). Additionally, the PEGASUS tool has been adjusted to use the PIANO software output figures as the input data sets.

Basic aircraft parameters such as aerodynamic fineness and the maximum take-off weight (MTOW), combined with the ambient atmospheric parameters, provide general requirements for the combination of the thrust and the flight trajectory (take-off and climb out profiles, for example). The KEEPER model allows the calculation of the emission indices on the basis of thrust required. For further verification, the KEEPER solution has also been applied to the CAEPPort pollutant inventory problem.

The results of the pollutant inventory analysis are shown in **Figure 4**. Two evaluation modes were used to perform the analysis. The Stat (blue) figures are related to the statistical-based methods. This approach may be very useful for the data sets with large sample set. It is not applicable to the problems

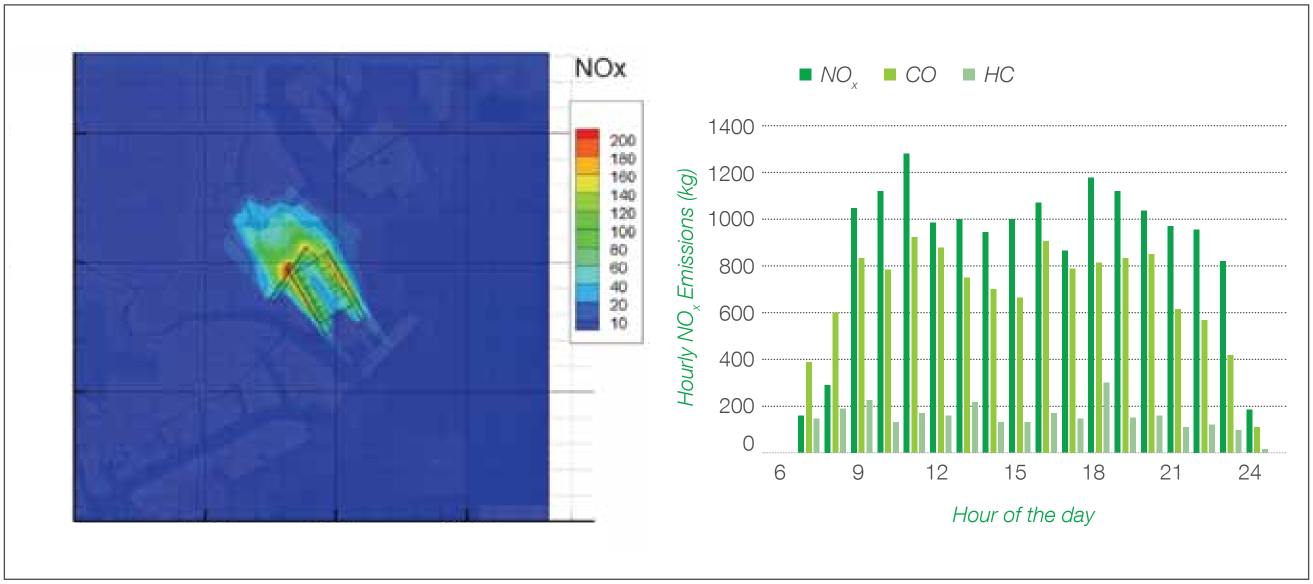


Figure 3: *Application of the PEGASUS for Haneda Tokyo International Airport LAQ: NO_x Contours (μg/m³, left) and Pollutant Day Inventory (kg, right).*

dealing with a small aircraft fleet. The TD (red) figures provide the results of the profound thermodynamic analysis mode. This method requires more input data, but is applicable for the analysis for a single aircraft type as well.

The results obtained show a satisfactory correlation with the outcomes provided by other tools applied to the CAEPort analysis. The ICAO EDB input data sets, when taking into account the standard Landing-Take off (LTO) cycle times, provide greater values for the pollutant inventory (the real LTO cycle duration may differ significantly from the standard one). The analysis shows how sensitive the results might be if the default values are used instead of the real times in mode.

NEW TECHNOLOGIES

In addition to improvements to the mathematics and physical methods, the programming code for the solutions is being further developed and upgraded. The current investigations being performed are aimed at the development of a third version

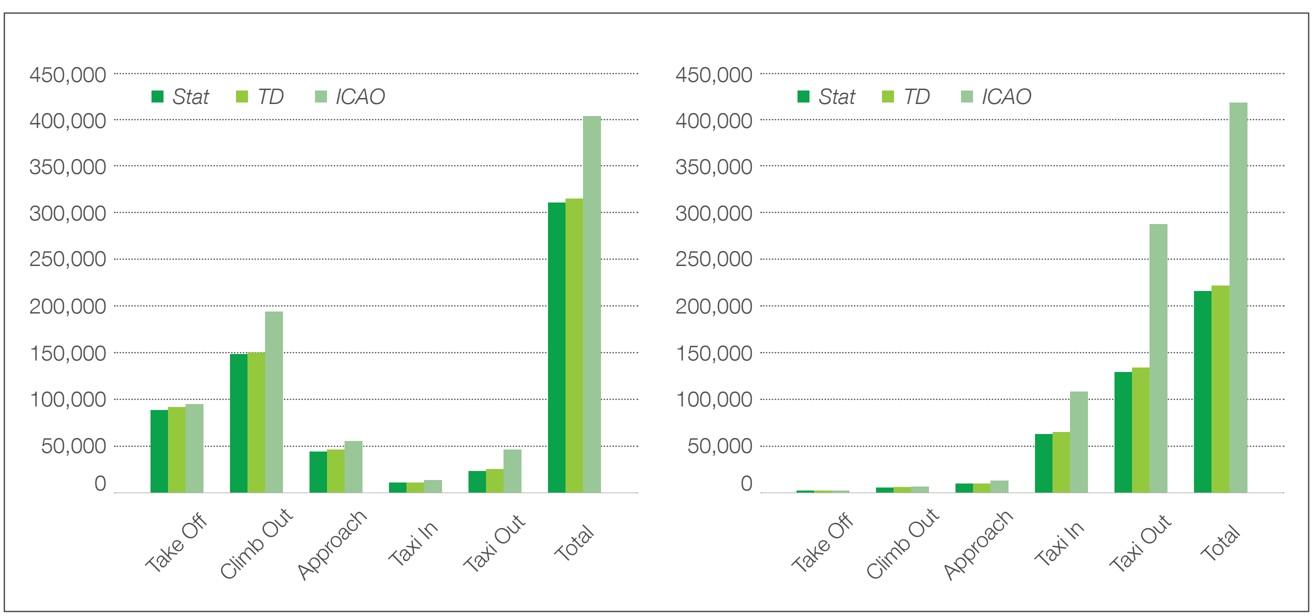


Figure 4: *CAEPort NO_x (left) and CO (right) Inventory (kg) by KEEPER.*

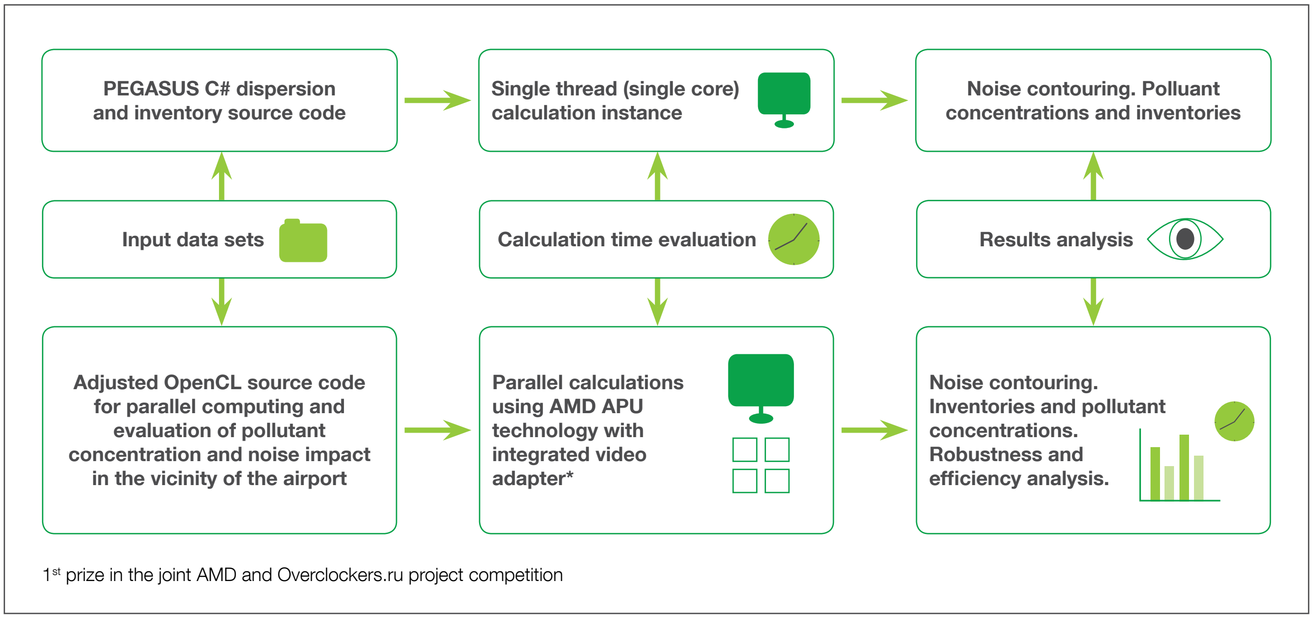


Figure 5: *Synthetic Testing of the Heterogeneous System Performance.*

of the complex solution that supports heterogeneous systems which allow calculating on hybrid systems (*e.g.* parallel calculations on both the central processing unit and graphics processing unit). **Figure 5** shows how the first synthetic tests were performed to evaluate the performance of the approach, and early results showed huge potential in this new area.

Further optimization of the programming code is under development in several modules. First, to decrease calculation time, adaptive grids instead of the uniform grids are proposed to be applied. These adaptive grids will be constructed in such a way that the concentration of the calculation nodes will increase in the areas close to the pollutant sources and will decrease in the regions distant from those; taking into consideration wind speed and direction. Secondly, special interpolation techniques will be used to adapt the obtained results to the standard uniform data presentation. This includes appropriate smoothing methods similar to those used in the numerical integration and error corrections. This project is focused on the high-load calculation system to perform real-time LAQ analysis for a large region, while taking into account forecasting and optimization research. The work is to be finalized during the CAEP/10 cycle.

CONCLUSIONS

The aircraft-centred approach[2] used in the solutions mentioned above in combination with the in-house noise modelling tool offers an integrated environmental protection analysis (including PM and GHG). In addition to potential applications for aircraft design, the approach presented may also be applied to the complex optimization of the procedural and technological aspects of the aircraft impact on the environment[3]. A number of test samples and additional validation and verification within the MDG group are still needed.

The development of the aircraft-centered unified environmental model is well underway. The basic LAQ module PEGAS/PEGASUS has been reviewed by CAEP and tested on the CAEPort sample problem. The pollutant inventory, including Particulate Matter (PM), was performed on the basis of the standard ICAO EDB input data sets, and additionally by the KEEPER tool. This approach has resulted in more precise and detailed evaluation of emission indices, and more realistic pollutant inventories.

The results obtained provide a good correlation between the methods implemented: standard, statistical, and thermodynamic. TsAGI is improving the current methodologies, software tools and approaches in the field of aviation ecology and in his capabilities to respond to specific CAEP tasks. The PEGASUS and KEEPER solutions have been upgraded with new modules and improved in order to increase their functionality. They allow the performance of multilateral environmental analyses on a local, regional and global scale. ■

REFERENCES

1 ICAO Aircraft Engine Emissions Databank: http://easa.europa.eu/environment/edb/aircraft-engine-emissions.php

2 V.F. Kopiev, Yu.V. Medvedev “Unified Approach to Evaluation of the Aviation Environmental Impact on Air Quality in the Vicinity of the Airport”, Aviation Science and Technology (ISSN 0868-8060), Vol. LXXXVII, No. 1 (710), 2013, pp. 42-49 (in Russian).

3 V.F. Kopiev, A.G. Munin, Yu.V. Medvedev “Effect of the New Aircraft Types on the Environmental Impact”, Herald of the SSAU (ISSN 1998-6629), No. 3 (34), part 1, pp. 247-252 (in Russian).

ICAO ENVIRONMENTAL TOOLS

BY ICAO SECRETARIAT

THE REQUIREMENT

Increasingly, people and organizations worldwide are interested in understanding the carbon footprint associated with their air travel and how they might reduce it in the future. Starting with the ICAO Carbon Emissions Calculator, first launched in 2008, ICAO has delivered accurate, impartial tools to fill this need. Today, the ICAO environmental tool suite comprises four modules. Two of these provide information on past emissions, while the other two help to evaluate scenarios for future emissions.

UNDERSTANDING HISTORICAL EMISSIONS

ICAO Carbon Emissions Calculator

Development of the ICAO Carbon Emissions Calculator began in 2006 in an effort to reduce widespread confusion about carbon footprint calculations. Up until then, individuals and organizations interested in understanding the size of their air travel carbon footprint were faced with hundreds of calculators that produced estimates that could vary widely for a given flight, and often without clear documentation of the data and methodologies used. ICAO developed the methodology through its Committee on Aviation Environmental Protection (CAEP) with the objective of delivering a transparent, easy-to-use calculator, suitable for use with offset programmes, and based on publicly-available data. The initial release of the carbon calculator was as a web-based application on the ICAO public website.

Since that time, a number of specialized interfaces to the calculator have been developed. In 2009, the ICAO Carbon Emissions Calculator was adopted as the official tool for estimating carbon emissions generated from air travel in support of the Carbon Neutral UN initiative, where it is now used UN-wide. That same year, ICAO made the calculator available for enterprise-level uses, such as integration into organization travel approval systems and for use by global distribution systems.

A specialized interface to the calculator that can be used by States to estimate their aviation sector carbon footprint was launched following the 37th Session of the ICAO Assembly. In 2012, the calculator was launched as a mobile app, making it possible for users anywhere to compute their carbon emissions footprint attributable to air travel.

Today, ICAO continues to work with CAEP to continuously improve the calculator, based on feedback received from its users worldwide.

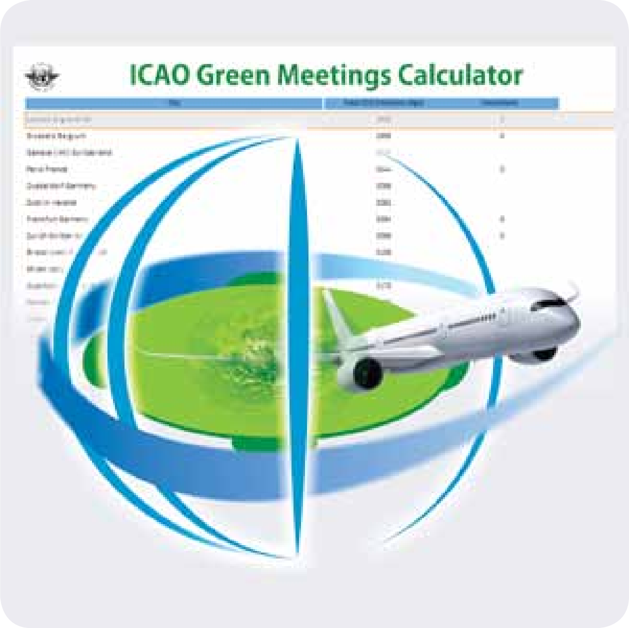
ICAO CO_2 Reporting and Analysis System (ICORAS)

As stated in ICAO Assembly Resolution A37-19, ICAO "resolves that States and relevant Organizations will work through ICAO to achieve a global annual fuel efficiency improvement of 2% until 2020 and an aspirational global fuel efficiency improvement of 2% per annum from 2021 to 2050, calculated on the basis of volume of fuel used per revenue tonne kilometre performed". Furthermore, it "requested the Council to 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". In addition to the CAEP environmental trends assessment which calculates fuel burn and CO_2 from international aviation via documented and approved models, the Secretariat is developing a capability, known as the ICAO CO_2 Reporting and Analysis System (ICORAS). This tool will allow the organization to report to the United Nations Framework Convention on Climate Change (UNFCCC) and measure progress achieved toward the global aspirational environmental goals. ICORAS delivers on this objective by integrating the air traffic and fuel consumption data reported by States through ICAO statistical forms. This data is validated and complemented with additional external data sources and models.

The ICORAS methodology is currently being evaluated by CAEP.

UNDERSTANDING FUTURE EMISSIONS

ICAO Green Meetings Calculator



United Nations staff members travel a significant amount each year in support of international meetings and other missions. It was not until the Climate Neutral UN initiative, when annual emissions inventories were generated, that it was understood just how much of the UN's footprint was attributable to air travel – around 50%. In order to help the UN system reduce its air travel emissions footprint, the UN Inter-Agency Travel Network (IATN) turned to ICAO for advice. What resulted was the ICAO Green Meetings Calculator, a publicly-available tool based on the ICAO Carbon Emissions Calculator. This tool allows a meeting planner to enter the list of cities where the participants are based. The ICAO Green Meetings Calculator then runs the ICAO Carbon Emissions Calculator for every possible combination of cities that can be reached by the participants by air with no more than one connection and provides a ranked list of locations where the meeting(s) could be held that would minimize the emissions caused by the air travel of participants.

As word of this calculator spread, requests from non-UN organizations and the public for the tool were made to ICAO. Today, the ICAO Green Meetings Calculator is available for Microsoft Windows and on mobile devices.

ICAO Fuel Savings Estimation Tool (IFSET)

Operational measures are among the instruments available to States to improve fuel efficiency and reduce CO_2 emissions. Historically, however, those States and air navigation service providers aiming to implement operational changes had essentially two options for estimating the fuel savings associated with a proposed change: (1) the use of sophisticated models or (2) the ICAO rules of thumb (see ICAO Environmental Report, 2007).

The ICAO Fuel Savings Estimation Tool (IFSET) has been developed by the Secretariat with support from States and international organizations to bridge the gap between those two extremes in order to assist States in estimating fuel savings in a manner consistent with the models approved by CAEP and aligned with the Global Air Navigation Plan.

IFSET is not intended to replace the use of detailed measurement or modelling of fuel savings, where those capabilities exist. Rather, it is provided to assist those States without such capabilities to estimate the benefits from proposed operational improvements in a harmonized way.

IFSET allows users to build both pre- and post-implementation scenarios using a series of flight phase procedure "building blocks": climb, level, descent and taxi. In addition, the mix of aircraft operating on the procedures is defined. The fuel consumption from those scenarios is then computed for each scenario based on pre-computed data from the US FAA's Aviation Environmental Design Tool, described in this chapter.

Today, IFSET is being used in every ICAO region to report on benefits from the implementation of operational improvements through the Planning and Implementation Regional Groups, and in support of the development of action plans on CO_2 emissions reduction.

CASE STUDY: ASECNA FUEL SAVINGS USING IFSET

BY L'AGENCE POUR LA SÉCURITÉ DE LA NAVIGATION AÉRIENNE EN AFRIQUE ET À MADAGASCAR, ASECNA

ASECNA

The Agency for Aerial Navigation Safety in Africa and Madagascar (L'Agence pour la Sécurité de la Navigation aérienne en Afrique et à Madagascar, ASECNA) is an air navigation Service provider (ANSP) for 17 western and central African countries and France. The headquarters are located in Dakar, Senegal with a representative in each of countries for operational activities (ATM, AIM, RFF, MET). It manages 16.1 million square kilometres of airspace (1.5 times the size of Europe) covering six Flight Information Regions (FIRs) – Antananarivo, Brazzaville, Dakar Oceanic and Terrestrial, Niamey and N'Djamena. ASECNA Air Traffic Control centres are based at international airports in each of these cities.

Member States: Benin, Burkina Faso, Cameroun, Central African Republic, Comoros, Congo, Côte d'Ivoire, France, Gabon, Guinea-Bissau, Equatorial Guinea, Madagascar, Mali, Mauritania, Niger, Senegal, Chad, Togo.

INTRODUCTION

This article describes an assessment of the reduction in fuel burn between 2005 and 2011 due to the navigational improvement initiatives adopted by the Agence pour la Sécurité de la Navigation Aérienne en Afrique et à Madagascar (ASECNA)[1]. Flight Information Region (FIR) traffic data covering level segments in ASECNA airspace was used to generate the estimated fuel savings achieved during the 2005 to 2011 period using the ICAO Fuel Savings Estimation Tool (IFSET). The information contained herein was also presented by ASECNA during the hands-on training workshop for State Action Plans, organized jointly by ICAO and the African Civil Aviation Commission (AFCAC) in Dakar, Senegal, in September 2012, as well as during the ICAO "Assistance for Action – Aviation and Climate Change" Seminar, held in October 2012, in Montréal, Canada.

OPERATIONAL IMPROVEMENTS BY ASECNA

The continued growth in air travel in the airspace controlled by ASECNA has placed greater demand on the region's Air Traffic Management (ATM) system. To respond to the expectations of airspace users, constant improvements to the ATM system are necessary to enhance efficiency, while maintaining or improving safety levels.

As part of the plan to improve the efficiency of the ATM system in the African (AFI) Region, since 2005, ASECNA, in coordination with its 18 Member States, has undertaken several initiatives to redesign airspace and implement new concepts of operations to increase capacity, measures which aim to cope with predicted air traffic growth. All of the initiatives seek to address the expectations of the aviation community, through better provision of air traffic services, and improved airspace management.

Using advanced capabilities onboard aircraft, along with enhanced processes to manage air traffic, separation minima and distances between city pairs could be reduced. Also, in light of better use of wind direction, flying time was reduced, fuel was saved and the impact on climate change was reduced through emissions reductions. This represents a step towards the achievement of global goals to reduce the impact of aviation on climate change.

Operational improvements were implemented in the Indian Ocean, European/South American Corridor (EUR/SAM), South Atlantic and AFI continental airspace. All capable flights operating in the mentioned airspace, meaning those that are properly equipped with flight crews trained in the procedures, can benefit from the operational improvements and therefore could contribute to the reduction of greenhouse gas (GHG) emissions.

In the Indian Ocean, following the implementation of Random RNAV airspace, flights operating between FL290 and 410 inclusive were no longer restricted to flying a fixed route structure. Aircraft were then able to fly on the route most efficient for their operation considering winds and weather without being constrained to a path defined by existing airways. This significant change involved the following FIRs: Antananarivo, Beira, Johannesburg Oceanic, Mauritius, and Melbourne. In the EUR/SAM corridor, Reduced Vertical Separation Minimum (RVSM), Required Navigation Performance 10 (RNP 10) and Automatic Dependent Surveillance (ADS) were implemented. This combination of changes allowed flights to operate closer to their optimum altitude and path and involved the Canarias, Sal Oceanic, Dakar Oceanic, Atlantico, and Recife FIRs. In the South Atlantic, implementation of RVSM and the Random RNAV Routing Area (AORRA) were realized, with similar benefits. In the continental airspace, the implementation of routes that use RNP10 capability, known as the “red carpet” routes, allowed reduction in lateral separation between routes and more direct routes between city pairs located in Europe, Africa and South America.

The operational improvements mentioned above impact aircraft operations directly and enable more efficient flights through the use of optimum altitudes, shorter routes, and more favorable tailwinds, all of which contribute to reductions in fuel consumption. These operational improvements were implemented throughout the period from 2005 to 2011 and savings were derived by monitoring differences in fuel consumption.

METHODOLOGY

The methodology used to arrive at the estimated fuel savings is detailed in the five steps below:
Step 1 – Match aircraft types in the ASECNA FIR database to IFSET aircraft categories.
Step 2 – Use IFSET and the time elapsed between entry and exit as indicated in the ASECNA FIR database to estimate fuel burn for each flight.
Step 3 – Group flights by origin, destination and aircraft category; estimate the number of flights and the fuel burn for the years 2005 and 2011.
Step 4 – For the year 2011, estimate the fuel burn; had the fuel burn per flight (for the same Origin, Destination and aircraft category) remained the same as in 2005.
Step 5 – Fuel savings are equal to the difference between the estimated fuel burn in 2011, as calculated in Step 3, and the estimated fuel burn had the fuel burn per flight (for the same Origin, Destination and Aircraft Category) remained the same as in 2005, as calculated in Step 4.

Combinations of origin, destination and aircraft category which were not available for both 2005 and 2011 were excluded from the analysis.

SAVINGS IN FUEL AND ASSOCIATED ENVIRONMENTAL BENEFITS

In total, there were 2,158 unique combinations of Origin, Destination and Aircraft Category representing 232,250 flights for the year 2011. These origin-destination pairs were available both in 2005 and 2011. In addition, based on the FIR database, ASECNA airspace handled more traffic, with 92,316 additional movements in 2011 compared to 2005.

Using the methodology indicated above, the IFSET analysis indicates that there was a benefit on 149,018 flights, representing 64% of the traffic, while on the remaining flights there was an increase in fuel burn. The net savings that resulted from the reduced fuel burn are estimated at around 144 million kg of fuel between 2005 and 2011, largely due to the shortening of level segments. Other reasons for the variance are changes in air speeds and in fuel burn on account of differential altitudes between 2005 and 2011. In monetary terms, this translates into fuel cost savings of approximately US$ 135 million during the period 2005 to 2011. The consequential environmental benefits accrued translate into a reduction of about 455 million kg of CO_2 during the 2005 to 2011 period.

Tables 1 and **2** summarize the benefits achieved, in terms of fuel savings and CO_2 reductions, as well as from the navigational and operational improvements implemented.

In the below **Tables**, the 2011 fuel burn is estimated using the fuel burns prevalent in 2005. The analysis conducted is indicative of the significant improvements achieved during the 2005 to 2011 period. On an annual basis, the improvements translate to around 2% in fuel burn reduction between 2005 and 2011. While this in itself has generated significant fuel savings of approximately 144 million kg, and the associated financial and environmental benefits, it also indicates that there is still considerable room for improvement.

In the Oceanic and Continental airspace, the use of advanced capabilities onboard aircraft, coupled with the provision of better communication and surveillance

Year	Area	Fuel burn (millions of kg)	CO_2 emissions (millions of kg)
2005	EUR/SAM	445	1405
	Continental/SAT	981	3097
2011	EUR/SAM	385	1215
	Continental/SAT	897	2832

***Table 1:** Fuel Burn and CO_2 Emissions Savings – 2011 vs. 2005.*

Operational Improvement	2011 Movements	Area	Net Fuel Savings (millions of kg)	CO_2 Savings (millions of kg)	% Savings During 2005 – 2011
RVSM/RNP10	32,490	EUR/SAM	60	189	13.5%
RVSM/Red carpet routes (RNP10), AORRA	199,760	Continental/SAT	84	265	8.6%
Total	**232,250**	**All Areas**	**144**	**455**	**10.1%**

Table 2: *Operational Improvements – Between 2005 and 2011.*

systems on the ground, will allow the reduction in separation minima, as well as better allocation of flight levels. This will improve operational efficiency of the system as a whole, and generate environmental benefits in terms of fuel burn and emissions reductions.

CONCLUSIONS

Understanding and quantifying the benefits from operational improvements in aviation operations is important in order to monitor that the measures implemented are meeting their objectives in terms of fuel burn and emissions reductions. It is also important to understand the potential benefits from planned improvements (such as in developing business cases) in order to justify decision making that could result in the planned improvements actually being implemented. The availability of global tools such as IFSET can highly facilitate the assessment of the environmental benefits in a global harmonized manner and the support of the ICAO Secretariat also contributes positively to its use and dissemination.

ASECNA, together with its Member States, supports future projects aiming at improvements in the ATM system that will also create environmental benefits. The ICAO Secretariat is also carrying out similar studies for other regions that will result in better insight into the reduction of fuel and emissions resulting from the implementation of operational initiatives. ■

REFERENCE

1 www.asecna.aero

ASSISTING CARBON EMISSION MANAGEMENT AT AIRPORTS

BY XAVIER OH AND CHRYSTELLE DAMAR

XAVIER OH

He is the Senior Manager Environmental Protection with Airports Council International (ACI). He has been with ACI since September 2005 and is based in the ACI Headquarters in Montreal. As an industry association, ACI is an official Observer at ICAO's Committee on Aviation Environment Protection (CAEP), represented by Xavier. 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.

CHRYSTELLE DAMAR

She joined ACI EUROPE in October 2009 and is responsible for the coordination of all aspects of the association's environmental strategy. In this regard, she represents ACI EUROPE in various high-level EU, ECAC and EUROCONTROL fora. Since October 2009, Chrystelle has been heavily involved in the development of the new guidelines for the TEN-T funding programme, thus contributing to establishing the SESAR programme as a political and financial priority for the European institutions. She also manages Airport Carbon Accreditation.

Since 2009, Airports Council International (ACI) and ACI Europe have launched two important and complementary initiatives to assist member airports with the management of CO_2 and other greenhouse gas (GHG) emissions, and to measure progress made.

AIRPORT CARBON ACCREDITATION

In June 2009, an *Airport Carbon Accreditation* (ACA) programme was launched by ACI Europe, as the first ever carbon mapping and carbon management standard specifically designed for the airport industry. It is a voluntary programme that is based on internationally acknowledged standards (Greenhouse Gas Protocol), adapted to the operational realities of an airport. Since airport operators are not all at the same stage on the journey to carbon neutrality, the programme has four (4) Levels of accreditation: (1) Mapping, (2) Reduction, (3) Optimisation, and (4) Neutrality. Although *Airport Carbon Accreditation* is owned by ACI Europe, it is independently administered by an external consultancy, WSP Environment & Energy, and its activities are overseen by an Advisory Board.

In November 2011, the programme was expanded to ACI Asia-Pacific and it was launched in ACI Africa in June 2013.

To date, 75 airports are certified in Europe, including 14 airports at the highest level – Neutrality. These airports represent a total of 58.6% of the passenger traffic in Europe. By mid-2013, 10 airports had been accredited in the Asia-Pacific Region. Combined, certified airports represent 21.7% of world passenger traffic. The first application from Africa was also received in June 2013.

The benefits that accrue from being certified under *Airport Carbon Accreditation* fall broadly into two categories: measurable and non-measurable. Measurable benefits include improvements to operational efficiency and identification of priority areas for emissions reductions. Being certified can even help to secure a license to grow operations at an airport by aligning emissions requirements with local planning conditions. Non-measurable benefits include better dialogue among airport departments on issues relating to CO_2 emissions and the fact that airports have the flexibility to set their own carbon reduction agenda. The achievement of real and verified emissions reductions gives further credibility to the industry, as it moves beyond compliance towards a strategic and comprehensive approach to carbon management.

Under the ACA programme, the carbon performance of accredited airports is tracked and verified externally by a third party. From May 2011 to May 2012, the cumulative absolute CO_2 emissions reductions achieved by European airports (scope 1, 2 and 3 emissions) were 414,128 tonnes; and between May 2012 and May 2013 total CO_2 emissions reductions were 170,164 tonnes[1]. Information on the Airport Carbon Accreditation programme was presented at the CAEP/9 meeting and many members expressed their support."

AIRPORT CARBON AND EMISSIONS REPORTING TOOL - ACERT

ACI and the Canadian Department of Transport have worked together to develop the Airport Carbon and Emissions Reporting

Airport: Seattle-Tacoma International Airport | **Country:** United States | **Aircraft mvmts:** 314,947
Report Date: 18/6/2012 | **Ems Factor:** 31.3 g CO_2/kWh | **Passengers:** 32,819,796

Entity	Source		Scope	Greenhouse Gases (t) CO_2	Greenhouse Gases (t) CH_4	Greenhouse Gases (t) N_2O	CO_{2e}	CO_{2e} %
Airport Operator	Airport Airside Vehicles		1	1,212	0.25	0.10	1,249	0.2%
	Airport Buildings (gas/oil/coal)		1	14,421	0.26	0.03	14,435	2.4%
	Airport Emergency Generator		1	16	0.00	0.00	17	0.0%
	Airport Electricity Purchase		2	4,537			4,537	0.8%
					Airport Operator Sub-total		20,238	3.4%
Tenants (including airlines, government, shops, etc.) and Employees	Tenant Aircraft (LTO & Taxi)		3	307,489	9.66	27.82	316,316	53.7%
	Tenant Aircraft APU		3	42,149	1.32	3.81	43,359	7.4%
	Tenant Aircraft Engine Run-ups		3	456	0.01	0.04	469	0.1%
	Tenant Aircraft De-icing		3	0			0	0.0%
	Tenant Airside Vehicles		3	8,947	1.73	0.74	9,211	1.6%
	Tenant Buildings (gas/oil/coal)		3	2,827	0.03	0.03	2,837	0.5%
	Tenant Electricity Purchase		3	-			-	
	Tenant Fire Training		3	48	0.08	0.39	170	0.0%
	Tenant Landside Vehicles		3	48,411	17.22	4.04	50,024	8.5%
	Tenant Employee Vehicles		3	3,142	1.14	0.26	3,246	0.6%
					Tenant Sub-total		425,634	72.2%
Public (including Passengers)	Ground Access Vehicles	Cars, taxi	3	126,643	40.71	10.57	130,776	22.2%
		Bus, shuttles	3	12,181	1.05	0.99	12,510	2.1%
		Rail	3	22	-	-	22	0.0%
					Public Sub-total		143,308	24.3%
Total	**Total Emissions (tonne)**			**572,502**	**73.47**	**48.82**	**589,180**	

Total CO_{2e} Emissions (t)	**589,180**	**100%**

Summary	**CO_2 (t)**	**CO_{2e} %**
Airport Scope 1	15,701	2.66%
Airport Scope 2	4,537	0.77%
Airport Scope 3	568,942	96.57%

The aircraft emissions calculations were based on generic aircraft data. The landside traffic calculations were based on estimated traffic data. (*Data for illustration only)

***Figure 1:** Sample ACERT Airport Emissions Activity Summary Report.*

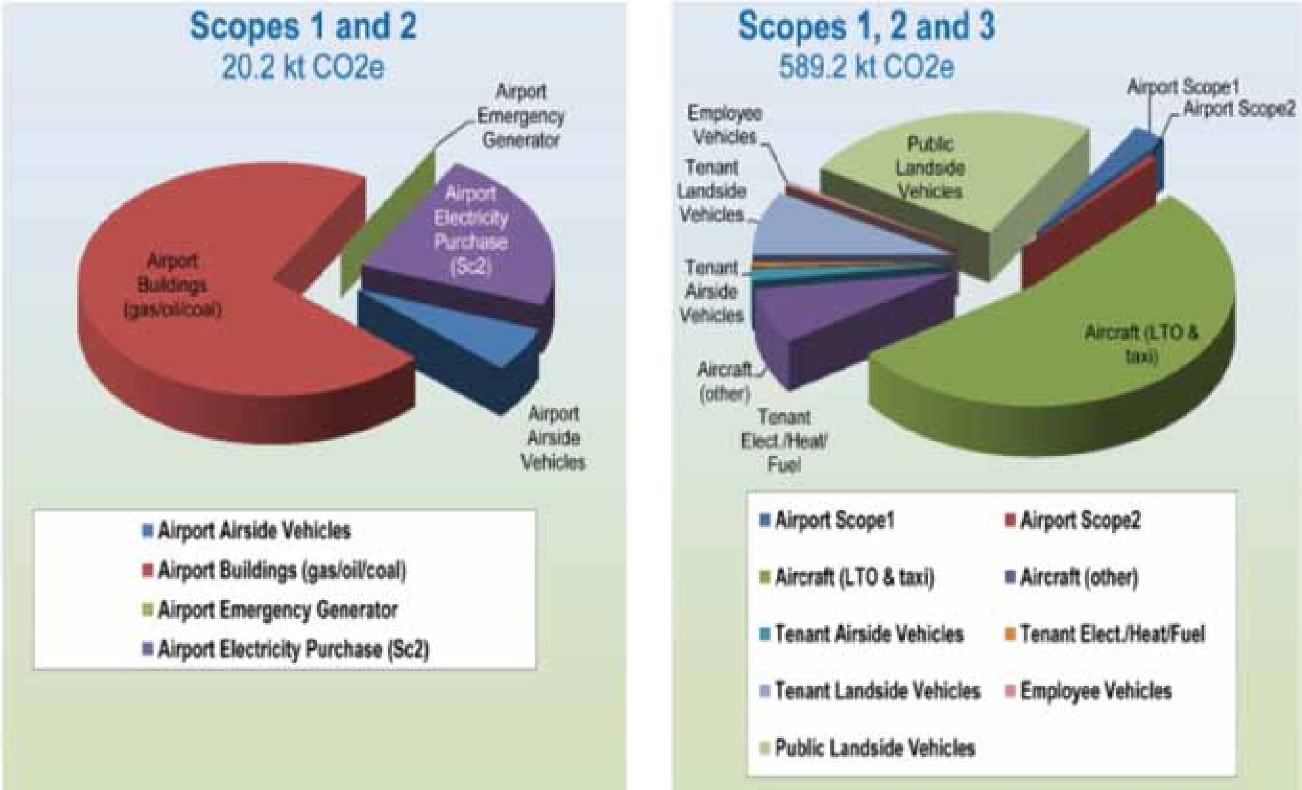


***Figure 2:** Sample ACERT Airport GHG Inventory Report.*

Tool (ACERT). This "Do-It-Yourself Airport Carbon Inventory" tool, which was launched in September 2012, is a self-contained Excel spreadsheet that enables an airport operator to calculate its own greenhouse gas (GHG) emissions inventory.

ACI ACERT AIRPORT CARBON AND EMISSIONS REPORTING TOOL

ACERT is available at no cost to airports and can be used without emissions or environmental expertise, by inputting readily available operational data. The tool will be useful for airports with no dedicated environmental staff or budget for consulting fees, and for airports developing GHG management on a voluntary (non-regulated) basis.

The main input data for ACERT includes: fuel and electricity use by the airport and tenants, aircraft activity statistics, passenger movements, and ground transportation activity. The software automatically generates an inventory report that includes a summary table of GHG emissions and associated pie charts, as illustrated in **Figures 1** and **2**. The inventory produced is of sufficient quality to help an airport identify energy saving initiatives and establish a GHG reduction program.

Originally developed for small airports, the tool can also be used for larger airports. ACI member Malaysian Airports Sdn Bhd uses ACERT at 21 of its 39 airports. ACERT is approved for the mapping requirements of Airport Carbon Accreditation at Levels 1 and 2 (only scope 1 and 2 emissions are covered at these levels). ACERT is available for free on the ACI website: www.aci.aero. ■

REFERENCE

1 Airport Carbon Accreditation Annual Report 2012-2013: www.airportcarbonaccreditation.org

AVIATION AND CLIMATE: STATE OF THE SCIENCE

BY D. W. FAHEY, S. L. BAUGHCUM, M. GUPTA, D. S. LEE, R. SAUSEN AND P. F. J. VAN VELTHOVEN

D. W. FAHEY, NOAA Earth System Research Laboratory, Boulder, Colorado, United States
S. L. BAUGHCUM, Boeing Company, Seattle, Washington, United States
M. GUPTA, Federal Aviation Administration, Washington, DC, United States
D. S. LEE, Manchester Metropolitan University, Manchester, United Kingdom
R. SAUSEN, Deutsches Zentrum für Luft-und Raumfahrt (DLR), Institut für Physik der Atmosphäre, Oberpfaffenhofen, Germany
P. F. J. VAN VELTHOVEN, Royal Netherlands Meteorological Institute (KNMI), De Bilt, The Netherlands

This article is based on a paper presented to the ninth meeting of the Committee on Aviation Environmental Protection (CAEP/9) by the CAEP Impacts and Science Group (ISG). The role of the ISG is to provide the best possible consensus information from the science community to CAEP on Aviation's impacts on climate, air quality and noise issues.

INTRODUCTION

Aviation represents a unique and important aspect of global society by transporting people and goods between essentially all nations. The technology of jet engines currently relies on fossil fuel combustion, which emits combustion products primarily at cruise altitudes. These emissions affect atmospheric composition differently than emissions from fossil-fuel combustion at the surface. In addition, aviation operations cause changes in cloudiness through contrail and contrail cirrus formation. Present and future changes in atmospheric composition and cloudiness from aviation have the potential to affect future climate.

Figure 1 shows the connections between aviation emissions and radiative forcing, climate change, and its impacts and potential damages. Direct emissions undergo various chemical transformations and accumulate in the atmosphere leading to changes in radiative forcing. Radiative forcing is a measure of the imbalance in the Earth's radiation budget caused by additional gases and aerosols in the atmosphere, or by changes in cloudiness. The principal gases emitted are carbon dioxide (CO_2) and water vapour (H_2O). Emissions of nitrogen oxides (NO_x) impact the concentrations of radiatively active gases such as ozone (O_3) and methane (CH_4). Black carbon (soot) is directly emitted as an aerosol, and sulfur oxides (SO_x) and hydrocarbons (HC) lead to aerosol production after emission. Water vapour emissions lead to contrail formation. Persistent contrails, which form when ambient humidity is high, can lead to other cloudiness changes. Additionally, aviation aerosol may modify natural clouds or trigger cloud formation. The chemical and aerosol pathways to climate change shown in **Figure 1** have been recognized for several decades and were first assessed comprehensively by the international community in 1999 (IPCC, 1999). There is high confidence that these are the primary pathways of importance for aviation operations to affect climate.

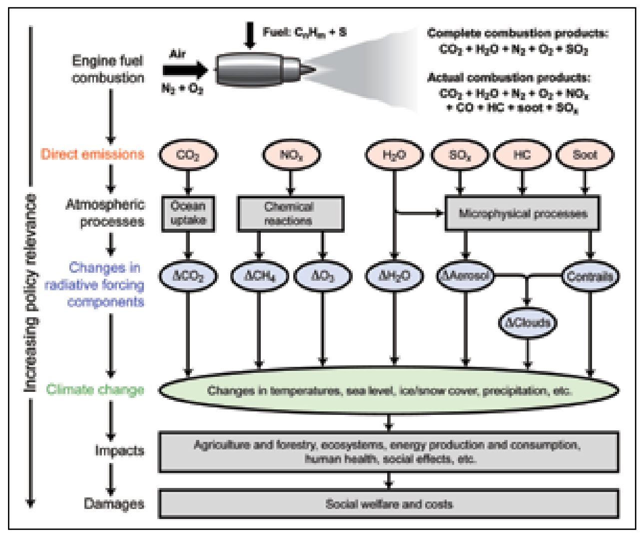


***Figure 1:** Schematic of the Principal Emissions from Aviation Operations and the Relationship of Emissions to Climate Change and Impacts. The terminology, ΔX, indicates a change in component X. The term, Δclouds, represents contrail cirrus and potential changes from other cloud effects (From Lee et al., 2009).*

Aviation's role in climate change is established by a quantitative evaluation of each of these pathways. This requires knowledge of specific thermodynamic, chemical, and microphysical processes and the ability to sum over emissions of a global aircraft fleet operating under diverse meteorological conditions in the upper atmosphere where most emissions occur. The *state of science* concerning aviation's contribution to climate change is summarized quantitatively in **Figure 2** by showing the radiative forcing (RF) values and their uncertainties for the principal pathways as assessed for 2005 (Lee *et al.*, 2009). The terms in the left-hand column of **Figure 2** correspond directly

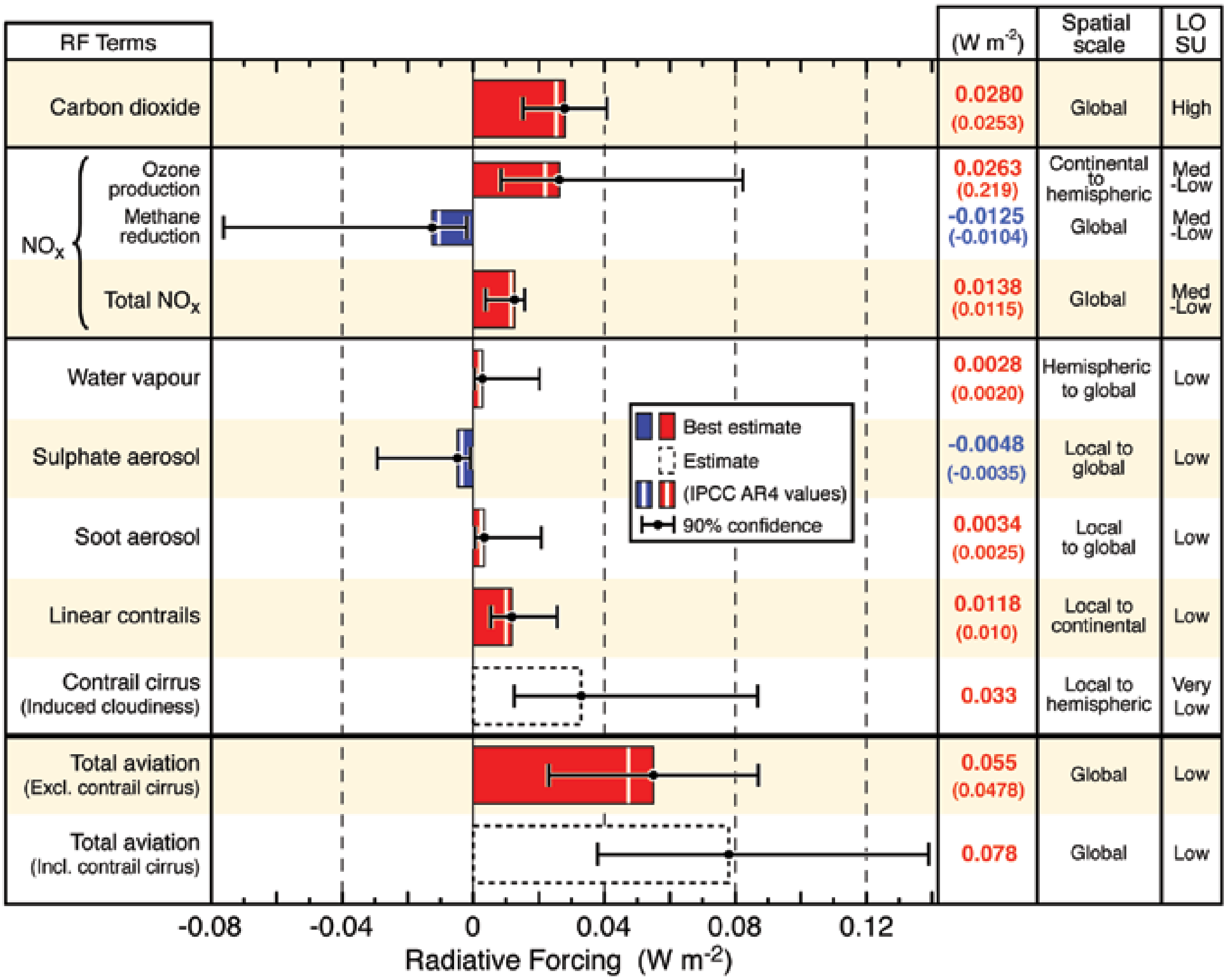


Figure 2: *Radiative Forcing Components from Global Aviation Operations for the Period from Preindustrial Times to 2005. Bars represent best estimates for each term. For aircraft-induced cirrus cloudiness, the estimate is shown with a dashed line. The total forcing is shown with and without cirrus cloudiness. Previous IPCC values are indicated by the white lines in the bars as reported by Forster et al. (2007). The columns show numerical values for each term (with IPCC values in parentheses) and spatial scale and level of scientific understanding (LOSU). Error bars represent the 90% likelihood range for each term. The total NO_x RF is the combination of the CH_4 and O_3 RF terms, which are shown separately. The uncertainty for "Total NO_x" is due to the assumption that the RFs from O_3 and CH_4 are 100% correlated. The term "contrail cirrus" is being used here instead of "induced cloudiness". (Adapted from Lee et al., 2009)*

with the radiative forcing components in the middle of **Figure 1** (blue ovals). The level of scientific understanding (LOSU) is noted in the far right-hand column. The CO_2 term is the only one considered to have a *high* LOSU, which is reflected by a smaller relative uncertainty. The other gas and aerosol terms are associated with less quantitative scientific understanding. Contrail cirrus stands out in this evaluation because it has no *best estimate* (*i.e.*, no solid colour bar) and a very low LOSU. Without this best estimate, the total contribution of aviation is given with and without the contrail cirrus term in the bottom of **Figure 2**. The lack of this best estimate adds uncertainty to the role of aviation in the climate system and to comparisons of aviation with other sectors.

Significant progress has occurred in the scientific evaluation of aviation climate terms since the publication of the Lee *et al.* (2009) results in **Figure 2**. Here, we briefly review CO_2 emissions and aerosol effects; report progress on quantifying aviation cloudiness and the effects of NO_x emissions; and briefly discuss alternative aviation fuels.

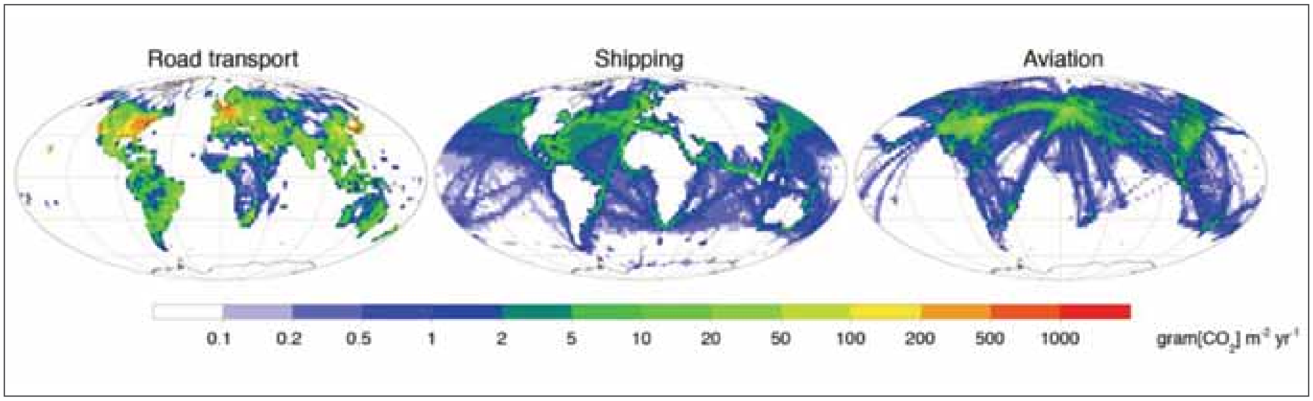


***Figure 3:** Global Distribution of CO_2 Emissions in the Year 2000 from the Transport Sectors. Total Emissions for Road Transport, Aviation, and Shipping are 4200, 677, and 626 Tg CO_2, Respectively (From Olivié et al., 2012).*

CO_2 EMISSIONS

CO_2 emissions are the most important climate contribution of aviation emissions because CO_2 represents a large fraction of the net radiative forcing in **Figure 1** and has the longest atmospheric lifetime of any of the components. CO_2 is ultimately removed from the atmosphere by a combination of mechanisms that require from decades (*e.g.*, ocean uptake) to millennia (*e.g.*, rock weathering) to be fully effective. Due to this long lifetime, the geographic location or altitude of CO_2 emissions does not affect the subsequent contribution to climate forcing, *i.e.*, emissions contribute equally irrespective of location. The geographical distributions of CO_2 emissions in the transport sector are contrasted in **Figure 3**. All of the sectors show their familiar respective source patterns. The annual emissions of aviation and shipping are comparable at 677 and 626 Tg CO_2 in 2000 (*e.g.*, Olivié *et al.*, 2012). Emissions from civil aviation alone are estimated to be approximately 630 Tg CO_2 in 2005 (ICAO, 2010).

Annual emissions from aviation, shipping and road transport are expected to grow in the remainder of the 21st century due in large measure to demand in the developing world. A variety of scenarios are available to describe growth projections that are influenced not only by demand but also changes in technological and operational aspects. In the strongest growth scenario (A1B in IPCC SRES), aviation emissions increase above year 2000 values by estimated factors of 3.6 and 7.5 by 2050 and 2100, respectively (Owen and Lee, 2011). Shipping emission growth is similar and road transport growth is substantially greater. Currently, aviation CO_2 emissions are approximately 2-3% of all anthropogenic CO_2 emissions. A significant fraction of CO_2 emissions from all sources and, hence, the associated radiative forcing, remain in the atmosphere for many centuries. In contrast, the other emissions and emission products have atmospheric removal lifetimes of weeks to several decades, and cloud changes have lifetimes of up to a few days. Thus, if aviation operations were to cease, only the radiative effects of accumulated CO_2 emissions would remain after a few decades.

In a hypothetical scenario in which aviation operations and the climate system are unchanged in future years, total aviation radiative forcing steadily increases as CO_2 emissions accumulate in the atmosphere while the non-CO_2 forcings remain unchanged. Thus, the fractional contribution of non-CO_2 emissions to aviation radiative forcing decreases with time in this scenario. This concept underlines why it is not valid to use the ratio of the CO_2 to non-CO_2 radiative forcings from the present day to project total aviation forcing in the future (Forster *et al.*, 2006). However, in terms of temperature change, in this hypothetical scenario the impact of the non-CO_2 forcings would increase for few decades until a quasi-equilibrium was obtained, and during the first years the increase could potentially be faster than the CO_2-induced temperature change. In the scenario with increasing aviation emissions the relative importance of the non-CO_2 effects would be even larger. Hence, a temperature-based metric for weighting the non-CO_2 aviation effects might be necessary.

AVIATION CLOUDINESS

Increased cloudiness from aircraft operating at or near cruise altitudes is a key aspect of aviation radiative forcing and one that is visible to the human eye (**Figure 4**). The increases are typically divided into contributions from persistent (linear) contrails and contrail cirrus. Aviation cloudiness and associated radiative forcing caused by individual aircraft or multiple aircraft in high traffic regions dissipate in the atmosphere within hours to a few days depending on meteorological conditions. The ambient humidity conditions necessary for linear contrail formation behind an engine are well described by the Schmidt-Appleman criterion while persistent contrail formation also requires high ambient humidity (*i.e.*, above 100% relative humidity with respect to ice). Aviation cloudiness forcing estimates represent attempts to integrate over the lifecycle of contrail cloudiness resulting from the diverse global aviation fleet operating in varying meteorological conditions.

The radiative forcing of persistent contrails has a best estimate of about 12 mW m^{-2} in **Figure 2**. In contrast, contrail cirrus lacks a best estimate with the consequence that total aviation

Figure 4: Satellite Photograph Showing Persistent and Aging Contrails Covering Central Europe on 4 May 1995 (Reproduced with Permission of DLR).

radiative forcing is shown with and without a contrail cirrus contribution. Including the current estimate of contrail cirrus forcing increases the *total* radiative forcing in **Figure 2** by about 40%, as well as the uncertainty in the total forcing. A contrail cirrus best estimate has been elusive because of the difficulties in distinguishing contrail cirrus cloudiness from background cloudiness in observations, and in the physical representation of the contrail spreading and dissipation processes in global models. These difficulties are reflected in contrail cirrus having the lowest LOSU amongst the terms in **Figure 2**.

A new comprehensive treatment of the radiative forcing from contrail cirrus has been conducted in a global climate model (Burkhardt and Kärcher, 2011). The lifecycle of contrails is simulated by parameterizing the processes by which young persistent contrails are formed and age into spreading cirrus cover. This modelling effort represents a major advance in representing the aviation contribution to climate change. The resulting direct radiative forcing from persistent and aged (spreading) contrails is estimated to be approximately 38 mW m^{-2} with the geographic distribution shown in **Figure 5**. This forcing is offset by 20% due to the reduction in natural cirrus that occurs in response to contrail formation, thereby resulting in net total forcing of 31 mW m^{-2}. The cause of this offset is lower relative humidity in the contrail formation region, which occurs in response to atmospheric warming due to contrails and to a reduction in water vapour available to form natural cirrus. A net forcing of 31 mW m^{-2} is considered very consistent with the total cloudiness estimate in **Figure 2** (about 45 mW m^{-2}), which is derived from regional observations and trends in cloudiness. The agreement found increases confidence that the parameterization in the global climate model is representative of contrail processes. The importance of these new results requires confirmation by other climate model studies. Significant uncertainties remain associated with the parameterization of contrail processes and the distributions of humidity and natural cloudiness at cruise altitudes.

While the total contrail radiative forcing is positive, this effect is the net of a much larger positive longwave forcing and a negative shortwave forcing. The relative magnitude to the two contributions depends on the solar zenith angle and, hence, on time of day and geographical latitude. For individual situations a contrail may cause a net cooling or warming. The warming dominates if averaged globally over all contrails formed.

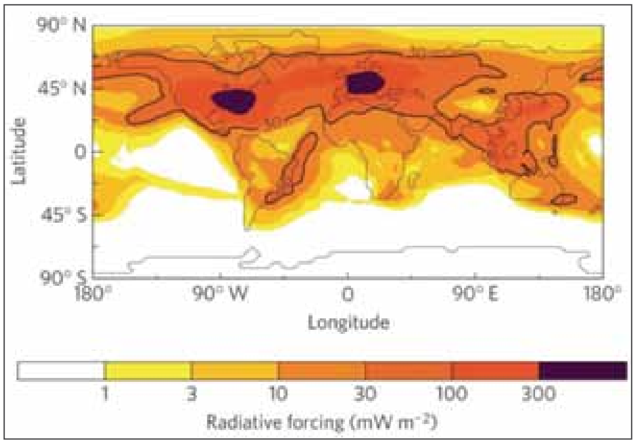


Figure 5: Global Distribution of Contrail Cirrus Radiative Forcing for the Aviation Fleet in Year 2002 from a Global Climate Model with Full Contrail Parameterization (From Burkhardt and Kärcher, 2011).

In another global climate model study, the efficacy of the climate forcing from linear persistent contrails was found to be about 31% of that of CO_2, the leading climate forcing agent (Rap *et al.*, 2010). This value is less than the value of about 60% reported by Ponater *et al.* (2005). The forcing efficacy describes the surface temperature response for a given radiative forcing value compared to the response for the same radiative forcing from CO_2. Thus, a key response of aviation cloudiness in the climate system is expected to be less than that of CO_2 for the same radiative forcing increase. Finally, notable progress has been made in developing numerical techniques for simulating the evolution of individual aircraft exhaust plumes on global and regional-scales while tracking changes in aerosol, gaseous species, and contrail ice particles (Naiman *et al.*, 2011).

AEROSOL EFFECTS

Aviation engines emit aerosols (small particles) and aerosol precursor gases that subsequently form aerosols in the exhaust plume or after dilution in the background atmosphere. A large number of very small (*i.e.*, with a diameter less than 0.050-µm) black carbon (*i.e.*, soot) particles are directly emitted because they are products of incomplete combustion that have high vaporization temperatures. Emitted gaseous sulfur species form sulfate aerosol in the exhaust plume as it expands and cools. Unburned hydrocarbons and other compounds also condense on existing aerosol or form new particles. Global aviation aerosol mass is a small addition to background aerosol amounts at cruise altitudes. **Figure 2** indicates that the accumulation of aviation soot particles leads to atmospheric warming in 2005 whereas aviation sulfate particles cause a cooling, both in a manner consistent with particle emissions from other anthropogenic surface sources. The aerosol terms in **Figure 2** do not include the potential of nitrate aerosol formation from NO_x emissions or aerosol indirect effects associated with changes in background cloudiness. For example, increases in aerosol number in the background atmosphere from aviation or other sectors can lead to reflectivity changes in cirrus clouds and ultimately to a negative radiative forcing. These effects are quite uncertain in model simulations, so that no estimates are available and, hence, they are not included in the total climate forcing of global aviation.

NO_X EFFECTS

Aircraft engines emit reactive nitrogen (NO_x) in the forms of NO and NO_2. While NO_x is not a greenhouse gas, it alters the abundance of two principal greenhouse gases, ozone (O_3) and methane (CH_4), through a complex photochemical process. NO_x acts as a catalyst to produce O_3 in the oxidation of CO, CH_4, and a variety of hydrocarbon compounds. The O_3 production efficiency is higher for NO_x emitted at cruise altitudes than at the surface due to atmospheric conditions in the upper troposphere. Increased O_3 leads to a positive radiative forcing (warming) as shown in **Figure 2**. Another photochemical response to increased NO_x is an increase in the hydroxyl radical (OH), which reacts with many atmospheric compounds including CH_4. The OH reaction with CH_4 reduces its atmospheric lifetime and, hence, atmospheric abundance. CH_4 reductions represent a negative radiative forcing (cooling) as shown in **Figure 2**. Finally, this long-term CH_4 reduction also leads to a relatively small long-term reduction of O_3, which has also not been taken into account in **Figure 2**. The long lifetimes associated with O_3 and CH_4 responses lead to hemispheric-to-global scale perturbations in these climate forcing agents and, hence, cause large differences between the geographical distributions of NO_x emissions and responses. Furthermore, the magnitude of the O_3 and CH_4 responses depends on the geographic location of the NO_x emissions.

A large and lingering uncertainty in deriving a best estimate for net NO_x radiative forcing is the large uncertainties in the opposing O_3 and CH_4 terms shown in **Figure 2**. More specifically, there has not been high confidence in the extent to which these uncertainties are correlated. For example, the net NO_x term and its uncertainty in **Figure 2** are shown under the assumption that the uncertainties are fully correlated. The uncertainty range would be far larger if the uncertainties had no correlation (*i.e.*, about six times larger).

A new study using a suite of chemical transport models to examine the underlying processes of the O_3 and CH_4 responses now provides strong evidence that the uncertainties are indeed highly correlated (Holmes *et al.*, 2011). Furthermore, the net NO_x radiative forcing and uncertainty values, estimated to be near 4.5 ±4.5 mW m^{-2} for 2005 emissions (*i.e.*, 1 TgN yr-1), are both significantly less than the values of 12.6 (3.8–15.7) mW m^{-2} in **Figure 2**. These results suggest with increased confidence that the likely contribution of aviation NO_x to climate forcing has been overestimated with previous best estimates. The model study also shows that some of the remaining forcing uncertainty for NO_x emissions lies with uncertainties in basic atmospheric process, such as the O_3 response to changes in CH_4, rather than in specific direct responses to aviation emissions.

An important distinction for NO_x emissions is that the climate forcing contribution per unit emission is not the same for all sources of NO_x as it is for CO_2, which has a much longer atmospheric lifetime. Transport sector emissions demonstrate this clearly. In year 2000, NO_x emissions from aviation were about 0.9 TgN yr-1, significantly less than emissions from the shipping and road transport sectors of 4.5 and 9 TgN yr-1, respectively (Myhre *et al.*, 2011). From several global chemistry models, the net radiative forcings from aviation, shipping, and road transport were 6, -18, and 16 mW m^{-2}, respectively, for 2000 emissions. Differences in the geographical locations of the emissions, the amounts of co-emitted species, and background atmospheric conditions lead to proportionately different changes in O_3 and CH_4 per unit NO_x emission and even differences in sign (*i.e.*, warming vs. cooling). Radiative forcing from aviation emissions is the largest per unit emission, in part, because most NO_x is emitted at cruise altitudes where it has a longer atmospheric lifetime than surface emissions.

EMISSIONS FROM ALTERNATIVE AVIATION FUELS

A number of alternative fuels are being considered for aviation. Both synthetic jet fuels derived from coal or natural gas via the Fisher-Tropsch process and hydrotreated esters and fatty acids (HEFA) fuels derived from plant oils have been approved as blends with conventional petroleum-derived Jet-A fuel. Research is underway to produce and evaluate other bio-derived fuels. Of these, biofuels have widely recognized potential for substantial reductions in CO_2 emissions from aviation. Assessing the suitability of alternative fuels for climate mitigation involves several aspects. Foremost is the lifecycle or well-to-wake evaluation of CO_2 emissions that demonstrates whether an alternative fuel reduces net emissions in aviation operations. Many of the controlling factors in the life-cycle analysis are currently outside of typical aviation operations and would undergo development as the use of alternative fuels increases globally (Stratton *et al.*, 2011).

Recent studies have characterized the emissions from alternative fuels using commercial engines in ground-based tests. The reduced sulfur and aromatic contents in synthetic, biomass, or fuel blends with JP8 or Jet-A result in significantly lower particulate matter emissions when measured as mass or number of particles (see Lobo *et al.* (2011)). Emitted particulate matter containing soot, sulfates and hydrocarbons along with background atmospheric particles contribute to aviation cloudiness. The consequences of particulate matter reduction for the amount or character of aviation cloudiness is not known currently, although a reduction in the number of ice particles produced will likely shorten the lifetime of the contrail as ice particles grow and precipitate. A complication is that aromatic content may be augmented to protect aircraft mechanical seals. NO_x and CO emissions are similar or reduced for Fisher-Tropsch fuels and fuel blends with JP8 compared to JP8 while VOCs show a mixed response (Timko *et al.*, 2011). Thus, current understanding suggests that alternative fuels and blended fuels will have similar or reduced climate forcings from the non-CO_2 contributions, although important uncertainties remain concerning aviation cloudiness. ■

REFERENCES

Burkhardt, U., and B. Kärcher: Global radiative forcing from contrail cirrus. Nature Climate Change, 1, 54-58 (2011). doi:10.1038/nclimate1068.

Forster, P. M. F., K. P. Shine, N. Stuber, It is premature to include non-CO_2 effects of aviation in emission trading schemes, Atmos. Environ., 40 (2006) 1117-1121.

Forster, P., V. Ramaswamy, P. Artaxo, T. Berntsen, R. Betts, D. W. Fahey, J. Haywood, J. Lean, D. C. Lowe, G. Myhre, J. Nganga, R. Prinn, G. Raga, M. Schulz, and R. Van Dorland (2007), Changes in atmospheric constituents and in radiative forcing, in Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change edited by S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor and H. L. Miller Cambridge University Press, New York.

Holmes, C.D., Q. Tang, and M.J. Prather: Uncertainties in climate assessment for the case of aviation NO, Proc. Natl. Acad. Sci., 108, 27, 10997-11002 (2011), doi: 10.1073/pnas.1101458108.

ICAO Environmental Report 2010. Montreal, Canada: International Civil Aviation Organization. Available at: www.icao.int/icao/en/env2010/environmentreport_2010.pdf (Accessed 28 October 2011)

IPCC, 1999: Aviation and the Global Atmosphere: A Special Report of IPCC Working Groups I and III [Penner, J.E., *et al. (eds.)*]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 373 pp.

Lee, David S., David W. Fahey, Piers M. Forster, Peter J. Newton, Ron C. N. Wit, Ling L. Lim, Bethan Owen, Robert Sausen, Aviation and global climate change in the 21st century, Atmos. Environ., 43, 3520-3537, 2009.

Lobo, P., D. E. Hagen, and P. D. Whitefield, Comparison of PM emissions from a commercial jet engine burning conventional, biomass, and Fischer-Tropsch fuels, Environ. Sci. Technol. 2011, 45, 10744-10749, dx.doi.org/10.1021/es201902e.

Myhre, G., K.P. Shine, G. Rädel, M. Gauss, I.S.A. Isaksen, Q. Tang, M.J. Prather, J.E. Williams, P. van Velthoven, O. Dessens, B. Koffi, S. Szopa, P. Hoor, V. Grewe, J. Borken-Kleefeld, T.K. Berntsen, J.S. Fuglestvedt, Radiative forcing due to changes in ozone and methane caused by the transport sector, Atmos. Environ., 45, 387-394 (2011) ISSN 1352-2310, doi:10.1016/j.atmosenv.2010.10.001.

Naiman, A. D., S. K. Lele, J. T. Wilkerson, and M. Z. Jacobson, Parameterization of subgrid plume dilution for use in large-scale atmospheric simulations, Atmos. Chem. Phys., 10, 2551-2560, 2010.

Olivié, D. J. L., D. Cariolle, H. Teyssèdre, D. Salas, A. Voldoire, H. Clark, D. Saint-Martin, M. Michou, F. Karcher, Y. Balkanski, M. Gauss, O. Dessens, B. Koffi, and R. Sausen, Modeling the climate impact of road transport, maritime shipping and aviation over the period 1860-2100 with an AOGCM, Atmos. Chem. Phys., 12, 1449-1480, 2012.

Owen, B. and D. S. Lee, Flying into the future: Aviation emissions scenarios to 2050, Environ. Sci. Technol. 2010, 44, 2255-2260.

Ponater, M., S. Marquart, R. Sausen, and U. Schumann (2005), On contrail climate sensitivity, Geophys. Res. Lett., 32, L10706, doi:10.1029/2005GL022580.

Stratton, R. W., H.M. Wong, and J. I. Hileman, Quantifying variability in life cycle greenhouse gas inventories of alternative middle distillate transportation fuels, Environ. Sci. & Tech. 45 (10), 4637-4644, 2011.

Timko, Michael T., Scott C. Herndon, Elena de la Rosa Blanco, Ezra C. Wood, Zhenhong Yu, Richard C. Miake-Lye, W. Berk Knighton, Linda Shafer, Matthew J. DeWitt & Edwin Corporan, Combustion products of petroleum jet fuel, a Fischer-Tropsch synthetic fuel, and a biomass fatty acid methyl ester fuel for a gas turbine engine, Combustion Science and Technology, 183, 1039-1068, 2011, DOI: 10.1080/00102202.2011.581717.

CHAPTER 2

AIRCRAFT NOISE

OVERVIEW

REDUCING AIRCRAFT NOISE

BY ICAO SECRETARIAT

INTRODUCTION

Aircraft noise is the most significant cause of adverse community reaction related to the operation and expansion of airports. This is expected to remain the case in most regions of the world for the foreseeable future. Limiting or reducing the number of people affected by significant aircraft noise is therefore one of ICAO's main priorities and one of the Organization's key environmental goals.

The noise emanating from aircraft operations in and around an airport depends upon a number of factors including the types of aircraft using the airport, the overall number of daily take-offs and landings, general operating conditions, the time of day that the aircraft operations occur, the runways that are used, weather conditions, topography, and airport-specific flight procedures.

ICAO provides guidance on employing a Balanced Approach to managing noise at airports that consists of identifying the noise problem and then analysing the various measures available to reduce noise through the exploration of four principal elements, namely:

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

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

The focus of this chapter is the *reduction of noise at source*. In the context of the ICAO balanced approach to noise management, this refers to the review of aircraft noise Standards to ensure that they reflect the current state of aircraft technology and thus, noise reduction achieved through the adoption and implementation of the noise certification Standards in Annex 16, Volume I, to the *Convention on International Civil Aviation*. Research and development aimed at reducing the impact of aircraft noise through aircraft technology improvements are ongoing activities, and ICAO continuously aims to reflect state-of-the-art technology within its standards. The maintenance and development of the ICAO aircraft noise Standards is within the purview of the ICAO Committee on Aviation Environmental Protection (CAEP).

Over the past three years, work has been conducted by CAEP to ensure the validity of the technical basis underpinning the ICAO Standards and Recommended Practices (SARPs) associated with reducing aircraft noise. This work has included, *inter alia*, the development of new noise Standards, investigations into emerging noise reduction technologies (which included an Independent Expert review of noise technology), and research into technology for future supersonic aircraft, including continuing to develop the basis for a future supersonic aircraft noise Standard. This chapter of the Environmental Report provides more details on each of the aforementioned topics. Details on the other elements of the balanced approach to aircraft noise management can be found in the ICAO Doc 9829, *Guidance on the Balanced Approach to Aircraft Noise Management* and at www.icao.int/environmental-protection/Pages/noise.aspx.

SETTING NEW NOISE STANDARDS

Aircraft Noise has been regulated since the 1970s by the setting of ICAO noise Standards for aircraft in Annex 16. Since then, ICAO has progressively monitored and updated these noise Standards in order to ensure that they are up-to-date and effective, whilst making sure that the certification procedures are as simple and inexpensive as possible. The objective is to ensure that the latest available noise reduction technology is incorporated into aircraft design, and that noise reductions offered by technology are related to the reductions around airports. Updates to the ICAO aircraft noise Standards were recommended by the ninth meeting of the CAEP (CAEP/9) which included a more stringent noise Standard for jet and propeller-driven aeroplanes. A new noise Standard for tilt-rotor type aircraft was also recommended (see article *Aircraft Noise Certification and New ICAO Noise Standards*, Chapter 2 in this report).

NOISE REDUCTION TECHNOLOGY

In order to set a new noise Standard, an understanding of current research and the development of technology is imperative. Technological progress continues to push the aviation community to delivering on the ICAO goal of limiting or reducing the number of people affected by significant aircraft noise. The CAEP continually monitors research and development in noise reduction technology, and this complements the standard-setting process. Thus, it has been possible to develop a comprehensive overview of ongoing worldwide aircraft noise efforts and associated goals (see article *Noise Research Aimed at Technology Solutions*, Chapter 2 in this report). This technology monitoring has also included contributions to the Noise Technology Independent Expert Review process which took place in both 2008 and 2011.

In 2007, the CAEP established the first Independent Experts Review (IER1) to recommend technology and operational goals for aircraft noise in the mid-term (10-year) and long-term (20-year). Novel design concepts with the potential to reduce noise, fuel burn, and emissions were not considered during the first review because of a lack of available information. The second review (IER2) was requested in 2010 to evaluate novel concepts possibly certifiable by 2030, and to comment on expected noise levels relative to advanced conventional turbofan and turboprop-powered aircraft (see article *ICAO Technology Goals for Noise Second Independent Expert Review*, Chapter 2 in this report).

SUPERSONIC AIRCRAFT

While defining new and complex technologies for supersonic transport is a major undertaking, it is the environmental acceptability of the impacts of supersonic operations which constitutes the main challenge, and this includes shaping a robust noise certification Standard. To this end, Research Focal Points (RFPs) continue to provide CAEP with details on important research associated with supersonic flight. This includes modelling research on urban canyon sonic boom noise, making available noise data from drop tests of scale aircraft-shaped designs, and preliminary results on the generation and capture of noise measurements in order to enable the development of modelling tools. In addition, industry efforts continue on several collaborative supersonic projects, although schedules for most programmes remain uncertain. CAEP continues its efforts towards developing a Standard for future supersonic aircraft, and discussions continue on the sonic boom measurement schemes and procedures for future supersonic aircraft (see article *Establishing New Noise Standards for Civil Supersonic Aircraft Status Report*, Chapter 2 in this report).

FUTURE ICAO WORK

ICAO continues to develop measures aimed at reducing or limiting the number of people affected by aircraft noise. Making sure that the international standards, guidance material, and technical documentation are all up-to-date and are appropriate for the needs of the international community, is crucial to this objective. This includes the maintenance of Annex 16, Volume I, the Environmental Technical Manual (Doc 9501), and the ICAO noise databank.

The future work on noise during the three years of the tenth CAEP (CAEP/10) cycle will focus on:

- monitoring and reporting on the various national and international research programme goals and milestones;
- assessing emerging noise reduction technologies;
- reviewing progress towards achievement of the 2020 and 2030 noise reduction technology goals; and
- continuing to develop certification procedures for possible future supersonic aircraft.

A further important piece of work on aircraft noise will be the assessment of interdependency effects of CO_2 emissions stringency options for the ICAO CO_2 Standard with respect to noise. ■

AIRCRAFT NOISE CERTIFICATION AND NEW ICAO NOISE STANDARDS

BY ICAO SECRETARIAT

The primary purpose of noise certification is to ensure that the latest available noise reduction technology is incorporated into aircraft design and demonstrated by procedures that are relevant to day-to-day operations, in order to ensure that noise reductions offered by technology are reflected in reductions around airports. Aircraft Noise ("*noise at source*") has been controlled since the 1970s by the setting of noise limits for aircraft in the form of Standards and Recommended Practices (SARPs) contained in Annex 16 to the *Convention on International Civil Aviation* (the "*Chicago Convention*")[1]. This continues to be the case today. Noise provisions appear in Volume I of Annex 16, with Volume II devoted to engine emissions (see article *Local Air Quality Overview*, Chapter 3 in this report).

The first meeting of the ICAO Committee on Aircraft Noise (CAN,1971), developed a noise Standard which aimed at ensuring that any new aircraft entering service would use the best available noise reduction technology. That Standard became applicable in 1973, setting noise limits as a direct function of Maximum Take-off Mass (MTOM) in order to recognise that heavier aeroplanes, which were of greater transport capability, produce more noise than lighter aeroplane types. This is the Chapter 2 noise Standard contained in Annex 16, Volume I. **Figure 1** shows a schematic of the noise certification test procedures.

Aeroplane Certification Procedures

Aeroplane acoustic certification involves measuring the noise level of an aircraft in Effective Perceived Noise Level (EPN) dB[2] at three reference points:

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

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

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

Over the years that followed the introduction of Chapter 2, much higher bypass ratio jet engines were introduced into service. Not only did this new technology deliver improved fuel efficiency, it also resulted in reductions in engine noise. This allowed for the ICAO noise Standard to be made more stringent in 1977. This is the Chapter 3 noise Standard contained in Annex 16, Volume I.

In the following years, further noise reduction technologies were incorporated into engine and airframe designs which led to incremental improvements in aircraft noise performance. At the fifth meeting of the CAEP (CAEP/5) it

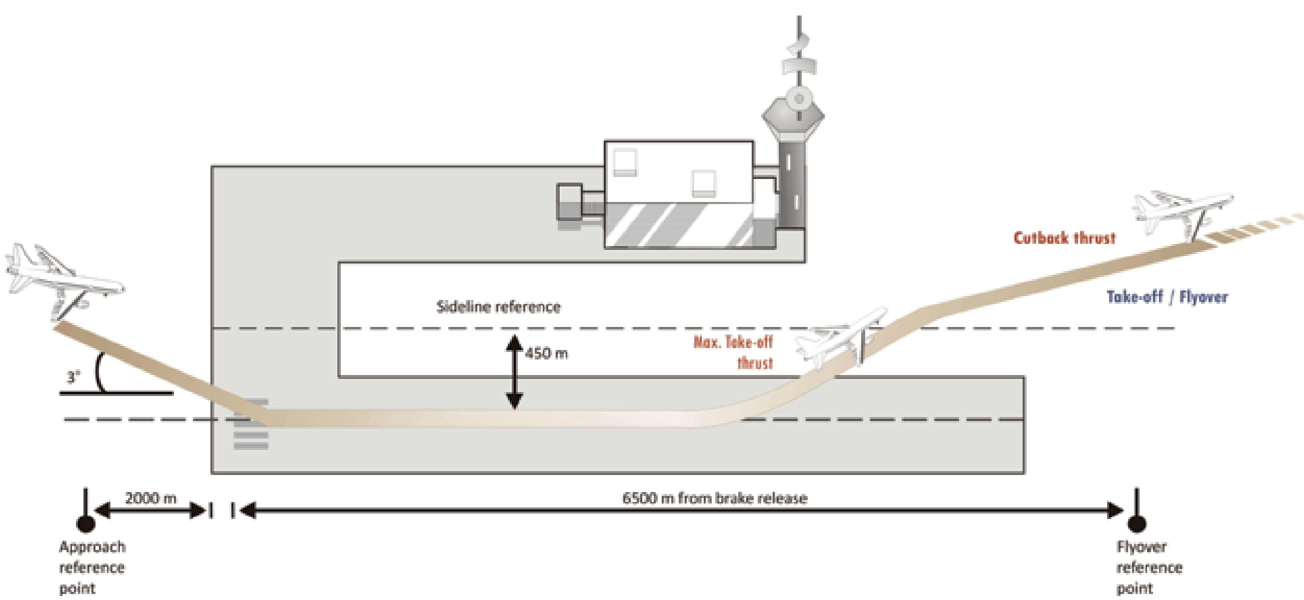


Figure 1: *Aircraft Noise Certification Reference Points.*

was agreed that more changes to the ICAO noise Standard limits were appropriate. The new Standard stipulated that the Chapter 3 noise limit at each of three certification reference point must not be exceeded (*i.e.* no trade-offs between points was permitted) and that relative to Chapter 3 the minimum margin at any two certification points must be at least 2 EPNdB. The new noise limit itself, represented by the sum of the noise limits at the three certification reference points (referred to as EPNdB – cumulative), was set as 10 EPNdB lower than the sum of the Chapter 3 noise limits.

The CAEP, through its Working Group 1 on Noise (WG1), continually aims to keep ICAO noise certification Standards (*i.e.* Annex 16, Volume I) up-to-date and effective, whilst ensuring that the certification procedures are as simple and inexpensive as possible. This involves support from CAEP Working Group 3 on Emissions (WG3), the Modelling and Database Group (MDG), and the Forecasting and Economic Analysis Support Group (FESG) (see the CAEP structure in the article *Committee on Aviation Environmental Protection: Outcomes from CAEP/9*, Introduction in this report). This allows CAEP to develop environmental standards that are technologically feasible, environmentally beneficial, economically reasonable, and that take into account interdependencies with other environmental impacts (*e.g.* Local Air Quality emissions). This process allows ICAO to adopt robust and effective noise standards.

This article provides an overview of the proposed new standards agreed at the CAEP/9 meeting for jet and propeller-driven aeroplanes, and for tilt-rotor type aircraft.

A NEW STANDARD FOR JET AND PROPELLER-DRIVEN AIRCRAFT

During the CAEP/9 cycle (2010 to 2013), the CAEP analysed a number of options for a new noise Standard for jet and propeller-driven aeroplanes. The options were 3, 5, 7, 9 and 11 EPNdB (cumulative) noise reduction relative to the Annex 16, Volume I, Chapter 4 noise Standard. Each of these stringency options was analysed for its environmental benefit, cost, and interdependency with emissions. Based on this, CAEP recommended an amendment to Annex 16, Volume I involving an increase in stringency of 7 EPNdB (cumulative) relative to the current Chapter 4 levels. The proposed new Standard would be applicable to new aeroplane types submitted for certification on or after 31 December 2017, and on or after 31 December 2020 for aircraft less than 55 tonnes in weight. The latter was included to recognise that the smaller jet aeroplanes have not to date seen the same noise reduction technologies as the larger aeroplanes. The proposed new noise Standard also contains a supplementary condition, included in addition to the cumulative stringency requirement, mandating a margin of not less than 1.0 dB below Chapter 3 limits at each of the three certification test points. This aims to maintain the progress in noise reductions, not only with

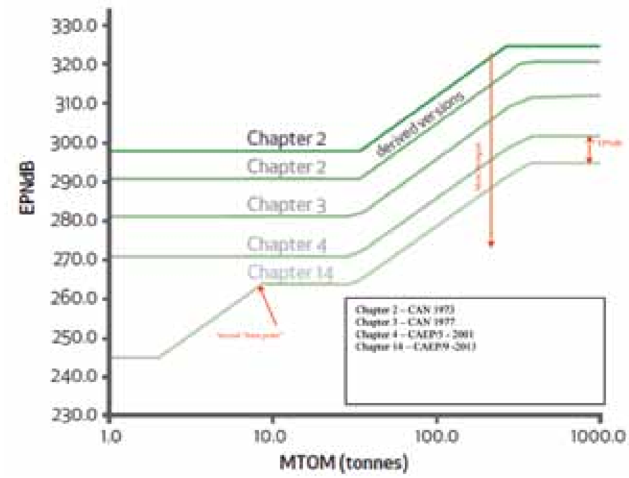


Figure 2: *The Progression of the ICAO Noise Standard.*

regard to a cumulative margin to the noise Standard limit line, but at each individual certification test point.

Along with the proposed increase in stringency, CAEP also recommended to change the noise limits applicable to subsonic jet aeroplanes with take-off masses less than 8,618 kg, through the introduction of a second "knee point" at 8,618 kg compared to the Chapter 4 Standard. The background to this is the continuing trend towards smaller jet aircraft (less than 30,000 kg and down to 2,721 kg) operating more often out of smaller municipal airports that, typically in the past, only supported propeller-driven aeroplanes. This new shape of the proposed noise limit line aims to deal with the ample margin these aeroplanes have, relative to the current Chapter 4 noise Standard. The proposed new Standard is currently under review by ICAO Member States and will be considered for adoption by the ICAO Council in early 2014. Once adopted, the new Standard should be included as Chapter 14 in Annex 16, Volume I. **Figure 2** shows the progression of the ICAO noise Standard from the adoption of Chapters 2, 3 and 4, through to the proposed Chapter 14 noise Standard limit line as agreed at the CAEP/9 meeting in 2013.

The CAEP/9 recommendation of a new noise Standard is the result of a significant data-driven exercise, including three rounds of cost-benefit modelling which, as mentioned earlier, analysed five potential noise stringency options. To reach the decision on the proposed Chapter 14 Standard, the CAEP/9 meeting reviewed the full environmental cost benefit analysis. This involved, for each option: areas and population counts within the 55, 60 and 65 dB Day-Night Average Sound Level (DNL) contours[3], computed by airport and aggregated by region and for the globe; the emissions benefits; and the recurring and non-recurring costs. The results were also combined to form a cost-effectiveness measure indicating the "cost per person removed" from the 55, 60 and 65 DNL noise contours. These cost-effectiveness measures were calculated for the cumulative numbers of persons removed from the contours, or reductions in affected areas, as well as the costs relative to the baseline scenario, for the years 2006 to 2036. As a result of the proposed Chapter 14 noise Standard, it is expected that the number of people affected by significant aircraft noise will be reduced, and that more than one million people could be removed from "Day Night average sound Level (DNL) of 55 dB affected areas" between 2020 and 2036.

A NEW STANDARD FOR TILT-ROTOR AIRCRAFT

A tilt-rotor (*noun*) is "a powered-lift [aircraft] capable of vertical take-off, vertical landing, and sustained low-speed flight, which depends principally on engine-driven rotors mounted on tiltable nacelles for the lift during these flight regimes and on non-rotating aerofoil(s) for lift during high-speed flight". During the CAEP/9 cycle, work on the development of a new noise Standard for tilt-rotors was carried out. This was in anticipation of the production of tilt-rotor types. An example of a tilt-rotor is the AgustaWestland Tilt-rotor Company (AWTRC) AW609 which is shown in **Figure 3**.

Powered-lift

A heavier-than-air aircraft capable of vertical take-off, vertical landing, and low-speed flight, which depends principally on engine-driven lift devices or engine thrust for the lift during these flight regimes and on non-rotating aerofoil(s) for lift during horizontal flight.

In 2001, ICAO adopted guidelines for the noise certification of tilt-rotors, and these were incorporated into Annex 16, Vol. I, Attachment F. The guidelines account for the worst case, noisiest operating condition (*i.e.* Helicopter mode), in order to determine the practicality of noise reduction technology. The significance of noise produced during the transition period from one nacelle angle to another, and by tilt-rotors in aeroplane-mode, was considered but it was agreed that these conditions do not require any special noise certification requirements. For a tilt-rotor operating in aeroplane-mode it was considered useful to measure and report these noise levels. In 2013, the CAEP agreed to recommend upgrading the current guidance material into a Standard (as Annex 16, Volume I, Chapter 13). The proposed new Standard uses the same noise limits (as contained in the guidance) as used for helicopters in Annex 16, Chapter 8, section 8.4.1. An increase in stringency is not proposed because the consensus of the technical experts in WG1, following review of information supplied by the manufacturers, was that since 2001 there have been no major noise reduction technologies developed for tilt-rotors that warrant making a new standard any more stringent than the existing certification guidelines. It was

Figure 3: *AgustaWestland Tilt-rotor Company AW609. Source: AgustaWestland.*

apparent that the knowledge of tilt-rotor aircraft in the last two decades from an acoustic point of view has increased and computational tools have shown possible improvements in noise reductions using advanced design methods. However, demonstrating the incorporation of the technical improvements into a cost-effective and manufacture-ready design has yet to be done.

In developing the proposed new tilt-rotor noise Standard, a significant amount of consultation was performed, and in this regard the CAEP asked relevant noise, airworthiness, operations, and legal experts for opinions before making a comprehensive proposal to form the Standard. This led to complementary recommendations by CAEP for ICAO to give consideration to tilt-rotor provisions in the following annexes: personnel licensing; nationality and registration marks; airworthiness; and operations. The proposed new noise Standard for tilt-rotors is currently under review by ICAO Member States and will be considered for adoption by the ICAO Council in early 2014 with an applicability date of 1 January 2018.

REFERENCES

1 *Convention on International Civil Aviation* (also known as *Chicago Convention*), Doc 7300, ICAO.

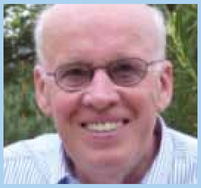
2 EPNdB; Is a measure of Effective Perceived Noise Level (EPNL) which is a single number evaluator of the subjective effects of aircraft noise on human beings. EPNL is adjusted for the spectral irregularities and the duration of noise.

3 Day-Night Average Sound Level (DNL): a noise measure used to describe the average aircraft noise levels over a 24-hour period, typically an average day over the course of a year. DNL considers aircraft operations occurring between the hours of 10 p.m. and 7 a.m. to be 10 decibels louder than the operations occurring during the daytime to account for increased annoyance when ambient noise levels are lower and residents are sleeping. The symbol for DNL is L_{dn}.

ICAO TECHNOLOGY GOALS FOR NOISE
Second Independent Expert Review
BY **DENNIS HUFF**, **ULF MICHEL** AND **BRIAN TESTER**

DENNIS HUFF

He is the Deputy Chief of the Aeropropulsion Division at the NASA Glenn Research Center. He served as Co-Chair in the first independent expert panel for noise, and was Chair for the second independent expert panel. Mr. Huff was previously Chief of the Acoustics Branch at NASA Glenn and has managed several engine noise reduction projects.



ULF MICHEL

He is retired from the German Aerospace Center DLR and currently consultant in Aeroacoustics. Recent research objects are the influence of source interference on jet noise, microphone arrays for localizing noise sources, noise reduction designs for fans and turbines, the benefits of variable area fan nozzles.

BRIAN TESTER

He is Principal Research Fellow at the ISVR, University of Southampton, UK. Brian co-chaired both the first and second expert panels. He received the European 2009 CEAS Aeroacoustics Award for "his pioneering contributions to the aeroacoustics of turbofan engine noise".

BACKGROUND AND INTRODUCTION

A second Independent Expert Panel (IEP2) has conducted a review for ICAO to assess commercial aircraft noise levels for the years 2020 (mid-term (MT)) and 2030 (long-term (LT)). The panel evaluated the market readiness, noise reduction capability and environmental efficiency tradeoffs of novel aircraft and advanced engine concepts, such as the open rotor, geared turbofan and blended wing body. It updated mid- and long-term aircraft noise goals that were established by a previous Panel (IEP1).

In 2007, the Committee on Aviation Environmental Protection (CAEP) established the first Independent Experts Review (IER1) to recommend technology and operational goals for aircraft noise in the mid- (10-year) and long- (20-year) term[1]. Novel concepts with the potential to reduce noise, fuel burn, and emissions were not considered during the first review because of a lack of available information. The second review (IER2) was requested in 2010 to evaluate novel concepts possibly certifiable by 2030, to comment on expected noise levels relative to advanced conventional turbofan and turboprop-powered aircraft, and to coordinate a technical approach with other panels of independent experts.

The members of the second Independent Experts Panel included Magdy Adib (ECAA, Egypt), Fernando Catalano (University of San Paulo, Brazil), Jim Hileman (FAA, USA), Dennis Huff (NASA, USA, IEP2 Chair), Takeshi Ito (JAXA, Japan), Alain Joselzon (Consultant, France), Yuri Khaletskiy (CIAM, Russia), Ulf Michel (Consultant, Germany, IEP2 Co-Chair), Luc Mongeau (McGill University, Canada), and Brian J. Tester (Southampton University, UK, IEP2 Co-Chair). A report was written and is available through ICAO[2].

NOVEL AIRCRAFT AND ENGINES

A Technology Scenario for Noise (TSN) approach was used to evaluate the market readiness of novel aircraft and advanced engine concepts. In TSN-1, a "tube-and-wing" aircraft design continues to evolve, but pressure on the aviation industry to reduce noise remains at current levels and is insufficient to achieve the Technology Readiness Level (TRL) required for unconventional, noise-driven aircraft concepts by 2030. In TSN-2, increased pressure to reduce noise, balanced with pressure to reduce fuel burn and emissions, makes noise reduction a primary design objective driving the development of unconventional aircraft concepts by 2030.

As part of its review, IEP2 examined NASA advanced aircraft studies and European Commission New Aircraft Concepts Research (NACRE) Pro-Green designs. The Panel used independent systems analyses from NASA ultra-high bypass (UHB) ratio turbofan and counter-rotating open rotor (CROR) studies, and applied noise reduction technologies (NRT) that are expected to be mature in this time period. It interviewed several organizations that conducted studies of novel aircraft to determine feasibility for Entry-Into-Service (EIS) by 2030. The review focused on Small/Medium Range Twin (SMR2) and Long Range Twin (LR2) aircraft because, according to IER2 and other open sources of information, novel concepts had theretofore been evaluated against a reference aircraft and mission corresponding to these classes.

The IEP2 concluded that conventional tube-and-wing aircraft are expected to prevail over more aggressive designs in which noise reduction is a primary objective. While novel *aircraft* with noise reduction features are only feasible by 2030 with increased resources and investment, some advanced *engine* concepts (*e.g.*, UHB, CROR) are possible at current investment levels.

NOISE REDUCTION

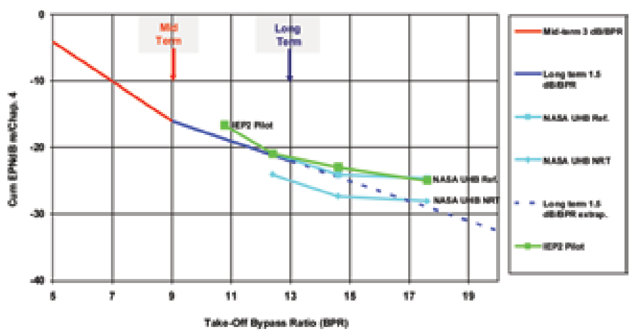


Figure 1: *SMR2 Noise Reduction Trends with Bypass Ratio at TRL 6, TSN-1, UHB (ultra-high bypass ratio engines), NRT (with noise reduction technologies).*

Ultra-high bypass turbofans are expected to be quieter than current designs with significant benefits up to a bypass ratio (BPR) of 13 in the long-term. However the noise reduction benefit is predicted to diminish with further increases in BPR, especially for values above 15, as shown in **Figure 1**. One reason for this is that the nacelles cannot be increased in size proportionally to the fan diameter. Short to medium range aircraft can be powered by CROR engines but are considerably noisier than the equivalent UHB turbofan, by 15 EPNdB cumulative (cum.) or more for the aft-mounted pusher configuration. Wing mounted (tractor) CROR are expected to be about 6 EPNdB (cumulative) louder than aft-mounted configurations.

NOISE TECHNOLOGY GOALS

The IEP2 provided recommendations using the TRL parameter, which numerically quantifies the state of a concept from idea (TRL1) to in-service demonstration (TRL9). The two levels used in this report are TRL6 (large-scale validation of technologies in a relevant environment, such as flight test demonstrators, static engine tests, large wind tunnel tests) and TRL8 (product noise certification tests).

The scope of the IEP2 review was limited to TRL6 for long-term novel aircraft configurations because there has not been enough development of the concepts at higher TRL to estimate noise levels that account for trades with other design parameters. Mid-term goals are given for TRL8 following the same approach used by the IEP1. Noise goals are specified for the nominal weight within each aircraft category and the expected maximum weight. There are four aircraft categories designated as regional jet (RJ), short medium range twin (SMR2), long range twin

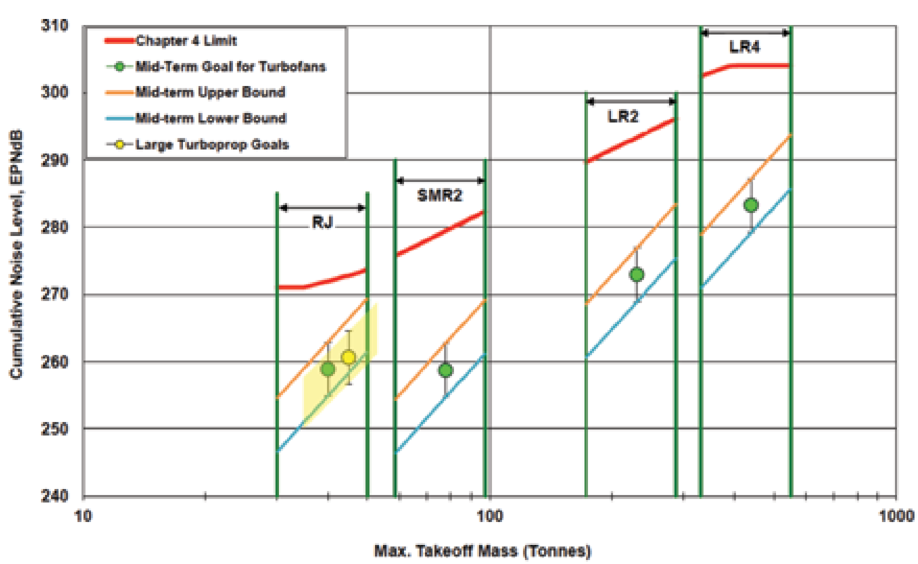


Figure 2: *Mid-Term (2020) Cumulative Noise Goals at TRL8 (including Large Turboprops).*

(LR2) and long range quad (LR4). Large turboprops and CROR powered SMR2 aircraft were studied as separate categories. The sensitivity of noise with increasing weight is shown in **Figures 2** and **3**. Note that the slope of the sensitivity is higher than the Chapter 4 rule and varies depending on if the aircraft is powered by a turbofan, turboprop, or CROR.

The mid-term goals are shown in **Table 1**. The goals for turbofans are the same as in the IEP1 review but those for large turboprops are new. Uncertainty values for noise estimates have been rounded to ±4 EPNdB.

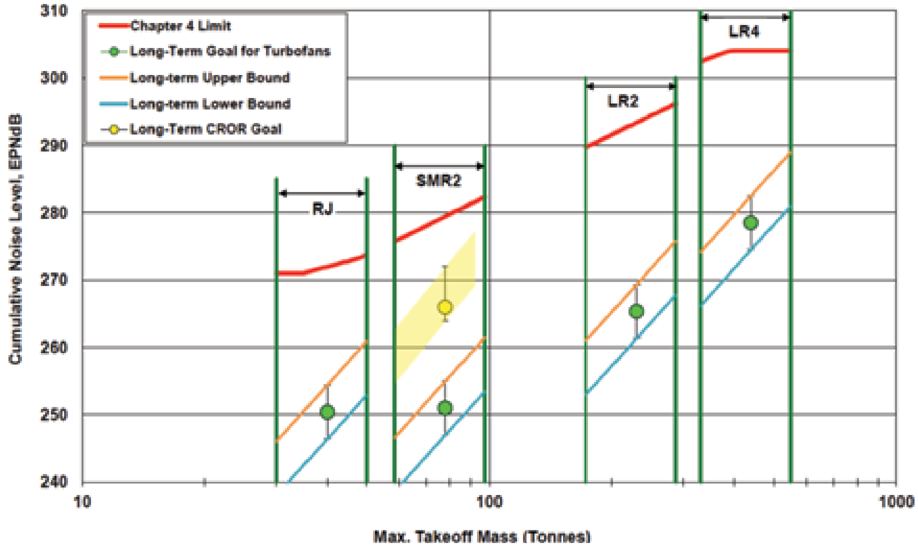


Figure 3: *Long-Term (2030) Cumulative Noise Goals at TRL6 (including CROR for SMR2).*

Aircraft Category	BPR Goal	NR TRL6	NR TRL8	Cum. Ref	Cum. Goal TRL6	Cum. Goal TRL8
Regional Jet (RJ)						
40 tonnes (nominal)	7±1	10	9	4	14	13±4
50 tonnes (max)	7±1	10	9	-0.5	9.5	8.5±4
Large Turboprops						
45 tonnes (nominal)	-	9.5	9	3	12.5	12±4
53 tonnes (max)	-	9.5	9	0.5	10	9.5±4
Short Medium Range Twin (SMR2)						
Turbofans: 78 tonnes (nominal)	9±1	17.5	16	5	22.5	21±4
98 tonnes (max)	9±1	17.5	16	1.5	19	17.5±4
CROR: 78 tonnes (nominal)	-	-	-	-	-	-
91 tonnes (max)	-	-	-	-	-	-
Long Range Twin (LR2)						
230 tonnes (nominal)	10±1	16	14.5	6	22	20.5±4
290 tonnes (max)	10±1	16	14.5	2.5	18.5	17±4
Long Range Quad (LR4)						
440 tonnes (nomimal)	9±1	17.5	16	5	22.5	21±4
550 tonnes (max)	9±1	17.5	16	-1.5	16	14.5±4

Table 1: *Mid-Term (2020) Cumulative Noise Margin Goals.*
BPR=Bypass Ratio, NR=Noise Reduction, Ref=Reference Levels.

Aircraft Category	BPR Goal	NR TRL6	NR TRL8	Cum. Ref	Cum. Goal TRL6	Cum. Goal TRL8
Regional Jet (RJ)						
40 tonnes (nominal)	9±1	17.5	-	4	21.5±4	-
50 tonnes (max)	9±1	17.5	-	-0.5	17±4	-
Large Turboprops						
45 tonnes (nominal)	-	-	-	-	-	-
53 tonnes (max)	-	-	-	-	-	-
Short Medium Range Twin (SMR2)						
Turbofans: 78 tonnes (nominal)	13±1	25	-	5	30±4	-
98 tonnes (max)	13±1	25	-	1.5	26.5±4	-
CROR: 78 tonnes (nominal)	-	8.5	-	5	13.5+2/-6	-
91 tonnes (max)	-	8.5	-	2	10.5+2/-6	-
Long Range Twin (LR2)						
230 tonnes (nominal)	13±1	22	-	6	28±4	-
290 tonnes (max)	13±1	22	-	2.5	24.5±4	-
Long Range Quad (LR4)						
440 tonnes (nomimal)	11±1	22	-	5	27±4	-
550 tonnes (max)	11±1	22	-	-1.5	20.5±4	-

Table 2: *Long-Term (2030) Cumulative Noise Margin Goals. BPR=Bypass Ratio, NR=Noise Reduction, Ref=Reference Levels.*

The long-term goals shown in **Table 2** have only been updated for the SMR2 and LR2 aircraft classes. The 3dB increase from the IEP1 review for turbofans is due to the BPR increase from 11 to 13. Goals have been added for SMR2 aft-mounted CROR.

CONCLUSIONS

An Independent Expert Panel has conducted a review for ICAO to evaluate expected commercial aircraft noise levels by 2020 and 2030. The review focused on new novel aircraft and advanced engine concepts. The major conclusions from the review are as follows:

- The IEP2 expects the evolution of conventional tube and wing aircraft to prevail over more aggressive aircraft designs where noise reduction is considered a primary design objective. Novel aircraft with noise reduction features are only feasible by 2030 with increased investment in resources.
- Novel engine concepts, however, can be developed by 2030, *i.e.*, ultra high bypass (UHB) engines, counter-rotating open rotors (CROR) and geared turbofans (GTF).
- IEP2 studies show that UHB turbofans are quieter than current designs, but the noise reduction benefit diminishes with increased BPR, especially for values above 15.
- Short to medium range aircraft can be powered by CROR engines but are considerably noisier than the equivalent UHB turbofan, by 15 EPNdB (cumulative) or more for the aft-mounted pusher configuration. Wing mounted (tractor) CROR are expected to be about 6 EPNdB (cumulative) louder than aft mounted configurations. ■

REFERENCES

1 P. R. Gliebe, *et al.*, “Report to CAEP by the CAEP Noise Technology Independent Expert Panel: Aircraft noise technology review and medium and long term noise reduction goals,” International Civil Aviation Organization, Doc 9943/ISBN 9789292315948, 2010.

2 D. L. Huff, *et al.*, “Report to CAEP by the CAEP Noise Technology Independent Expert Panel: Novel aircraft noise technology review and medium and long term noise reduction goals,” ICAO, Doc 10017, 2014.

NOISE RESEARCH AIMED AT TECHNOLOGY SOLUTIONS

BY DOMINIQUE COLLIN

This article is based on the work carried out within the Technology Task Group (TTG) of CAEP Working Group 1. Contributors include Dominique Collin (Snecma – TTG Focal Point), James Skalecky (FAA, USA), Rhett Jefferies (FAA, USA), Fay Collier (NASA, USA), Ruben Del Rosario (NASA, USA), Andrew Kempton (Rolls-Royce), Pierre Lempereur (Airbus), Tatsuya Iishi (JAXA, Japan), Tsutomu Oishi (IHI), Benny Pang (Bombardier), Mark Huising (Bombardier), Victor Kopiev (TsAGI, Russian Federation), Yuri Khaletskiy (CIAM, Russian Federation), Carlos Grandi (Embraer) and Micael Do Carmo (Embraer).

BACKGROUND

Noise – Technical Working Group 1 (WG1) of the ICAO Committee on Aviation Environmental Protection (CAEP) has been monitoring noise technology research programmes since the CAEP/6 cycle (2001-2004). As a result, over the last ten years it has been possible to develop a broader view of the noise technology related research activities worldwide and place them into perspective with respect to the aspirational goals established for the wider environmental initiatives.

Information on worldwide noise research efforts has been regularly updated since the first dedicated CAEP Noise Technology Workshop was held in São Paulo, Brazil in 2001. These updates have included contributions to the Noise Technology Independent Expert Reviews held in both 2008 and 2011, as well as information papers provided at regular CAEP meetings every three years.

This article presents the status of noise research efforts aimed at technology solutions as they stood at the end of 2012. It covers national and regional research initiatives and provides an up-to-date view of ongoing and planned efforts in terms of their technical scope and objectives.

OVERVIEW OF TECHNOLOGY PROGRAMMES AND RESEARCH INITIATIVES

The overall situation with respect to noise technology research initiatives worldwide is summarized in **Figure 1**. It covers a 15-year period (2001-2015), providing an evolutionary perspective from the time the original noise technology workshop took place in 2001.

The major initiatives (*e.g.* USA, EU, Japan) reviewed at the first workshop in 2001 have been sustained and generally expanded, while significant new efforts have been initiated over the years in Canada, the Russian Federation, and Brazil, representing what is now a true worldwide effort. A summary of each of these research programmes is provided in the following sections.

United States Noise Technology Research Programmes

In 2007, the U.S. National Science and Technology Council (NSTC) established a National Plan for Aeronautics Research and Development and Related Infrastructure, including Energy and Environment R&D Goals and Objectives. **Table 1** depicts the current U.S. noise technology research programme goals that have evolved from the National Plan, alongside other environmental goals.

The Continuous Lower Energy, Emissions, and Noise (CLEEN) Programme is the U.S. Federal Aviation Administration's (FAA) principal Next Generation Air Transportation System (NextGen) environmental effort that will develop and demonstrate new aircraft technologies and sustainable alternative jet fuels. In addition, CLEEN contributes to the development of operational procedures. That Programme focusses on maturing technology (Technology Readiness Level (TRL) 5-7) in support of the near term (<5 years) Environment and Energy R&D goals for noise, NO_x emissions, and fuel burn. Under CLEEN, the FAA forms partnerships with industry to cost-share technology maturation efforts.

The primary goals of the National Aeronautics and Space Administration's (NASA) Environmentally Responsible Aviation (ERA) Project are to: 1) explore and mature conventional and unconventional aircraft and propulsion system designs with the potential to simultaneously meet mid-term goals (5-10 years) for community noise, fuel burn and NO_x emissions; 2) determine the potential impact of these alternate aircraft designs and technologies if successfully implemented into the air transportation system (ATS); and 3) determine the potential impact of these technologies on advanced tube-and-wing designs if successfully implemented into the ATS. ERA will advance broadly applicable technology to TRL 5-6 by 2015 through the execution of eight technology demonstrator projects.

The NASA Fixed Wing (FW) Project (known prior to 2012 as the Subsonic Fixed Wing Project) explores and develops technologies and concepts for vastly improved energy

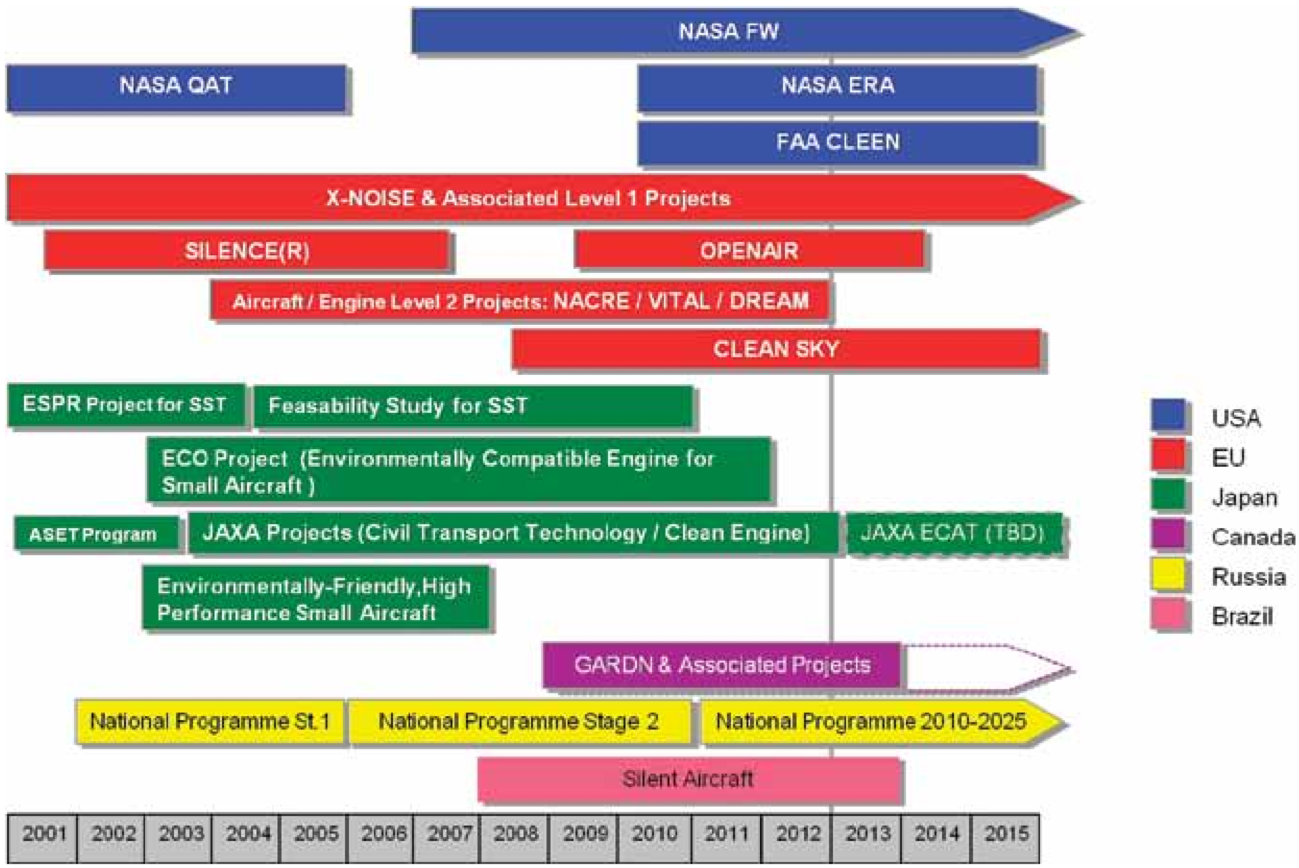


***Figure 1:** Committed Major National and Regional Initiatives as of the end of 2012.*

Corners of the Trade Space	N+1 (2015)* Technology Benefits Relative to a Single Aisle Reference Configuration	N+2 (2020)* Technology Benefits Relative to a Large Twin Aisle Reference Configuration	N+3 (2025)* Technology Benefits
Noise (cumulative below Stage 4)	-32 dB	-42 dB	-52 dB
LTO Nitrogen Oxide (NO_x) Emissions (below CAEP/6)	-60%	-75%	better than -75%
Performance Aircraft Fuel Burn	-33%	-50%**	better than -70%

* Technology Readiness Level for key technologies = 4-6
** Additional gains may be possible through operational improvements

***Table 1:** U.S. Noise Technology Research Programme Goals.*

efficiency and environmental compatibility of fixed wing, subsonic transport aircraft. FW research primarily focuses on the N+3 generation; that is, vehicles that are three generations beyond the current state of the art (*i.e.* "N"), and requiring mature technology solutions in the 2025-30 timeframe.

As shown in **Figure 2**, the scope of the U.S. aircraft noise research effort encompasses: airframe noise (flap, slat, trailing edges, and landing gear); propulsion noise (open rotors, geared turbofan, ultra high bypass, embedded engines, core and combustor); advanced tube and wing and novel configurations (shielding, scattering, propulsion-airframe interaction, and liners); as well as tools and methods (high-fidelity component prediction tools, acoustics modelling framework).

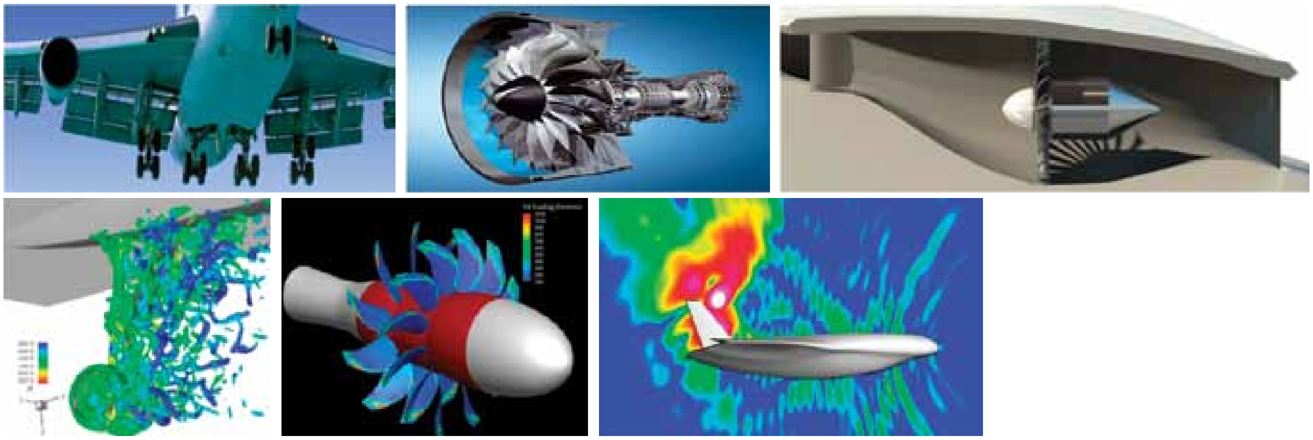


Figure 2: *Scope of U.S. Aircraft Noise Research.*

European Union Noise Technology Research Programmes

In 2002, the newly created Advisory Council for Aeronautics Research in Europe (ACARE) issued its first Strategic Research Agenda (SRA). The ACARE SRA established a general framework for European aviation-related research, including the definition of quantified targets for 2020. As part of the recommended strategy to address noise reduction, four main contributors were identified which would allow the achievement of the -10dB operation target, using a phased approach, as described in **Figure 3**. These four main contributors were:

- Generation 1 Noise Technologies: improved/novel passive noise reduction techniques.
- Noise Abatement Procedures: continuous descent approach and optimized take-off procedures.
- Novel Architectures: Advanced aircraft/engine concepts and optimized power plant installation.
- Generation 2 Noise Technologies: multidisciplinary aeroacoustic design, using active techniques.

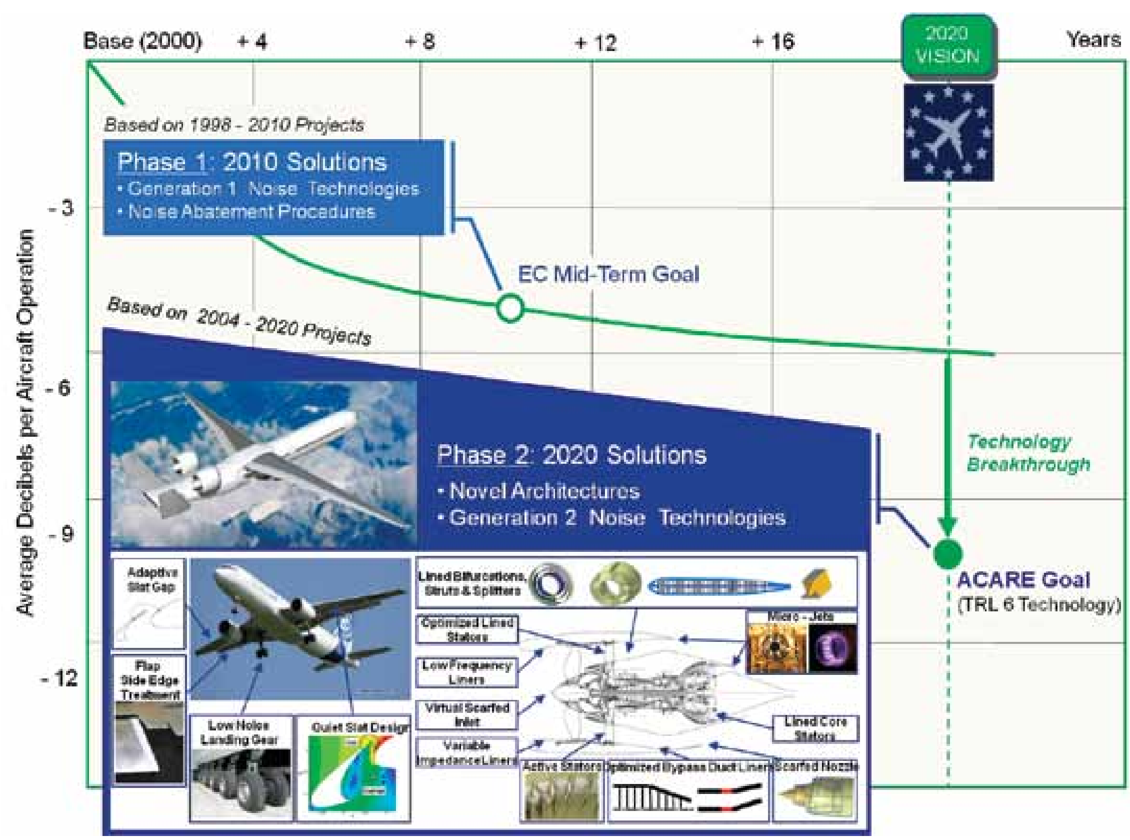


Figure 3: *Steps to ACARE 2020 Noise Target.*

In association with a coordination structure (X-NOISE network), this approach led to the effective implementation of a number of complementary projects that addressed turbo-machinery noise, exhaust noise, and airframe noise, all through advanced source modelling and development of technology solutions in relation with current and novel engine and airframe architectures. The Phase 1 effort was completed at the end of the SILENCE(R) project in 2007, demonstrating that with contribution from novel noise abatement procedures (investigated in parallel projects such as SOURDINE and OPTIMAL) the interim noise reduction goal would be met.

The Phase 2 effort has been subsequently initiated to achieve the technology breakthroughs needed for full achievement of the ACARE goals. Such breakthroughs encompass a wider range of areas including: aircraft and engine (low noise) architectures; individual component aeroacoustic design associated with low weight technologies; and innovative noise reduction techniques such as active/adaptive systems. Each of these provides technology building blocks along the multidisciplinary path that leads to aircraft designs optimized for minimal environmental impact. Initial investigations, carried out through the New Aircraft Concepts Research (NACRE) and Optimisation for low Environmental Noise impact (OPENAIR) projects in particular, have led to successfully improve the maturity of a number of such novel solutions. However, further significant efforts will be needed before 2020 in order to achieve the established noise reduction targets with a satisfying level of technology readiness across the board. More information can be found at www.xnoise.eu.

Japanese Noise Technology Research Programmes

Organization: Good cooperation has been achieved among government, industries, research institutes, and universities in Japan. On the government side, the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) has coordinated the domestic discussion on CAEP programmes. Research activities on noise technology have been supported by the New Energy and Industrial Technology Development Organization (NEDO), the Ministry of Economy, Trade and Industry (METI), and the Ministry of Education, Culture, Sports, Science and Technology (MEXT). The engine and airframe manufacturers which are involved in the worldwide aircraft and engine markets are engaged in continued research efforts to improve and advance technological quality. Research institutes including JAXA (Japan Aerospace eXploration Agency) have carried out a wide range of research programmes to meet industrial and academic needs.

Engine Noise: Noise-related projects on supersonic propulsion systems, HYPR and ESPR, resulted in reduced jet noise levels, as confirmed in engine noise tests. The successive projects by NEDO/METI focused on R&D related to subsonic engines and aircraft. The environmentally compatible engine (ECO) project aimed at a technology goal of reducing noise levels by -20 EPNdB cumulative margin to ICAO Annex 16, Chapter 4; together with a reduction in direct operating costs of 15%. JAXA has supported industry in its efforts to develop clean engine technologies designed to reduce NO_x, and CO_2 emissions, as well as reduction in noise levels. Computational Fluid Dynamics (CFD) tools and low noise designs have contributed to fan noise reduction. A notched nozzle has proven to be a promising simple device that will reduce jet noise.

Airframe Noise: Research activities related to airframe noise have been underway since 2003. Computational tools and wind-tunnel tests have been used to investigate noise reduction measures related to landing gear, slats, and flaps. In addition, acoustic diagnostic technology has been developed in flight tests using small jet aircraft. JAXA intends to use a phased-array microphone to pick up the unexpected noise sources that could not be detected in wind-tunnel tests. With respect to supersonic transport (SST), Japan leads the sonic boom study in cooperation with the US and the EU. As a flight demonstration of the low-boom design concepts, JAXA is promoting D-SEND (Drop test for Simplified Evaluation of Non-symmetrically Distributed sonic boom) that would contribute to establishing noise regulations for SST aircraft.

Figure 4 summarizes the scope of Japanese research and development (R&D) activities with respect to aircraft noise reduction efforts.

Canadian Technology Research Programmes

The Green Aviation Research and Development Network (GARDN) was jointly funded from 2008 to 2013 by Canadian aerospace manufacturers and the Government of Canada through the business-led Networks of Centres of Excellence programme. Recognized as important to the advancement of strategic technologies by the Canadian Aerospace Environmental Technology Roadmap and to the implementation of Industry Canada's Sustainable Development Strategy, GARDN was created to address the lack of support for mid-TRL research and development, specifically in the environmental area (see **Figure 5**).

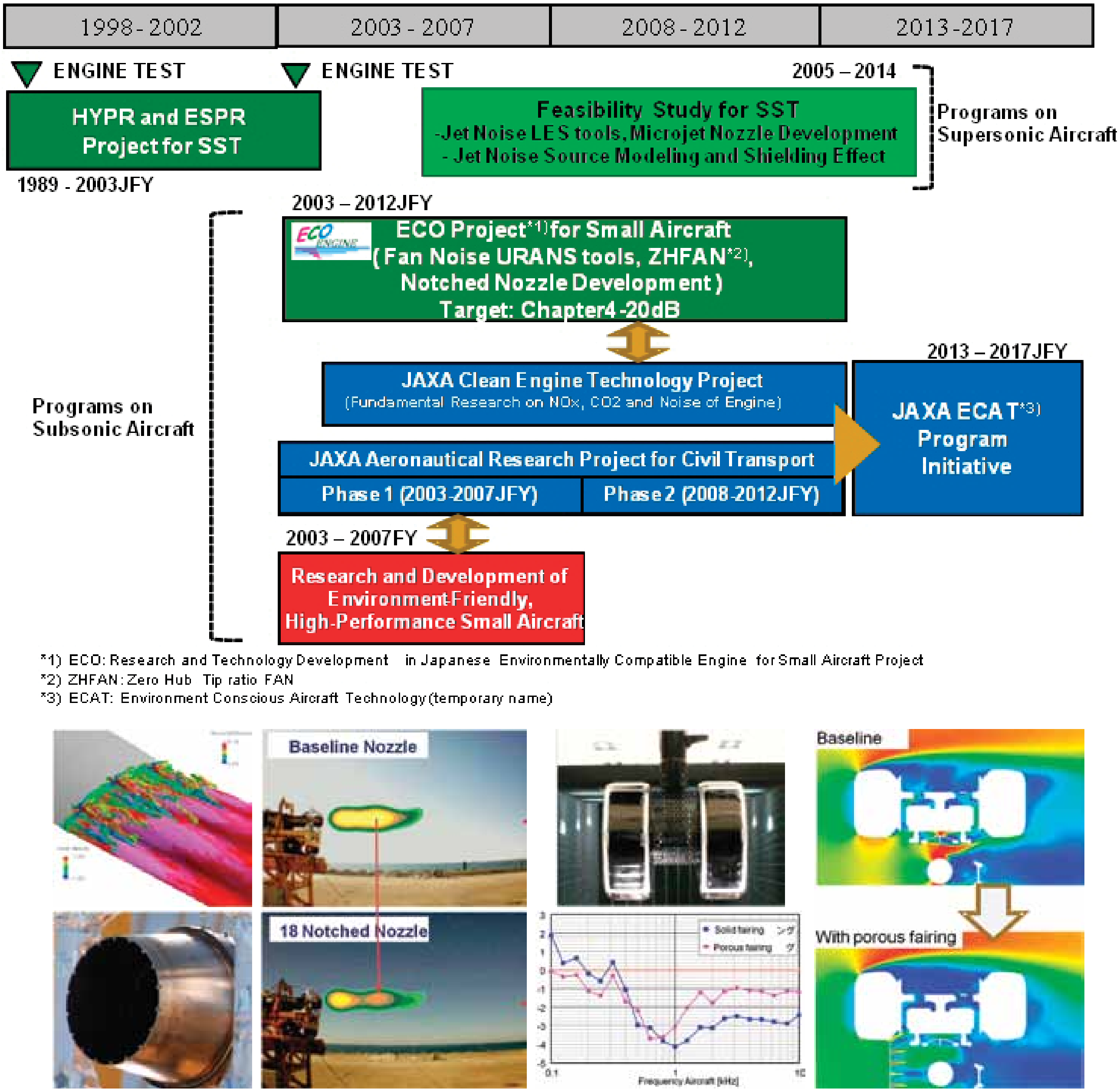


Figure 4: *Scope of Japanese R&D Activities Dedicated to Noise Reduction.*

Source noise reduction was one of the seven GARDN themes, and projects included:

- Forced Mixer & Nozzle Noise Reduction;
- High Speed Fan Noise Reduction;
- Airframe Noise Reduction; and
- Landing Gear Noise Diagnostics and Prediction.

These GARDN projects yielded higher technology readiness and set the foundation for strong and fluid collaboration among Canadian industry, universities and research establishments. Although continued funding for GARDN is under review, the intention is to focus on integrating technologies at a system level, yielding substantial innovation which will benefit the public by reducing noise and emissions well below current levels. More information can be found at www.gardn.org.

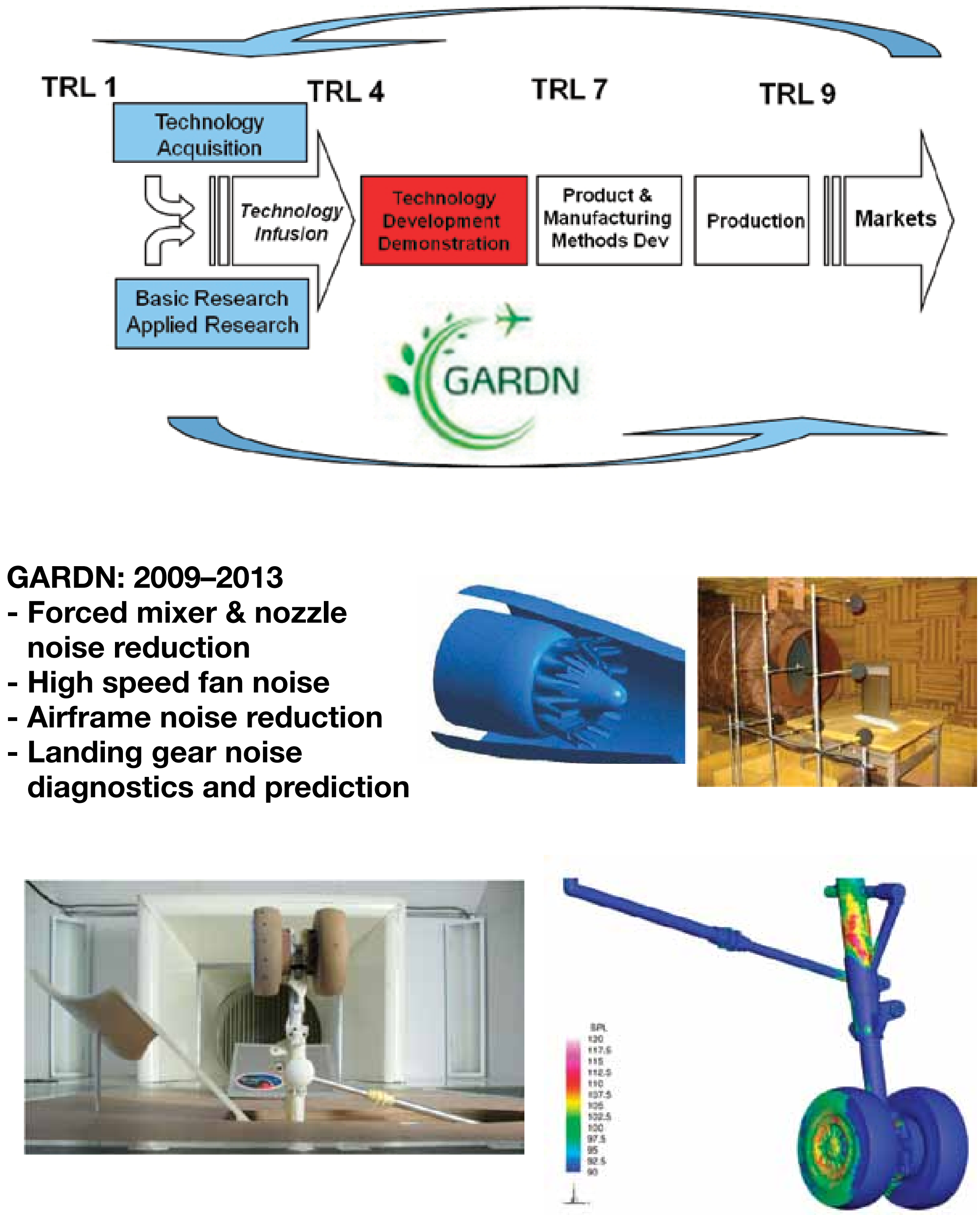


__Figure 5:__ Role of GARDN in Maturing Technologies and Scope of Noise Reduction Projects.

Russian Federation Technology Research Programmes

Under the Ministry of Industry and Trade of the Russian Federation, the Programme for Aviation Ecology (2012 – 2025) was developed by the Central Aerohydrodynamic Institute (TsAGI) in collaboration with the Central Institute of Aviation Motors (CIAM), Aviadvigatel, State Research Institute of Aviation (GosNIIGA), Sukhoy CAC, among others. This Programme is now under consideration by industry partners.

The main noise reduction targets are:

Community noise	**Cabin noise**
• 2015: – 15 EPNdB	• 2015: – 78 dBA
• 2020: – 20 EPNdB	• 2020: – 75 dBA
• 2025: – 30 EPNdB	• 2025: – 70 dBA

For the period 2013-2015, a number of direct contracts have been awarded by the Ministry of Industry and Trade of the Russian Federation (Minpromtorg) for technology research which covers the aeroacoustics field. These contracts are known as: “Aircraft 2020”, “Omega”, “Breathing”, and “Transport”, and are summarized below:

Aircraft 2020: Is a programme focused on the development of new aircraft design concepts, including flying wing, elliptic fuselage, and supersonic aircraft, all of which will aim to meet any new standards.

Omega: Is focused on the main technology problems of modern aircraft: jet noise, airframe noise, acoustic liners, installation effect, diffraction and refraction problems, inlet orifice mode transformation due to inflowing flow, and cabin noise sound absorption materials and construction.

Breathing: Concentrates on the development of engine noise reduction technologies at the source (e.g. fan, turbine, combustor, jet), as well as the development of advanced hush kits.

Transport: Focuses on the aerodynamic problems of subsonic and supersonic aircraft, including the estimation of acoustic screening effects by airframe design details.

There are also several programmes led by the Russian Federation aviation industry that are focused on improving the aeroacoustic characteristics of new generation Russian Federation aircraft, such as the MS-21 equipped with PD-14 engines.

Brazilian Technology Research Programmes

The Brazilian Silent Aircraft Programme (Programa “Aeronave Silenciosa”) is an initiative of six Brazilian universities and institutes: University of São Paulo – Polytechnic School (USP-Poli), University of São Paulo – Sao Carlos Engineering School (USP/EESC), Federal University of Santa Catarina

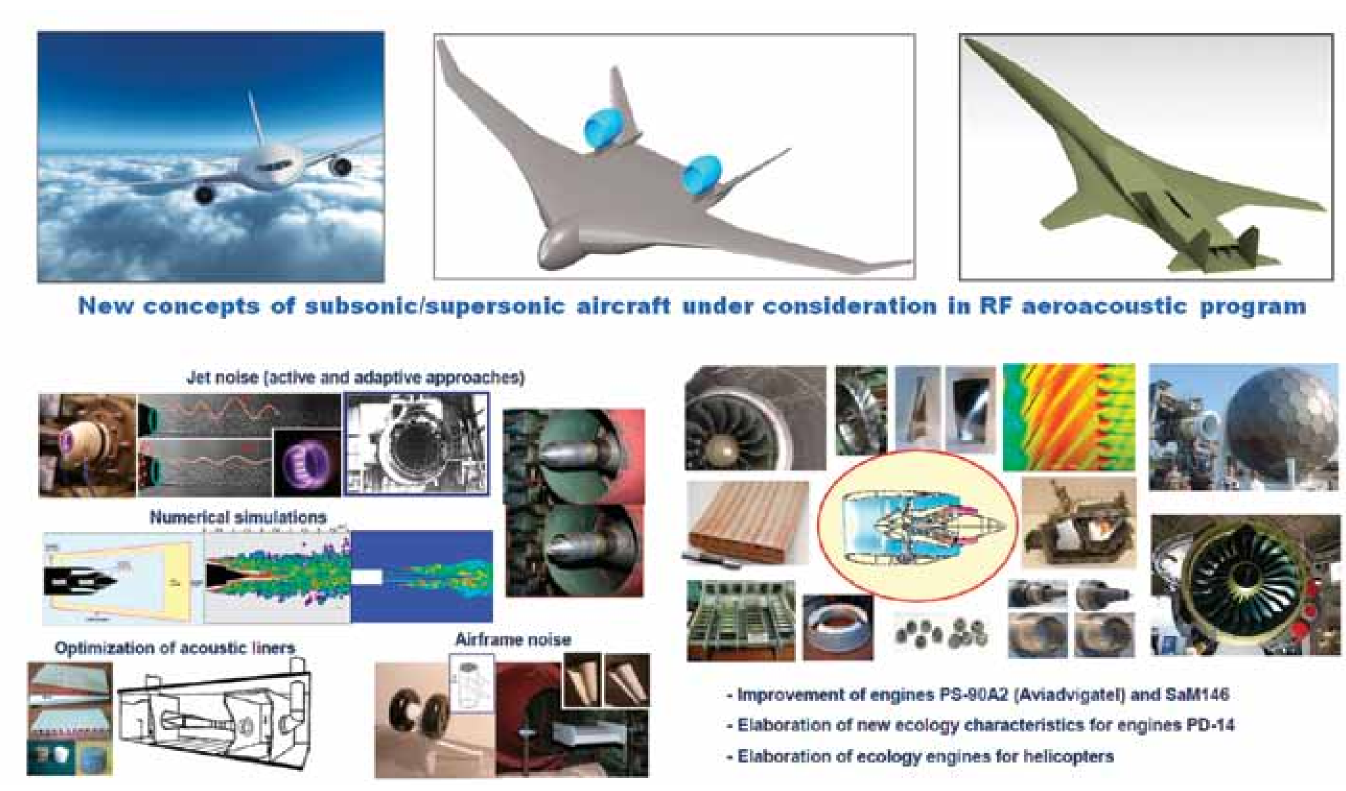


Figure 6: *Scope of Russian Federation Research Efforts Dedicated to Noise Reduction.*

(UFSC), Federal University of Uberlandia (UFU), University of Brasilia (UnB), and the Brazilian Institute of Aeronautics and Space (IAE). These institutions are working together with Embraer to develop methodologies and solutions for the aircraft external noise problem.

The main goal of this initiative is to study and develop methodologies that will facilitate the estimation of aircraft noise generation and propagation using three main approaches: 1) numerical simulation (CAA); 2) analytical and semi-empirical models; and 3) wind tunnel and flight tests. The intention has been to create a joint effort including Brazilian aerodynamic and acoustic researchers to explore and integrate the three approaches, opening up the possibility for a new technological level in this area in Brazil. This programme was launched in 2005 and will be finished by the end of 2015.

The Brazilian Silent Aircraft Programme was organized in two phases, the first one was completed by the end of 2011, and the second one started at the beginning of 2012. The main packages of the Programme are shown in **Figure 7**.

The first phase is based mainly on prediction methodologies and beamforming techniques. The main objective in this initial phase is to study existing and most-used methodologies for numerical analysis and experimental tests. The second phase will focus on the design and construction of test rigs in order to enable the acquisition of experimental data to develop and match complex numerical models and semi-empirical methodologies. The second phase will involve the design and assembly of a special wind tunnel, with low turbulence intensity, for aeroacoustic measurements. There will be one rig for jet noise measurements; one rig for fan noise measurements; and one rig for acoustic treatment measurements.

CONCLUSIONS

This overview of the worldwide aviation noise research situation demonstrates a significant commitment of all research stakeholders (*e.g.* manufacturers, research establishments, academia and government agencies) to investigate and develop novel technology solutions aimed at reducing noise at source. The research monitoring activities within CAEP/WG1, which now cover a 15-year period (2001-2015), provide an evolutionary perspective which confirms that while the major initiatives reviewed in 2001 (US, EU, Japan) have been sustained and generally expanded, significant new efforts have also been initiated over the years in Canada, the Russian Federation and Brazil as part of a true worldwide effort.

It should however be noted that, beyond stated research goals (which consider the availability of technologies at TRL6, or below), anticipated progress trends will be dependent on several success factors such as the capability to ensure viable industrial “TRL8” application for promising technology breakthroughs, as well as the commitment to maintain steady funding support over a significant period of time. ■

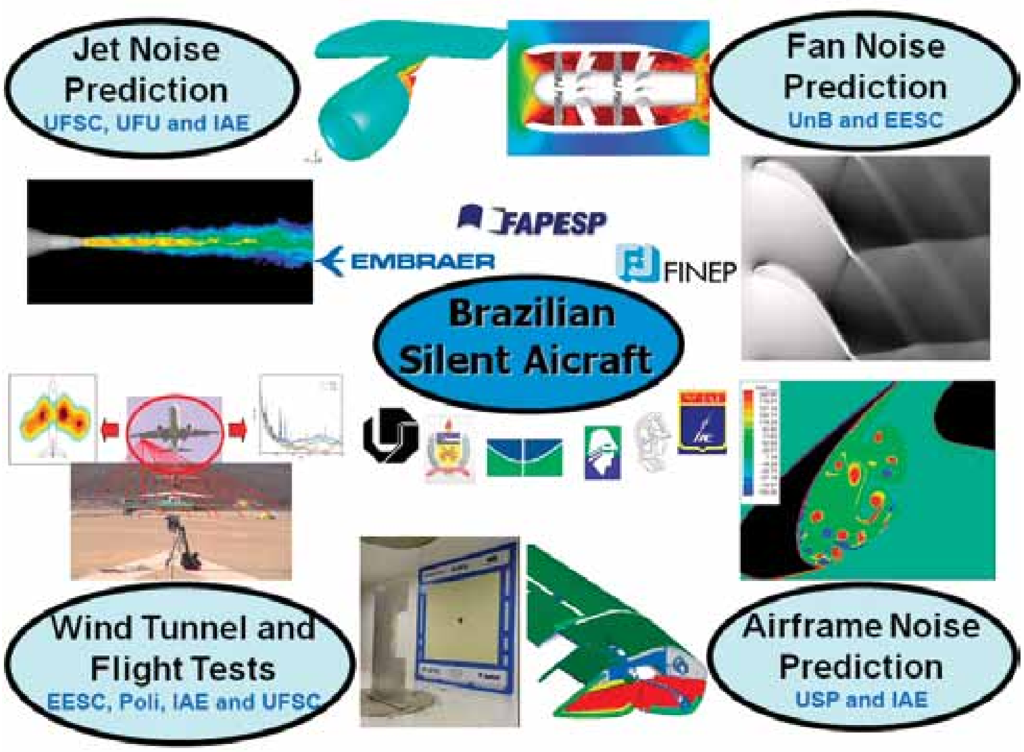


Figure 7: *Brazilian Silent Aircraft Program Framework Packages.*

ESTABLISHING NEW NOISE STANDARDS FOR CIVIL SUPERSONIC AIRCRAFT: STATUS REPORT

BY SANDY LIU, VICTOR SPARROW, AND YOSHIKAZU MAKINO

SANDY LIU

He is an AeroAcoustics Engineer in the Noise Division for the Federal Aviation Administration (FAA) – Office of Environment and Energy. He leads the development of technical noise certification policy, procedures and regulations that fosters environmental protection for the public. With 25-years of experience in government and the aviation industry, he's been actively involved in CAEP activities for over a decade in the development of international standards for commercial transport airplanes, helicopters and tiltrotors. He received his Master of Science (Mech. Eng.) degree from San Francisco State University, CA and his Bachelor of Science (Aerospace Eng.) degree from Syracuse University, NY. Currently, Mr. Liu is the Focal Point for ICAO's Working Group 1 – Noise, Supersonics Task Group (SSTG) formulating noise standards for civil supersonic airplanes.

VICTOR SPARROW

He has been a faculty member in the Pennsylvania State University Graduate Program in Acoustics since 1990. He has served as the Interim Head of the Graduate Program in Acoustics since 2010. He serves as a U.S. Research Focal Point for the ICAO Committee on Aviation Environmental Protection's Noise Working Group and Supersonic Task Group since 2005. His usual duties include research and teaching graduate level courses such as The Acoustics of Fluid Media, Nonlinear Acoustics, Computational Acoustics, Virtual Acoustics, and Outdoor Sound Propagation.

YOSHIKAZU MAKINO

He is a senior researcher at Institute of Aeronautical Technology, Japan Aerospace Exploration Agency (JAXA). He received his Dr. (Eng.) degree in aeronautics and astronautics from the University of Tokyo in 1998. His research topics are supersonic aircraft design including sonic-boom minimization and multidisciplinary design optimization. He has been appointed as a Research Focal Point (RFP) in ICAO CAEP since 2007.

In aviation, a number of companies continue to have interest in developing new, small supersonic jets for civilian use. In the United States, the National Aeronautics and Space Administration (NASA) supports the research and development of technologies that would enable such supersonic jets. Similarly, the Japan Aerospace Exploration Agency (JAXA) actively supports development of these technologies. It is a given that these types of "low-boom" aircraft will have to meet numerous constraints on engine pollutant emissions, subsonic terminal area noise, and marketable fuel efficiency. However, the most difficult environmental constraint to overcome is the noise heard at ground level during supersonic cruise flight, known as "sonic boom" noise.

This report is an update of the efforts by the International Civil Aviation Organization (ICAO) Committee on Aviation for Environmental Protection (CAEP) Working Group 1 (WG1) – Noise Technical Issues, on its development of future noise standards for supersonic aircraft within the scope of current policy[1]. The work is being conducted through the WG1 Supersonic Task Group (SSTG). The following section of this article provides some background on the nature of sonic boom noise, and the issues involved. That is followed by an overview of some of the recent technical findings in the SSTG that could inform future standards. The final section revisits the early guidance and expectations specified almost a decade ago on key steps for international noise certification acceptance. We review those key challenges in light of actual achievements, and reflect on the major activities that still remain to be accomplished during upcoming CAEP cycles.

BACKGROUND

A sonic boom is the sound heard on the ground whenever an aircraft is flying supersonically, *i.e.* faster than the speed of sound. At an altitude of 40,000 feet, that speed is about 300 m/s, or 934 ft/s or 670 mph. The only civilian aircraft to routinely fly supersonically was the, now retired, British-French Concorde airliner, developed in the 1960s and 70s (**Figure 1**). That aircraft was very successful in filling a niche demand to fly at high speed on transatlantic routes from 1976 to 2003. However, Concorde was expensive to fly and very loud at take-off. In addition, with ICAO resolutions dictating that no unacceptable situation for the public would be created by sonic boom from supersonic aircraft in commercial service[1], the large amplitude sonic boom of the Concorde led to it being restricted to subsonic flight

Figure 1: *Supersonic Civil Airplanes: Past (Concorde) and Future (Aerion and Gulfstream) Aircraft.*

over land, with supersonic flight only allowed over water. By today's standards, Concorde was relatively large and heavy, and since boom intensity is proportional to size, it represented the high end of the sonic boom range.

NASA continues its supersonics research initiatives to establish tools and techniques for use by commercial airframe manufacturers to design small to medium size supersonic aircraft with body shapes that will cause minimal sonic boom to be heard on the ground. The envisioned "low-boom" aircraft could potentially be acceptable to the majority of the public (although this is speculative), enabling anytime-anywhere operation of the new supersonic aircraft. The benefits of flying at Mach 1.6 to 1.8 (1.6 to 1.8 times the speed of sound) would enable coast-to-coast round trips in North America in a single day, allowing potential new markets.

SONIC BOOM PHENOMENON

Sonic booms can be thought to act similar to the wake of a boat traveling on a calm lake, except in three dimensions. As a listener waits for a supersonic aircraft to go by, the airplane first passes by, and then in a few seconds, the wake, called a sonic boom, eventually can be heard. At supersonic cruise, the aircraft might be at 12 to 15 km altitude (40,000 to 50,000 ft) to travel above the subsonic aircraft traffic. This cruise altitude means that the sonic boom will be heard over a plus or minus 40 km (25 mile) extent to the right or left of the aircraft flight path. Thus, while the aircraft is flying supersonically, it could be heard by anyone within an 80 km (50 mile) wide "carpet" spread on the ground during the flight (**Figure 2**) making avoidance of populated areas by aircraft manoeuvres difficult. So, the actual physics of sonic boom noise result in the exposure of many individuals even for a single flight. But in the 21st century, the new "low-boom" sonic booms may be much quieter, and might almost be missed if there is any background noise present.

There are several technical issues that need to be addressed before new supersonic cruise noise standards would be considered by ICAO in order to ensure that no unacceptable situations for the public are created by sonic boom. Certainly, the first issue is how loud will the new "low-boom" events be, and secondly, what is an appropriate metric to measure the noise. This will be discussed later in this article.

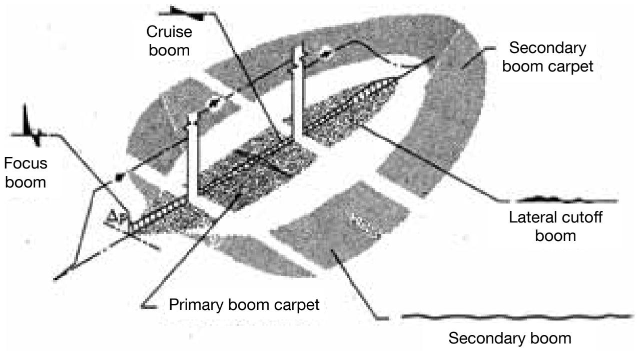


Figure 2: *Main Components of the Sonic Boom Carpet (from Maglieri and Plotkin, 1991).*

Another issue is how communities will react to this new sonic boom noise being introduced into their local environments. Most people associate aircraft noise with the noise in and around airports, or they might hear faint aircraft noise while airplanes are at high altitude. But how will a community react to the new “low-boom” sonic boom noise being added to their daily lives? Although the envisioned new supersonic aircraft will be much quieter, most of the improvement will be in the reduction of the high frequency components of the noise. It is likely that substantial low-frequency components of the sonic boom noise will be retained, as this is the hardest part to minimize. So although the human ear may not perceive the new “low-boom” sonic boom sounds directly, people may hear (or otherwise perceive) secondary sounds such as rattling of windows or pictures on the wall due to the low-frequency vibration in their dwellings caused by the sonic boom noise.

An additional issue is the phenomenon of focused sonic booms. As a supersonic aircraft accelerates up to cruise speed, it will transition from subsonic fight to supersonic flight. At the time that the aircraft reaches Mach 1, the rays of sound emanating from the aircraft cross each other, and a louder than normal sonic boom, called a focus boom, is created. This focal region of 100 to 200 m (300 to 600 ft) thick, and a few kilometers wide is quite small in extent compared to the 80 km (50 mile) wide sonic boom carpet created during cruise. However, the focus boom region is not minimized like the cruise signature, and hence is the loudest event during a supersonic flight. Studying the focus boom is important when trying to assess what an individual on the ground might hear.

The next section addresses the current work by the SSTG to account for these and other issues associated with potential supersonic aircraft in the future.

RECENT WORK IN SSTG

SSTG began its activities in 2004 as part of the CAEP/7 cycle. The major work items of the SSTG call for monitoring various aspects of Super Sonic Transport (SST) projects including: assessing their prospects for operation, monitoring research to characterize, quantify and measure sonic boom signatures and their acceptability, and continuing to work on noise certification standards for supersonic aircraft. Throughout the CAEP cycles since 2004, the SSTG has defined and tracked progress of supporting research on a notional supersonics R&D roadmap in order to advise on potential sonic boom standards development (**Figure 3**).

Initially, that R&D roadmap identified that a metric should be defined which is appropriate for both outdoor and indoor sonic boom response. Since the subjective test results of NASA’s flight tests in 2006[2] showed that the sonic boom noise felt indoors might be more annoying than that heard outdoors, NASA built a new Indoor Effects Room (IER) where a typical room of a house is exposed to synthesized sonic booms. The subjective testing in the IER indicates that the Perceived Level (PL) metric continues to show a good dose-response relationship[3] for indoor boom as well as outdoor boom. The subjective testing in JAXA’s sonic boom simulator booth shows similar results as the IER, that PL has a high correlation with the subjectively evaluated loudness as well as A- and E-weighted sound exposure levels (where A-weighted represents people’s subjective assessment of loudness and E-weighed represents perceived levels). For the CAEP/10 cycle, SSTG will begin to consider an appropriate metric based on published research.

Second, the roadmap outlines that community exposure tests are necessary for standards development. Although a community response study was conducted in Oklahoma City, U.S.A. in 1965 for conventional “large” sonic boom noise, the roadmap suggested that community exposure tests of “low-boom” sonic boom noise should be conducted with a demonstrator designed to generate a “low-boom” sonic boom signature. As a pilot test for future community exposure and response testing but using a “surrogate” aircraft, NASA conducted a community response study named WSPR (Waveforms & Sonic boom Perception and Response) in the base housing areas at Edward's Air Force Base[4]. The low-boom “surrogate” airplane was derived using a conventional military aircraft capable of generating the low-overpressure N-waves while flying a very special dive manoeuvre. One important contribution of this study was that it demonstrated the capability to assess the community response to future flight studies with a research aircraft.

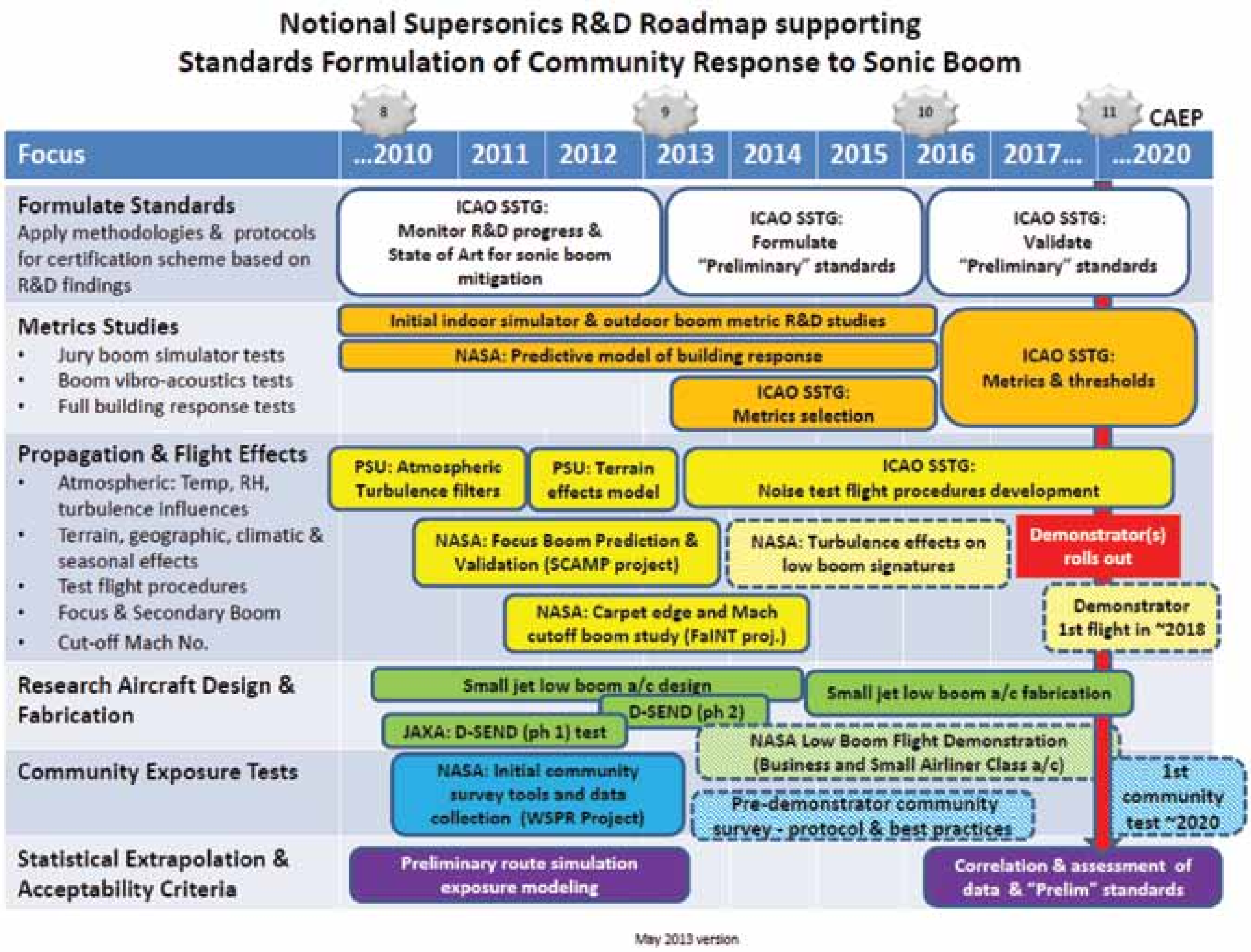


Figure 3: *Notional Research Roadmap for Future Supersonic Cruise Noise Standards.*

The R&D roadmap also suggests several important research topics including the effects of the atmospheric conditions and flight operations on sonic boom signatures. As the sonic boom propagates over long distances, it is significantly influenced by the local atmospheric state. The atmospheric effects include: geographical climatic variations, seasonal or daily meteorological variations, and variations associated with atmospheric turbulence. Concerns about the sensitivity of the sonic boom in different climates, led to a prediction study by Gulfstream to investigate the effects of low-boom signals on the ground as a function of global climates. The simulation predicted a climatic variability with more sensitivity with seasons at high latitudes. In studying the effects of flight operations, a flight test named Superboom Caustic Analysis and Measurement Programme (SCAMP) was conducted by NASA in 2011 to validate several prediction tools for sonic boom focusing. Another flight test named Far-field Investigation of No boom Thresholds (FaINT) was recently conducted in 2012[5] to investigate weakened, scarcely perceptible (boom) waves generated during the "Mach cut-off" flight (when atmospheric conditions lead to diminished boom strength at surface) even though the airplane is operating at a supersonic speed of about Mach 1.2 or less at high altitude. The resulting data will be utilized for a better understanding of the "boom less" flights. JAXA's flight test programme called D-SEND (Drop test for Simplified Evaluation of Non-symmetrically Distributed sonic boom) continues to demonstrate advanced low-boom design concepts, and it captured measured signatures.

THE FUTURE

As there has been an industry commitment to pursue small supersonic jets as the next technological "stepping-stone" in an overall new strategy for advancing civil supersonic aeronautics and global transport, we must remember that this "new" strategy for any supersonic aircraft must be developed in concert with today's stringent environmental requirements.

The aircraft industry recognizes that dealing with sonic boom is critical and is therefore working within ICAO to track scientific progress as it advances. Carefully tailoring an airplane's size and shape, and incorporating advanced systems realized since the Concorde era, has identified reductions in the sonic boom signature for future supersonic aircraft designs. Data tells us that the potential for lowering sonic boom levels by decreasing airplane size and weight exists; further reductions continue with the overall tailoring of the configuration design for low boom when analytically modelled. But, there are still several key challenges before successfully commercializing supersonic aircraft in the future.

First, and foremost, is to tailor a design that is environmentally acceptable, but designed to as yet undefined sonic boom requirements. Second, the aviation industry must define and successfully demonstrate the critical technologies. Third, the industry must prove, with a flight demonstrator, that sonic boom suppression technology is adequate. The latter implies substantial research to define "acceptable" sonic boom. Lastly, and equally important, the international community of aviation regulatory authorities must collaborate to define certification and operational standards for supersonic operations with acceptable low sonic boom.

With this understanding, and after almost a decade since the formation of ICAO's SSTG under CAEP WG1, the scientific progress on supersonics research has sufficiently progressed in sonic boom mitigation that the industry is preparing to build a demonstrator aircraft, thus stepping up to the third key challenge. As for the first and second key challenges, new designs have been studied and economic estimates made that still support positive customer demand. So as a demonstrator takes shape, the SSTG is continuing to work on noise certification standards for supersonic aircraft. Of course, such preliminary standards developed ahead of true aircraft will continue to evolve and rely on demonstrator flight data for validation and to test procedural implementation. Current scientific knowledge will shape the standards and the demonstrator flights will be the proof as to whether the standards are appropriate for meeting public acceptability.

In summary, the future for supersonic aircraft continues to advance. The key challenge will not only be in defining the complex technologies that will integrate and define a low boom supersonic airplane, but also the tremendous challenge of shaping an environmental protection scheme that will invoke comprehensive and robust noise certification standards, supported by demonstrator data, that regulates and controls the noise and sonic boom sounds to offer public acceptability. The research community continues to conduct ongoing studies to inform regulators and to minimize the future potential environmental impacts of supersonic transport on the public. ■

REFERENCES

1 International Civil Aviation Organization. Doc 9958, *Assembly Resolutions in Force* (as of 8 October 2010), A37-18: *Consolidated statement of continuing ICAO policies and practices related to environmental protection – General provisions, noise and local air quality*, Appendix G, 2011.

2 B.M.Sullivan, et al., "Human Response to Low-Intensity Sonic Booms Heard Indoors and Outdoors", NASA TM-2010-216685, 2010.

3 A dose-response relationship describes how the likelihood and severity of adverse effects (the responses) are related to the amount and condition of exposure to noise (the dose provided).

4 "Waveforms and Sonic boom Perception and Response (WSPR) Project, the National Aeronautics and Space Administration's pilot program for sonic boom community response research," Acoustical Society of America Conference, Montréal, Québec, Canada – June, 4, 2013.

5 www.nasa.gov/centers/dryden/news/X-Press/studying_faint_sound.html

CHAPTER 3

LOCAL AIR QUALITY

OVERVIEW

LOCAL AIR QUALITY

BY ICAO SECRETARIAT

INTRODUCTION

For many years, ICAO has been developing measures to reduce the impact of aircraft emissions on Local Air Quality (LAQ). In particular, the ICAO Committee on Aviation Environmental Protection (CAEP) and its predecessor, the Committee on Aircraft Engine Emissions, have, since the late 1970s, continually developed emissions Standards for new engine types, their derivatives, and new production engines. One of the principal results arising from the work of these groups is the development of the ICAO Standards and Recommended Practices (SARPs) on engine emissions contained in Volume II of Annex 16 to the *Convention on International Civil Aviation* (the "*Chicago Convention*")[1] and related guidance material and technical documentation. These SARPs aim to address potential adverse effects of air pollutants on LAQ, primarily pertaining to human health and welfare. Among other issues, these provisions address: liquid fuel venting, smoke, and the main gaseous exhaust emissions from jet engines, namely; hydrocarbons (HC), oxides of nitrogen (NO_x), and carbon monoxide (CO). Specifically, the Annex 16 engine emissions Standards set limits on the amounts of gaseous emissions and smoke allowable in the exhaust of most civil aircraft engine types.

Over the past three years work has been conducted by CAEP to ensure the validity of the technical basis underpinning the ICAO SARPs associated with reducing the impact of civil aviation on LAQ. This work has included, inter alia: development of a non-volatile Particulate Matter (nvPM) Standard, a NO_x technology review, and the publication of aircraft local air quality guidance material. This chapter of the environmental report provides more details on each of the aforementioned topics.

ICAO ENGINE EMISSION STANDARDS

Concerns about local air quality in the vicinity of airports focus on the effects of aircraft engine emissions released below 3,000 feet (915 metres) and emissions from airport sources, such as airport traffic, ground service equipment, and de-icing operations. The current ICAO Standards for emissions certification of aircraft engines (contained in Annex 16, Volume II) state that to achieve certification, it must be demonstrated that the characteristic emissions of the engine type for HC, CO, NO_x and smoke are below the

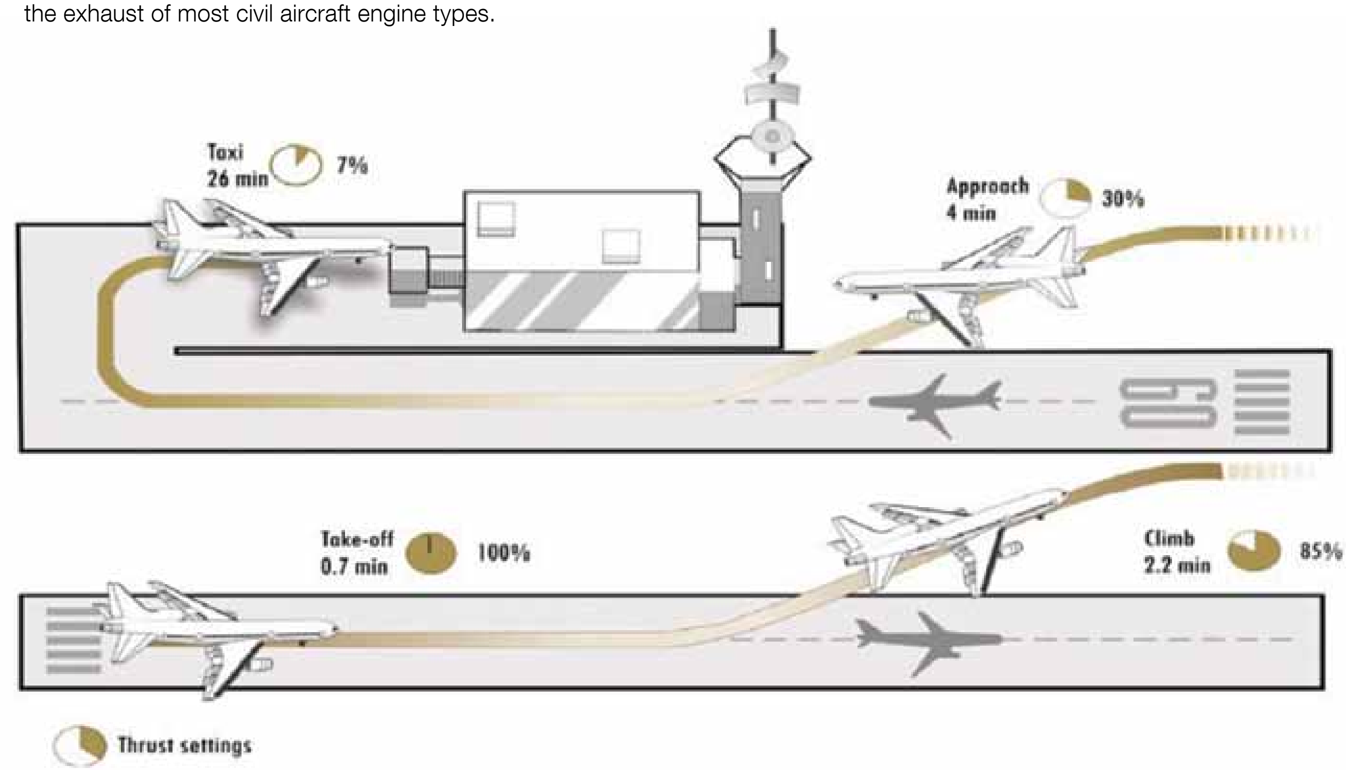


Figure 1: *Illustration of ICAO Emissions Certification Procedure in the LTO Cycle.*

limits defined by ICAO. The certification process is based on the Landing Take-off (LTO) cycle, shown in **Figure 1**, which is representative of the emissions emitted in the vicinity of airports. The LTO cycle contains four modes of operation, which involve a thrust setting and a time-in mode. These are as follows:

- Take-off: (100% available thrust) for 0.7 minutes;
- Climb: (85% available thrust) for 2.2 minutes;
- Approach: (30% available thrust) for 4.0 minutes;
- Taxi: (7% available thrust) for 26 minutes.

The engine certification process itself is performed on a test bed where the engine is run at each thrust setting in order to generate the data for each of the modes of operation. The result of the engine emissions certification test includes: fuel flow (kg/s), emissions index for each gaseous pollutant (g/kg), and the measured smoke number. This allows for the calculation of four data values: 1) emission rate (*i.e.* emission index × fuel flow (g/s)) for each gaseous pollutant, 2) total gross emission of each gaseous pollutant measured over the LTO cycle (g), 3) values of *Dp/Foo* for each gaseous pollutant (g/kn)[2], and, 4) maximum Smoke Number. The submission of these data are mandated as part of the engine emissions certification. All of these data are stored in the publically available ICAO emissions databank[3].

NO_x STANDARDS AND TECHNOLOGY

While Standards have been developed for HC, CO and smoke, and a significant effort is currently underway to develop a PM Standard, much of the focus of international efforts have been on the reduction of NO_x. The Standard for NO_x was first adopted in 1981, and then made more stringent based on the recommendations of four CAEP meetings in 1993 at the second meeting of CAEP (CAEP/2), 1999 (CAEP/4), 2005 (CAEP/6) and 2011 (CAEP/8). The latest NO_x Standard improves on the previous (CAEP/6) Standard by 5% to 15% for small engines, and by 15% for large engines and has an applicability date of 1 January 2014. In addition, in 2011 a NO_x production cut-off requirement was adopted stating that individual engines produced on or after 1 January 2013 have to comply with the previous 2005 (CAEP/6) NO_x Standard. Together, these two measures will help to ensure that the most efficient NO_x reduction technologies are being employed in the production of aircraft engines.

The setting of standards is closely linked to the research and development of technology. Technological innovations in aviation continue to lead the way towards effective and efficient measures in support of ICAO's environmental goals of limiting or reducing the impact of aircraft emissions on LAQ. To complement the standard-setting process, CAEP developed, with the assistance of a panel of independent experts, medium- and long-term NO_x technology goals (10 and 20 years, respectively). While CAEP did not conduct a NO_x technology review over the past three years (the most recent IE review was published in 2010), an industry-led NO_x technology review was performed and presented to CAEP (see article *Industry led NO_x Emissions Technology Review*, Chapter 3 in this report).

DEVELOPING A NEW STANDARD FOR PARTICULATE MATTER

Aircraft engines emit both nvPM (*i.e.* soot) and gases that condense to form volatile PM. Condensable gases can both form new particles and coat the emitted soot particles. Organic volatile PM species dominate total aviation particle number at idle powers while soot particle numbers become as important at take-off powers where soot also dominates the mass emissions. Sulphur-related condensable emissions are important in nucleating new particles with typical fuel sulphur levels in jet fuel. Despite smaller mass emissions from newer technology engines, the local and regional health implications of directly emitted and secondarily-formed PM requires quantification and assessment. Quantification of emitted PM number concentrations may also be important for health characterisation, related to elevated exposures in close proximity to aircraft operations[4]. In order to limit or reduce the impact of aircraft engine nvPM emissions on both local air quality and global climate, ICAO is developing an nvPM Standard. Crucial to this work is the development of a standardised measurement methodology to quantify nvPM emissions, and this is currently under development by the SAE E-31 Committee[5] in coordination with CAEP. This measurement methodology is the reference used for all testing towards establishing the first ICAO nvPM Standard, and will likely form the technical basis of the Annex 16, Volume II nvPM certification requirement (see article *Development of a Particulate Matter Standard for Aircraft Gas Turbine Engines*, Chapter 3 in this report).

GUIDANCE ON AIRPORT AIR QUALITY

One of ICAO's objectives is to develop harmonised best practices related to civil aviation. In keeping with this objective, CAEP has developed and updated guidance on how to implement best practices with respect to local air quality at airports. This work resulted in the publication in 2011 of the *ICAO Airport Air Quality Manual* (Doc 9889), which includes chapters on the regulatory framework and drivers for local air quality measures, emissions inventory, emissions temporal and spatial distribution, dispersion modelling, airport measurements, mitigation options, and interrelationships associated with methods for mitigating environmental impacts (see article *The ICAO Airport Air Quality Manual*, Chapter 3 in this report).

FUTURE ICAO WORK

ICAO continues to develop measures aimed at mitigating the impact of aviation on air quality in the vicinity of airports (*i.e.* LAQ). The core of this objective is to keep international standards, guidance material, and technical documentation up-to-date and appropriate for the needs of the international community, including the maintenance of Annex 16, the environmental technical manuals, and the ICAO emissions databank. The CAEP has a large workload during its tenth triennial cycle (CAEP/10) and LAQ work focusses on PM, which will see progress made on the development of a nvPM emissions certification requirement and a new Standard. Advancing the understanding of volatile PM formation will also be pursued. CAEP will also continue to monitor and review technology developments, including combustion technologies and advances in engine combustor design, with a view to understanding how these technologies may impact the production of gaseous emissions and particulate matter. ■

REFERENCES

1 *Convention on International Civil Aviation* (also known as *Chicago Convention*), Doc 7300, ICAO.

2 *Dp /Foo* relates to the mass of any gaseous pollutant emitted during the LTO cycle (*Dp*) divided by the rated engine thrust (*Foo*).

3 ICAO Engine Emissions Databank, www.icao.int/environmental-protection/Pages/environment-publications.aspx

4 Based on the work of Miake-Lye R. C., Baughcum S. L., Levy J. I., Hileman J. I. on Aircraft PM Emissions: State of the Science. Presented by the CAEP Impacts and Science Group to the CAEP/9 meeting, February 2013.

5 SAE – E-31. Under the SAE Aerospace Council sits a set of Aerospace Propulsion Systems Group Commitees. One of these is the E-31 on Aircraft Exhaust Emissions Measurement.

DEVELOPMENT OF A PARTICULATE MATTER STANDARD FOR AIRCRAFT GAS TURBINE ENGINES

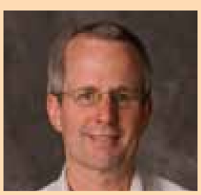
BY THEO RINDLISBACHER, S. DANIEL JACOB AND RICK MIAKE-LYE

THEO RINDLISBACHER

He serves as an advisor on environmental subjects and expert for aircraft environmental certification for the Swiss Federal Office of Civil Aviation (FOCA). He started his career as a school teacher and graduated as a physicist for atmospheric science and environmental remote sensing. He also holds a commercial pilots licence. After joining FOCA in 2002, he became CAEP WG3 member for Switzerland. In 2011 he engineered and built the prototype aircraft engine PM measurement system at the SR Technics facility in Zurich, Switzerland. He is currently co-leading the Particulate Matter Task Group of CAEP WG3.

S. DANIEL JACOB

He co-leads the Particulate Matter Task Group of the CAEP WG3. He is a Physical Scientist and Program Manager at the U.S. Federal Aviation Administration Office of Environment and Energy. His educational background includes engineering, earth system modeling and observing system development. His research was focused on understanding the physical aspects of weather and climate. In his capacity as Program Manager at the FAA, he oversees projects that investigate air quality and climate impacts of aviation. He also manages the development of operational benefits-costs analyses tools that incorporate state-of-the-art science to inform policy and decision making.



RICK MIAKE-LYE

He is a Vice President, Principal Scientist, and director of the Center for AeroThermodynamics at Aerodyne Research, Inc. His work in this area started with NASA's Atmospheric Effects of Aviation Project and was recognized for contributions leading to the IPCC's 2007 Nobel Peace Prize. He was a member of the EPA 2007 Climate Protection Award team that quantified PM emissions from the JSF engine. He is active now and has been the Chair of SAE's E-31 committee, and currently serves ICAO on the Impacts and Science Group (ISG), and as a lead of PMTG's METRICS ad hoc group.

INTRODUCTION

Aircraft engines burning hydrocarbon-based fuels emit gaseous and particulate matter (PM) emissions as by-products of combustion. At the engine exhaust, particulate emissions mainly consist of ultrafine soot or black carbon emissions. Such particles are called “non-volatile” PM (nvPM). They are present at the high temperatures at the engine exhaust and they do not change in non-volatile mass or number as they mix and dilute in the exhaust plume behind an aircraft.

Compared to traditional diesel engines, gas turbine engine non-volatile particles are typically smaller in size. Their geometric mean diameter ranges roughly from 15 nanometres (nm) to 60nm (0.06 micrometres; 10nm = 1/100,000 of a millimetre), including from older commercial and military engines. Additionally, engine emitted gases can also condense to produce new particles (*i.e.* volatile particulate matter – vPM), or coat the emitted soot particles. Other gaseous species react chemically with ambient chemical constituents in the atmosphere to produce secondary particulate matter.

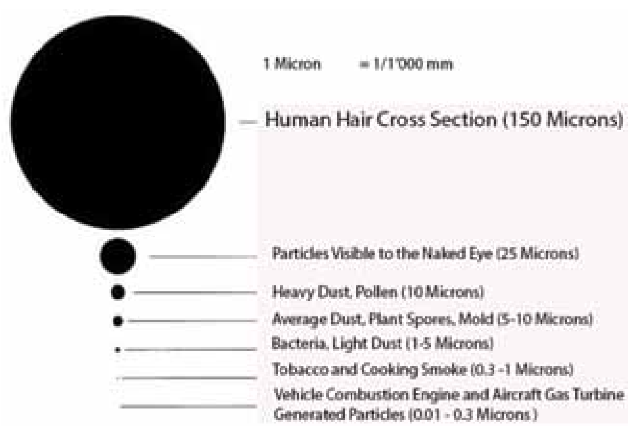


Figure 1: *Relative Size of Aircraft nvPM in Comparison to Other Material.*

Epidemiological evidence indicates that these fine particles produced by various emission sources contribute to premature mortality and other health effects by degrading local air quality. Ultrafine soot particles have been shown to be able to penetrate deep into the lung and cells of the human body, causing adverse health effects. Soot or black carbon particles have also been shown to have climate impacts due to the high absorption of radiation from the sun leading to local heating and warming.

The automotive vehicle sector as one of the major sources of nvPM emissions, has been regulating particulate matter emissions for a long time, with tremendous success in nvPM reduction while the aviation sector is still lacking such regulation. Since the 1970s, aircraft gas turbine engine certification has required the measurement of a Smoke Number. This measurement was a response to visible smoke trails left by aircraft engines built in the 1960s and earlier, and the result has been that current engine designs no longer leave a visible smoke trail on take-off. So the Smoke Number measurement requirement has had the desired goal of a less visible exhaust and has probably resulted in lower PM mass emissions. The Smoke Number measurements have been correlated to nvPM mass emissions from various aircraft engines to quantify nvPM emissions inventory contributions within the vicinity of airports. However they do not provide a useful metric for measuring the mass and number of ultrafine PM emissions from current engines, nor for continuing to reduce the ultrafine PM emissions from future aircraft engines.

While aviation's contribution to inventories of ultrafine particles likely remains small in comparison to other emission sources, environmentally responsible aviation growth not only necessitates an understanding of the health and climate impacts from aircraft particle emissions, but also a thorough quantification and reduction through ICAO's standards-setting process. The development of the aircraft engine PM standard is following two of ICAO's environmental goals, to develop, adopt and promote new measures to limit or reduce the impact of aircraft engine emissions on local air quality and limit the impact of aviation on the global climate.

This article outlines the efforts of the ICAO Committee on Aviation Environmental Protection (CAEP) to develop a non-volatile particulate emissions standard.

A MILESTONE: DEVELOPMENT OF A nvPM MEASUREMENT SYSTEM METHODOLOGY

Standardization is an important task for ICAO and it is even more critical for the technically demanding measurement of ultrafine particles from aircraft engines. The first step towards developing an nvPM standard is therefore finding a common measurement system and methodology. Development of the measurement methodology was delegated to the SAE International Aircraft Exhaust Emissions Measurement Committee (SAE E-31), comprised of individuals with expertise in aircraft emission measurements and particulate matter science. In April 2011, the first prototype PM measurement system permanently installed in an aircraft engine test cell was established in Switzerland, using the engine maintenance runs to conduct system calibration and measurement performance tests.

Results from seven test campaigns involving international collaborations led to a major breakthrough for the SAE E-31 Committee by: defining the extractive sampling process, providing methodology for determining sampling train particle size penetration, making measurements of nvPM

Figure 2: *Engine in Test Cell with Sampling Probe Behind (Red Bar), SR Technics Zurich, Switzerland.*

mass and number at the end of the sampling train, defining instru-mentation specification, and developing calibration procedures as well as a procedure for reporting the data as emission indices. The document called Aerospace Information Report (AIR 6241) is currently being prepared for publication. It contains sufficient information for engine manufacturers to begin purchasing the capital equipment needed to start the measurement activity at their own engine test cell sites with confidence. The AIR 6241 is the reference for all testing towards establishing the first nvPM standard, and is likely to be the basis for the methodology text to be included in ICAO Annex 16, Volume II – *Aircraft Engine Emissions*.

The nvPM sampling system (as shown in **Figure 4**) splits from the existing gaseous and smoke measurement sampling line at a maximum distance of 8 metres from the sampling probe tip. The exhaust sample is diluted and at the same time cooled to 60°C before it is pumped at a high flow rate through a standardized

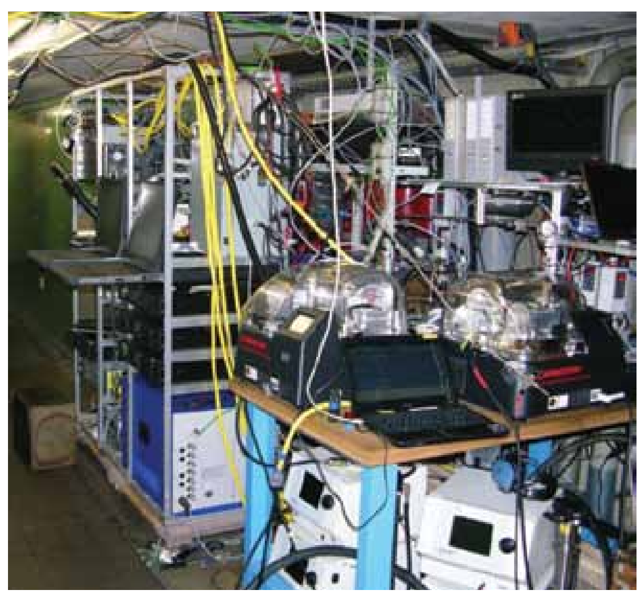


Figure 3: *Aviation Particle Regulatory Instrumentation Demonstration Experiments, A-PRIDE 4, November 2012, SR Technics Zurich, Switzerland.*

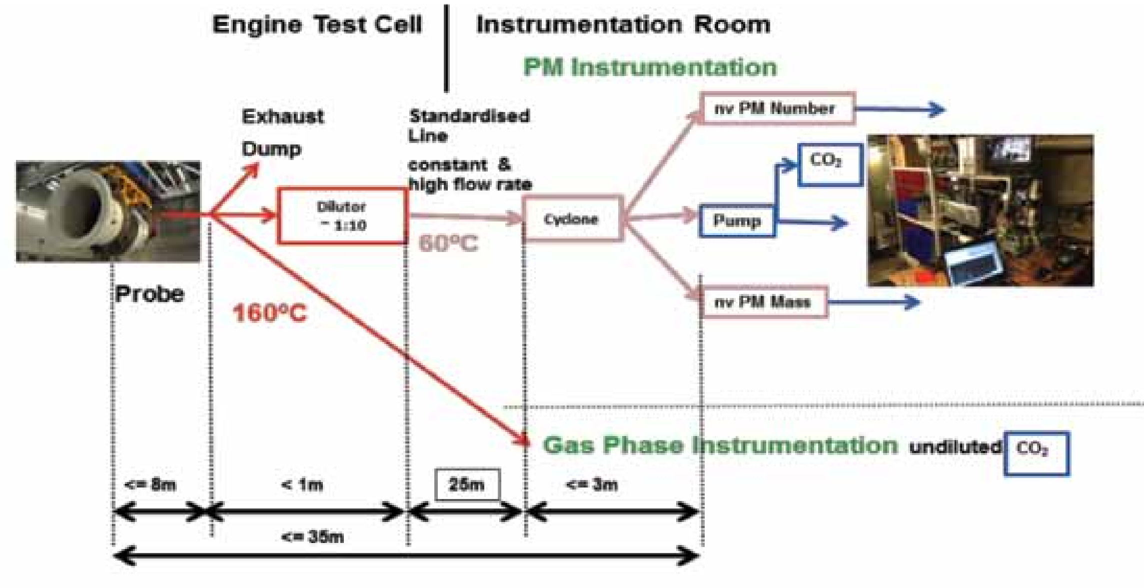


Figure 4: *The Standardized Non-volatile PM Measurement System.*

25m long line to the instruments, making sure it fits the required dimensions of the largest engines and test cells in the world. In front of the instruments, there is a cyclone, removing larger particles that can build up in the sampling system that are not originating from the engine. The instruments measure nvPM mass and number concentrations. For particle number, the whole size range of emitted nvPM is counted. From sampling probe tip to the instrument inlet, the sampling system line length must not exceed 35m. Measurements are normalized by CO_2, resulting in nvPM mass and number emissions per kg of fuel as a function of engine thrust. The standardized system and instrumentation is characterized for particle losses and the measurements can be loss corrected, if necessary.

ICAO/ CAEP10 ACTIVITIES TOWARDS A PM STANDARD

Following the announcement of AIR 6241 finalization, the ninth meeting of CAEP (CAEP/9), held in February 2013, made important decisions regarding the introduction of a first nvPM standard by 2016:

- Develop an aircraft engine based non-volatile PM mass and number metric and methodology for application as a non-volatile PM mass and number emissions certification requirement for turbofan/turbojet engines >26.7 kN with input from SAE-International E-31 Committee.
- Develop an aircraft engine based non-volatile PM mass and number standard for turbofan/turbojet engines >26.7 kN.

Turbofan/turbojet engines > 26.7 kN thrust are currently regulated for gaseous emissions and represent the highest portion of global aviation fuel burn. The CAEP agreed to first move forward with a certification requirement and subsequent nvPM emissions standard for this type of engine, aiming to complete this at, or before, the CAEP/10 meeting in 2016. This objective establishes the data collection methodologies, reporting requirements and database structures necessary to assist CAEP in making an informed decision on a nvPM certification requirement and emissions standard. Secondly and concurrently, the technical work should be conducted for other engine categories, to apply a potential nvPM emissions standard to turbofans/turbojets ≤26.7 kN, turboprops, helicopter turboshaft, and APU engines at a later date. This technical work would include defining an appropriate landing take off (LTO) or other operating cycle for each engine category, which could be used for both certification and emission inventory purposes.

Acquisition of sufficient amounts of nvPM engine emissions data with the standardized system while informing the ICAO Standard-setting process will also help in the development of inventories to assess the relevant health and climate impacts.

OUTLOOK

The main priority at this time is to obtain engine nvPM emissions data. This is being undertaken with the A-PRIDE project in Zurich, and more importantly at the engine manufacturers' facilities, using AIR6241 compliant measurement and ICAO Annex 16 compliant certification probe systems. An important aspect of the final validation of AIR 6241 for inclusion of the methodology into Annex 16 is proof of operation with certification probe systems. This requires substantial additional funding to be provided by ICAO CAEP Member States over the next two years in order to be successfully completed.

In addition to data collection, assessment of the data quality and the organization of data sharing and analysis, the development of a robust and relevant metric to make effective use of the collected

Figure 5: *A Validation Issue: Representative Sampling of the Entire Exhaust Plane with Certification Probe Systems.*

data for regulatory rule making is necessary. **Figure 6** shows a simplified roadmap and organizational structure of the CAEP WG3 Particulate Matter Task Group (PMTG). Following the CAEP/9 remits for PMTG, this illustrates an ambitious work plan. PMTG will deliver details on the needed engine test program at the CAEP Steering Group meeting in November 2013 (SG1). PMTG will need to develop a proposal for the certification requirement by the CAEP Steering Group in September 2014 (SG2). Suggestions for first regulatory levels will have to be made by June 2015, in order to meet the CAEP timeline. During the data collection process and metrics development, the CAEP Modelling and Database Group (MDG) may need to perform emissions calculations, including emissions from the other engine categories, to estimate their emissions contributions for CAEP deliberations about a future PM standard for engines that will not be covered in the first PM standard.

SUMMARY

Development of an nvPM Standard for aircraft jet turbine engines > 26.7 kN will address one of the gaps in the ICAO emissions Standards. Based on the knowledge gained from these engine categories, and using data from future measurement campaigns the importance of the contribution from the other engine categories for standard setting will be evaluated. A successful nvPM standard will, in the near-term, align aviation with other transportation modes and in the long term will lead to better assessment of nvPM impacts and the development of stringency options. Timely availability of nvPM emissions data and related resource requirement are major challenges that will need to be overcome for an nvPM standard to be developed by the CAEP/10 meeting in February 2016.

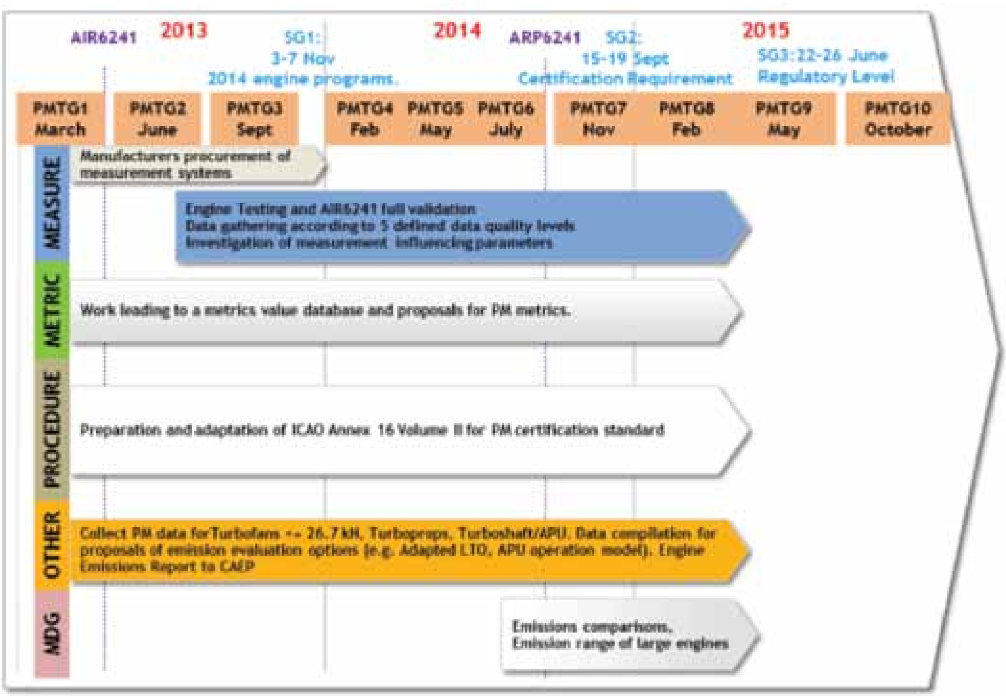


Figure 6: *Roadmap and Organizational Structure of the CAEP WG3 Particulate Matter Task Group (PMTG).*

INDUSTRY LED NO_x EMISSIONS TECHNOLOGY REVIEW

BY **PAUL MADDEN**, AND **THE INTERNATIONAL COORDINATING COUNCIL OF AEROSPACE INDUSTRIES ASSOCIATION (ICCAIA)**

PAUL MADDEN

He works for Rolls-Royce plc. as a specialist in the combustion department with over 20 years of experience in gas turbine combustion design and engine emissions. His current role is the company Engine Emissions Expert and he recently Chaired the manufacturers International Environment Committee and was therefore ICCAIA Observer to CAEP. He has been involved in the work of CAEP for nearly 15 years and helped facilitate the NO_x review, that is reported on here. Paul was helped by the following co-authors Dom Sepulveda (P&W), Joe Zelina (GE), Rudy Dudebout (Honeywell), Kian McCaldon (P&W(C)), and Olivier Penanhoat (Snecma).

The International Coordinating Council of Aerospace Industries Association (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).

INTRODUCTION

Currently, certification standards are in place for civil turbojet and turbofan aircraft engines, with the most recent stringency standard adopted at the eighth meeting of ICAO's Committee on Aviation Environmental Protection (CAEP/8) in 2010, for application to new engine types from 1 January 2014. Allowable Oxides of Nitrogen (NO_x) regulatory values for current production engines are ~50% below those levels that were first put in place in 1986 when the first Standard became applicable. As a result of this continuous reduction in the allowable NO_x levels for new production engines, there are ongoing efforts by engine manufacturers to reduce NO_x emissions to meet future more-stringent standards and CAEP goals. This article is an overview of the industry-led aero gas turbine combustion technology NO_x review which was held on 20 October 2011 in Toulouse, France.

BACKGROUND

Before discussing combustion technology designed to meet lower emissions standards, it is important to understand the typical emissions generated from gas turbine engines. **Figure 1** shows typical emissions from gas turbine engines at cruise speed. As shown, emissions levels for currently regulated emissions (NO_x, Carbon Monoxide (CO), Unburned Hydrocarbons (HC)) are relatively small compared to major exhaust species such as CO_2 and H_2O, making reductions in these species especially challenging for future combustor designs.

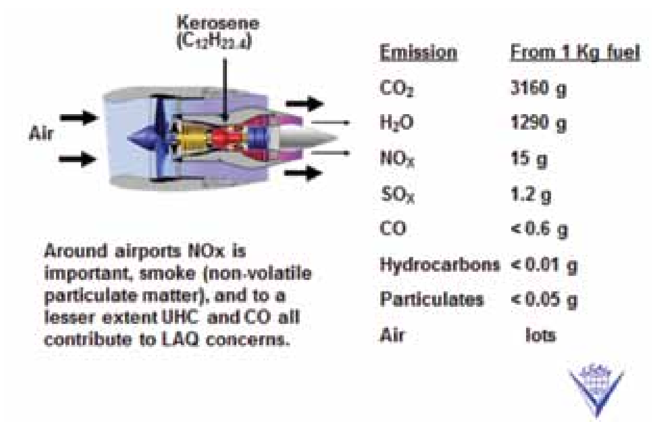


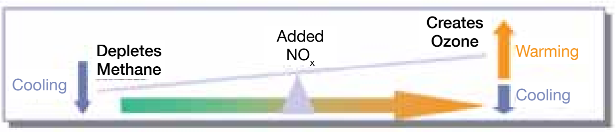
Figure 1: *Typical Aviation Gas Turbine Emissions Levels at Cruise.*

IMPACT OF POLLUTANTS ON THE ENVIRONMENT

It has been known for some three decades or more that subsonic aircraft NO_x emissions perturb the chemical composition of the atmosphere resulting in enhancement of tropospheric O_3 (ozone), a greenhouse gas. Work in the late 1990s showed that the impact of aviation NO_x emissions also has an impact on the ambient CH_4 (methane) atmospheric budget, through the increase in hydroxyl radical (OH), and therefore the consequential reduction in CH_4 lifetime and abundance, since the principal sink term for CH_4 is reaction with OH. The reduction of CH_4 lifetime and abundance was highlighted in the 1999 report of the Intergovernmental Panel on Climate Change (IPCC). More recently, it has been appreciated that in terms of studying the atmosphere as a chemical system, there is an associated small decrease in ambient O_3 levels from the reduction in ambient CH_4, as the chemical system is tightly coupled. Thus if CH_4 is reduced, the decomposition products are also reduced, and may give rise to a negative forcing. This is shown pictorially in

Figure 2. Most studies indicate that aviation NO_x results in an overall positive radiative forcing (Lee *et al.*, 2009; 2010) and positive net Global Warming Potential (Fuglestvedt *et al.*, 2010). Recent work comparing the impact of different aviation NO_x inventories has helped to reduce uncertainties, confirming that the more accurate inventories result in an overall warming (Skowron *et al.*, 2013).

Environmental effect of altitude NO_x



NO_x emissions within days help form ozone a global warming gas in the troposphere and this extra ozone warms the atmosphere. The reactions also produce OH radicals.

The OH radicals react with atmospheric methane and depletes the methane budget in the atmosphere over a number of years, and as methane is a global warming gas the result of this is a cooling of the atmosphere.

As the methane budget in the atmosphere is reduced there is an interaction with the ozone budget which reduces so this means there will be a final cooling of the atmosphere from reduced ozone.

These reactions are quite complex.

Figure 2: *Pictorial View of the Effect of NO_x on Atmospheric Ozone and Methane.*

Thus, the effect of an addition of NO_x from subsonic aircraft can be seen to have a complex series of effects on atmospheric composition, which gives rise to long-term positive (warming) and negative (cooling) effects. In conclusion, the overall impact of NO_x emissions on climate from subsonic aircraft is still an issue of importance (Fahey *et al.*, 2013) (see article *Aviation and Climate: State of the Science*, Chapter 1 in this report). Furthermore, NO_x is known to be a local air quality concern and both NO_2 and ozone (it creates) are regulated by States. Since the review in 2011, additional atmospheric studies have come to light. Taking these into consideration is part of ICAO's ongoing Impact Science Group (ISG) updates to be pursued during the CAEP/10 work programme.

LOW EMISSIONS COMBUSTOR DESIGN CHALLENGES

NO_x formation is a function of temperature and residence time at higher temperatures. In addition to the challenges that the combustion designer faces to reduce NO_x, the designer is also faced by the trade-offs that exist between CO_2 (carbon dioxide) and NO_x. One way to reduce CO_2 emissions, which is directly related to fuel burn, is to increase engine operating temperatures. This, however, directly impacts NO_x emissions, which increase with both pressure and temperature. Other trade-offs, which challenge the combustor designer, include NO_x and smoke trades on rich burn combustors, NO_x and CO/HC trades on lean burning combustors, and the reduced combustor volumes of modern gas turbine engines. Furthermore, the importance of cooling technology, use of fuel staging, and the aim to minimize combustor pressure loss need to be considered in future combustion system designs.

CAEP NO_X GOALS

Following the first NO_x review in 2006, an Independent Expert (IE) group, in consideration of the significant NO_x improvements that had been made by the engine manufacturers, issued a report highlighting future NO_x goals (ICAO Doc 9887 – *Report of the Independent Experts on the LTTG NO_x Review and the Establishment of Medium and Long Term Technology Goals for NO_x*). Medium and long term NO_x goals were set based on input from both industry and research agencies. The report stated that NO_x goals were set for leading edge technology as -45% of CAEP/6 for 2016, and -60% of CAEP/6 for 2026. The CAEP/6 standard was taken as the starting point. This standard is applicable for new types of engines from the year 2008, making these very challenging goals.

ENGINE MANUFACTURER HIGHLIGHTS

Large engine manufacturers showed progress on NO_x reductions, with one recent certification of a lean burn combustor meeting the 2016 goal. Progress was also reported on advanced rich burn combustors that also might meet such levels before 2016. Each engine application must be assessed separately for the most appropriate technical solution, as it is important to note that the effect of overall engine cycle and suitability of different sizes of engines to different solutions drives the decision of the designers. Whether the choice of combustor is lean burn or rich burn will depend on many factors including the technology maturity level. **Figure 3** shows the variety of combustor technologies explored by the engine manufacturers to meet low emissions requirements.

Small engine manufacturers demonstrated significant progress on NO_x reduction in recent certifications, which indicates that progress is being made in transitioning low-emissions combustor technology to other engine categories, including Turbofans (<26.7 kN), turboprops, and Auxiliary Power Units. Nevertheless, the challenges in small gas turbine combustors can make low emission designs more difficult than their large engine counterparts. Controlling emissions requires the use of so much of the total air flow entering the combustor that

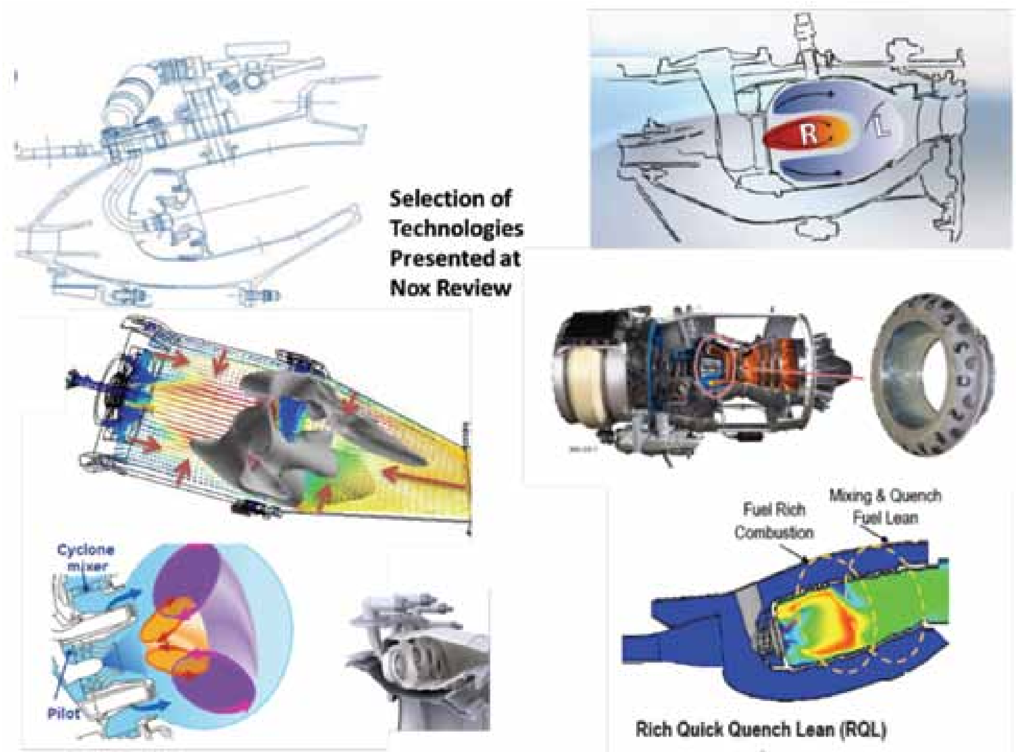


***Figure 3:** Combustor Technologies Explored by the Engine Manufacturers to Meet Low Emissions Requirements.*

there is often insufficient air left for wall cooling, even when the most modern cooling techniques and wall materials are used. This effect is a result of the high surface-area-to-volume ratio for smaller combustors. The requirement for temperature uniformity, coupled with low total air flows and fuel flows, require better control over air and fuel flow distribution than has been traditionally used, thus creating significant manufacturing challenges. The modern, short, low residence time combustor can affect combustion efficiency, engine starting, and altitude relighting. The small combustor brings the walls so close to the fuel injectors that burning the fuel before it encounters a wall is difficult, leading to concerns about combustor wall durability. The above issues and the fact that small turbofan engines have lower bypass ratios and therefore poorer fuel efficiency compared to large turbofans means meeting the NO_x emissions regulations has been challenging. The so-called “thrust alleviation”, whereby the CAEP/6 NO_x Standard has been set at the CAEP/2 Standard for engines at 26.7 kN, accommodates this constraint, but has not yet been accounted for in the CAEP goals.

RESEARCH AGENCY HIGHLIGHTS

Research and Development (R&D) for reduction of cruise NO_x as well as LTO (landing and take-off) NO_x is being conducted in Japan by KHI-JAXA joint research, which is especially important for SSTs/SSBJs (supersonic transports/supersonic business jets). AAP (Auto-Adjustable Premix) burner was introduced as one of the methods to reduce the total amount of NO_x emissions produced during a flight mission. JAXA is now conducting research on the technologies for the next generation supersonic transport. The NO_x emission objectives at cruise or during flight mission will be useful to clarify the environmental acceptability of the next generation SST/SSBJ.

To meet the challenges of reducing aircraft generated emissions and achieving the US’s vision of reducing its dependency on foreign oil, the next generation of propulsion systems will require a greater fundamental understanding of current and future combustion processes and the use new alternative fuels in those systems. Efficient, robust, clean and controlled combustion lies at the heart of NASA’s activities in enabling concepts and technologies toward dramatically reducing or eliminating harmful emissions affecting local air quality/health and global climate change attributable to aircraft energy consumption. NASA has made progress on the SFW (subsonic fixed wing) and ERA (environmentally responsible aviation) projects in exploring low emissions concepts, numerical modelling of combustion processes, validation experiments, and the characterization and use of alternative fuels for aircraft systems.

ANALYSIS AND RESULTS

Figure 4 shows the recent certification results presented at the 2011 NO_x review compared to the recent certification data from the previous two NO_x reviews, as well as the

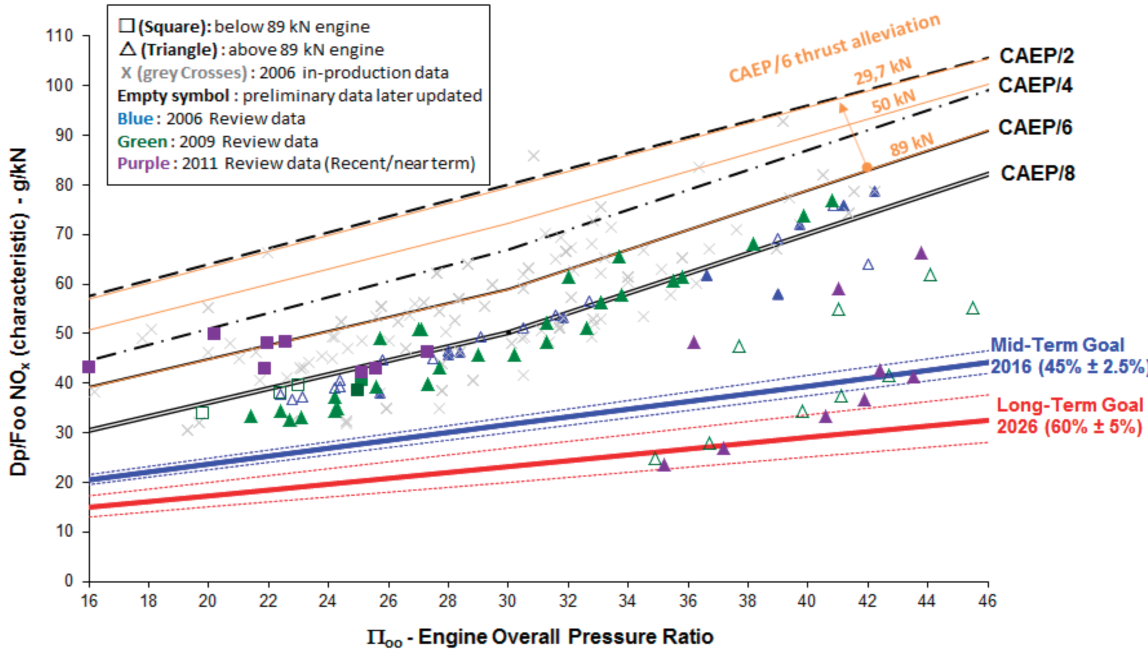


***Figure 4:** Data Presented at the 2011 NO_x Review Compared to Stringency Lines and Older Data.*

in-production engines in the emissions databank. Several engines have moved a small amount relative to the data presented in 2009 either to slightly better or slightly worse levels. It can be assumed that the conclusions reached by the IEs in 2009 should generally hold for the data presented in 2011. If anything, the industry-led review concluded that the progress made in the single aisle aircraft market with rich burn developments was the most significant thing seen at the meeting.

Regarding engines < 89 kN's, though significant NO_x reductions relative to CAEP/2 have been achieved, the figures above and below highlight the fact that all recent small engines certifications are a long way from the actual CAEP LTTG goals, as those goals do not include any thrust alleviations (noting that this issue has been acknowledged within the past two IE reports on NO_x technology). The small engine CAEP/6 regulations are shown in **Figure 4** in orange for different thrusts as the regulations for these engines include thrust alleviation.

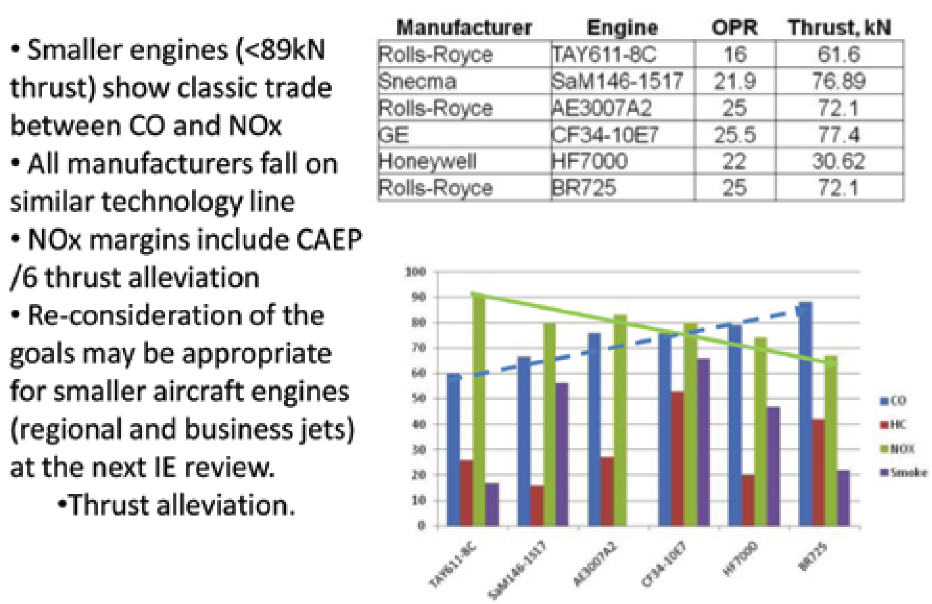


***Figure 5:** Trade-off of NO_x and CO on Small Engines.*

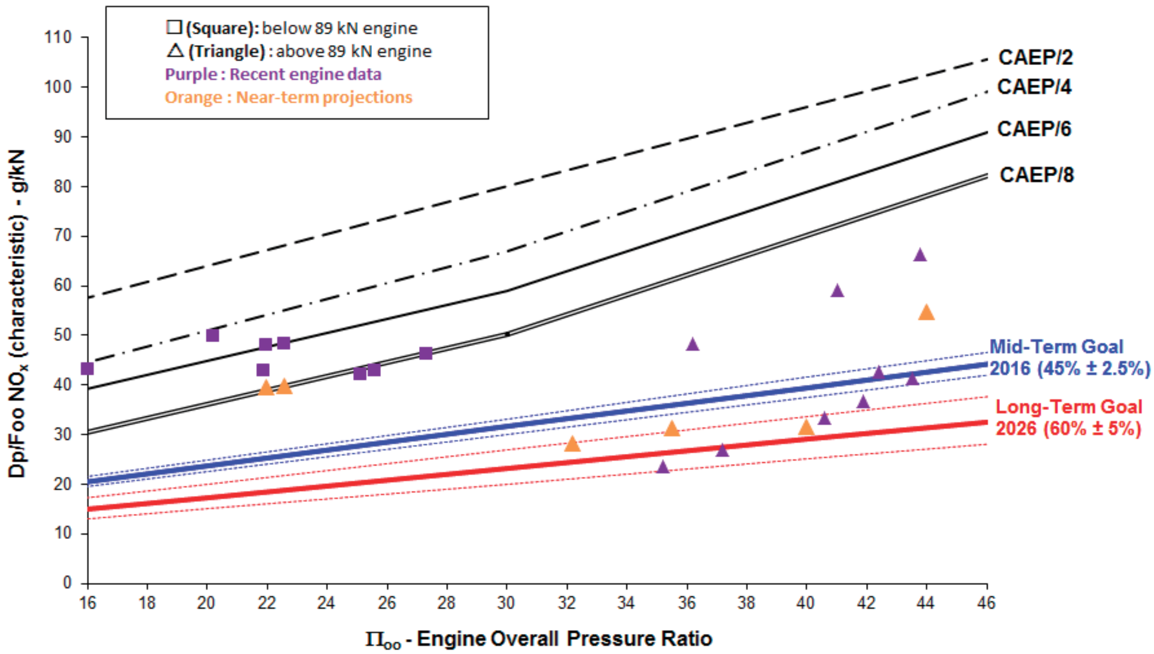


***Figure 6:** Recent Results and Technology Projections.*

Figure 5 shows the recent certification results and highlights that there are issues not just for NO_x but also related to CO. There are significant challenges for the small engines category, and while great work has been conducted, future work is needed. It is probably important that the goals for small engines be re-considered in the future.

Figure 6 is based on the data presented only at the 2011 review and it shows all of the new results presented at the NO_x review including projections for several engines and technologies.

Engines aimed at the single aisle market segment will probably meet the MT goals utilizing both lean burn technology and with advanced rich-quench-lean (RQL) combustors. For smaller engines (<89 kN's) that are designed to power regional and business jets, significant research and development programme data was presented which demonstrated good progress against significant technical challenges. However, it is not possible to conclude at this time, that those developments will be sufficient to meet the 2016 goal (ICAO Doc 9887).

The more challenging Long Term (LT) goal is not demonstrated as having been met by any entire engine family. The advent of novel cycles that increase bypass ratios is important. The incorporation of lean burn technology into engines for the single aisle and larger aircraft is also significant. The research presented demonstrates a possibility of meeting the goals as this technology matures. Evidence was presented that the RQL technology is being further developed and has demonstrated significant reductions in NO_x emissions towards the LT goal in engine testing at TRL6 levels for the single aisle aircraft with turbofan engines. New engine concepts with increased, higher, or ultra-high, bypass ratios may achieve the goal using advanced RQL combustors. However, this could be attributed to the LTO cycle and may not be reflected across the whole mission. Incorporating lean burn combustors into smaller engines faces significant technical challenges, and no evidence was presented as a way towards achieving that goal.

REFERENCES

Fahey, D. W., Baughcum, S. L., Gupta, M., Lee, D. S., Sausen, R., van Velthoven P. (2013) Aviation and climate: state of the science. Aviation Overview, ICAO Environmental Report 2013.

Fuglestvedt J. S., Shine K. P., Cook J., Berntsen T., Lee D. S., Stenke A., Skeie R. B., Velders G. J. M. and Waitz I. A. (2010) Transport impacts on atmosphere and climate: Metrics. *Atmospheric Environment*, 44, 4648–4677.

IPCC (1999) *"Aviation and the Global Atmosphere"* J. E. Penner, D. H. Lister, D. J. Griggs, D. J. Dokken and M. McFarland (Eds). Special Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge.

Lee D. S., Pitari G., Grewe, V., Gierens K., Penner J. E., Petzold A., Prather M., Schumann U., Bais A., Berntsen T., Iachetti D., Lim L. L. and Sausen R. (2010) Transport impacts on atmosphere and climate: Aviation. *Atmospheric Environment* 44, 4678–4734.

Lee D. S., Fahey D., Forster, P., Newton P. J., Wit, R. C. N., Lim L. L., Owen B., and Sausen R. (2009) Aviation and global climate change in the 21st century. *Atmospheric Environment* 43, 3520–3537.

Skowron A. M., Lee D. S. and Rodriguez-Leon R. (2013) The assessment of the impact of aviation NO_x on ozone and other radiative forcing repsonses – the importance of representing cruise altitudes accurately. *Atmospheric Environment* 74, 159–168.

International Civil Aviation Organization (ICAO) Doc 9887 – *Report of the Independent Experts on the LTTG NO_x Review and the Establishment of Medium and Long Term Technology Goals for NO_x.*

THE ICAO AIRPORT AIR QUALITY MANUAL

BY ICAO SECRETARIAT

INTRODUCTION

ICAO has been involved with airport-related emissions for many years. In addition to the technology related standards developed by ICAO, guidance material to help States implement best practices related to assessing airport-related air quality was developed and published in 2011 as the *Airport Air Quality Manual*, ICAO Doc 9889[1]. This article presents some of the main areas from the aforementioned document.

In most areas, air quality is regulated by a combination of national, regional and/or local regulations that establish Standards on emissions sources and/or ambient (*i.e.* outdoor) levels of various pollutants and define the procedures for achieving compliance with these Standards. An example relationship of the principle requirements for an air quality assessment in order to show compliance regulations and standards are shown in **Figure 1**. This includes the development of emissions inventories and the dispersion modelling of pollution concentrations. These are the two main areas of an air quality assessment.

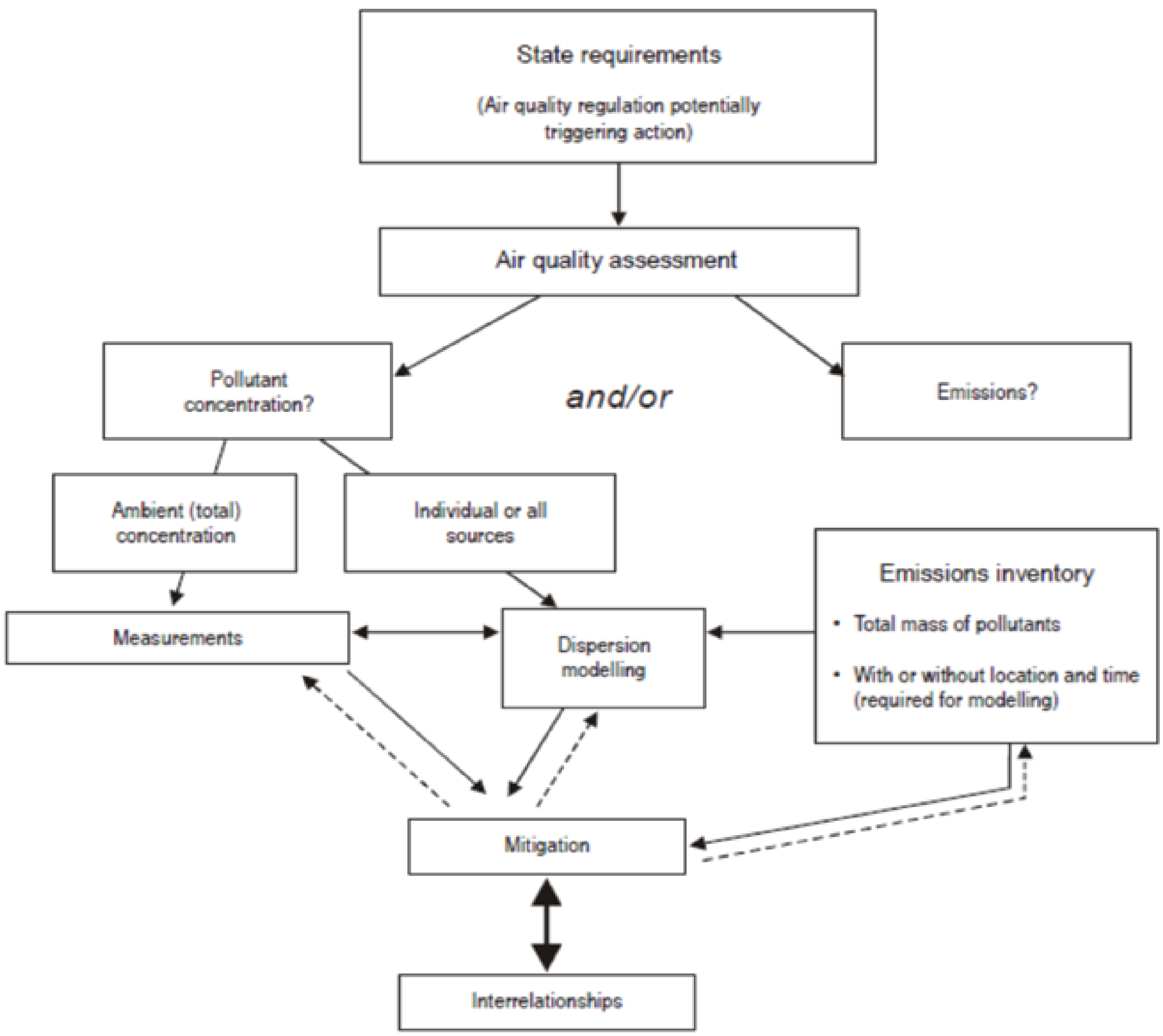


Figure 1: *Principle Elements of an Air Quality Assessment.*

EMISSIONS INVENTORIES

An emissions inventory gives the total mass of emissions released into the environment and provides a basis for reporting, compliance, and mitigation planning, and it can be used as input for modelling pollution concentrations. Emissions inventory objectives can include, but are not necessarily limited to: (a) collecting information on emissions while monitoring trends and assessing future scenarios, (b) benchmarking emissions against legal requirements (*e.g.* thresholds), (c) creating input data for dispersion models in an effort to determine pollution concentrations, and (d) establishing mitigation programme baselines. A bottom-up process is typically used to calculate emissions inventories because this approach can provide a high level of accuracy. As such, the first step requires the calculation of the emissions mass, by source, time period, and pollutant. These variables are calculated by using information about individual emissions sources with their associated emission factors (expressed as g/kg of fuel, g/hr of operation or g/kwh), and the respective operational parameters over a determined period of time. The total emissions source can then be expressed in various forms such as an individual source or a group of sources, by pollutant or by period of time.

Aircraft main engines may, at times, receive the most attention from the parties concerned with aviation emissions because they are usually the dominant airport-related source. Main engines are generally classified as either gas turbine turbofan (sometimes referred to as turbojet) and turboprop engines fuelled with aviation kerosene (also referred to as jet fuel). They can also be internal combustion piston engines fuelled with aviation gasoline. The ICAO engine emissions Standards cover emissions of CO, HC, NO_x and smoke, and apply only to subsonic and supersonic aircraft turbojet and turbofan engines of thrust rating greater than or equal to 26.7 kN (Annex 16, Volume II). ICAO excluded small turbofan and turbojet engines (thrust rating less than 26.7 kN), turboprop, piston and turboshaft engines, APU and general aviation aircraft engines from its Standards. For the purpose of certifying and demonstrating compliance with the engine emissions Standards, ICAO has defined a specific reference Landing Take Off-Cycle (LTO cycle), which includes four modes of operation (Taxi, Take-off, Climb, and Approach) below a height of 915 m (3,000ft) (see article *Local Air Quality – Overview*, Chapter 3 in this report) and some States use the LTO cycle as a method for local air quality assessment purposes.

It has been recognised that, even for aircraft of the same type, there are large variations in actual operating times and power settings between different international airports, and even at a single airport there can be significant variations within a single day. While not capturing the detail and variations that occur in actual operations, the emissions certification LTO cycle was designed as a reference cycle for the purpose of technology comparison, and has been repeatedly reaffirmed as adequate and appropriate for this purpose.

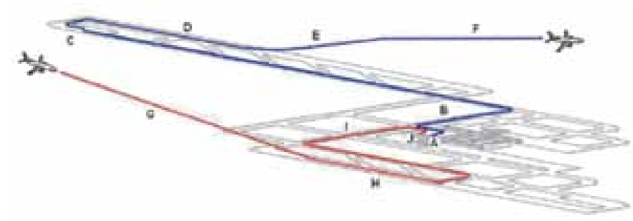


Figure 2: *An Example Operational Flight Cycle.*

While in some instances the LTO cycle may be adequate for simple emissions inventory calculations, the use of this cycle typically would not reflect actual emissions. Actual cycles employ various aircraft engine thrust settings, and the times at those settings are affected by factors such as aircraft type, airport and runway layout characteristics, and local meteorological conditions. **Figure 2** shows an example flight cycle, which includes, for departure: (A) Engine start, (B) Taxi to runway, (C) Holding on ground, (D) Take-off roll to lift-off; (E) Initial climb to power cutback; and for arrival, (G) Final approach and flap extension, (H) Flare touchdown and landing roll, (I) Taxi from runway to parking stand/gate, and (J) Engine shutdown. In other words, the departure and arrival phases of actual commercial aircraft operations are more complex than the four modal phases used for ICAO certification.

As part of the aircraft emissions sources, use of other engine categories outside of the ICAO engine emissions Standards (*e.g.* turboprops) and Auxiliary Power Units (APU)[2] should also be accounted for in the emissions inventory. Furthermore, in order to perform a complete assessment of airport air quality, other than direct aircraft emissions, three additional categories must be accounted for, *viz*: aircraft handling emissions (*e.g.* ground support equipment), infrastructure or stationary related sources (*e.g.* aircraft maintenance), and vehicle traffic sources (*e.g.* cars).

Unless required otherwise, for specific legal reasons or regulatory compliance, it is good practice to make use of the best available data for creating emissions inventories while considering the level of accuracy and confidence-level required. This could involve using advanced and/or sophisticated approaches rather than a simple approach, depending on the various parameters needed to calculate the emissions mass.

POLLUTION CONCENTRATIONS AND DISPERSION MODELLING

At an airport, emissions typically occur at multiple locations during various time periods, depending on the purpose and operational characteristics of the source. For example, stationary sources such as generators or heating plants emit from fixed locations and may be either continuous or intermittent. By comparison, aircraft emissions are more mobile, occurring at various locations at the airport, at different times of day, and at a range of intensities. This results in the dispersion of emissions being both a temporal and spatial three-dimensional

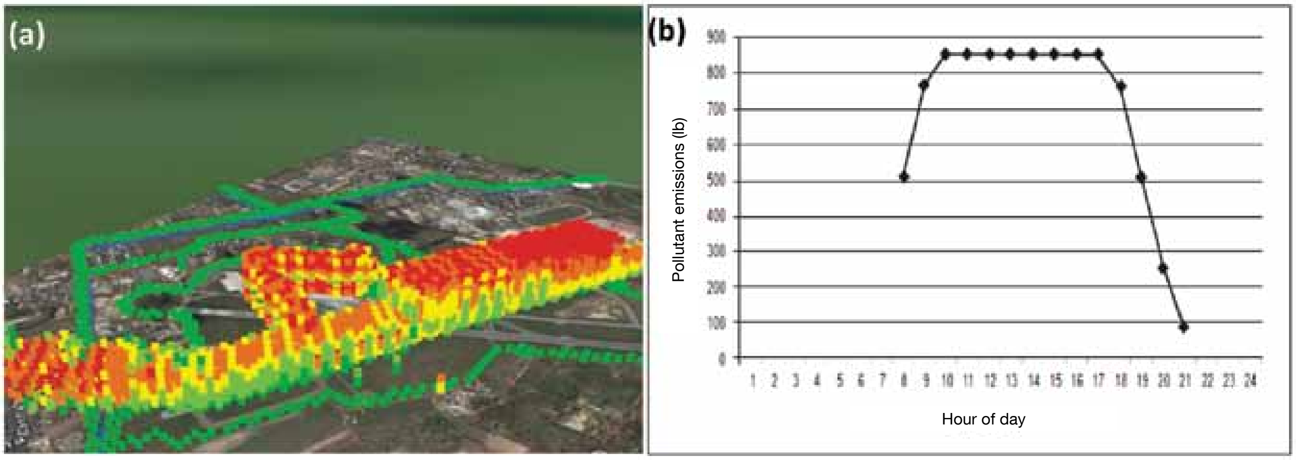


Figure 3: *(a) An Example 3-dimensional Geospatial Emissions Inventory; and (b) a Diurnal Profile Plot of Emissions Mass.*

consideration. The assessment of this variability of location and emissions density must be done by spatial and temporal distribution of the emissions (as shown in **Figure 3**). This is especially true if dispersion modelling is to be performed as part of the overall air quality analysis.

The total mass emitted and local concentrations does not account for mixing in the atmosphere, and atmospheric dispersion modelling is required to estimate the local ambient concentrations. This involves the release of a trace substance from a source into the free atmosphere, which will be transported by the mean wind field and dispersed by atmospheric turbulence. The trace substances most often evaluated are regulated atmospheric pollutants, and in an airport-related dispersion calculation, the atmospheric mixing of these, emitted from local sources, is modelled based on scientific principles and the resulting concentration distributions (usually near the ground) are predicted. The results, or predicted atmospheric concentrations, form the basis for LAQ impact studies and are used to demonstrate compliance with required regulations and standards.

Existing pollution concentrations can also be assessed by in-situ observation (*e.g.* sampling and monitoring) of ambient conditions, although this assessment method can include contributions from other nearby and distant sources, including those that are non-airport related. Depending on the specific task, modelling results and ambient observations can be used for evaluating existing or historical conditions. In contrast, future conditions can only be modelled.

FINAL REMARKS

The emissions inventory, concentration and dispersion modelling, and ambient observation elements of an air quality assessment can be used individually or in combination. Using these can aid the process of understanding, reporting, and compliance and/or mitigation planning, by providing information on overall conditions as well as on specific source contributions. Subsequent air quality mitigation or other implemented mitigation measures (with full consideration of the interrelationship with noise and other environmental factors) can have beneficial results for the total emissions mass, the concentration model results, and measured pollutant concentrations. ■

REFERENCES

1 ***Auxiliary power unit (APU).*** A self-contained power unit on an aircraft providing electrical/pneumatic power to aircraft systems during ground operations.

2 ICAO, *Airport Air Quality Manual*, Doc 9889 (2011).

CHAPTER 4

GLOBAL EMISSIONS

OVERVIEW

GLOBAL EMISSIONS

BY ICAO SECRETARIAT

INTRODUCTION

Resolution A37-19, adopted by the 37th Session of the ICAO Assembly in 2010, set forth an overarching policy for the Organization to address climate change issues related to international aviation, and was instrumental in making international aviation the first sector with global aspirational goals for improving annual fuel efficiency by 2%, and stabilizing its global CO_2 emissions at 2020 levels.

With a view to achieving a sustainable future for international aviation, ICAO has made important progress on the key areas of work as requested by the 37th Assembly, focusing on:

- the development of key elements from a basket of mitigation measures to reduce CO_2 emissions from international aviation, including the establishment of standards to reflect technology innovation, operational improvements, sustainable alternative fuels, and market-based measures;
- facilitating the implementation of concrete actions to reduce CO_2 emissions from international aviation, through the development of guidance material and establishment of a capacity building programme for the preparation and submission of State action plans for the reduction of international aviation CO_2 emissions to ICAO, as well as the provision of assistance to States to implement the measures identified therein; and
- the review and further exploration of global aspirational goals, based on sound technical information and data.

STANDARDS AND TECHNOLOGY

A major area of activity in the field of aviation and climate change is the development of a CO_2 emissions certification standard for aircraft. The development of this standard has been one of the most challenging tasks being undertaken by the ICAO Committee on Aviation Environmental Protection (CAEP).

Since its eighth meeting (CAEP/8) in February 2010, CAEP has directed significant efforts toward the development of the CO_2 Standard. At its ninth meeting (CAEP/9) held in February 2013, CAEP reached an agreement on the CO_2 certification requirements for this Standard, setting the basis for further work, including the analysis of an appropriate regulatory limit for the development of a full CO_2 Standard (see article *Development of an ICAO Aeroplane CO_2 Emissions Standard*, Chapter 4 in this report).

An important part of the work of ICAO is improving the understanding of potential future technologies and the setting of technology goals. The CAEP uses an Independent Expert (IE) process to assess technology goals, and this has been used in the past for both noise and NO_x technology goal setting. CAEP/7 held in February 2007, requested advice from IEs on the prospects for reduced aviation fuel burn from technology advances. The resulting IE review was published by ICAO in 2010 and included fuel burn reduction goals from technology for the medium term (2020) and long term (2030) (see article *ICAO Goals for Aviation Fuel Burn Reduction from Technology*, Chapter 4 in this report). Input from the manufacturing community is also crucial to understanding potential future aircraft and engine technology developments. This includes understanding the research and technology development carried out by the manufacturers, and through national and international research programmes (see article *Pushing the Technology Envelope*, Chapter 4 in this report).

OPERATIONAL IMPROVEMENTS

Operational measures are among the elements in the basket of measures available to States to address the impact of aviation on the environment. Improved operational measures have the potential to reduce fuel consumption, and in turn, CO_2 emissions. For every tonne of fuel reduced, an equivalent amount of 3.16t of CO_2 are avoided.

CAEP has developed updated guidance material to replace ICAO Circular 303, *Operational Opportunities to Minimize Fuel Use and Reduce Emissions*. This was done in order to provide States and other stakeholders

Figure 1: *ICAO Regional Hands-on Training Workshop for States' Action Plans on CO_2 Emissions Reduction Activities, ICAO Asia and Pacific Office, Bangkok, 25 to 27 May 2011.*

with information on a state-of-the-art variety of measures and best practices to reduce aviation emissions, ranging from weight reduction, to airport operations, as well as other operational improvements. Guidance material on conducting CNS/ATM environmental assessment, referred to as *Environmental Assessment Guidance for Proposed Air Traffic Management Operational Changes*, was also developed and endorsed by the ICAO Council (see article *Two New ICAO Manuals on Reducing Emissions Using Enhanced Aircraft Operations*, Chapter 4 in this report).

Moreover, ICAO continues to develop and make available new tools to provide States with the ability to assess the environmental impacts of aviation operations. For instance, ICAO recently launched the ICAO Fuel Savings Estimation Tool (IFSET), which was developed to assist States to estimate the fuel savings and corresponding environmental benefits from the implementation of operational improvements (see article *ICAO Environmental Tools*, Chapter 1 in this report).

In addition, CAEP, in partnership with the operational community, is in the process of assessing the first modules of the Aviation System Block Updates (ASBU), in order to quantify their environmental benefits. This is a major initiative to improve global air navigation efficiency and safety. The results of this analysis will be included in the Global Air Navigation Report in 2014 (see article *ICAO Block Upgrades*, Chapter 4 in this report).

SUSTAINABLE ALTERNATIVE FUELS FOR AVIATION

Sustainable alternative fuels represent a win-win-win solution for aviation's future, as they contribute to the three pillars of sustainable development (environmental, social and economic) by: reducing greenhouse gas emissions while improving local air quality; providing new sources of employment; and facilitating economic development in non-traditional fuel producing regions of the world.

Impressive progress in the development and deployment of sustainable alternative fuels for aviation was achieved over just a few years. Commercial flights using sustainable drop-in alternative fuels, from a variety of feedstocks are now a reality, and hundreds of aviation alternative fuel initiatives are currently underway worldwide. Working in close cooperation with its industry partners, ICAO successfully demonstrated the reality of drop-in alternative fuels for aviation during the Rio+20 Conference in June 2012, as the ICAO Secretary General travelled from Montréal to Rio de Janeiro on a series of four connecting commercial flights, all powered by sustainable alternative fuels, and significant progress has been achieved since (see article *Flightpath to a Sustainable Future*, Chapter 8 in this report).

The next challenge is to facilitate the timely availability of such fuels in sufficient quantities for use in aviation in a sustainable manner. In 2012, ICAO established a multidisciplinary expert group to develop policy recommendations on this subject (see article *Sustainable Alternative Fuels for Aviation*, Chapter 4 in this report).

MARKET-BASED MEASURES

The 37th Session of the ICAO Assembly agreed on the development of a framework for market-based measures (MBMs), including the elaboration of the guiding principles adopted by the Assembly. The Assembly also agreed to explore the feasibility of a single global MBM scheme for international aviation.

In cooperation with experts nominated by Member States and international organizations, ICAO has undertaken intensive work to respond to the Assembly's request. Much progress has been achieved on the development of the MBM framework, as well as the evaluation of options for a global scheme, including the quantitative analysis of MBMs' environmental benefits and economic impacts (see article *Market-based Measures*, Chapter 4 in this report).

STATE ACTION PLANS

While ICAO has traditionally played a "Standards and policy-setting" role in the field of international aviation and climate change, agreement by the last Assembly on the voluntary submission of State action plans transitioned the Organization's policy outlook to a more action-oriented "implementation" mode. ICAO is encouraged by the active engagement of its Member States and the synergies created for action, as a result of the action plan initiative.

Action plans allow States to showcase national mitigation measures to reduce CO_2 emissions from international aviation, as well as identify any assistance needs to implement such measures. In turn, the compilation of information contained in the State action plans enables ICAO to assess progress toward the achievement of the global aspirational goals, as well as to identify the areas of implementation support needed in order to effectively provide assistance to States.

In 2011 and 2012, ICAO set forth a capacity building programme, which included seven hands-on training workshops held across all ICAO regions to provide information and training on the actions plans to national action plan focal points (see **Figure 1**). In addition, guidance material, an interactive website, and tools were developed to support the development of State action plans. Member States representing almost 80% of global international air traffic developed and submitted action plans to ICAO by mid-2013 (see article *State Action Plans to Reduce Aviation CO_2 Emissions*, Chapter 5 in this report).

ASSISTANCE TO STATES

In order to facilitate the provision of technical and financial assistance, access to existing and new financial resources, technology transfer, and capacity building for developing countries, and in order to respond to the assistance needs of States, as identified in the submitted action plans, an ICAO "Assistance for Action – Aviation and Climate Change" (ACLI) Seminar was held in October 2012 in Montréal, Canada[1].

The ACLI Seminar highlighted the synergies and constructive engagement among ICAO, its Member States, stakeholders, and other international organizations during the first phase of the action plan initiative. During the session on financing, speakers from six international organizations and financial institutions discussed tangible opportunities to build partnerships to provide the financial assistance required to implement the measures identified by States in their action plans.

After the successful completion of the initial phase of work on State action plans, the focus is now to support those States requiring assistance to implement the measures identified in the action plans. This support includes collaborating with the ICAO Technical Cooperation Bureau and establishing partnerships with other UN organizations and multilateral funding agencies (see article *Assistance and Financing for International Aviation Emissions Reduction*, Chapter 6 in this report).

GLOBAL ASPIRATIONAL GOALS

The initiatives highlighted above constitute the key components of the basket of mitigation measures that has been developed by ICAO to provide its Member States and the aviation industry with the means to reduce the climate impact of aviation operations. Through the implementation of these measures, ICAO aims toward the achievement of the global aspirational goal of 2% annual fuel efficiency improvement with objective of stabilizing global CO_2 emissions from international aviation at 2020 levels.

CAEP undertook the update of the CO_2 trends assessment by estimating the contribution of various categories of mitigation measures including: aircraft-related technology development, improved air traffic management and infrastructure use, and alternative fuels. This was done in order to estimate current and future progress toward the achievement of global aspirational goals (see article *Environmental Trends in Aviation to 2050*, Chapter 1 in this report).

Work to estimate and verify the current global fuel consumption from international aviation directly supports the request of the 37th ICAO Assembly to regularly report CO_2 emissions from international aviation to the UNFCCC. The methodologies used for reporting emissions and the results of estimating fuel consumption will be reviewed by CAEP (see article *ICAO Environmental Tools*, Chapter 1 in this report).

In support of measuring future progress toward the achievement of global aspirational goals, the Secretariat has been compiling and interpreting the data contained in State action plans to determine a global figure, which is being integrated with the CO_2 trends assessment prepared by CAEP for the period of 2010 to 2050. The assessment will support the review of the medium-term global aspirational goal and the exploration of a long-term global aspirational goal for international aviation. Data collection and analysis will remain important elements of the decision-making process at ICAO, and the Secretariat will continue to make the results of its analyses widely available to facilitate consensus-based decisions. ■

REFERENCE

1 www.icao.int/meetings/acli/

TECHNOLOGY

PUSHING THE TECHNOLOGY ENVELOPE

BY **LESLIE RIEGLE** AND **MUNI MAJJIGI**

LESLIE RIEGLE

Director of Environmental Policy, she is responsible for Aerospace Industry Association's (AIA), civil aviation issues and policies including aircraft noise, emissions, alternative fuels and restricted and banned chemicals. Riegle also worked at the American Association of Airport Executives (AAAE) focusing on airport environmental issues, airport operations and safety. Prior to AAAE, Mrs. Riegle was a legislative and public policy advisor at Arnold & Porter LLP, and also worked with the U.S. Department of Transportation, Office of the Inspector General. She holds a Master of Business Administration from Embry-Riddle Aeronautical University in Florida, and graduated with honors from Western Michigan University.

MUNI MAJJIGI

He is the Acoustics Consulting Engineer for GE Aviation, responsible for acoustic technology roadmap, acoustic guidance to new products and noise technology development programs in jet noise, fan noise, open rotor, combustor and LPT among other duties. Dr. Majjigi is also member of the Design Board for GE Aviation and advisor for FAA's PARTNER, having a vast experience on national and international noise regulations and standards. He is member of CAEP WG1 since 2006 and for the CAEP10 cycle he was nominated as ICCAIA's Observer. Dr. Majjigi holds multiple patents and has published a number of articles on aero-acoustics of aviation propulsion systems. He holds a B Tech degree from the Indian Institute of Technology, Bombay, a Master of Science in Aerospace Engineering from Georgia Institute of Technology and a Ph.D. from Georgia Institute of Technology.

This article was written in collaboration with: Olivier Husse, Thierry Nowaczyk, Sarah Le Brocq, Kevin Goddard (all Airbus); Kevin Morris (ADS); and Dan Allyn, Sean Newsum, Steven Baughcum, Douglas DuBois, David Forsyth, Mike Garrison, Ricky Mack, Matthew Muehlhausen, Robert Peterson, Robert Solaimani (all Boeing).

The aerospace industry is a dynamic, advanced-technology, high-value sector that incorporates engineering, manufacturing, and service industries, to generate significant returns to stakeholders and to the global economy. The principal mission of the air transport industry is to provide a service to safely carry passengers and cargo between two city pairs while minimising the environmental impacts of the operation.

In order to achieve this, airframe, aero-engine, and aircraft systems manufacturers continuously strive to develop new and innovative technology. To do this effectively, there are a number of challenges that have to be balanced, particularly regarding technical, economic, and environmental issues, with safety always remaining of paramount importance.

From a global perspective, modernisation of aircraft and engine technology will be a key contributor to reducing the environmental footprint of the aviation industry. Already we are seeing the introduction of new engine technologies and airframe designs that will reduce fuel burn and make a significant contribution to the industry's commitment to carbon-neutral growth by 2020.

IMPROVING FUEL/CARBON EFFICIENCY BY REDUCING WEIGHT AND USING HIGH BYPASS RATIO ENGINES

A key factor that must be addressed when looking for ways to reduce fuel burn is the mass of the aircraft. Reducing the aircraft's empty mass improves its fuel efficiency and hence reduces CO_2 emissions. High By Pass Ratio (BPR) engines deliver thrust at lower fuel consumption due to improved propulsive efficiency thereby contributing to improved carbon efficiency.

New aircraft models are set to come on-line, starting now with types such as the Airbus A380, and Boeing 787, with the Airbus A350 XWB and Bombardier's C Series in the next few years, all providing step gains in fuel efficiency over previous technologies. These models use advanced composite materials for much of the aircraft airframe, demonstrating a considerable leap forward in their construction over traditionally constructed aluminium airframe structures. (see **Figures 1** and **2**).

The Airbus A380 is an early example where composites are used for significant parts of the airframe structure; composite material accounting for about 25% of the total. Similarly, about 20% of the Bombardier C Series, by weight, is of composite construction in the centre and rear sections of the fuselage, the tail cone, empennage, and wings.

More recent technological developments have pushed up this Carbon Fibre Reinforced Plastic (CFRP) composite content to about 50% or more by weight for Boeing's 787 Dreamliner and the Airbus A350 XWB. These models use other advanced materials as well, such as titanium and advanced aluminium alloys. The combination of lighter weight materials and innovative structural technologies result in lower weight airframes and therefore lower fuel consumption.

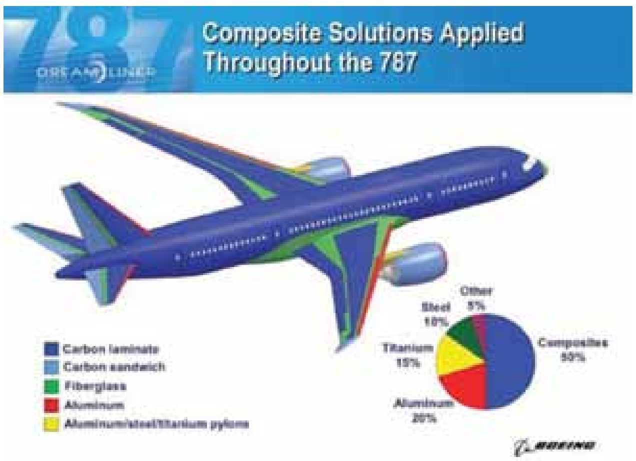


Figure 1: *Boeing 787 Airframe Use of Composites.*

Figure 2: *Airbus A350 XWB Airframe Use of Composites.*

New aircraft types are utilising advances in propulsion technology through the use of higher by-pass ratio engine architectures, and lighter and high temperature materials which contribute to increased propulsive efficiency and reduced fuel burn.

New aircraft types also incorporate a high level of electrical systems and controls that contribute to a low operating weight and help further enhance the operating efficiency of the aircraft.

INTERNATIONAL RESEARCH PROGRAMMES

Many international programmes focused on environmental research, development and deployment-facilitation are illustrative of successful Public-Private Partnerships. NASA's *Environmentally Responsible Aviation* (ERA) Project, for example, explores and documents the feasibility, benefits and technical risk of vehicle concepts and enabling technologies to reduce aviation noise and emissions. The programme is helping enable advanced aircraft configurations that would potentially go into service by 2025, and simultaneously reduce: aircraft drag by 8%, aircraft weight by 10%, engine-specific fuel consumption by 15%, NO_x emissions by 75%, and aircraft noise by 1/8 compared with current standards.

Open to bids from any interested aerospace company, the FAA's *Continuous Lower Energy, Emissions and Noise* (CLEEN) Program is more focused on helping to accelerate the development and commercial deployment of environmentally promising aircraft technologies. The programme has specific goals including development and demonstration of: certifiable aircraft technology that reduce noise levels by 32 dB cumulative (relative to the Stage 4 standard), certifiable engine technology to reduce landing and takeoff cycle (LTO) NO_x emissions by 60% below the 2004 ICAO standard, certifiable aircraft technology to reduce aircraft fuel burn by 33% relative to current aircraft technology; utilizing "drop-in" sustainable alternative jet fuels; and suitability of new technology for engine and aircraft retrofit in order to accelerate these into the existing commercial fleet. Some of the developed technologies within the programme have included noise reducing engine nozzles; lighter, more efficient gas turbine engine components; advanced wing trailing edges; optimized flight trajectories using onboard flight management systems; and open rotor and geared turbofan engines. The CLEEN programme will help accomplish the goals of achieving carbon neutral growth by 2020 (using a 2005 baseline). The next iteration, *CLEEN II* is currently underway and expecting to award agreements in spring, 2015.

Also, the European Union's Joint Technology Initiative *CleanSky*, aims to develop a range of fuel-efficient, low-emission vehicle sub-systems. The Programme's objectives are closely linked to the *Advisory Council for Aeronautics Research in Europe's* (ACARE) Vision 2020, which seeks to reduce (from 2000 levels) fuel consumption and CO_2 emissions by 50%, reduce perceived external noise by 50%, and reduce NO_x by 80%, by the year 2020. Examples of technologies created within this project include active wing and new aircraft configuration; innovative blades and engine installation for noise reduction, lower airframe drag, integration of diesel engine technology and advanced electrical systems for rotorcraft; engine demonstrators to integrate technologies for low noise and emissions, to include open rotors and intercoolers;

all-electrical aircraft equipment and systems architectures, thermal management, capabilities for "green" trajectories and mission and improved ground operations to give aircraft the capability to fully utilize the benefits of Single European Sky.

As 2020 approaches, over 15 European industrial and research partners have renewed their commitment for continued and increased investment in research and technology. Industry foresees a continuation of the current *CleanSky* programme in the next European Research Framework Programme Horizon 2020 to run from 2014 to 2020.

Beyond 2020, there is a real need to work towards even wider-ranging R&D development goals, as laid out in ACARE's *Flightpath 2050*. This long-term vision places future R&D development at the heart of meeting aviation-related societal and market needs, maintaining industrial leadership as well as protecting the environment and the energy supply. To this end, ACARE's Strategic Research and Innovation Agenda is designed to ensure that *Flightpath 2050*'s goals of 75% reduction of CO_2 emissions, 90% reduction of NO_x emissions and 65% reduction of noise – compared to 2000 levels, can be met through adequate public and private support and funding.

CONCLUSION

Airframe and engine manufacturers will continue to deliver innovative designs that use new technologies which optimise both the economics and performance of their products for stakeholders in the markets they serve. Aircraft and aero-engine manufacturers must, however, seek a balanced approach when optimising their aircraft designs. Manufacturers need to identify technologies that are mature enough to help tackle all environmental issues at the same time, while seeking to minimise the trade-offs that have to be made as a result of the physical properties of the engine-airframe combination. This type of balanced approach is actively supported by ICAO, which seeks to continuously push for increased stringency on noise and NO_x emissions, and is currently working on creating a CO_2 standard for aircraft.

The industry also continues to work towards ambitious environmental targets. In 2008, operators, manufacturers, air navigation service providers and airports signed a commitment to a pathway toward carbon-neutral growth. In the short term, between 2010 and 2020, the aviation industry is committed to improving its fuel efficiency by an average of 1.5% per year. From 2020, the aviation industry is committed to cap its CO_2 emissions (CNG2020) at those levels, and by 2050, it plans to halve net emissions based on 2005 levels.

Over the past decade there have been at least eight new airliner programme launches, including the Airbus A350XWB, the Boeing 787, and Bombardier's C Series, with fuel efficiency gains of up to 25% per aircraft programme. Meanwhile, existing aircraft programmes are also continuously upgraded and retrofitted with design innovations and the latest technologies.

Billions of dollars are invested for R&D and hundreds of thousands of people around the globe, including research institutions and universities are working every day to deliver on these new technologies and innovations. Aviation is a global industry providing global solutions. The technology pipeline is full; we need now to ensure the market dynamics that enable operators and airlines to upgrade their fleets with the newest generation aircraft and technologies to most effectively reduce aviation's impact on the environment. ■

TECHNOLOGY

ICAO GOALS FOR AVIATION FUEL BURN REDUCTION FROM TECHNOLOGY

BY LOURDES MAURICE

LOURDES Q. MAURICE

She is the Executive Director for the Office of Environment and Energy (AEE-1) 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 Chief Scientific and Technical Advisor and previously 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.

This article was written in collaboration with the ICAO Secretariat and has been reviewed by the Independent Expert Panel on Fuel Burn technology.

BACKGROUND AND INTRODUCTION

The seventh meeting of the ICAO Committee on Aviation Environmental Protection (CAEP/7) held in February 2007 requested advice from Independent Experts (IEs) on the prospects for reduced aviation fuel burn from technology advances over the medium term (MT) and long term (LT), at specifically ten (2020) and twenty years (2030) into the future respectively. The assessment by the IEs of the reduction in aviation fuel burn from technology advances followed a two-step process: an industry led Fuel Burn Reduction Technology Workshop held in London UK in March 2009 followed by a formal Fuel Burn Reduction Technology Goals Review, held in Atlanta U.S. in May 2010 that was led by the IEs. The Fuel Burn Reduction Technology Independent Experts (IEs) nominated by various CAEP Members and Observers were:

The Independent Expert Panel for Fuel Burn

- Nick Cumpsty, UK (Chair)
- Juan J. Alonso, U.S.
- Serge Eury, France
- Lourdes Maurice, U.S.
- Bengt-Olov Nas, IATA
- Malcolm Ralph, UK
- Robert Sawyer, ICSA

The use of IEs is a method used by CAEP to assess technology goals, and has been used in the past for both Noise and NO_x technology goal setting. The task of assessing prospects for fuel burn reduction technologies and setting fuel burn goals was one of great complexity as, unlike Noise and NO_x, it considered an issue which is central to the competitive position of all stakeholders in the aviation industry. Furthermore, fuel burn does not lend itself to convenient demarcation between engines, airframes, aircraft mission specification and the way the aircraft is operated; all of these variables impact fuel burn and therefore need to be considered.

The policy importance of this particular IE review is clear. Many governments now advocate that to avoid the most dangerous climate change it will be necessary to hold temperature rise to less than about 2°C above pre-industrial values, and this is reflected in the UNFCCC Copenhagen Accord. To date, over half of the amount of CO_2, which corresponds to this temperature rise has been released. ICAO has continued to develop policies, standards, guidance and tools to facilitate fuel burn reductions through a basket of measures. Each element of the basket can be used towards achieving ICAO's collective global aspirational goals of improving annual fuel efficiency by 2% and stabilizing global CO_2 emissions at 2020 levels. This will require significant resources and investments to reduce emissions from the aviation sector. It is therefore important to understand what reductions in fuel burn and hence CO_2 emissions aircraft technology can be expected to deliver. To this end the IEs were tasked with the following:

- A review of the status of aircraft technology developments for fuel burn reduction;
- An assessment of potential fuel burn reductions in the future;
- Issuing recommended mid- and long- term fuel burn/efficiency technology goals at the overall aircraft level;
- An assessment of the possibility of success in achieving the mid- and long-term fuel burn/efficiency technology goals.

The outcome of the review was presented to CAEP in November 2010 and was published as an ICAO doucument[1], of which this article is a summary.

THE IE REVIEW APPROACH

Currently there is no existing ICAO Standard for fuel burn (and therefore CO_2) and so, at the time of the IE review, there was no prescribed ICAO metric by which fuel efficiency of an individual product could be measured. Given this, the IEs adopted a fuel burn metric for the purpose of their study, whilst recognising that discussions were ongoing within CAEP to choose a metric for setting a Standard for CO_2 emissions. For this study the metric used was "kilogram of fuel burned per available-tonne-kilometre (kg/ATK)", calculated at the maximum payload maximum range condition. This allowed the IEs to develop aeroplane reference points (*i.e.* the baseline) for each aeroplane category (mostly focused on Single Aisle and Small Twin Aisle aircraft types) in order to benchmark the technology potential for future time frames (*i.e.* 2020 and 2030). The baseline represented in-production technology of 2010, while recognising that the technologies embodied were mature and design decisions had been made long before. In practice the IEs judged the reference aircraft to embody, on average, technology that was available to aircraft designers in the year 2000 (based on A320-200/737-800 and A330-300/777-200ER and a High Growth Weight (HGW) version.).

The IEs concentrated on two aircraft categories, the Single Aisle (SA) and Small Twin Aisle (STA) aircraft in which, according to CAEP 2006 goals, 85% of the aviation fuel is burned. Additional modelling of Regional Jets (RJ) and Large Twin Aisle (LTA) categories was also carried by some of the organizations and research establishments involved in the Review. The Single Aisle category considered had a maximum payload maximum range (R1) of 2125 nm whilst the Small Twin Aisle had an R1 range of 5750 nm.

The IEs also adopted three Technology Scenarios (TS) for 2020 and 2030, which are intended to reflect a range of possible future scenarios and represent technology responses to increasing pressure for improvement dependent on, for example, a variety of future environmental pressures and fuel prices.

- TS1 – "Continuation": a continuation of the current trend of improvement, resulting from current market forces and environmental pressures.
- TS2 – "Increased pressure": increased pressure to incorporate more technologies to reduce fuel burn though still with "tube and wing" architecture.
- TS3 – "Further increased pressure": justifying more radical technology innovations and allowing "doing things differently" – including modest alterations to aircraft configuration and/or modest alterations to aircraft mission specifications. The open rotor applied to the single-aisle aircraft is included in this category.

The scenarios were used in conjunction with consideration of technologies as assessed for predicted level of impact (high, medium, low) and predicted likelihood of adoption (high, medium, low), with more technologies being assumed to be harvested when moving from 10 years to 20 years and from TS1 to TS3. The 10 year outlook was developed from TS2, and the 20 year outlook was developed from TS2 and elements of TS3.

Whilst the remit of the task was to develop goals that can be delivered through aircraft technology progress, there are significant inter-relationships with other variables: changing the specification of the mission or the aircraft can change the technologies available and the magnitude of the benefits produced. The IEs have considered that a large part of the benefit of improved technology introduced in the past has been used to improve the performance of the new aircraft, mainly range, rather than to reduce fuel burn per ATK. They therefore concluded it is essential to look at alterations in terms of aircraft mission specification, particularly for the longer term.

THE TECHNOLOGICAL POSSIBILITIES

During the industry-led London Workshop and the IE-led Atlanta Review, a number of organizations including DLR, Georgia Tech, ICCAIA, ICCT (part of ICSA), NASA and QinetiQ presented their evaluation of possible technologies for improving fuel burn. The resulting list of technologies was analysed using publicly available information, and was considered to be comprehensive with respect to technologies that could be utilized up to 2030. The technologies were grouped according to their impact on five aircraft performance parameters that affect fuel burn, as follows:

- Thermodynamic propulsion efficiency;
- Propulsive efficiency (includes transfer efficiency of the LP turbine and fan);
- Viscous drag;
- Induced non-viscous drag;
- Structural weight.

Out of all the technologies considered, two particular technologies stood out with large potential benefits: (1) for propulsion the Open Rotor and (2) for reducing aircraft drag, hybrid laminar flow control. These two concepts or technologies each offer a large fuel burn improvement. Although they are both feasible, it is still not clear that they will be used in the future, and especially across the full range of aircraft sizes and missions.

> The "Open Rotor" could improve the fuel burn by roughly 10% relative to a new turbo-fan engine, but with a potential penalty on noise. The concept is feasible and has already flown as a demonstrator. If Open Rotors were used for twin aisle aircraft with an

	Single Aisle (SA)					Small Twin Aisle (STA)				
	2020	**2030**	**2020**	**2030**	**2030**	**2020**	**2030**	**2020**	**2030**	**2030**
	TS1	**TS1**	**TS2**	**TS2**	**TS3**	**TS1**	**TS1**	**TS2**	**TS2**	**TS3**
Propulsive efficiency	13	14	14	15	28*	6	9	7	10	12**
Thermodynamic efficiency	3	4	4	5	3*	2	3	3	4	5**
Induced non-viscous drag	2	4	4	6	7	2	4	4	6	7
Viscous drag	2	4	4	7	9	2	6	4	8	10
Structural weight	10	15	15	20	20*	10	15	15	20	25**

* With Open Rotor compatible with the level of thrust of SA
** Without Open Rotor, which is judged incompatible with the high thrust requirement of twin engine STA

***Table 1:** IE Assumptions for Expected Per Cent Improvements in Propulsion, Aerodynamic, and Structural Efficiencies in Each Technology Scenario, Time Frame and for the Two Aircraft Categories (SA and STA). The Percentage Changes Refer to the Parameters Listed in the Table Relative to the Year 2000 Technology Baseline.*

acceptable diameter of propeller, four engines would be required. When taken into account, the Open Rotor was given a benefit of 13% in propulsive efficiency but a penalty of 2% on thermal efficiency and 5% on global weight for the aircraft. It may be noted, however, that if some reduction in cruise Mach number were allowed, single rotor propellers could be used, which is already a proven technology avoiding many of the complexities and the noise concerns of the twin rotor.

The "hybrid laminar flow control" could reduce drag by roughly 10%. The concept is also feasible and some demonstrations in flight have already been made. The uncertainties of the concept are linked to the real weight of the aspiration system, to the behaviour of the aspiration holes versus time in operation due to pollution and dirt, and to the real possibilities of easy and cheap cleaning on ground. If "hybrid laminar flow control" will not be practically feasible, then natural laminar flow could be implemented for SA aircraft, but extensive natural laminar flow for bigger STA types is improbable, though possible. In the natural laminar flow case the assumption of drag improvement at 2030 in scenarios TS2 and TS3 should be reduced by at least 5% relative to hybrid laminar flow.

The global evaluation of technological possibilities was based on the "engineering judgement" of the IEs. **Table 1** shows, for each of the five aircraft performance parameters, an evaluation of the potential progress for the entire category taking into account the fact that not all of the potential progress on the various technologies would be attained. These data were used to re-size and re-optimize aircraft, in order to model their fuel burn performance.

MODELLING AND ANALYSIS

Different conceptual-aircraft analysis and design optimization tools were used to calculate the effectiveness of new technologies aimed at reducing fuel burn. Several organizations agreed to supply modelling data to supplement the IEs own analysis which was carried out by Stanford University (using the PASS program). These institutions include DLR (using the PrADO software), ICCT (using the PIANO tool), Georgia Tech (using the EDS system) and QinetiQ (also using the PIANO tool). The four tools used by these organizations all target the conceptual analysis and design of current and future tube-and-wing configurations, and aim at providing information that is appropriate for conceptual-level assessment of aircraft designs and the technologies that are used in those designs. The results supplied by the different organisations agreed sufficiently closely to confirm the trends and estimates of fuel burn used in setting the goals. These data and analysis underpin the resulting IE fuel burn technology goals.

THE FUEL BURN TECHNOLOGY GOALS

TS1 is believed to represent what would happen with continued and consistent funding and dedicated programs, and without additional pressure other than market forces: TS1 does not therefore represent a goal. TS2, however, does represent a clear challenge. Therefore the goals from the IE review have been set as a band in kg/ATK below TS2, as shown in **Figure 1**, which shows two bands of kg/ATK anchored at the SA and STA reference aircraft (the anchor points are shown in **Table 2**) as a function of R1 range. These bands were derived by the panel of experts for the MT (10 year) and the LT (20 year) fuel burn technology goals.

For the 2030 goals the upper level corresponds to TS2 and the lower level to TS3, whilst for the 2020 goals the upper level is TS2 and the lower level a further reduction of 4%.

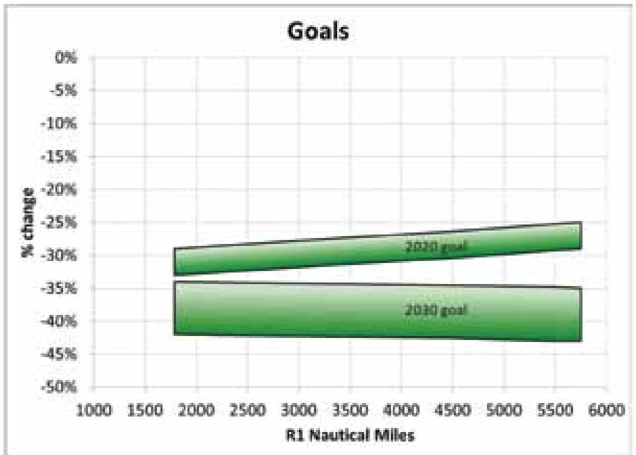


***Figure 1:** MT 10 Year and LT 20 Year Fuel Burn Technology Goals Versus Maximum Payload Maximum Range R1.*

	2020		**2030**	
	SA	**STA**	**SA**	**STA**
TS1	23	19	29	26
TS2	29	25	34	35
TS3			41	41
TS3 Open Rotor			48	

***Table 2:** Estimated Per Cent Reduction in Fuel Burn Metric at the SA and STA Anchor Points Relative to 2000 Technology Baseline at Maximum Payload Maximum Range.*

As with other ICAO goal setting efforts, expressing goals in terms of bands accounts for uncertainties, and the goals represent levels of potential achievement by the industry, not individual companies or designs. There is also an inherent assumption of sufficient funding to develop, mature and commercialize the technologies. However, the underlying technologies or different aircraft configurations considered in setting the goals are firmly based on those presented by the industry during the IE review. In addition, altered aircraft mission specifications, grounded in analyses, were used to explore potential additional gains in fuel efficiency. These in turn increase the likelihood of meeting the predicted goals from technology and hence influenced the goal setting.

Achieving the fuel burn technology goal was defined by the IEs as being below the upper line of the TS2 band, but additional progress would be indicated by moving down towards the TS3 line and the band has been included to indicate what level of further progress might be possible.

The IEs felt that reaching the level corresponding to TS2 by technology alone was possible though by no means certain, but, when coupled with the potential arising from the changes in aircraft mission specification and aircraft configuration, the probability of achievement is substantially higher. Therefore the goal will be said to have been achieved in 2020 if the fuel burn reduction relative to the 2000 technology baseline exceeds 29% for the SA reference aircraft and exceeds 25% for the STA aircraft with suitable interpolation and extrapolation for other aircraft categories. In 2030 the goal will be achieved with similar interpolation across the range of aircraft from single- to twin-aisle aircraft if the reduction exceeds 34% to 35% relative to the 2000 technology baseline. A 35% reduction by 2030 corresponds to an annual compound reduction of about 1.4%, which may be compared with the ICAO aspirational goal of 2% per annum fuel efficiency improvement out to 2050, though it should be noted that because major technology improvements come in large but infrequent increments, the IEs expressed reservations about using compound annual rates. The ICAO aspirational goal relates to the entire commercial aircraft/air-traffic system as a whole, whereas the IEs have only considered individual aircraft design and only its technology aspect. The modelling by the IEs and other organisations confirms the view that technology on its own is not able to deliver the reductions required by the ICAO goals.

Further reductions are possible and the ultimate goal for 2030 with TS3 could be as large as 41% with a turbofan engine or 48% if open rotors were used. In addition, it has been found that quite modest changes in design Mach number, design range and wing span (the latter having an effect on airport layout) can lead to additional savings which are comparable to a change in TS level from 1 to 2 or from TS2 to TS3.

BEYOND 20 YEARS - ACHIEVING GREATER AMBITION 2030-2050

The Copenhagen Accord noted that to avoid the most dangerous climate change it will be necessary to hold temperature rise to less than 2°C above pre-industrial values.[2] The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) indicates that to achieve this goal will require global greenhouse gas emissions to be 50% to 80% lower in 2050 than in 2000, and to begin declining by 2015.[3] Hence there is a period beyond the 20 year, (2030) goal where there is a need for a further reduction. Technologies and concepts not taken into consideration in setting the 20 year LT goal could become viable beyond 2030 and contribute toward meeting the challenging aspirational goals the aviation industry is trying to achieve in order to mitigate its impact on the earth's climate. However, even this ambition from technology to fuel burn reduction is unlikely to keep up with even the *least* ambitious growth scenarios. Meeting the system goals will require continued advances in operations and air traffic management.

CONCLUSIONS AND RECOMMENDATIONS

As a result of the IE work a number of conclusions and recommendation were drawn:

- The 2020 goal would be met if an aircraft at maximum payload maximum range achieves a reduction in excess of between 29% and 25% (with the former anchoring the band for the SA size and the latter for the STA) relative to baseline aircraft of 2000. For 2030 the goal would be achieved if the corresponding reduction were between 34% and 35% (with the former anchoring the band for the SA size and the latter for the STA) relative to baseline aircraft of 2000.
- The IEs recommend that when the ICAO CO_2 Standard certification procedure has been agreed to, the goals should be re-examined. This should also include the regional jet and the large twin-aisle.
- The IEs also believed that it is important to conduct system analyses to evaluate the contributions of various strategies toward meeting these goals, particularly the overall system effects of changes in Mach number and design ranges, including potential effect on number of operations, which could affect safety, operating costs, noise exposure and air quality impacts.
- The present study would have been virtually impossible without the IEs having direct access to modelling capability. It is recommended that for any future fuel burn review carried out by IEs, it is ensured that the team has access to modelling capability and appropriate resources to use it.
- Any future review should consider for the purposes of transparency, and in order to monitor progress, the separate and cumulative effects, on fuel burn goals, of new technology and changes to aircraft capability and mission specification.
- Based on the knowledge gained the IEs recommend that any future review has as one of its members someone familiar with the business of taking potential new commercial aircraft from concept through to delivered products.
- The present review was carried out entirely by IEs from Western Europe and the U.S., and it is recommended that any further review should have wider geographical representation. ■

REFERENCES

1 International Civil Aviation Organization, Doc 9963. (2010). *Report of the Independent Experts on the Medium and Long Term Goals for Aviation Fuel Burn Reduction from Technology, Montreal.*

2 www.denmark.dk/en/menu/Climate-Energy/COP15-Copenhagen-2009/cop15.htm

3 IPCC-Synthesis. (2007). *Climate Change 2007 Synthesis Report: Summary for Policymakers. Contributions of Working Groups I, II, and III to the Fourth Assessment Report of the IPCC.* Geneva, Switzerland: Intergovernmental Panel on Climate Change.

TECHNOLOGY

DEVELOPMENT OF AN ICAO AEROPLANE CO_2 EMISSIONS STANDARD

BY **STEVE ARROWSMITH** AND **MIKE SAMULSKI**

STEVE ARROWSMITH

As an Environmental Protection Officer at the European Aviation Safety Agency (EASA), he has over 15 years of experience working in industry and aviation authorities on environmental certification requirements and regulatory impact assessments. He has led various type certification and rulemaking projects, including work within ICAO CAEP Working Group 3 (WG3) that resulted in a new aircraft engine NO_x emissions standard at CAEP/8. Mr. Arrowsmith is currently co-Lead of the WG3 CO_2 Task Group which is responsible for developing the ICAO aeroplane CO_2 standard.

MIKE SAMULSKI

Mike Samulski directs the Large Marine and Aircraft Center within the Office of Transportation and Air Quality of the U.S. Environmental Protection Agency. Although Mr. Samulski has only been serving in ICAO CAEP Working Group 3 for two years, he has more than two decades of experience in developing domestic and international air pollution standards, including work at the International Maritime Organization. Mr. Samulski is currently co-Lead of the WG3 CO_2 Task Group which is responsible for developing the ICAO aeroplane CO_2 standard.

This article was written in collaboration with the ICAO Secretariat.

INTRODUCTION

ICAO's Committee on Aviation Environmental Protection (CAEP) is currently focussed on developing an Aeroplane Carbon Dioxide (CO_2) Emissions Standard which was one of the recommendations that came out of the ICAO Programme of Action on International Aviation and Climate Change in 2009[1]. This was part of a "basket of measures" to reduce greenhouse gas emissions from the air transport system. The 37th Assembly (Resolution A37-19) subsequently requested the development of an ICAO CO_2 Emissions Standard in 2010. Over the past three years the CAEP, through its Working Group 3 – Emissions Technical (WG3), has conducted a significant amount of work towards this end.

The CO_2 Standard will consist of a certification requirement and regulatory limit (see **Figure 1**) and the work to develop the Standard has been divided in two phases. Phase 1, which was completed and approved at the ninth meeting of the CAEP (CAEP/9) in February 2013, resulted in the approval of some of the details regarding the applicability of the Standard, in the delivery of a CO_2 Metric System and the development of a mature CO_2 Standard certification requirement. During Phase 2, which was well-underway by mid-2013, the CAEP aims to complete the CO_2 Standard by developing the regulatory limit and final applicability requirements such as scope and date. This article summarises the work undertaken during Phase 1.

Figure 1: *The Framework of the CO_2 Standard.*

APPLICABILITY OF THE CO_2 STANDARD

One of the first Phase 1 decisions made by the CAEP was taken in November 2010 when it was agreed that the future CO_2 Standard will be applicable to subsonic jets and turboprops with a weight threshold of Maximum Take-Off Mass (MTOM)>5700kg (12566lb) for subsonic jet aeroplanes and MTOM>8618kg (19000lb) for propeller driven aeroplanes. This represented more than 99% of global fuel burn, flight distance, and operations. Agreements were also reached to include "new", but not "out of production", aeroplane types within the scope of applicability. It was also agreed that new "in-production" types should not be ruled out at this time.

DEVELOPING A CO_2 METRIC SYSTEM

In order to develop a global ICAO CO_2 Standard, it was essential that a way of measuring aircraft CO_2 emissions be determined. Consequently, the selection of a CO_2 metric system, which will underpin the CO_2 Standard, was a crucial milestone in the work programme. To help make this selection, WG3 developed Key Criteria (KC) and High-Level Principles (HLP) as a basis for evaluating a large list of proposed CO_2 metric systems, which included metrics, correlating parameters and test points. This assessment took the form of both qualitative and quantitative analyses, and required WG3 to develop an understanding of how to account for the KC and HLP within a metric system, and their potential trade-offs.

The HLP state that, within the basket of measures, an aeroplane CO_2 Standard should focus on reducing CO_2 emissions through the integration of fuel efficiency technologies (*i.e.* structural, propulsion and aerodynamic) into aeroplane type designs. The aim was to design a metric system (which includes a metric, a correlating parameter and test points) which will permit transport capability neutrality at a system level and allow for equitable recognition of fuel efficiency improvement technologies in an aeroplane type design.

A Transport Capability Neutral Metric System
In a transport capability neutral metric system aeroplane types with diverse transport capabilities (*e.g.* payload, range), but similar levels of fuel efficiency technology/ design, have similar margins to the regulatory limit.

The KC were grouped into six areas, in total containing 15 statements to guide the CO_2 metric system development (see **Figure 2**). For example, *inter alia*: under "*Effective*", improvements observed via the CO_2 certification requirement should correlate with reduction of CO_2 emissions at the aeroplane level as demonstrated by procedures which are relevant to day-to-day operations; under "*General*", the CO_2 certification requirement should be aeroplane performance-based, and should reflect CO_2 emissions at the aeroplane level. It should also allow for the differentiation of products with different generations of CO_2 reduction technologies and should aim to be independent of aeroplane purpose or utilization; As another example of a KC, under "*Robust*" the metric should minimise the potential for unintended system and aeroplane design consequences, limit interdependencies and limit any influence on other standards.

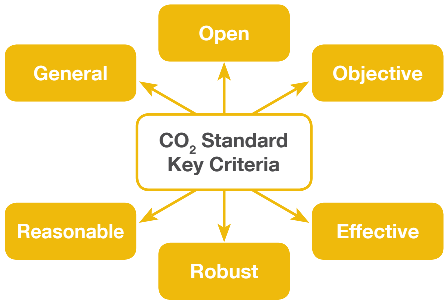


Figure 2: *The Key Criteria to Assess the CO_2 Metric System.*

Working Group 3 recognised that a balance was required between the KC and HLP, and that there was no one metric system which would perfectly satisfy all elements. This balance was found on 11 July 2012 when the CAEP Steering Group agreed unanimously on a CO_2 metric system to measure the aeroplane fuel burn performance and therefore the CO_2 emissions produced by an aeroplane.

THE BASICS OF THE CO_2 METRIC SYSTEM

To establish the fuel efficiency of an aeroplane, the CO_2 metric system uses "1/Specific Air Range" (1/SAR) at multiple test points to represent fuel burn performance during cruise. Three equally weighted points are used to represent aeroplane weights at high, middle and low percentages of MTOM, and each of these represents an aeroplane cruise gross weight that could be seen in service (see **Figure 3**). The objective of using three gross weight cruise points is to make the evaluation of fuel burn performance more relevant to day-to-day aeroplane operations.

Specific Air Range (SAR)
The fuel efficiency performance of an aeroplane is represented by 1/Specific Air Range (1/SAR), which represents the distance an aeroplane travels in the cruise flight phase per unit of fuel consumed.

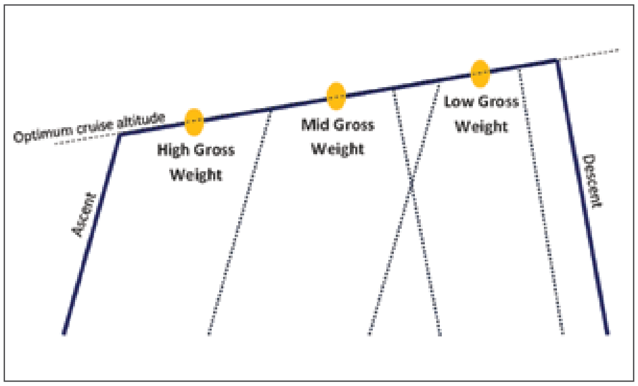


Figure 3: *An Illustrative Example of the Three Representative Cruise Points.*

In some aeroplane designs there are instances where changes in aeroplane size may not reflect changes in aeroplane weight, such as, when an aeroplane is a stretched version of an existing aeroplane design. To better account for such cases, not to mention the wide variety of aeroplane types and the technologies they employ, an adjustment factor was used to represent aeroplane size. This is defined as the Reference Geometric Factor (RGF), described in **Figure 4**, and is a measure of aeroplane fuselage size. Including this factor, improved the performance of the CO_2 metric system, making it fairer and better able to account for different aeroplane designs.

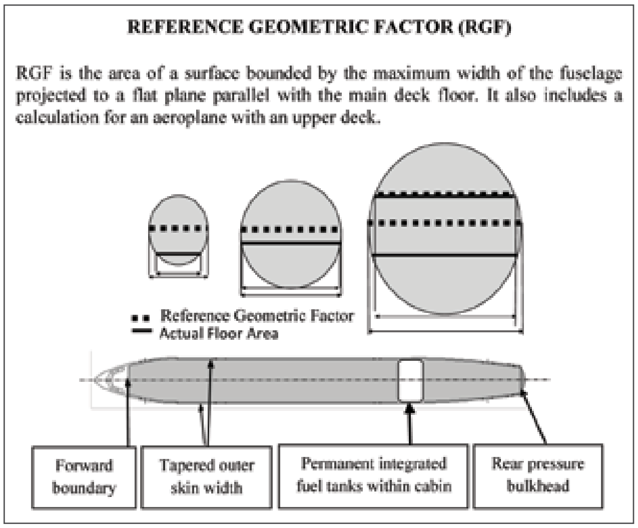


Figure 4: *A notional example of the Reference Geometric Factor.*

The overall design of the aeroplane is represented in the CO_2 metric system by the certified MTOM. This accounts for the majority of aeroplane design features which allow an aeroplane type to meet market demand.

The development of the CO_2 metric system was a critical step towards the finalisation of a full Aeroplane CO_2 Emissions Standard. It is based on extensive and consensus-based technical analyses and discussions over the past three years within the CAEP. The progress made over the past three years did not end here, and based around the CO_2 metric system, WG3 moved on to develop the certification procedures to underpin a mature CO_2 Standard certification requirement.

THE CERTIFICATION REQUIREMENT

Based on the CO_2 metric system the CAEP developed procedures for the certification requirement including, *inter alia*, the flight test and measurement conditions; the measurement of SAR; corrections to reference conditions; and the definition of the RGF used in the CO_2 emissions metric. The CAEP established and utilised a Certification Expert (CE) group to support the discussions on the certification requirement, and to facilitate oversight of commercially sensitive information. The CE group identified the manufacturers' existing practices in measuring aeroplane fuel burn and high speed performance in order to understand how current practices could be leveraged and built upon. Based on this information, a mature CO_2 Standard certification requirement, to be included as Volume III to Annex 16[2], was developed and this was approved by the CAEP/9 meeting in February 2013.

Recognising that the work on the certification procedures has progressed at a rapid pace with limited access to data, a number of additional work items have been identified which when completed will help reinforce the certification requirement and ensure a smooth implementation in Type Certification projects once adopted by ICAO and its Member States. These include: stability criteria and confidence intervals; methodologies to correct test data to reference conditions; extrapolation of data; fuel used in SAR flight tests; verifying test aeroplane mass determination; demonstrating nominal operating values for power extraction; RGF for unpressurised aeroplanes; numerical model confidence intervals; correction of engine fuel efficiency performance; and alternatives to ground speed. With these current tasks in mind it is true to say that the CO_2 Standard certification requirement is currently a work in progress.

THE WAY FORWARD

The work to finalise the CO_2 Standard continues into Phase 2, and in order to complete the aeroplane CO_2 Standard, the following three work items will be addressed:

1. Definition of a no-change criteria to avoid having to recertify aeroplanes after small modifications;
2. Applicability requirements in order to clearly define if, and when, the new CO_2 standard is applicable to "new" aeroplane types and possibly new "in-production";
3. Regulatory limit.

Phase 2 work will include the assessment of stringency options for “new” aeroplane types, but not “out of production”, with applicability dates of 1 January 2020 and 1 January 2023. In addition, proposed stringency options, applicability requirements, and applicability dates will also be assessed for new “in-production” aeroplane types. It has been agreed, in principle, that the CO_2 Standard should only be applied to the highest of all certificated MTOMs for the specific airframe/engine combination, and any other MTOM for which CO_2 emissions certification is requested by the applicant. This is on the basis that the highest mass variant will have the smallest margin to the regulatory limit, while all lower mass variants would automatically comply. This will all be verified during Phase 2 of the CO_2 Standard work.

The complexity of the CO_2 Standard work has been significant from both the technical and political perspectives, and along with the commercial sensitivity of the topic, this has resulted in the development of the CO_2 standard taking longer than originally envisaged. To move forward and to build on the significant progress made, the CAEP reviewed a comprehensive work plan for the CO_2 Standard setting process and agreed on a late-2015 deliverable date, in time for approval by the tenth meeting of the CAEP (CAEP/10) in 2016. ■

REFERENCES

1 ICAO Programme of Action on International Aviation and Climate Change, www.icao.int/environmental-protection/Pages/programme-of-action.aspx, 2009.

2 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*. This Annex at present consists of two volumes, viz., Volume I: Aircraft Noise and Volume II: Aircraft Engine Emissions.

OPERATIONS

OPERATIONAL IMPROVEMENTS TO REDUCE GLOBAL EMISSIONS

BY ICAO SECRETARIAT

INTRODUCTION

Operational improvements are an important element of the basket of mitigation measures to limit or reduce CO_2 emissions from international aviation. Assembly Resolution A37-19 requested that ICAO undertake further work to develop and facilitate the implementation of operational measures, including the development of tools to assess the benefits associated with air traffic management (ATM) improvements and guidance material on operational measures to reduce international aviation emissions.

The ICAO Committee on Aviation Environmental Protection (CAEP) continues to serve as the key technical forum for the development and enhancement of guidance on operational opportunities to save fuel and reduce emissions, as well as methodologies to assess the environmental benefits accrued from changes in operational measures. At its ninth meeting (CAEP/9) in February 2013, CAEP recommended a new set of guidance materials and tools that will provide States and the aviation community with state-of-the-art information on these areas.

GUIDANCE AND TOOLS

ICAO has put significant effort in delivering meaningful guidance and practical tools to support the assessment of environmental benefits related to operational measures.

Leading to CAEP/9, Working Group 2 – Airports and Operations (WG2), which undertakes work to address aircraft noise and emissions linked to airport and aircraft operations, was tasked with completing two crucial ICAO publications (see article *Two New Manuals on Reducing Emissions using Enhanced Aircraft Operations*, Chapter 4 in this report).

The first was an update to ICAO Circular 303, which is to be published as a new ICAO manual entitled, *Operational Opportunities to Reduce Fuel Burn and Emissions*. The new manual contains information on current operational practices being implemented by aircraft operators, airport operators, air navigation service providers (ANSPs), other industry organizations and ICAO Member States. It includes information on airport operations, maintenance, weight reduction, the effect of payload on fuel efficiency, air traffic management, flight and route planning, and other aircraft operations.

The second publication contains guidance material on conducting CNS/ATM environmental assessments, to be issued as the new ICAO manual, *Environmental Assessment Guidance for Proposed Air Traffic Management Operational Changes*. This document focuses on environmental impact assessments (including both engine emissions and noise), related to proposed changes to operational procedures, airspace re-designs, and other related operational aspects. The information contained in this new guidance document was made available to States in 2011 on a preliminary basis to assist in the development of State action plans on CO_2 emissions reduction activities.

The ICAO Secretariat has continued to create new tools to assess the environmental impact of international aviation operations. Most recently, the ICAO Fuel Savings Estimation Tool (IFSET) was developed by the Secretariat, with support from States and international organizations, to estimate fuel savings resulting from the implementation of operational measures, in a manner consistent with the models approved by CAEP, and in line with the ICAO Global Air Navigation Plan (GANP). IFSET is not intended to replace the use of detailed measurement or modelling of fuel savings, where those capabilities exist. Rather, it is provided to assist those States without such capabilities to estimate the benefits from operational improvements in a harmonized way. In addition, this tool can be used by States in the development of their action plans on CO_2 emissions reduction activities (see article *States' Action Plans to Reduce Aviation CO_2 emissions*, Chapter 5 in this report).

FUEL BURN OPERATIONAL GOALS

Consistent with its mandate to develop fuel burn operational goals, CAEP's Independent Experts on Operational Goals Group (IEOGG) undertook a comprehensive review of the operation of civil aircraft, across all gate-to-gate phases of a flight, both in the air and on the ground, in order to develop challenging aspirational operational environmental goals. During the CAEP/9 meeting, operational goals for fuel burn (for 2020, 2030 and 2040) were recommended (see article *Impacts of Operational Changes on Global Emissions Level - Finding of the Operations Goals Group*, Chapter 4 in this report).

These operational goals represent fuel savings that can be achieved by new operations, and reflect the percentage of fuel usage and emissions that can be reduced relative to 2010 by eliminating inefficient operational practices. To be achieved, they also require technology investments and changes in policies. The operational goals are 3.25% in 2020, 6.75% in 2030, and 9% for 2040. CAEP/9 agreed to publish the fuel burn operational goals, which were included in the future CAEP environmental trends analysis as a new scenario (see article *Environmental Trends in Aviation to 2050*, Chapter 1 in this report).

ASBU STRATEGY

A key challenge for the aviation community in recent years has been to prioritize and build consensus around the latest technologies, procedures and operational concepts. This is because such a wide variety of national and regional ATM modernization programmes have been emerging worldwide. The multidisciplinary and interrelated aspects of these modernization efforts require ongoing collaboration among stakeholders representing every aspect and component of the international air transport system.

In an effort to assist with this effort, ICAO has developed the Aviation System Block Upgrade (ASBU) strategy. Created with its industry partners and based on extensive feedback from States, this strategy forms a critical element of the implementation planning mechanism of ICAO's Global Air Navigation Plan.

This also includes work by CAEP to develop a compendium of illustrated "best practice" environmental assessment case studies that demonstrate the application of the principles outlined in the document *Environmental Assessment Guidance for Proposed Air Traffic Management Operational Changes* (see article *ICAO Block Upgrades*, Chapter 4 in this report). ■

OPERATIONS

ICAO BLOCK UPGRADES

Minimizing Adverse Environmental Effects of Civil Aviation Activities

BY ICAO SECRETARIAT

Air traffic growth expands two-fold every 15 years[1]. If not properly supported by the necessary regulatory and infrastructure framework, this kind of growth can lead to an increase in safety risks and negative environmental impacts. A careful balance between these factors is critical for maintaining continued air traffic growth. The real challenge for the aviation community lies in achieving safety and operational improvements on a globally harmonized basis, while being environmentally responsible and cost-effective.

In order to meet this challenge, ICAO collaborated with States, industry and international organizations to develop the Aviation System Block Upgrades (ASBU) concept. This concept aims to ensure that aviation safety is maintained and enhanced, that air traffic management improvement programmes are effectively harmonized, and that barriers to future aviation efficiency and environmental gains are removed, at reasonable cost.

As shown in **Figure 1**, at the core of the Block Upgrade concept is a pragmatic system of Modules – each one comprised of technologies and procedures that are organized towards achieving a specific performance capability. Each of these modules is then linked to one of four specific and interrelated performance improvement areas: airport operations; globally interoperable systems and data; optimum capacity and flexible flights; and efficient flight paths. This concept allows for a flexible global systems approach, enabling all States to advance their Air Navigation capabilities based on their specific operational requirements.

The implementation of many of these modules can minimize the adverse environmental effects of civil aviation activities. For example, modules that allow for improved flexibility and efficiency in descent and departure operations significantly reduce fuel burn and therefore provide fuel savings and reduced CO_2 emissions.

Modules which apply the concept of continuous descent operations (CDO) feature optimized profile descents that allow aircraft to descend from the cruise to the final approach to the airport at minimum thrust settings. Besides the significant fuel savings achieved, CDO decrease aircraft noise levels, significantly benefiting local communities. In addition to the general benefits in this regard, derived from less thrust being employed, the use of performance-based navigation (PBN) ensures that the lateral path can also be routed to avoid more noise-sensitive areas.

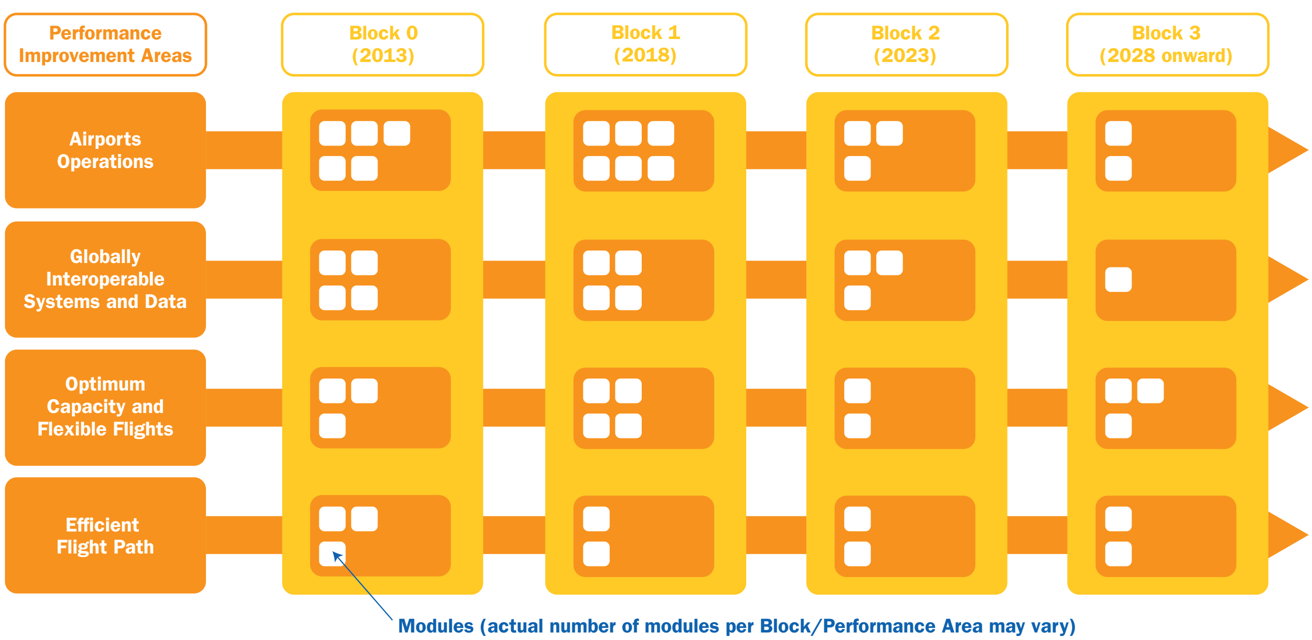


Figure 1: *Aviation System Block Upgrade Methodology.*

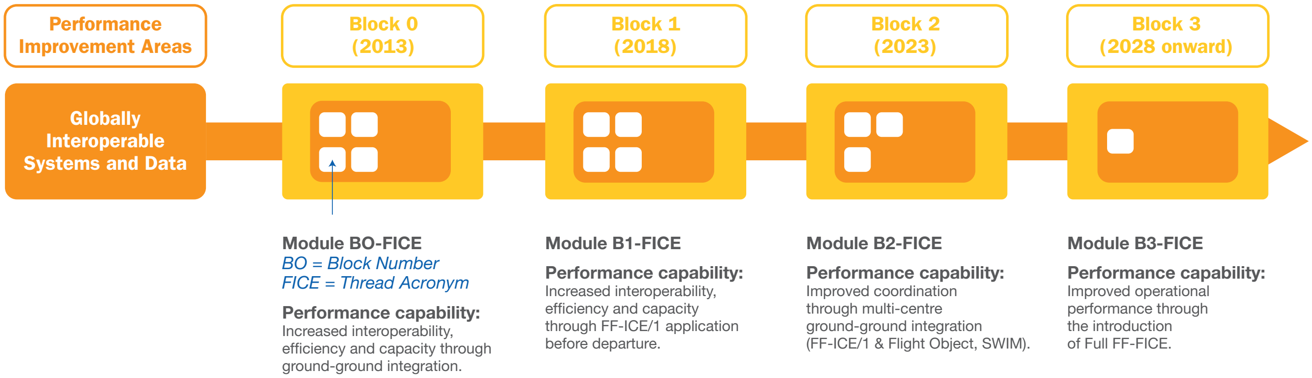


Figure 2: *Example of a Performance Improvement Area and the Associated Modules.*

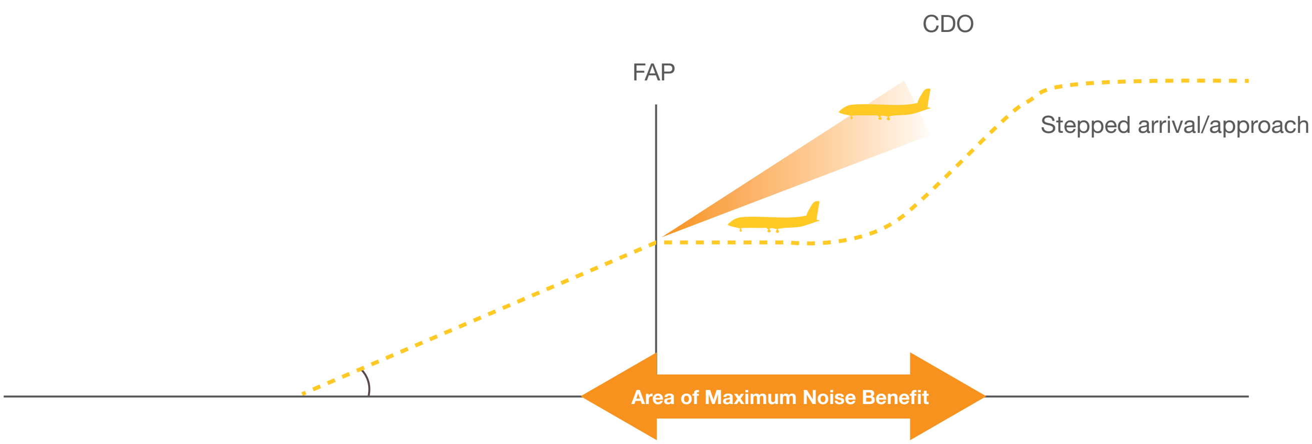


Figure 3: *Example of a Continuous Descent Operation (CDO).*

As depicted in **Figure 3**, CDOs feature optimized profiles that allow aircraft to descend from high altitudes to the airport at minimum thrust settings, thus decreasing noise in local communities and using up to 30% less fuel than standard "stepped" approaches.

Continuous climb operations (CCO) do not require a specific air or ground technology. They are derived from aircraft operating techniques aided by the appropriate airspace and procedure design. Since a large proportion of fuel burn occurs during the climb phase, enabling an aircraft to reach and maintain its optimum flight level without interruption will optimize fuel efficiency and reduce emissions. CCO can also provide for a reduction in noise, while increasing flight stability and the predictability of flight paths for both controllers and pilots.

Another good example is the use of collaborative decision-making (CDM) to improve airport operations, also known as A-CDM. Modules relating to A-CDM allow for the implementation of a collaborative set of applications and permit the sharing of surface operations data among the different operators at the airport. A-CDM aims to improve the management of surface traffic, leading to reduced delays on movement and maneuvering areas. Apart from the enhanced safety, efficiency and situational awareness gained, A-CDM contributes to reduced taxi time, reduced fuel and carbon emissions, and reduced aircraft engine run time.

Several other modules are expected to deliver benefits through fuel savings and reduced CO_2 emissions. The Committee on Aviation Environmental Protection (CAEP) has undertaken an initiative to quantify these reductions, in order to provide States and stakeholders with a better assessment of the expected environmental benefits. ■

REFERENCE

1 Global Air Navigation Capacity & Efficiency Plan – 2013–2028, ICAO; Source Airbus.

OPERATIONS

TWO NEW ICAO MANUALS ON REDUCING EMISSIONS USING ENHANCED AIRCRAFT OPERATIONS

BY KEVIN MORRIS AND SHANNON SCOTT

KEVIN MORRIS

He has been involved with the aerospace industry since 1980, with the last 25 years focussing on the environmental impacts of aviation, and is a Council member of the UK's "Sustainable Aviation". Currently Environment Manager at ADS, Kevin spent 21 years at British Airways dealing with aircraft performance, noise and local air quality issues, developing BA's BEAM emissions model. Before that he was an aerodynamicist at British Aerospace, Hatfield. With both ICCAIA and IATA, Mr. Morris has been involved with CAEP since 1991 contributing to the original ICAO Circular 303, the Airport Air Quality Manual, and recently led the group that developed the "Environmental Assessment Guidance for Proposed Air Traffic Management Operational Changes".

SHANNON SCOTT

He is a Senior Policy Advisor at the Civil Aviation Authority of New Zealand (CAA), which he joined in 2009. He is the New Zealand Observer on CAEP, and led work on the Manual on Operational Opportunities to Reduce Fuel Burn and Emissions, the replacement to ICAO Circular 303, from 2011 to its completion in 2013. Mr. Scott joined the CAA from the former New Zealand Ministry of Research, Science and Technology, where he was responsible for developing international science cooperation programmes with partners in North Asia. He has degrees in Geography (with a Climatology focus) and Chinese.

The structure of the Committee on Aviation Environmental Protection (CAEP[1]) leading to the ninth meeting of CAEP (CAEP/9) consisted of three specialized Working Groups (see article *Committee on Aviation Environmental Protection: Outcomes from CAEP/9*, Introduction in this report).

During the last CAEP cycle, Working Group 2 Airports and Operations (WG2), which undertakes work to address aircraft noise and emissions linked to airport and aircraft operations, was tasked with completing two crucial ICAO publications[2]. The first was an update to ICAO Circular 303, which is to be published as a new ICAO manual titled, "*Operational Opportunities to Reduce Fuel Burn and Emissions*". The second publication was guidance material on conducting CNS/ATM[3] environmental assessments, to be issued as the new ICAO manual, "*Environmental Assessment Guidance for Proposed Air Traffic Management Operational Changes*".

BACKGROUND

At the eighth meeting of CAEP (CAEP/8) in February 2010, WG2 was tasked with the completion of updates to chapters previously contained in ICAO Circular 303. Four chapters were completed and approved at the CAEP Steering Group meeting in November 2010. Then in September 2011, it was decided to make the approved chapters available on the ICAO public website. The draft manual was subsequently reviewed by the ICAO Operations Panel (OPSP), which reports to the Air Navigation Commission (ANC).

In addition, two tasks initiated at the CAEP/8 meeting in 2010 aimed at the development of CNS/ATM environmental assessment guidance material, with an associated programme plan. These tasks were directed towards WG2, and were completed at CAEP/9 in February 2013.

The first of these tasks was to draft a programme plan to develop CNS/ATM environmental assessment guidance material. The plan required compiling information on current best practices in use for environmental assessments and identifying high-level guiding principles to inform States, airports, Air Navigation Service Providers (ANSPs) and others. The second task was to draft the actual guidance document itself, including the CNS/ATM environmental assessment guidance material, information on environmental assessment best practices, and high-level principles.

MANUAL: "*OPERATIONAL OPPORTUNITIES TO REDUCE FUEL BURN AND EMISSIONS*"

Introduction

In 2004, ICAO published Circular 303, *Operational Opportunities to Minimize Fuel Use and Reduce Emissions*. That circular, developed by CAEP, reviewed a wide range of operational opportunities and techniques for minimizing fuel consumption, and therefore reducing emissions, in civil aviation operations. It was based on the premise that the most effective way to minimize aircraft emissions is to minimize the amount of fuel used in operating each flight. The circular was aimed at airlines, airport operators, air traffic management and air traffic control service providers, airworthiness authorities, environmental agencies, other government bodies, and other interested parties, and has since become an essential reference document.

Since the publication of Circular 303, the aviation industry has developed and implemented many new techniques to reduce fuel usage. As a result, CAEP agreed to update the material in Circular 303 and convert it into a new ICAO manual.

To undertake that task, CAEP established a multi-disciplinary team comprised of experts from States, the airport sector, airline sector, air navigation service providers (ANSPs), aircraft manufacturers, other industry organizations, and the ICAO Secretariat. The resulting ICAO manual, titled "*Operational Opportunities to Reduce Fuel Burn and Emissions*", will replace Circular 303 when it is published.

The New Manual

The manual contains information on current practices followed by aircraft operators, airport operators, ANSPs, other industry organizations, and States. The information is intended to help any group that uses it to reduce fuel use and emissions from civil air transport.

The objectives of the manual are to:

a) Document industry experience and the benefits in terms of reduced emissions resulting from optimizing the use of current aircraft and infrastructure, and other related benefits of infrastructure improvements;
b) Identify improvements that could result in measurable fuel savings;
c) Demonstrate that the more efficient use of infrastructure is an effective means of reducing civil aviation emissions, and therefore promote the enhanced use of the capabilities inherent in existing aircraft, ground service equipment and infrastructure.

The manual is not intended to be the basis for regulatory action, and the particular choice of operational procedures can depend on many factors other than environmental benefits. For example, safety must always be the overriding consideration in all civil aviation operations. Another important consideration is that many operational opportunities require collaboration and cooperation among all civil aviation stakeholders for effective planning and implementation.

The structure of the manual features some differences from the original Circular 303. Three of the chapters from the circular were not incorporated into the manual, as they covered material that was considered to be better provided elsewhere. Chapters on the phases of flight were merged into a single chapter addressing opportunities across the full flight envelope.

The final manual reviews the fuel burn reduction opportunities related to:

- airports;
- maintenance;
- reducing the aircraft dry operating weight;
- air traffic management (ATM);
- across all phases of flight.

It also includes chapters on the effects of payload on fuel efficiency, and a review of flight planning and related issues from the aircraft operator's point of view, as well as background information with respect to global emissions and climate change issues.

Operational techniques and opportunities will continue to evolve into the future, and readers are encouraged to submit comments on the manual to ICAO. These comments will be taken into account in the preparation of subsequent editions.

MANUAL: "*ENVIRONMENTAL ASSESSMENT GUIDANCE FOR PROPOSED AIR TRAFFIC MANAGEMENT OPERATIONAL CHANGES*"

Introduction

At CAEP/8 in 2010, it was agreed to develop a document that provides guidance for assessing the environmental impacts of Air Traffic Management operational changes. As the task progressed, it became clear that the guidance would be useful to assist ICAO Member States in developing action plans for CO_2 emissions reductions, and the task group was asked to move forward its completion. The drafting process was subsequently accelerated in an effort to produce usable material, ahead of the original 2013 target completion date.

To accelerate the process, the task group worked using WG2 meetings, email, and dual conference calls (one Eastern hemisphere, and one Western hemisphere) to fast track the production of a draft document, without appendices, which was then duly submitted to the 2011 CAEP Steering Group meeting, and published on the ICAO Action Plan Emissions Reduction (APER) secure website for States to use. The process of finishing the remaining material continued, and a completed draft was presented at the 2012 Steering Group meeting. After

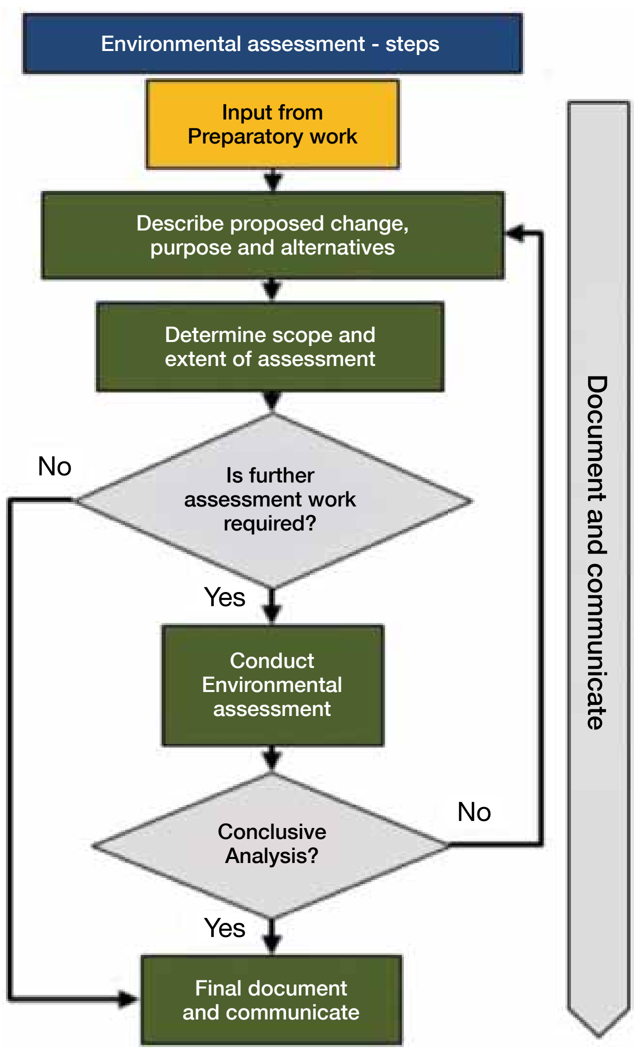


***Figure 1:** Environmental Assessment Process.*

final editing and conversion into the standard ICAO format, the final document "*Environmental Assessment Guidance For Proposed Air Traffic Management Operational Changes*", with appendices and a form for reporting future examples, was approved at the CAEP/9 meeting in February 2013.

The Guidance

The document itself contains high-level principles for environmental assessment to guide States to ensure that a consistent approach can be maintained to support sound and informed decision making.

The recommended process is outlined in **Figure 1.** The manual also provides advice on preparatory work including: criteria for triggering assessments; environmental parameters; potential methodologies; and the type of documentation and communication that may be required.

Advice is also given on describing: proposed changes and investigating alternatives; how to determine the scope and extent required; whether appropriate "short-cuts" are possible; conducting the assessment; and analysing and communicating the results.

Finally, the document notes the importance of considering and evaluating interdependencies, both environmental (*e.g.* noise vs. fuel burn, etc.) and non-environmental (*e.g.* fuel efficiency vs. airspace capacity, etc.) to ensure that, to the extent possible, an achievable and acceptable compromise can be made.

Four appendices are included in the guidance, containing:

- examples of formal requirements;
- assessment methods and key environmental parameters;
- advice for avoiding common mistakes;
- assessment examples.

A standard reporting form is also provided to help keep the document up to date.

A Living Document to Build on for the Future

The guidance was always intended to be a "living document" that could be updated as more experience was gained. To start the process, assessment examples for local, non-local, intercontinental, and oceanic regions were included in the initial guidance document and users are encouraged to submit their own experiences to ICAO for potentially inclusion in future updates.

An important example is one that used the 2011 draft guidance material and "road-tested" it on a Functional Airspace Block proposal. The results were very encouraging, and experiences from this study were fed back into the Task Group to refine the final guidance. In the future it is hoped that more examples and experiences can be used to continually refine the document. ■

REFERENCES

1 ICAO website on CAEP's activities www.icao.int/ENVIRONMENTAL-PROTECTION/Pages/CAEP.aspx

2 List of ICAO publications related to environment: www.icao.int/environmental-protection/Pages/environment-publications.aspx

3 Communications, Navigation, Surveillance/Air Traffic Management – CNS/ATM.

OPERATIONS

IMPACT OF OPERATIONAL CHANGES ON GLOBAL EMISSION LEVELS – FINDINGS OF THE OPERATIONAL GOALS GROUP

BY LEE MERRY BROWN

LEE MERRY BROWN

She has over twenty-five years of experience working in the aviation arena. Ms. Brown has award winning industry-wide recognition as an integrator and an innovator in the field of airspace design and procedure development. She has been consulted on or was directly involved with every large airspace project conducted by the FAA since 1998. Recently, Ms. Brown has applied her expertise to the FAA's Next Generation Air Transportation System, serving as a lead for concept development, experimentation and evaluation, and performance planning and measurement. She is currently a Managing Director at Landrum & Brown, working on airport and airspace projects.

INTRODUCTION

Operational improvements, in conjunction with aircraft technology improvements, are key elements that contribute to the achievement of ICAO's environmental sustainability goals for the aviation sector. ICAO therefore requires the thorough assessment and definition of potential environmental goals. The high-level purpose of operational goals is to inform decision-makers of achievable environmental benefits if the potential improvements are implemented.

The Independent Expert (IE) review process was originated in support of the Committee on Aviation Environmental Protection (CAEP) work programme during the CAEP/7 cycle (2004-2007) when the first IE group was established to develop medium-term and long-term technology goals for oxides of nitrogen (NO_x) emissions. Various IE review groups and processes were established during the CAEP/8 cycle (2007-2010) including: noise technology goals review, second NO_x technology goals review, fuel burn technology goals review, and operational goals review.

The operational goals IE review conducted during the CAEP/8 cycle produced a report summarizing future environmental goals for air traffic management (ATM) operations. CAEP requested that the group further elaborate the goals. A second operational goals review was conducted under the CAEP/9 cycle (2010-2013). The second Independent Expert Operational Goals Group (IEOGG) was established to undertake this task.

INDEPENDENT EXPERT OPERATIONAL GOALS GROUP COMPOSITION

As with the first operational goals IE review, IEOGG members were selected as individual experts. In contrast to the first IE review, nominees could not be direct representatives of a national service authority. The CAEP/9 IEOGG consisted of eight members from a variety of industry groups, bringing relevant knowledge of a number of relevant disciplines, including: air traffic system performance; airspace design; airline operations; airport management; air transport and international affairs; aircraft system engineering; and system modernization programmes (SESAR and NextGen). Similar to the first operational goals IE review, because the IEOGG membership represented a wide variety of different expertise domains, their consensus is considered as being fairly representative of the overall expert community perspective on the related issues covered.

SCOPE AND ANALYSIS

The IEOGG's scope was defined to address the impact of operations-based changes. The Terms of Reference for the IEOGG defined Operations as "… encompass[ing] the direct facilitation of the utilization of civil aircraft in any phase of the Gate-to-Gate regime, both in the air and on the ground". Future activities that did not directly affect gate-to-gate operations were not included in the IEOGG's analyses. However, the IEOGG attempted to include the potential impact of these actions in the context of other in-scope activities.

The Group's scope was also defined to include a baseline year of 2010, with two target goal years 2020 (mid-term) and 2030 (long-term). At the inaugural workshop, the IEOGG was asked to add the year 2040 in order to coincide with the modelling timeframes planned for CAEP/10.

The analysis approach used by IEOGG was devised to take advantage of a variety of recent research, demonstration projects and studies that estimate both potential benefit pools, and also benefits that could be achieved using certain technologies and procedures.

SUMMARY OF FUEL AND ATMOSPHERIC EMISSION GOALS

The operational fuel and atmospheric goals express the degree to which fuel usage and emissions can be reduced by eliminating inefficient fuel-usage operational practices. The IEOGG first estimated an associated "benefit pool", which represents the 2010 level of fuel-usage inefficiency. The IEOGG goals express the degree to which these inefficiencies can be eliminated by implementing new operational practices for the years in question. Thus, the associated benefit pool is the level of fuel-usage inefficiency.

Based on its analyses, the IEOGG estimates the 2010 worldwide operational fuel and atmospheric emissions benefit pool to be 12.75%. If the ultimate goal is to be 100% efficient, this corresponds to a worldwide system efficiency level of 87.25%. The lower limit of the IEOGG confidence range for the benefit pool is 10.25%, which corresponds to a worldwide efficiency level of 89.75%.

The size of this benefit pool is larger than the size estimated by the prior IEOGG and earlier Civil Air Navigation Services Organization (CANSO) estimates. The IEOGG used an alternate methodology compared with the prior work so there could be many reasons for differences; however three factors stand out:

1. The IEOGG estimated the benefit pool for those regions based on limited data availability. For example, the figures used for Middle East, China, India, South America and Africa were larger than the pools estimated previously. This difference was based on access to additional data and also anecdotal evidence obtained in discussions with local experts.
2. IEOGG considers all taxi-in and taxi-out emissions to be part of the benefit pool due to the potential for electric taxi systems to eliminate the majority of these emissions.
3. The IEOGG analysis took into account recent research that estimated inefficiencies in typical cruise speed and altitude values.

The following table lists the IEOGG worldwide operational fuel usage and atmospheric emissions reduction goals.

	2020	2030	2040
Goal	3.25%	6.75%	9.00%
Lower Confidence Limit	2.25%	4.50%	5.75%

Table 1: *IEOGG Worldwide Operational Fuel Usage and Atmospheric Emissions Reduction Goals.*

The goals shown in **Table 1** indicate a reduction in fuel usage/emissions relative to 2010 levels. For example, the estimated emissions reduction goal for the year 2030 is 6.75% from the 2010 levels. As these are estimates, a lower confidence limit is also provided, or a 4.5% reduction from the 2010 levels.

As the previous IEOGG analysis observed, under a static ATM system congestion levels would increase and this increased congestion would lead to less efficient operations. This would lead to more excess fuel usage on a per flight basis and an overall degradation of the worldwide system efficiency level. As depicted by the blue line in **Figure 1** below, the IEOGG estimates that, under a static ATM system, overall system efficiency would degrade by 2% by 2020 and an additional 2% in each of the succeeding decades, so that the 2010 87.5% efficiency level mentioned above would decrease to 81.5% by 2040. Thus, the goals listed in **Table 1** represent even greater emissions reductions relative to a static ATM system. Specifically, the IEOGG worldwide operational fuel usage and atmospheric emissions goals expressed as reductions in overall fuel usage and atmospheric emissions relative to a static ATM system are: 2020: 5.25%, 2030: 10.75%, 2040: 15%, as represented by the difference between the red and blue lines in **Figure 1**.

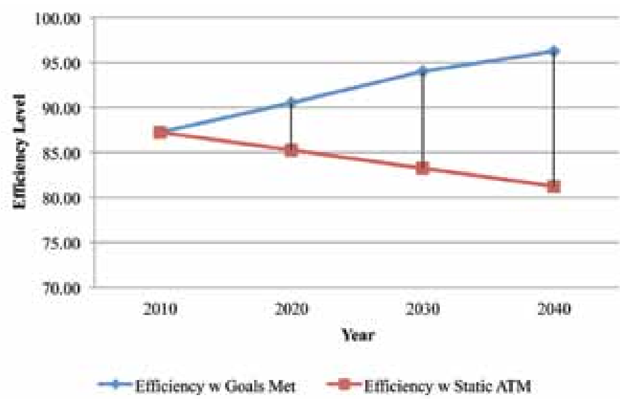


Figure 1: *Goals Relative to Static ATM System.*

The IEOGG analysis produced a benefit pool and goals for each phase of flight: taxi-out, climb, cruise, descent, and taxi-in. The phase-of-flight specific benefit pool and goals are given below.

MECHANISMS TO ACHIEVE GOALS

The stated goals are aspirational ones that the IEOGG believes are feasible. However, in order to achieve them the international aviation community must make strong and concerted efforts. To be achieved, a variety of performance enhancing measures must be implemented over time. The specific measures underlying the goals by phase-of-flight are given below.

- **Taxi-Out:** Minimum engine taxi and better surface management, especially reduction in physical taxi-out queues in the near-term; electric taxi in the longer term.
- **Climb:** Dynamic airspace configuration; denser terminal area operations, including performance-based navigation; better traffic flow management, especially coordination between surface and airspace; time-based metering; trajectory-based operations.
- **Cruise/speed and altitude optimization:** Satellite-based surveillance and datalink; better traffic flow management,

Benefit Pool	Taxi-Out	Climb	Cruise	Descent	Taxi-In
2010 Pool	100.00%	1.50%	6.25%	19.75%	100.00%
LCL	76.75%	1.25%	4.25%	15.25%	76.75%
Goal	**Taxi-Out**	**Climb**	**Cruise**	**Descent**	**Taxi-In**
2020 Goal	33.50%	0.50%	1.50%	4.75%	27.25%
LCL	22.25%	0.25%	0.75%	3.25%	18.75%
2030 Goal	62.25%	0.75%	3.50%	12.00%	50.50%
LCL	39.00%	0.50%	1.75%	7.50%	30.75%
2040 Goal	81.25%	1.00%	4.75%	14.75%	66.50%
LCL	49.75%	0.75%	2.50%	9.00%	40.75%

LCL = Lower Confidence Limit

***Table 2:** Emission Reduction Benefit Pools and Goals, by Phase-of-flight.*

especially relative to reducing overall congestion; performance-based navigation; increased carrier priority/attention to fuel-optimal speed control.

- **Cruise/2-D trajectory optimization:** Satellite-based surveillance and datalink; better traffic flow management; improved weather information and prediction, including wind forecasts; trajectory-based operations; better access to special use airspace.
- **Descent:** Optimized profile descents; speed control en route to reduce congestion in terminal in near term; time-based metering in intermediate term; performance-based trajectories and full trajectory-based operations in longer term; dynamic airspace configuration; denser terminal area operations, including performance-based navigation; better traffic flow management, especially coordination between surface and airspace.
- **Taxi-in:** Minimum engine taxi and better surface management in near term; in North America, some move toward common use gates in mid-term; electric taxi in longer term.

LIMITATIONS AND FURTHER CONSIDERATIONS

The goals developed by IEOGG are contingent on improvements in operational efficiency at the individual flight level. To illustrate, the IEOGG 2040 goal could be interpreted as follows: on the average, an equivalent flight, *e.g.* a B737-800 from ATL to ORD, should use 9% less fuel in 2040 than the same flight would use in 2010 (see **Table 1**). Specifically, these goals do not account for growth in the overall number of flights, nor on changes in the characteristics of an "average" flight, which will likely become longer and use a larger aircraft.

The emissions reduction goal is expressed as a reduction in fuel usage, implicitly assuming that total emissions (all else being equal) are proportional to total fuel usage. In the case of CO_2, this is a reasonable assumption, however, for NO_x the relationship between emissions and fuel usage may be more complex.

The IEOGG goals represent savings that can be achieved by new operational practices. However, in many cases these will require new technology investments on the part of both Air Navigation Service Providers and flight operators, such as those associated with modernization efforts such as the Next Generation Air Transportation System (NextGen) and Single European Sky Aviation Research (SESAR). In addition, it is important to note that achieving the goals will require substantial reduction in taxi-in and taxi-out emissions through efficient queuing and by the eventual use of electric taxi systems.

The goals, at least in part, may require changes in policies and practices, not only for Air Navigation Service Providers (ANSPs), but also for flight operators and States. For example, achieving certain cruise benefits may require flight operators to give higher priority to the use of fuel-efficient speeds. Also, some cruise benefits may require that States provide additional access to special use airspace.

OVERVIEW - SUSTAINABLE ALTERNATIVE FUELS

SUSTAINABLE ALTERNATIVE FUELS FOR AVIATION

BY ICAO SECRETARIAT

BACKGROUND

Environmental benefits gained through technological progress and operational improvements remain instrumental to limiting the impact of aviation on the global environment. However, even under the most aggressive technological and operational assumptions, the anticipated gains in efficiency will not offset the expected fuel consumption increases, based on air traffic growth forecasts for the next 40 years.

In under a decade, sustainable alternative fuels have emerged as a promising solution that can close part of this gap. When produced from renewable sources or waste materials, alternative fuels have the potential to yield substantial greenhouse gas (GHG) emissions reductions, on a life-cycle basis. Indeed, CO_2 emissions from biofuel combustion can be considered as neutral, since the emitted carbon comes from biomass and will return to that same material. As a result, only the emissions induced by feedstock production, transportation, and processing have to be accounted for in a field-to-tank approach. Similarly, producing fuel from industrial waste, both solids and gases, generates emissions reductions through the cascading use of fossil carbon.

A major step towards the development of sustainable alternative fuels for aviation was the 2009 approval of "drop-in" fuels. This was considered as a significant breakthrough since these fuels are fully compliant with the stringent requirements for aviation fuels, preserving safety, as well as compatibility with existing systems, meaning that they can be "dropped in" or substituted for conventional fuels.

PROGRESS IN SUSTAINABLE ALTERNATIVE FUELS FOR AVIATION

Commercial Use of Alternative Fuels

The door to the first commercial use of sustainable alternative fuels in aviation was opened following two landmark approvals by ASTM[1] (formerly known as the American Society for Testing and Materials) for the use of up to 50% alternative fuel blended with conventional fuel: Fischer-Tropsch[2] fuel in 2009 and Hydroprocessed Esters and Fatty Acids (HEFA)[3] fuel in 2011.

The hydroprocessing of vegetable oils and animal fats to produce HEFA fuel is a mature process which allowed the production of the first batches of biofuel for commercial flights, the use of which has multiplied since September 2011, demonstrating the viability of these fuels for aviation.

As of June 2012 more than 18 airlines had collectively performed over 1,500 commercial flights that used alternative fuels, including regularly scheduled flights. Further initiatives are currently underway in all regions of the world to introduce sustainable alternative fuels into commercial aviation. Airlines and airports have entered into agreements for sustainable alternative fuels in North America, Europe, the Middle East, Latin America, South America, and the Asia-Pacific region, making this a truly global activity. The map below (**Figure 1**) illustrates where activities are currently taking place.

Technology Developments

While Fischer-Tropsch and HEFA fuels were the first alternative fuels approved for use in aviation, additional processes are currently under approval by ASTM, and will diversify available pathways for aviation fuel supply:

- The "alcohol-to-jet" processes use ethanol or butanol as intermediate products in order to produce jet fuel grade hydrocarbons from starch and sugar feedstock.
- The "sugar-to-hydrocarbon" process uses advanced fermentation to convert starch and sugar feedstock directly into hydrocarbons.

These two families of processes will also enable the use of lignocellulosic feedstock such as woody biomass, herbaceous crops or agricultural residues, which will allow for the production of jet fuel from sources that are less expensive than vegetable oil, without the capital expenditure involved in Fischer-Tropsch conversion. Pyrolysis and catalytic cracking are additional processes currently under development which produce a kind of "bio-crude" that can be refined into jet fuel using an approach similar to the refining of crude oil.

The range of available and future pathways allows the transformation of all existing types of feedstock and should support regional adaptation, as well as optimization of economic efficiency.

Government and Stakeholder Initiatives

In 2006, the "Commercial Aviation Alternative Fuels Initiative" (CAAFI), founded by U.S.-based aviation stakeholders, was the first worldwide initiative promoting the development of alternative fuels for aviation. CAAFI supports the approval of alternative jet fuels by ASTM, as well as any policy actions for their deployment. It also produces tools and guidance to assist stakeholders, and it connects producers and

Figure 1: *Aviation Alternaitve Fuel Initiatives. Source: ICAO Global Framework for Aviation Alternative Fuels.*

customers to facilitate the deployment of these fuels on the market place. In addition, the United States is home to the Northwest Advanced Renewables Alliance (NARA) and Midwest Aviation Sustainable Biofuels Initiative (MASBI) regional initiatives.

The European Union has launched the "Initiative Towards sustainable Kerosene for Aviation" (ITAKA) to produce sustainable bio-jet-fuel at a large enough scale to test its use in normal flight operations. The "Aviation Initiative for Renewable Energy" in Germany (AIREG) and "Bioqueroseno" in Spain, are also pursuing the development of a sustainable bio-jet fuel industry.

National programmes have also been initiated in Mexico (Plan de Vuelo), Brazil (SABB) and Australia/New Zealand (Flight Path to Sustainable Aviation Fuels), all to explore possible options and perform feasibility assessments related to the development of national alternative jet fuel industries. The United Arab Emirates and Qatar launched research projects to develop jet fuel production from "next generation" feedstock such as halophytes and microalgae. Major aircraft manufacturers are also engaged in cooperative initiatives for the deployment of alternative fuels.

Airlines formed the "Sustainable Aviation Fuel Users Group" (SAFUG) in 2008, which was established to support the development of government policies that promote the development, certification, and commercial use of sustainable low carbon aviation fuels.

ICAO Initiatives

ICAO Assembly Resolution A37-19 recognized sustainable alternative fuel as being part of the basket of measures needed to achieve the aspirational goals to stabilize international aviation emissions from the year 2020 onward. It requests ICAO and its Member States to participate in further work for the development and deployment of such fuels.

Over the last three years, ICAO has engaged in a number of activities to promote and facilitate the emergence of sustainable alternative fuels in aviation through the exchange and dissemination of information, as well as fostering dialogue among States and stakeholders. The Global Framework for Aviation Alternative Fuels (GFAAF, www.icao.int/altfuels) was created by ICAO as a platform to provide up-to-date information on recent developments related to alternative fuels, including descriptions of ongoing initiatives and documentation.

A workshop was held in Montréal, Canada in October 2011 to promote dialogue among States and stakeholders. Building on conclusions from that workshop and in light of discussions of the ICAO Council, in June 2012 ICAO created the Sustainable Alternative Fuels (SUSTAF) Experts Group with the mandate to issue recommendations to facilitate the emergence of alternative fuels in aviation. These recommendations will be presented at the next session of the ICAO Assembly in September/October 2013 (see article *Challenges for the Development and Deployment of Sustainable Alternative Fuels for Aviation*, Chapter 4 in this report).

Figure 2: *ICAO Global Framework for Aviation Alternative Fuels, www.icao.int/altfuels.*

Another significant alternative fuels achievement was the ICAO "Flightpath to a Sustainable Future" initiative, that was launched on the occasion of the Rio+20 conference in June 2012, in cooperation with aviation industry partners. As part of the initiative, the ICAO Secretary General travelled from Montréal, Canada to the Rio+20 Summit in Rio de Janeiro, Brazil, on four connecting flights, all using alternative fuels. As the first ever flight operation connecting passenger flights using alternative fuels, it set a record for the greatest number of passengers carried on commercial biofuel flights within 24 hours, and it was also the longest international itinerary using biofuels (11,525 km). (see article *Flightpath to a Sustainable Future*, in Chapter 8 in this report).

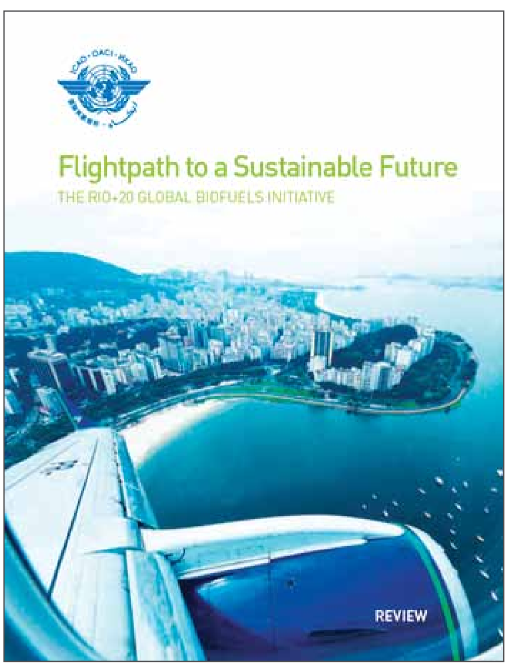


Figure 3: *Rio+20 "Flightpath to a Sustainable Future" Review.*

The first anniversary of the launch of the Rio+20 "Flightpath to a Sustainable Future" initiative coincided with the 2013 Le Bourget – Paris Air show. ICAO was invited to participate in the Alternative Fuels Pavilion and to commemorate, with its industry partners, the series of landmark biofuels flights and showcase the substantial progress achieved since Rio. At the Pavilion, ICAO showcased the initiatives currently being undertaken by the Organization in the field of sustainable alternative fuels for aviation and summarized the progress achieved in this area since the previous year.

Figure 4: *Partners in the Rio+20 initiative at the 2013 Le Bourget Paris Air show.*

THE CHALLENGES

There have been significant achievements over the last three years to support the deployment of sustainable alternative aviation fuels. However, despite this progress, the use of alternative fuels in regular aviation operations remains limited, as full commercial production of these fuels has not yet started.

A major hurdle to deployment is the current price gap with conventional jet fuel, which is likely to continue during the initial development phase before technological progress and economies of scale combine to result in cost reductions. Without incentives or pricing mechanisms that reflect the environmental benefits of using these fuels, airlines are currently not in a position to buy them. This, in turn, makes investment in the industry less attractive. At the same time, renewable energy policies in most countries support the deployment of biofuels for road transportation. Hence, there is a critical need for governments to define long-term policies that consider the use of these fuels for aviation as well, along with associated supporting measures, including support to research and development programmes that will lead to a reduction in the cost of aviation biofuel production.

Ensuring sustainable deployment is also a challenge. Commercial-scale deployment should consider all three pillars of sustainability: environmental, social, and economic. Sustainability certification sought by producers themselves from voluntary standards and certification schemes (such as Round-table for Sustainable Biofuels, RSB) appears to be a useful approach that ensures sustainable practices at production-chain level. Additional measures like monitoring of impacts at national or regional levels are also required to account for the cumulative impacts of multiple production-chains deployment. Last, possible indirect impacts, such as repercussions on the global food market or on land use, need to be considered which may require dedicated policy measures as well as as additional research and methodological work.

In these efforts to ensure sustainability, given the global nature of international aviation, the emergence of different systems and regulations may cause some additional challenges. Increased harmonization and the definition of mutual recognition mechanisms would be desirable to facilitate the deployment of alternative fuels on a commercial scale.

NEXT STEPS

There has been significant success in the early development of aviation alternative fuels, and airlines have been proactive in demonstrating their feasibility. All aviation stakeholder groups are actively promoting the use of these fuels to limit aviation's environmental footprint.

ICAO is a facilitator that supports States and stakeholders in their efforts to address the remaining challenges to initiate commercial-scale deployment and create a viable and sustainable aviation alternative fuels industry. It will continue to foster dialogue and information exchange on progress, regulations, and best practices for the emergence of alternative fuels in aviation. The GFAAF will continue to serve as an independent and comprehensive platform to gather and exchange information in the field of alternative fuels.

In addition, consistent with its policy on environmental protection, ICAO will continue to work toward quantifying the effects of alternative fuels as a mitigation measure for aviation's greenhouse gas emissions. The environmental trends assessment presented in Chapter 1 of this report, which are used to inform decision-making, reflect the Organization's initial efforts in this area. Work is ongoing to develop more comprehensive projections of the future contribution of alternative fuels.

In order to make those projections a reality, collaboration need to be continued among aviation stakeholders and to be developed with the other players of the bioenergy sector to evaluate fuel sustainability and life cycle GHG emissions reductions, as well as to develop common projections for biomass availability and use.

Given the increase in activities and cooperation in the field of alternative aviation fuels, many positive developments in this rapidly-evolving area can be expected in the coming years. ■

REFERENCES

1 ASTM International, formerly known as the American Society for Testing and Materials (ASTM), develops international voluntary consensus standards and plays a leading role in aviation fuel approval.

2 The Fischer-Tropsch pathway produces liquid hydrocarbons from a synthesis gas, made up of carbon monoxide and hydrogen, obtained by the gasification of carbonaceous feedstock such as coal, gas or biomass.

3 Hydroprocessed Esters and Fatty Acids (HEFA) are synthetic hydrocarbon fuels produced by hydroprocessing of vegetable oils and animal fats in order to remove the oxygen contained in these feedstocks.

SUSTAINABLE ALTERNATIVE FUELS

CHALLENGES FOR THE DEVELOPMENT AND DEPLOYMENT OF SUSTAINABLE ALTERNATIVE FUELS IN AVIATION

Outcomes of ICAO's SUSTAF Experts Group

BY ICAO SUSTAINABLE ALTERNATIVE FUELS (SUSTAF) EXPERTS GROUP

INTRODUCTION

Building on the outcomes of the ICAO Aviation and Sustainable Alternative Fuels (SUSTAF) Workshop held in October 2011, and on the discussions at the 194th Session of the ICAO Council, the SUSTAF Experts Group was created in June 2012 to develop recommendations relating to ongoing challenges in the development and deployment of sustainable alternative fuels for aviation, with a view to supporting States and the industry in their efforts to develop and deploy alternative aviation fuels.

The Group focused its work on the identification of the major near-term challenges related to the deployment of sustainable alternative fuels for aviation and on the solutions to overcome them. In particular, the issue of the sustainability of such fuels was addressed, and the group focused on possible options that States might use to deal with this issue. In the course of the work, additional considerations were also identified that may affect the deployment and are worth considering in the overall plan to facilitate the emergence of sustainable alternative fuels in aviation. The analysis led the group to a number of conclusions that support the recommendations made to the ICAO Council.

In the context of the group's work, "sustainable alternative fuels" are understood to be fuels that are consistent with the environmental, social, and economic pillars of sustainability and, in particular, are fuels that can have a lower life cycle greenhouse gas (GHG) footprint than conventional fuels. In line with ICAO's environmental goals, the use of sustainable alternative fuels should result in the future, through continuous improvement, in significant reductions of greenhouse gas emissions compared with conventional jet fuels.

Only drop-in fuels were considered within the discussions of the group. Drop-in fuels are fully compatible with current aircraft and infrastructure with no modification or limitation of use. This characteristic is seen as a mandatory requirement for the short to medium-term deployment of alternative fuels.

In identifying the challenges for deployment, as well as the variety of options for States to address sustainability, the group took into account the global nature of international aviation with aircraft operating worldwide over multiple geographic areas where different regional regulations apply. Similar to other areas of international aviation, coexistence of disparate policies and procedures could indeed be a challenge.

MAJOR CHALLENGES FOR COMMERCIAL DEPLOYMENT OF SUSTAINABLE ALTERNATIVE FUELS

Challenges

While the availability of sustainable feedstocks and the impacts of their production in the required quantities are significant challenges for a commercial-scale deployment of alternative fuels in aviation over the long-term, overall economics appear to be the main issue in the near-term. Today, the most significant challenge is stimulating the necessary capital investment to ramp up production.

To date, economic assessments of alternative fuels for aviation converge on a lack of economic competitiveness when compared with conventional jet fuels. This will continue during the initial deployment phase, before research and development, production technology progress and economies of scale result in production cost reductions.

With no compensation mechanism to reward airlines for using environmentally beneficial fuels, there are small, limited markets for aviation biofuels at current prices, which is higher than prices for conventional jet fuel. Without the ability to compete on price, it is difficult for companies in the entire value chain of alternative jet fuels to demonstrate their viability and thus complete financing for commercial projects.

In addition, advanced biofuels in general are currently perceived by investors and lenders as a less attractive investment that has more risk than other, more mature, renewable energy technologies, such as wind and solar.

Furthermore, with respect to the development of alternative fuels, aviation currently faces an unbalanced competition with road transportation. Indeed, producing alternative fuels for aviation is more costly than for road transportation because aviation's requirement for "drop-in" fuels calls for more advanced processes than those used for the first generation of road transportation biofuels (*e.g.* ethanol and FAME[1]), and for further upgrading of the fuel in order to meet jet fuel specifications. Furthermore, alternative fuel policies tend to favour road transportation: more public research has been funded in this area, the use of biofuels is often enforced through mandatory incorporation in gasoline and diesel ("blending mandates"), and tax exemptions are used to compensate the extra cost compared to conventional fuels.

Although there has been significant success in the early development of aviation alternative fuels, this is a young sector where many technologies are not yet mature. Research and development are of major importance to accelerate the move towards commercial production by:

- Improving the efficiency and decreasing the cost of the feedstock and fuel production;
- Qualifying additional emerging production pathways (such as alcohol to jet, pyrolysis, catalytic and direct methods of converting sugars to hydrocarbons, etc.) for use in aviation;
- Bringing new production pathways from laboratory to commercial scale.

Beyond research, demonstrating a biojet technology at sufficient scale is a critical step of the development to convince investors of the viability of the technology and to complete the fuel approval process. Demonstration projects also provide a base to build larger commercial facilities to achieve economies of scale. The cost of such demonstrations range from US$ 20 to $50 million and is a serious barrier to technology start-up.

Changes in regulations and policies are also strong concerns for the development of the industry. With a favorable context for the development of alternative fuels in aviation, the time frame is currently projected to be not less than ten to fifteen years for a bio-jet pathway to reach established commercial production from the demonstration step. A stable regulatory and political environment over ten years or more is thus required from States in order to attract investors into the development and deployment of alternative fuel technologies for aviation.

Possible Solutions

A priority for the deployment of sustainable alternative fuels in aviation is to create a long-term market perspective and address the initial price gap that exists with conventional jet fuel in order to initiate viable commercial production. A first step in that direction is for States to include sustainable aviation fuels in their global renewable energy and biofuels policies.

A number of measures can be considered to promote the deployment of sustainable alternative fuels in aviation. Based on experience to date with incentives and supporting measures, the following trends may be able to support the development of new policies in the area.

Access to commercial loans and other conventional funding options for the development of advanced biofuels have proven to be difficult due to the technology risks and, in the case of aviation alternative fuels, of market uncertainties. The renewable fuels companies that have received guaranteed government loans are those that can produce fuels at the current market price, have been able to establish long-term sales agreements at prices close to parity with conventional fuels, and have answered technology concerns regarding the commercial scale-up.

Loan guarantees are important instruments to help with financing new facilities, but by themselves do not assist in creating the market. They do not provide any bridge or subsidy rate for the extra cost of alternative fuels, and thus are not a tool for offsetting the initial price gap between alternative fuels and conventional fuels.

Mandatory incorporation of biofuels in conventional fuels has proven to be effective for developing the production of biofuels at the stage when the industry has reached the commercial phase and the business model is well understood. For aviation, alternative fuels have not yet reached this level of development so that mandatory production could be premature. Mandatory production quotas also need to be established based on a solid resource assessment, and flanked by sustainability indicators in order to determine the sustainably feasible potential. Nevertheless, mandatory production quotas are parts of the possible options that may support industry scale-up. Careful attention should then be paid to the accompanying sustainability assurance as well as to possible competition distortion in the international context of aviation operations.

Finally, grants and tax exemptions have been very effectively used by countries to promote the development of renewable energies. Tax reductions on final products is a common practice for road transportation fuels. This is not relevant for international aviation where no tax is applied on jet fuel but could be implemented in some domestic markets where such taxes exist. Examples of other forms of tax incentives include tax credits for the development of wind energy in the United States, or tax breaks for sugar cane ethanol in Brazil. A wide range of similar measures to support the initial development of the industry can be considered at different levels of the value chain.

As part of the possible measures to create the market perspective and support the initial development of alternative aviation fuels, States could use grants, tax incentives and other forms of assistance to encourage and support research and development in technology processes and feedstock production in order to decrease costs, meet price parity with conventional jet fuel, and increase the maturity of the sector. In a similar way, they could also support the development and scale-up of production pathways to full commercial scale through the funding of demonstration projects and of fuels approvals. Lastly, States could fund long-term fuel purchases of alternative fuels for use in military or other state-owned aircraft, eventually in association with collective procurement from airlines, in order to provide a stable sales platform and offset customer risk.

A possible option to provide incentives for sustainable alternative fuels for aviation might also be to credit them with reduced CO_2 emissions in the framework of measures designed to limit or compensate aviation's greenhouse gas emissions.

ADDITIONAL DEPLOYMENT CONSIDERATIONS

Feedstocks

Sustainable feedstock supply is a critical issue tied to the development of sustainable alternative fuels projects. Feedstocks are indeed a major component of the cost of alternative fuels. As such, they need to be included in supporting policies as well as in research and development efforts.

In addition, securing a long-term sustainable feedstock supply at competitive prices together with long-term sales agreements with end-users are key assets for successful financing of alternative jet fuel projects. From this point of view, involving feedstock producers at the early stages of the development process provides needed input and commitment from which to develop the project. Preparing long-term feedstock and sales agreement contracts in a manner that de-couple feedstock costs from the current fossil fuel market is also an important long-term viability guideline.

Therefore, building an integrated value chain from the beginning of project development is a pathway to secure both feedstock supplies and sales agreements. It could provide an effective model for the initial deployment phase of alternative fuels in aviation which States are interested in supporting.

An integrated approach to alternative fuel production for aviation should also consider the secondary products (or co-products) generated together with the fuel (such as seeds cake in case of fuels made from oil seeds) and their valuation. It could improve global sustainability through opportunities for cascading use of feedstocks.

In the development of biomass production for alternative fuels, the implementation of new agricultural practices, and the need for new forms of harvesting and transportation equipment represent significant effort and investment. This should be taken into account, together with agro-climatic characteristics and logistics and infrastructure considerations, when mapping out the most suitable geographic areas for energy biomass development. However, once this is achieved, it is likely to lead to significant progress on scale, cost and overall environmental benefits related to the use of alternative fuels. This may also be compulsory for the deployment of emerging advanced technologies.

Operational Aspects

In the effort to facilitate the development and deployment of alternative fuels in aviation, a number of operational aspects should not be forgotten.

Recognizing that safety is paramount for the acceptance of technically suitable alternative aviation fuels, airlines need to be reassured that alternative aviation fuels will be provided on a continuous basis with the same levels of suitability and quality as conventional fuels. This will involve a thorough approval process using internationally recognized standards such as the ones of ASTM International. Indeed, the supply of alternative aviation fuels will need to be subject to the same rigorous internationally accepted standards of quality control all along the logistical steps that are involved in the production and distribution supply chain.

As an incentive for the deployment of alternative fuels, airlines need to be recognized and rewarded for using them. To do this requires the set-up of a practical system to account for their consumption. In most airports, alternative fuels will be delivered through the same supply infrastructure as conventional jet fuel and they will be mixed together at source in airport fuel farms. Hence, there will be no direct link between the alternative fuel bought by a particular airline and the aircraft to which the fuel is ultimately delivered. A solution which will capture the difference in fuels used before the mixing in fuel farms is to record the use of alternative fuels by the airlines at the time of purchase, in what often is referred to as a "book and claim" accounting process.

Local administrative processes and/or policies affecting feedstock production and logistics implementation can also be bottlenecks that should not be underestimated in the deployment of alternative fuels for aviation. Examples of this include the registration, protection, and authorization of energy crops, and the acquisition of crop insurance for farmers.

POSSIBLE OPTIONS FOR A SUSTAINABLE COMMERCIAL-SCALE DEPLOYMENT

A significant motivator for deploying alternative fuels in aviation is their potential, if properly produced, to reduce aviation greenhouse gas (GHG) emissions and to contribute to ICAO's goal of carbon neutral growth from the year 2020 onward. Thus, GHG emissions over the entire life cycle of the fuels are of particular interest.

Achieving sustainability is however not limited to reducing GHG emissions. When applied to alternative fuels, sustainability means the preservation of a long-term continued production capacity of natural resources, in an economically feasible, socially, and environmentally acceptable way. Accordingly, the management and control of environmental, social, and economic impacts are the three pillars of a successful sustainable development of aviation alternative fuels.

Sustainability of a particular fuel cannot be assumed; it needs to be demonstrated. It depends mostly on the way the feedstock and the fuel are produced or sourced. It also depends on the interaction between the production, other activities and the global ecosystem. GHG emissions associated with alternative fuels, like other environmental, social, and economic performance attributes of alternative fuels, are directly determined by the conditions of production.

While the three pillars of sustainability are well accepted[2], there is no globally recognized approach to determining the sustainability of alternative fuels. Three complementary approaches have been deployed to define and address sustainability: 1) consideration of sustainability indicators, such as those identified by the Global Bioenergy Partnership (GBEP); 2) implementation of voluntary standards and certification schemes; and 3) regulations introduced in some States or groups of States. The following paragraphs elaborate on these three factors.

Sustainability Indicators: the Global Bioenergy Partnership (GBEP), which is an international initiative bringing together public decision-makers, representatives of the private sector, and civil society, as well as international agencies, has defined a set of 24 indicators of sustainability for bioenergy production[3]. These indicators are intended to provide guidance for any bioenergy analysis that may be undertaken at the domestic level, with a view to informing decision-making and facilitating the sustainable development of bioenergy. The GBEP approach is non-prescriptive. Measured over time, the indicators show progress towards or away from a nationally defined sustainable development path. They are value-neutral, do not feature directions, thresholds or limits, and they do not constitute a standard, nor are they legally binding.

Voluntary Sustainability Standards and Certification Schemes: these initiatives propose a set of sustainability principles, further detailed in criteria, with guidelines to fulfill the criteria, and indicators to measure compliance. Independent of the bioenergy debate, many systems have emerged to improve sector specific practices[4] for specific value chains like sugarcane, palm oil, and soy. Some certification schemes were more generally designed for biomass and bioenergy or, in the case of Round-table on Sustainable Biomaterial (RSB)[5], more specifically for biofuels. The overarching principle is that a producer voluntarily seeks certification from a third party to get a competitive advantage by demonstrating the sustainability of its products.

Sustainability Regulations: Some States have introduced sustainability criteria, within biofuel or bioenergy policies, which require compliance for the fuels to be recognized in the application of the policy, and to benefit from supporting measures. Examples appear in the Renewable Energy Directive[6] in Europe, the Renewable Fuels Standards programme[7] in the United States, and the alternative fuel production provisions in Brazil[8]. The U.S. regulations primarily address global environmental impacts related to GHG emissions, while the European regulations also consider biodiversity. Both are applied to domestically produced and imported biofuels. Brazilian regulations include a set of environmental and social requirements for domestic production[9].

The above approaches represent significant and still progressing effort. Each one responds to distinct types of needs and objectives, and they have complementary roles in insuring the sustainable development of alternative fuels which may require them to be combined in the alternative fuels policy of States. The indicators are useful measurement tools for monitoring, but they need to be associated with a policy defining principles and targets. In the case of sustainability regulations, they may only require compliance with a limited number of criteria and not cover all aspects of sustainability (in particular, for compliance with international rules), which makes voluntary certification systems valuable complementary tools. However, even if these systems are effective for evaluating individual value-chains, not all impacts may be fully assessed at this level. This applies particularly in the case of the cumulative impacts of commercial-scale deployment of biofuels and for the competition for resources between food, feed, fibre and bio-energy sectors. In these instances, monitoring at regional or national levels is a relevant complementary approach.

Finally, commercial-scale deployment of alternative fuels may have indirect impacts, such as affecting the global food market, or land-use changes in other geographic areas due to the displacement of previously existing crops (a phenomena referred as indirect land use change and recognized to possibly induce GHG emissions). Neither indicators, nor existing regulations applied at a national level, may be able to fully address these indirect impacts which can also not be handled at value-chain level by voluntary certifications schemes. Therefore, existing approaches to ensuring sustainability for alternative fuels – while providing a strong basis for sustainability policies – have the potential for further improvements and the likely addition of complementary measures.

Given that existing voluntary standards and certifications schemes were designed over time to answer specific sectoral needs, they naturally vary in their level of ambition and coverage, as well as the ways in which they have been developed and they are implemented. In light of that, increased convergence and cooperation, without compromising on the level of requirements are likely to yield benefits.

In the field of regulation, different regional systems are also emerging. If not harmonized or accompanied by mutual recognition mechanisms, this could hinder the commercial-scale deployment of alternative fuels for aviation. A good example of this type of divergence is the current implementation of different requirements for life cycle GHG emissions; which may not only differ in threshold value, but could also be based on non-comparable methodologies.

CONCLUSIONS

The balance between environmental benefits and the cost of deploying alternative fuels is deemed to be important to States and may currently look more favourable for deployment in road transportation. However, it is important to include aviation fuels in the alternative fuels policies of States. Indeed, aviation has no alternative to liquid fuels in the foreseeable future; unlike road transportation which has electricity or fuel cell options. The aviation industry is also keen to use sustainable alternative fuels to improve its environmental footprint.

Airlines have been very proactive in demonstrating the feasibility of alternative fuels through flight tests and more than 1,500 commercial flights. All major aviation industry stakeholder groups such as Airports Council International (ACI), International Air Transport Association (IATA), International Coordinating Council of Aerospace Industries Associations (ICCAIA) in coordination with ICAO, foster their use. Furthermore, the concentration of aviation operations and infrastructure (*i.e.* over 80% of the world's air traffic is operated by just over 200 airlines and through 190 airports) might be an advantage to the deployment of alternative fuels in aviation because it will involve less infrastructure and logistics than for road transportation. Ground-based operations at airports, such as auto rentals and ground cargo delivery, also create demand for other fuels produced along with alternative jet fuel.

With respect to the short-term deployment of alternative aviation fuels, the first need is to create a long-term market perspective and address the initial price gap with conventional jet fuel, in order to attract investors and initiate viable commercial production. This requires a combination of measures and the inclusion of aviation in the renewable energy and biofuels policies of States. Provisions and measures to ensure the sustainability of alternative aviation fuels need to be part of these policies. In addition, incentives and policies by States should have a long-term stable view for ten years or more in order to provide market assurance for investors and to allow the industry to develop.

Developing and deploying alternative fuels in aviation is a multidisciplinary issue closely connected to other types of renewable energy. It calls for a multi-sectoral approach that coordinates energy, environment, agriculture and transport, with aviation. This approach should include:

a) Evaluating biomass resources and supporting solid biomass production planning by mapping the most suitable geographical areas for its development, considering agro-climatic characteristics, logistics, and existing infrastructure, as well as environmental protection criteria; while always taking into account the competing demands for food, feed and fibre biomass.
b) Allocating aviation's share of the available biomass in the global picture of energy demand.
c) Facilitating the implementation of policy and addressing administrative barriers with clear, understandable and implementable processes and procedures.
d) Assessing all impacts of commercial-scale deployment.

Developing public/private stakeholder groups is also an effective way to facilitate the development of the renewable jet fuel industry, and support the building of complete value chains. Examples include the Commercial Aviation Alternative Fuels Initiative (CAAFI), the Aviation Initiative for

SUSTAF EXPERTS GROUP

Jan Bode (Germany), Barbara Bramble (RSB), Tania Buenrostro (Mexico), Delia Dimitriu (Manchester University), Frédéric Eychenne (ICCAIA), Thimothy Fenouhlet (EC), Johnston Glenn (Gevo), James Hileman (USA), Nicolas Jeuland (France), Christopher Jessberger (Aireg), Virpi Kröger (Neste Oil), Michael Lunter (The Netherlands), Chris Malins (ICCT), Philippe Marchand (Total), Bruno Miller (Metron Aviation), Shumani Mugeri (South Africa), Philippe Novelli (ICAO), Xavier Oh (ACI), Martina Otto (UNEP), John Plaza (Imperium Renewables), Gerard Ostheimer (USA), James Rekoske (ICCAIA), Thomas Roetger (IATA), Shona Rosengren (Australia), Andrea Rossi (FAO), Arne Roth (Bauhaus Luftfahrt), Marcelo Saito (Brazil), Alfredo Iglesias Sastre (Spain), Andreas Sizmann (Bauhaus Luftfahrt), Laurens Van Sterkenburg (The Netherlands), Michael Sicard (France), Cindy Thyfault (Westar Trade Resources), Terry Thompson (Metron Aviation), Cesar Velarde Catolfi-Salvoni (Spain), Arnaldo Vieira de Carvalho (IDB), Hoang Vu Duc (EC), Kevin Welsch (USA), David White (Australia), Zheng Xingwu (China), Nancy Young (A4A). Coordination: ICAO Secretariat

Renewable Energy in Germany (AIREG), Australian Initiative for Sustainable Aviation Fuels (AISEF), and the Brazilian Alliance for Aviation Biofuels (ABRABA), Bioqueroseno, and Biofuels Flightpath initiatives.

Regarding sustainability, the SUSTAF group agreed that the following general principles should be considered for the deployment of alternative fuels in aviation:

a) Sustainable alternative fuels produced for aviation should achieve a net reduction of GHG emissions on a life cycle basis, compared with the use of conventional jet fuels. Particular attention should be paid to the carbon stocks of the land converted for the feedstock production and to continuous progress towards higher emission reductions.
b) Geographic areas of high importance for biodiversity, conservation, and ecosystem services[10] should be identified and preserved.
c) Sustainable alternative fuels produced for aviation should contribute to local social and economic development; and competition with food should be minimized.

Beyond these principles, States should build on existing approaches to determining the sustainability of alternative aviation fuels in order to develop their policies and monitor the impacts of commercial scale deployment at the national level. Improvements and complementary measures are also required, in particular with respect to global and indirect impacts of such deployment.

Finally, an increased convergence between national policies on the definition of mechanisms for interoperability and mutual recognition should be sought by States since it would significantly facilitate the deployment of sustainable alternative fuels in aviation. This applies to both technical suitability and sustainability of the fuels. ■

REFERENCES

1 Fatty Acid Methyl Esters, commonly called biodiesel.

2 UN 2005 World Summit Outcome (United Nation General Assembly – October 2005).

3 www.globalbioenergy.org/programmeofwork/task-force-on-sustainability/gbep-report-on-sustainability-indicators-for-bioenergy/fi/

4 A compilation of bioenergy sustainability initiatives has been done by FAO/BEFS and is available at www.fao.org/energy/befs/compilation/en/

5 Initially “Round-table on Sustainable Biofuels”, it has now enlarged its scope and become “Round-table on Sustainable Biomaterial” (http://rsb.org/).

6 Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources.

7 www.epa.gov/otaq/fuels/renewablefuels/index.htm

8 R.M. Teixera de Andrade – Policies and institutional and legal frameworks in the expansion of Brazilian biofuels – CIFOR working paper 71, 2011.

9 EU RED includes requirements on agricultural practices for domestic production.

10 Millennium Ecosystems Assessment: “Ecosystem services are the benefits people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as flood and disease control; cultural services such as spiritual, recreational, and cultural benefits; and supporting services, such as nutrient cycling, that maintain the conditions for life on Earth” – Ecosystems and Human Well-being – A Framework for Assessment. www.millenniumassessment.org

SUSTAINABLE ALTERNATIVE FUELS

STAKEHOLDER INITIATIVES – DEVELOPMENT OF ALTERNATIVE FUELS IN AVIATION

There have been important developments in the area of alternative fuels for aviation since the 2010 edition of the ICAO Environmental Report. This article provides an overview of several stakeholder initiatives that were launched over the past three years to promote the deployment of alternative fuels in aviation.

AVIATION INITIATIVE FOR RENEWABLE ENERGY IN GERMANY – AIREG E.V.

By **Christoph Jessberger**, Chairman of the AIREG working group, "Sustainability"

CHRISTOPH JESSBERGER

He studied economics and did his PhD at the University of Munich. He joined Bauhaus Luftfahrt in 2011 as project manager of a national research project on "quality and sustainability standards for the provision of bio-fuels for aviation" which aims at developing economic and technical incentive structures for the production of aviation biofuels. As a scientific member of the "Economics and Transportation" team he is an expert in sustainability, renewable energies, scenario analysis, and economic evaluation. He was elected chairman of the aireg (Aviation Initiative for Renewable Energy in Germany e.V.) working group "sustainability" in March 2012 and joined the ICAO SUSTAF expert group in June 2012.

AIREG, headquartered in Berlin, Germany, was established by air carriers, airports, research facilities, the aviation and alternative fuels industry, and other partners in 2011.

In AIREG's view, the voluntary commitment of the aviation industry towards carbon-neutral growth from 2020 onwards can only be achieved through quick and targeted action. Air carriers and aircraft manufacturers, together with the aviation research community, have pursued technological approaches to reduce fuel consumption and the emission of pollutants by undertaking technical improvements to aircraft and their engines, and by optimizing air traffic at the operational level. These measures alone will be insufficient to reach the ambitious goals of the aviation sector to reduce CO_2 emissions in the face of the expected continued increase in the volume of international civil air traffic.

AIREG is aware that research activities and demonstration projects need to be implemented, to provide opportunities for developing, demonstrating and evaluating options for producing and using sustainable alternative fuels. In addition to developing highly efficient aircraft with ever-decreasing emissions within the overall system, manufacturers and aircraft operators, in conjunction with researchers, are now focusing on the search for sources of alternative fuels. The only practicable replacements to fossil fuels in aviation are alternative, renewable, and drop-in liquid fuels.

The goals established by AIREG in this area are implementation of research and demonstration projects, and introduction of renewable fuels for aviation in Germany, as well as the provision of information concerning the demand, origin, availability and use of renewable fuels for aviation. The AIREG working groups, cover the core areas from crop to tank including: provision of feedstock; fuel production technologies; fuel utilization; quality and certification; and sustainability. Through these activities AIREG is connecting knowledge and expertise, and propelling the progress of sustainable alternative fuels for aviation to identify the most efficient pathways to fulfil ambitious emissions reduction goals. For this purpose, AIREG is actively lobbying the German Mobility and Fuels Strategy, and it participates in the EU Advanced Biofuels Flightpath dialogue toward the EU's goal of "2 million tonnes in 2020". Additionally, AIREG contributes to the development of recommendations to further facilitate global R&D and deployment of sustainable alternative fuels for aviation through its participation in the ICAO SUSTAF Expert Group and has developed a comprehensive strategy paper in this regard.

GREENSKY LONDON CASE STUDY: BRITISH AIRWAYS-SOLENA FUELS LOW CARBON FUELS PROJECT

By **Leigh Hudson**, Environment Manager, British Airways

LEIGH HUDSON

She currently leads British Airways carbon management portfolio including an extensive biofuels programme, as well as carbon accounting and efficiency initiatives. She also oversees the company's One Destination Carbon Fund, which aims to increase customers' awareness of climate change by investing in small-scale community projects to install renewable energy. A Chartered Chemist, Ms. Hudson has extensive experience of environmental management within multinational corporations. She holds an MSc in Corporate Environmental Management from the University of Surrey.

British Airways is working with the US-based sustainable energy company Solena Fuels to develop Europe's first waste-to-biojet-fuel plant, the "Greensky" project. This first-of-a-kind facility, currently at the planning stage, will be constructed east of London.

As depicted in **Figure 1**, the project will use Solena's single phase high temperature gasification enabled solution to convert ~ 500,000 tonnes of low-value residual waste (*i.e.* material that is presently going to landfill) into a renewable biosynthetic gas, or "BioSynGas". The BioSynGas will then be cleaned and passed through a Fischer-Tropsch system to produce a bio-crudewax fuel to be upgraded into low carbon fuels, yielding ~50,000 tonnes each of biojet (FT-SPK) and biodiesel (ASTM975/D4294), and ~20,000 tonnes of bionaphtha.

Independent greenhouse gas life (GHG) cycle analysis has confirmed that the process will meet the sustainability standards required by the EU Renewable Energy Directive and the Roundtable on Sustainable Biofuels. The sustainability benefits of this fuel are wide ranging, as using waste avoids the indirect land use change impacts associated with many crop-based biofuels. In addition, the fuels produced are clean burning and provide air quality benefits, as the fuels emit very low levels of particulates. The renewable naphtha can be used to make renewable plastics or be blended into transport fuels, and the process also produces a solid aggregate material that can be used in construction.

INITIATIVE TOWARDS SUSTAINABLE KEROSENE FOR AVIATION – ITAKA PROJECT

By **Inmaculada Gomez**, ITAKA project coordinator

INMACULADA GOMEZ

Inmaculada Gomez is the Project Coordinator of ITAKA. As an environmental expert at the Observatory of Sustainability in Aviation of SENASA since its creation in 2007, she was involved in the creation of the Spanish Initiative for aviations biofuels (Bioqueroseno.es), leading it Secretariat since 2010. She is also member of the working group for alternative fuels of ACARE. She received her M.Sc in Environmental Sciences from the University of Avila, where she has been professor of Environmental Economics.

As the first project of its kind in the European Union, the Initiative Towards sustAinable Kerosene for Aviation (ITAKA) will link supply and demand by establishing a relationship under guaranteed conditions among feedstock growers, biofuel producers, distributors, and final users. The ITAKA project began at the end of 2012 and will conclude in 2015.

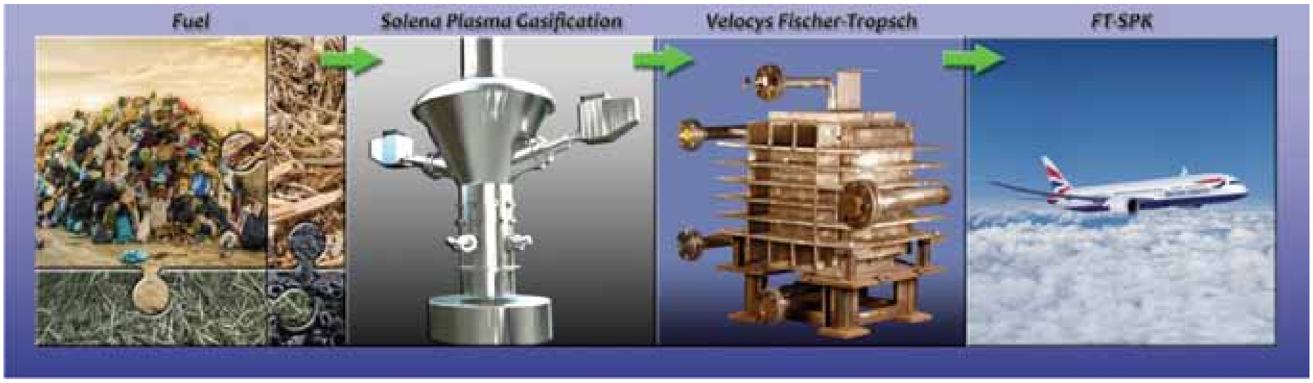


Figure 1: *Solena's Single Phase High Temperature Gasification Enabled Solution.*

ITAKA's main objective is to facilitate the deployment of aviation biofuels in an economically, socially and environmentally sustainable manner, by improving the readiness of existing technologies and infrastructures. It addresses the challenges to the deployment of alternative fuels for aviation in two main areas:

- Development of commercial scale production and study of the implications of large-scale use;
- Research on sustainability, economic competitiveness, and technology readiness.

To achieve its general objectives, ITAKA will build up a full value-chain in Europe to produce sustainable kerosene (*i.e.* Hydroprocessed Esters and Fatty Acids – HEFA) on a scale large enough to allow its testing in existing logistic systems and in normal flight operations in Europe. The knowledge generated will aim to identify and address the barriers to innovation and commercial deployment. In particular, ITAKA will evaluate the technical and operational impacts of the use of biofuels in normal flight operations and logistic systems.

In the case of feedstocks, ITAKA targets European camelina oil and used cooking oil, in order to meet a minimum 60% saving on GHG emissions compared to the fossil Jet A-1. The project aims to certify the entire supply chain of renewable aviation fuel, based on the Roundtable on Sustainable Biofuels (RSB) – EU RED standard. In addition, the production and use of camelina as a biofuel feedstock will also be assessed with respect to its contribution to food and feed markets, and its potential impact on direct and indirect land use change. The research will also evaluate the economic, social, and regulatory implications of the large-scale use of biofuels in aviation. ITAKA is also coordinating with other initiatives to enhance synergies and maximize the impact of research and innovation in the aviation biofuels sector at a global level.

ITAKA is a collaborative project developed by companies and research centres that are leaders in: feedstock production (BIOTEHGEN and Camelina Company España); renewable fuel production (Neste Oil, RE-CORD); fuel logistics (CLH, SkyNRG); air transport (Airbus, EADS IW UK, Embraer, SENASA); and sustainability assessment (EADS IW France, EPFL, MMU), with the collaboration of KLM. The project is funded by the European Union Seventh Framework Programme.

KLM'S INTEGRATED BIOFUEL APPROACH

By **Fokko Kroesen**, Environmental Manager, CSR & Environmental strategy – KLM

FOKKO KROESEN

He is corporate environmental manager at KLM Royal Dutch Airlines. He joined KLM Corporate to manage Environmental Strategy from 2005 and currently is responsible for KLM's sustainability policy on biofuels and climate issues. After an MSc degree in chemistry and postgraduate courses on environmental sciences in 1991, Mr. Kroesen worked at the University of Groningen and as consultant in Utrecht on environmental performance and certification projects, before joining KLM Engineering & Maintenance, to implement ISO 14001 and train staff, being environmental representative for KLM Ground operations at Schiphol airport.

The strategy of the AIR FRANCE-KLM group is to explore the entire value chain from research to commercialization, in order to achieve a breakthrough for scalable and affordable sustainable biofuels. Within its partnership with the World Wildlife Federation – Netherlands (WWF-NL), KLM has declared its intention to strive for a 1% mix of sustainable biofuel throughout its entire aircraft fleet by 2015.

KLM's integrated biofuel approach focuses on four main activities: innovating the (upstream) supply chain; enforcing government incentives; stimulating an industry push; and involving customers and partners. By engaging the whole supply chain and carrying out concrete projects with actual flights using sustainable biofuels, KLM is pro-actively investing in the availability of its own resource supply for the medium and long term. In this way, the company is also able to further develop an international market for sustainable biofuels as a contribution to the transition towards sustainable energy.

In this regard, in 2009 KLM, together with ARGOS (North Sea Petroleum), and Spring Associates, initiated the SkyNRG venture. SkyNRG is currently the world's market leader for sustainable kerosene, supplying more than fifteen carriers worldwide.

In November 2009, KLM operated the world's first demonstration flight with observers on board using one engine running on 50% Camelina biofuel. In late 2011, KLM initiated a series of 100 biofuel-powered flights from Amsterdam to Paris, followed by a series of another

100 flights in February 2012, burning used cooking oil. In June 2012, KLM operated the longest biofuel flight ever, from Amsterdam to Rio de Janeiro. At the same time, KLM launched its Corporate Biofuel Programme with SkyNRG. The programme enables companies to operate some of their flights on sustainable biofuel, thereby stimulating the further development of biofuels. Major corporate customers such as Nike, Heineken, and Philips, were among the first seven companies to join the programme and begin biofuel flights. The number of partners in the programme has more than doubled to fifteen, since its start in 2012.

In March 2013, KLM launched a weekly flight from New York City's John F. Kennedy Airport to Amsterdam's Schiphol Airport using sustainable biofuel. This is the result of a joint effort and expanded cooperation between KLM, Schiphol Group, John F. Kennedy International Airport, and Delta Air Lines. Cooperation is a priority for the future of sustainable biofuel in the aviation industry. Through this initiative, KLM is demonstrating that sustainable biofuel in the airline industry is here to stay.

For KLM, biofuel is only an option if it does not have a negative impact on biodiversity, local development, and/or local food supplies. SkyNRG is advised by a Sustainability Board including representatives from WWF-NL, Solidaridad and the Copernicus Institute of the University of Utrecht. As of March 2013, SkyNRG holds the first fully certified renewable jet fuel supply chain by the Roundtable on Sustainable Biofuels (RSB).

THE MIDWEST AVIATION SUSTAINABLE BIOFUELS INITIATIVE (MASBI)

By **Jimmy Samartzis**, United Airlines

JIMMY SAMARTZIS

He is Managing Director of Global Environmental Affairs and Sustainability at United Airlines. As head of the division, Mr. Samartzis leads United's overall environmental efforts on a global level including environmental policy, sustainability, alternative fuels, regulatory compliance, and environmental remediation and liability management. As an active leader in national and international aviation environment policy, operations, alternative fuels, and sustainability, He currently serves as Chairman of the Airlines for America Environment Council and is a member of the International Air Transport Association (IATA) Environment Committee.

United Airlines continues to lead in the advancement and commercialization of the alternative aviation fuels industry. From the company's early demonstration flights in 2009, and its historic partnership with AltAir for the supply of aviation biofuel, United has been instrumental in the advancement of alternative fuels for aviation.

United Airlines and AltAir Fuels partnership

In June 2013, United Airlines announced a partnership and definitive off-take agreement with AltAir Fuels for cost-competitive, sustainable, advanced biofuels that will power its flights departing Los Angeles International Airport. AltAir Fuels will use process technology developed by Honeywell's UOP to retrofit part of an existing petroleum refinery and create a biofuel refinery that converts non-edible natural oils and agricultural wastes into approximately 30 million gallons of low-carbon, advanced biofuels and chemicals each year.

United has agreed to buy 15 million gallons of lower-carbon, renewable jet fuel from AltAir over a three-year period, with the option to purchase more. United is purchasing the advanced biofuel at a price that is competitive with traditional, petroleum-based jet fuel. AltAir expects to begin delivering five million gallons of renewable fully drop-in jet fuel per year to United starting in 2014. The fuel is expected to achieve at least a 50% reduction in GHG emissions on a lifecycle basis.

The Midwest Aviation Sustainable Biofuels Initiative

In June 2012, United and Boeing, Honeywell's UOP, the Chicago Department of Aviation and the Clean Energy Trust, launched the Midwest Aviation Sustainable Biofuels Initiative (MASBI), which leveraged the expertise of more than 40 public and private stakeholders from across the aviation biofuels value chain to develop an action plan to accelerate the development of the advanced biofuels industry.

According to the final report, issued in June 2013, the commercial aviation industry has a clear path toward cleaner, more economical and more secure energy alternatives through the increased use of advanced biofuels developed in the Midwest. This region of the U.S. is a natural fit to advance aviation biofuels given that it is home to one of the world's largest airlines and also offers feedstock availability and viability, a concentration of clean technology leaders, a vibrant funding community, airports supporting sustainability, and policymakers focused on advanced biofuels.

Recommendations included:

1. Streamline the approval process for new biofuel production methods;
2. Level the policy playing field for advanced biofuels with the conventional petroleum industry;
3. Tailor agriculture products such as oil-seed crops for jet-fuel production;
4. Pursue deal structures that balance risk and reward for early adopters of technology.

In addition to endorsing the report's recommendations, several MASBI members made new commitments to help secure a robust future for biofuels including academic research and innovation funding by Boeing, Honeywell's UOP, and United Airlines; a cooperation agreement with United Airlines and the Chicago Department of Aviation to identify alternative aviation fuel opportunities, and United will issue a Request for Proposal for the development and purchase of cost-competitive, sustainable, renewable jet fuel and diesel.

The full report is available at www.masbi.org.

NORDIC INITIATIVE

By **Martin Porsgaard**, Director Environment & CSR – SAS

MARTIN PORSGAARD

Mr. Porsgaard is Director, Environment & Sustainability at Scandinavian Airlines. He has extensive experience in developing and coordinating strategies and policies for the development of new energies for future sustainable transport.

The main players within the Nordic aviation sector, namely the Nordic airports, airlines and their associations, as well as aviation authorities, with the support of Boeing and Airbus, are joining forces to develop sustainable aviation fuels, recognizing that alternative fuels are one of the means to render international civil aviation more sustainable. Accordingly, these parties have formed a network organization which aims to secure a share of the limited biofuel resources for the aviation industry as sustainable crops, raw materials and surplus products from forests, agriculture, industry and households are increasingly in demand.

Although the technology to produce alternative jet fuels is in its infancy, the aviation industry is open to the use of alternative fuels. The current internationally approved specifications for the production and use of alternative fuels are fully in line with those for the jet fuel used today. These specifications ensure that these fuels can be used in existing engines on all models of jet aircraft.

In seeking to obtain a share of the limited biofuel resources, the aviation industry is concerned that the energy sector, road transport and other modes of transportation are receiving higher priority. In contrast to other transport sectors, the aviation sector, at least provisionally, has no alternative to liquid fuel. To address this situation, the Nordic initiative focuses on bringing together stakeholders from across the supply chain to find the best, most energy efficient solutions, while at the same time, placing pressure on policy makers to ensure that the aviation secures its share of alternative fuel resources. This task is far-reaching and involves numerous stakeholders from various sectors including: agriculture, technology suppliers, investors, regulators, producers, and oil suppliers. While currently aviation is not seriously considered in energy policy discussions in any Nordic country, aviation is an integral part of national infrastructures, and therefore needs to be given a higher priority with respect to the other sectors. Some international competitors are already undertaking research and development of alternative fuels for aviation, many of them involving public-private partnerships. Such an approach should also be on the political agenda in Nordic countries.

As this is also an international issue, the Nordic Initiative has started a dialogue with parallel initiatives in the EU, with individual States, and with international organizations. The Initiative is also supported by Boeing and Airbus, which is of paramount importance as both aircraft manufacturers participated in the establishment of similar networks of organizations in other regions.

Nordic Initiative participants are:

- Airlines: SAS, Finnair, Norwegian, Icalandair, Air Greenland, Malmo Aviation, Atlantic Airways;
- Organizations: DI/Transport, Svenskt Flyg, Svenska FlygBranchen, NHO, IATA;
- Authorities: DK/Trafikstyrelsen, SV/Transportstyrelsen, NO/Avinor, FL/Transport;
- Airports: DK/CPH, SV/Swedavia, NO/Avinor, FL, Island;
- Producers: Boeing, Volvo, Airbus.

OPENING THE PATH FOR SUSTAINABLE AVIATION BIOFUELS IN BRAZIL (SABB)

By **Luis Augusto Barbosa Cortez**

LUIS AUGUSTO BARBOSA CORTEZ

He is a Professor at the Faculty of Agricultural Engineering at UNICAMP and Adjunct Coordinator for Special Programs at São Paulo Research Foundation. Mr. Cortez has coordinated projects in bioenergy, such as a study on sugarcane ethanol expansion in Brazil, and the FAPESP Public Policy Ethanol Project in R&D for sustainable ethanol production. Presently he is coordinating the FAPESP/IANAS/LACAf-I Project to promote bioenergy in Latin America and Africa, and the project on Sustainable Biofuels for Aviation in Brazil. Mr. Cortez holds a B.Sc. in Agricultural Engineering from UNICAMP, Brazil, a M.Sc. from Université Laval, Québec, Canada and a Ph.D. from Texas Tech University, USA.

Developing renewable alternatives to jet fuels that will substantially reduce GHG emissions and contribute to easing the high cost of energy is a challenging task that involves many variables, in terms of feedstock and processes, scale, logistics, production model, and implementation concept.

The Sustainable Aviation Biofuels for Brazil (SABB) project, which involves several stakeholders, and is supported by São Paulo Research Foundation (FAPESP), Embraer, and Boeing, promotes dialogue on aviation biofuels in Brazil, and is particularly eager for the deployment of alternative aviation biofuels. The conditions for deployment are favorable, as automotive biofuels (ethanol and biodiesel) have been widely adopted for use in Brazilian road vehicles, air transport growth has been accelerating and a modern aircraft industry is currently in place.

The introduction of biofuels for the aviation industry has been intensely evaluated, with the replication of the experiments carried out for ethanol and biodiesel adoption in light and heavy vehicles in many countries. Yet, the adoption of biofuels in aviation faces challenges, especially their use at global scale and the stringent fuel certification requirements that must be met. Thus, to reach effective technical feasibility and to attain the conditions needed to develop an international market, aviation biofuels must have high energy density, meet rigorous quality specifications, be "drop-in" fuels (*i.e.* fully compatible with current infrastructure and flight equipment), and enhance the operational safety. In addition, they must be environmentally sustainable and achieve minimum levels of economic competitiveness.

In order to explore the diverse issues discussed above, a series of workshops were held across Brazil between May and December 2012, attracting participants from public and private institutions, both from Brazil and abroad. Workshops covered all topics from feedstock to policy, including sustainability, technology and others. Workshop presentations were followed by discussions involving qualified audience participants whom identified the most promising feedstock and conversion technologies, as well as the issues related to logistics and the regulatory framework. These discussions enabled basic guidelines to be set for a national strategy on sustainable aviation biofuels. The main aim of the workshops was to establish clear and well-founded recommendations for:

- filling research and development gaps in the production of sustainable feedstocks;
- more incentives to overcome conversion technologies barriers, including scaling-up issues;
- greater involvement and interaction among private and government stakeholders;
- creation of a national strategy to make Brazil a leader in the development of aviation biofuels.

The Action Plan that emerged from this project was to be launched and the full report made available, in June 2013, at FAPESP headquarters in São Paulo, Brazil. ■

OVERVIEW - MARKET-BASED MEASURES

MARKET-BASED MEASURES

BY ICAO SECRETARIAT

INTRODUCTION

Market-based measures (MBMs) have been on the ICAO agenda for a number of years as a potential means to mitigate the climate change impacts of international aviation. MBMs are one of the important tools available to address greenhouse gas (GHG) emissions amongst a range of other measures including: operational improvements, new technologies, alternative fuels, action plans, and assistance to States.

Sometimes referred to as market instruments, MBMs provide financial incentives and disincentives to guide the behaviour of regulated entities towards lowering emissions. These measures can be implemented to reduce damage to the environment. The investigation of MBMs as a potential option for international aviation began in the late 1990s through ICAO's Committee on Aviation and Environmental Protection (CAEP).

In 2010, ICAO Assembly Resolution A37-19 adopted guiding principles for the design and implementation of MBMs (See **Box** on Assembly Resolution A37-19, Annex). The Resolution also requested that the Council explore the feasibility of a global MBM scheme, develop a framework for MBMs, review the *de minimis* threshold for MBMs, taking into account the specific circumstances of States and potential impacts on the aviation industry and markets, and undertake a study on the possible application of Clean Development Mechanisms of the Kyoto Protocol to international aviation.

GLOBAL CONTEXT

Worldwide, there is increasing interest in using MBMs to address climate issues. The largest emission trading scheme in the world, the European Union Emission Trading Scheme (EU-ETS), decided to include aviation under its scheme from 1 January 2012. However, in November 2012, a decision was made to suspend the application of the EU-ETS to international aviation (referred to as "stop the clock"). For a period of one year, all international flights would be excluded from the EU-ETS, and only intra-European flights remained covered.

The first commitment period under the Kyoto Protocol was completed at the end of 2012, and at the 18th Meeting of the Conference of the Parties (COP18) to the United Nations Framework Convention on Climate Change (UNFCCC), held in Doha, Qatar, in December of that year, governments agreed to continue with an eight year second commitment period from 2013 to 2020. It was also agreed that a legally binding accord on climate change should be adopted at COP21 in 2015 for implementation beginning in 2020. Many States did not commit to binding emissions targets for the second commitment period resulting in the weakening of market-based mechanisms under the Kyoto Protocol (see article *Market-Based Measures and the United Nations*, Chapter 4 in this report).

In June 2013, at its 69th Annual General Meeting, the International Air Transport Association (IATA) endorsed a resolution on the "Implementation of the Aviation Carbon-Neutral Growth (CNG2020) Strategy". This resolution is meant to provide governments with recommendations on how a global MBM for aviation could be implemented (see article *IATA Agreement on Carbon Neutral Growth*, Chapter 4 in this report).

WHY MARKET-BASED MEASURES?

GHG emissions from international aviation are growing rapidly. ICAO data shows that international CO_2 emissions grew from approximately 185 megatonnes (Mt) in 1990 to 448 Mt in 2010. Recent analysis by CAEP on fuel trends estimated that the average annual growth of aviation traffic will likely range between 5.2% and 4.2%. This means that the continued growth of fuel consumption is projected to be from 2.8 to 3.9 times higher in 2040 than the 2010 value.

CAEP also concluded that, beyond the forecasted aircraft technology and operational improvements, additional measures will be needed to achieve carbon neutral growth by 2020. Sustainable alternative fuels have the potential to make a contribution to the remaining gap, but it is too early to confidentially predict their availability and potential contribution. More detailed results of the ICAO's CAEP analysis on trends are further discussed in this report (see article *Environmental Trends in Aviation to 2050*, Chapter 1 in this report).

Market-based measures are therefore believed to be an important gap filler, that can be characterized as an efficient way to reduce emissions. MBMs provide participants with flexibility to choose between the implementation of emission reduction measures within their own sector, or offsetting those CO_2 emissions in other sectors. This is particularly important for the aviation industry, where in-sector emissions reductions are expensive and limited.

ASSEMBLY RESOLUTION A37-19 ANNEX

The guiding principles for the design and implementation of market-based measures (MBMs) for international aviation:

a) MBMs should support sustainable development of the international aviation sector.
b) MBMs should support the mitigation of GHG emissions from international aviation.
c) MBMs should contribute towards achieving global aspirational goals.
d) MBMs should be transparent and administratively simple.
e) MBMs should be cost-effective.
f) MBMs should not be duplicative and international aviation CO_2 emissions should be accounted for only once.
g) MBMs should minimize carbon leakage and market distortions.
h) MBMs should ensure the fair treatment of the international aviation sector in relation to other sectors.
i) MBMs should recognize past and future achievements and investments in aviation fuel efficiency and in other measures to reduce aviation emissions.
j) MBMs should not impose inappropriate economic burden on international aviation.
k) MBMs should facilitate appropriate access to all carbon markets.
l) MBMs should be assessed in relation to various measures on the basis of performance measured in terms of CO_2 emissions reductions or avoidance, where appropriate.
m) MBMs should include de minimis provisions.
n) Where revenues are generated from MBMs, it is strongly recommended that those funds should be applied in the first instance to mitigating environmental impacts of aircraft engine emissions, including mitigation and adaptation, as well as to support and assist developing States.
o) Where emissions reductions are achieved through MBMs, they should be identified in the emissions reporting of States.

Finally, economic instruments such as MBMs provide "financial incentives to guide behaviour towards environmentally responsible activity". For example, an MBM that places a price on carbon, encourages further efficiency improvements and the adoption of new technologies.

PROGRESS AT ICAO

During the three years since the last Assembly, ICAO undertook work on each of the requests made by Resolution A37-19. One of the first deliverables completed was the "*de minimis* study" to assess the impact of applying a *de minimis* threshold which would exempt States which had less than 1% of the total international revenue tonne kilometres, from implementation of MBMs. That analysis demonstrated that if a *de minimis* exemption was introduced, there would be substantial market distortions between the operators that were subject to an MBM and operators not subject to an MBM. For example, it was estimated that impacts on traffic demand could be approximately 50% more significant for operators under an MBM than for operators with an exemption.

A process was established for work on MBMs at ICAO with the support of experts nominated by States and international organizations from around the world. The progress of the work was reviewed by an Ad Hoc Working Group on Climate Change, comprised of the ICAO Council Representatives from each of the six ICAO regions. The Ad Hoc Working Group provided recommendations to the Council up until June 2012.

The assessment of MBMs for a global scheme started with six possible MBM options, which were narrowed down to four in early 2012, and further reduced to three by the ICAO Council in June 2012. The three remaining options that were subject to more detailed analysis were: global mandatory offsetting; global mandatory offsetting with revenue; and global emissions trading. The qualitative and quantitative assessment of the three options was performed by the ICAO Secretariat and the experts, with the results presented to the ICAO Council in November 2012. The analysis determined that MBMs can contribute to achieving carbon neutral growth from 2020 at relatively low cost, compared to the cost of in-sector reductions, and with marginal differences between regions and groups of States.

To support MBM policy considerations, a High-level Group on International Aviation and Climate Change (HGCC), comprised of high-level government officials, was created by the ICAO Council at the end of 2012. Its role was to develop policy recommendations on issues such as design features that could be most appropriate for implementation of an MBM.

A quantitative assessment in 2012 estimated the costs and emissions reductions of the different MBM options for a global scheme. It was complemented by a supplementary study in 2013 which used the latest fuel burn and emissions data produced by CAEP. More detailed findings of both studies on MBMs are provided in the article *Potential Impacts of MBMs on the International Aviation*, Chapter 4 in this report.

The development of an MBM framework was undertaken in parallel with the work on the feasibility of a global MBM scheme. The MBM experts provided support on the framework for MBMs, including the role and purpose, the guiding principles, and the main elements of a framework. This work was also considered by the HGCC.

UNDERSTANDING THE IMPORTANCE OF CARBON MARKETS TO INTERNATIONAL AVIATION

To understand the trends in the development of carbon markets and to identify implications for international aviation, ICAO has been monitoring MBMs globally. Lessons from the development of MBMs, such as the Kyoto mechanism, have provided useful information on how the market has responded to new mechanisms, policies and regulations. Trading platforms, international trading rules, State regulations for carbon trading, accepted verification methodologies and the international trading registry can all provide inputs for consideration by international aviation. The financial, intellectual and regulatory infrastructure created in the existing carbon market could facilitate the implementation of a sectoral-based MBM for international aviation. International aviation could build on these tools and avoid the cost of developing its own or new infrastructure.

Under the Kyoto Protocol, Clean Development Mechanism (CDM) carbon credits, known as certified emission reductions (CERs), may be issued to approved projects in developing countries for emissions reductions achieved. Approximately 1.2 billion CERs were issued under the Protocol's first commitment period (2008-2012). Demand for CERs created under the Kyoto Protocol have weakened significantly. At the end of the first commitment period of the Kyoto Protocol, the CER market was in a situation of oversupply. Hundreds of millions of CERs were estimated to be available. In this context, estimates in 2012 showed that any demand created by international aviation for offset credits was not expected to significantly impact the price of CERs. The surplus of CERs was considered a readily available supply of offset credits for the international aviation sector. More information on the state of the carbon markets as it relates to international aviation is available in the article *Achieving Carbon Neutral Growth form 2020*, Chapter 4 in this report.

In addition to the CDM which has a strict and transparent verification process, there are an increasing variety of offset credits certified under different carbon programmes. Should there be a decision to develop an international aviation MBM using offset credits, it may be necessary to establish standards and quality criteria for offset credits to ensure the environmental integrity of emission reductions. The international aviation sector has the opportunity to consider existing criteria, standards, and verification practices, when defining what would be acceptable for the sector. The importance of flexibility in choosing emissions units for a potential aviation scheme is also discussed in the article *Offset Credits As An Option For Destination Green*, Chapter 4 in this report.

MARKET-BASED MEASURES

POTENTIAL IMPACTS OF MARKET-BASED MEASURES ON INTERNATIONAL AVIATION

BY ICAO SECRETARIAT

BACKGROUND

Under the policy framework adopted by the International Civil Aviation Organization (ICAO) in 2010 (Assembly Resolution A37-19), market-based measures (MBMs) are included in a "basket of measures" that Member States can use to address CO_2 emissions produced by international aviation. To better understand and assess these measures, ICAO undertook a number of different studies. In 2001, ICAO's Committee on Aviation Environmental Protection (CAEP) performed an economic analysis of various MBMs[1] that might be used to reduce CO_2 emissions from aviation. Following that, further studies and research were performed by CAEP, and several ICAO Documents have been published on the subject since 2007 (see **Box** on ICAO Policies and Guidance Material on Climate Change).

In 2010, the ICAO Assembly requested that the Council, "…with the support of Member States and international organizations, continue to explore the feasibility of a global MBM scheme by undertaking further studies on the technical aspects, environmental benefits, economic impacts and the modalities of such a scheme, taking into account the outcome of the negotiations under the UNFCCC (United Nations Framework Convention on Climate Change) and other international developments, as appropriate, and report the progress for consideration by the 38th Session of the ICAO Assembly"[2].

The research into options for a global MBM scheme involving international aviation began in 2011, with an initial literature review of planned and existing MBMs, in particular those related to aviation. In early 2012, six potential options for a global MBM scheme for aviation were identified, and the criteria by which they would be evaluated were elaborated, building upon the guiding principles (Annex to Resolution A37-19). In June 2012, the ICAO Council narrowed the MBM options to three – global mandatory offsetting, global mandatory offsetting with revenue, and global emissions trading; and requested that further quantitative and qualitative assessment of these options be undertaken.

This article provides an overview of the results of the two studies undertaken by the ICAO Secretariat to assess the feasibility of a global MBM scheme. This work was undertaken during 2012 and 2013 with the support of the MBM Experts nominated by Member States and international organizations.

ICAO POLICIES AND GUIDANCE MATERIAL ON CLIMATE CHANGE

- ICAO 37th Assembly Resolution (A37-19)
- ICAO's *Policies on Charges for Airports and Air Navigational Services* (Doc 9082)
- ICAO's *Policies on Taxation in the Field of International Air Transport* (Doc 8632)
- ICAO Council Resolution on Environmental Charges and Taxes (9 December 1996)
- *Guidance on the use of Emission Trading for Aviation* (Doc 9885)
- *Scoping Study of Issues Related to Linking "Open" Emissions Trading Systems Involving International Aviation* (Doc 9949)
- *Report on Voluntary Emissions Trading for Aviation* (Doc 9950)
- *Offsetting Emissions from the Aviation Sector* (Doc 9951)
- *Report on the Assessment of Market-Based Measures* (Doc 10018)

ASSESSING THE IMPACTS OF MBMs

The first study, in which the three MBM options were analysed, is referred to as the core study and was conducted in 2012. The core study assessed the possible economic and environmental impacts of: global mandatory offsetting, global mandatory offsetting with revenue, and global emissions trading (see **Box** on Global MBM Options for International Aviation). The study was comprised of two parts: quantitative and qualitative. In the quantitative assessment, impacts at a global level and on developing countries were assessed. In the qualitative assessment, the main design features were identified for each of the three MBM options. This evaluation helped identify the main differences between MBM options and highlight the differences in the administrative complexity of these options.

The second study, known as the supplementary study was limited to a quantitative assessment of the impact of a single global MBM measure on international aviation. It used the updated traffic forecasts and emissions trends prepared in 2013 by CAEP to further assess the impacts of MBMs on international aviation. The economic and environmental impacts were assessed only at a global level in the supplementary study.

MODELLING TOOLS USED IN THE QUANTITATIVE ASSESSMENTS

The quantitative assessment of the core study was undertaken using aviation-specific economic models. Two models were employed in the evaluation of MBM options. The first model, the Aviation Emissions and Evaluation of Reduction Options – Modelling System (AERO–MS), was developed in Europe, while the second model, Aviation Portfolio Management Tool for Economics (APMT – Economics), was developed in North America. Both tools were developed for the purpose of testing the environmental and economic consequences of implementing various measures to reduce global aircraft engine emissions and validated by CAEP.

The supplementary study used a simplified spread sheet model that was developed by the ICAO Secretariat in association with MBM Experts.

APPROACH USED IN THE QUANTITATIVE ASSESSMENT

To assess the impact of MBMs, it is first necessary to know the emissions reduction goals they will achieve and the timeline for their implementation. Then, the future of the aviation sector both with and without MBMs is forecasted and the results are compared to reveal the impact of MBMs. Assumptions defined for the analysis were kept consistent for both studies. These assumptions are:

- the environmental objective is to maintain CO_2 emissions at the same level from the year 2020 (*i.e.* carbon neutral growth);
- the impacts of MBMs would be evaluated from 2020 to 2036 (timeline);
- the future price of carbon per tonne of CO_2 (2010 USD): $30 in 2020, $40 in 2030, and $45 in 2035[3];
- the future price of fuel based on crude oil per barrel (2010 USD): $109 in 2020, $117 in 2030, and $120 in 2035[4];
- the cost of purchasing emissions units would be passed through to ticket prices (100% cost pass through);
- use of alternative fuels would result in zero CO_2 emissions; and
- only CO_2 emissions from international aviation are considered (*i.e.* non-CO_2 impacts of aviation are not included in this assessment).

In the quantitative assessment portion of the core study, six scenarios were developed using the above listed assumptions for all MBM options, including different levels of revenue generation for those options that can generate revenue.

The core study also assessed the impacts of MBMs on developing countries. Three different approaches were used: 1) evaluating six regions; 2) comparing differences between Least Developed Countries (LDCs) and non-LDCs; and 3) a sample analysis of countries which took into account the level of development by per capita income, and international aviation activity in terms of available seat kilometres (ASK).

The supplementary study assessed MBM impacts using two scenarios. Emissions reduction potentials from both new technologies and operational improvements were analyzed. The study also looked at the impacts of the potential use of alternative fuels.

RESULTS OF THE QUANTITATIVE ASSESSMENT

In the 2012 core study, the cost of introducing an MBM was found to be relatively small. Under a scenario of keeping net carbon emissions at the same level from the year 2020, MBMs would need to reduce or offset 464 Mt of CO_2 by 2036 to cover emissions increases from 2020 to 2036. In the cases where 100% of the costs of an MBM would be passed on to customers through increases in the price of tickets, the quantitative assessment showed that:

Traffic Impact: Under an MBM scenario, international aviation traffic would grow 107% from the years 2020 to 2036. Without an MBM, traffic would grow 110% between 2020 and 2036. Thus, the traffic level in 2036 would be 1.2% lower as a result of an MBM.

GLOBAL MBM OPTIONS FOR INTERNATIONAL AVIATION

GLOBAL MANDATORY OFFSETTING

Offsetting operates through the creation of emissions units which quantify the reductions achieved. These emissions units, which would generally be created outside the international aviation sector, can be bought, sold or traded.

A global mandatory offsetting scheme for international aviation would require participants to acquire emissions units to offset CO_2 above an agreed target. Emissions units would need to conform to agreed eligibility criteria to ensure adequacy of emissions reductions. No specific aviation allowances or revenues would be created under this scheme.

GLOBAL MANDATORY OFFSETTING WITH REVENUE

Global mandatory offsetting complemented by a revenue generation mechanism would generally function the same way as the mandatory offsetting scheme. A key difference would be that in addition to offsetting, revenue would be generated by applying a fee to each tonne of carbon, for instance, through a transaction fee. The revenue would be used for agreed purposes, such as climate change mitigation or providing support to developing States to reduce GHG emissions.

GLOBAL EMISSIONS TRADING

The global emissions trading scheme (ETS) would use a cap-and-trade approach, where total international aviation emissions are capped at an agreed level for a specified compliance period. Specific aviation allowances (one allowance is equivalent to one tonne of CO_2) would be created under this scheme for all the emissions under the cap within the international aviation sector. These allowances would then be distributed for free, or auctioned, to participants using an agreed method.

At the end of each compliance period, participants would need to surrender allowances, or other emission units, equal to the emissions generated during that period, including those above their allocation.

Extract from *Report on the Assessment of Market-based Measures* (ICAO Doc 10018)

Profit Impact: Profits for the international aviation sector in 2036 would be $33.3 billion under the scenario with an MBM. This would be $0.4 billion lower than the profit level without the MBM.

Cost Impact: The cost of an MBM in 2036 would be approximately $10 per seat for a flight of 10,000 to 12,000 kilometers, and $1.50 per seat on a flight of 900 to 1,900 kilometers.

The supplementary study in 2013 confirmed the results of the core study that an MBM could achieve the environmental target of stabilizing CO_2 emissions at a relatively low economic cost. With an MBM, the traffic level in 2036 would be up to 1% lower than the traffic level without the MBM, and the cost of an MBM as a proportion of total revenue would be up to 1%, in the worst case scenario studied.

The quantitative assessment demonstrated that the differences of MBM impacts on developing countries were marginal. For example, the MBM impacts on traffic demand for the six regions were generally consistent with the global average of a 1.2% reduction. The change in operating result (profit) brought about by an MBM was relatively consistent among regions, varying from 1.0% to 1.3%. This was generally consistent with the global average of 1.1%.

The comparison of LDCs and non-LDCs showed a similar pattern to that of the regions in terms of consistency with the global results. However, LDCs were not as affected as non-LDCs by MBMs. Impacts on traffic levels and profits were smaller in LDCs, although reductions in CO_2 were also smaller. No differences were noted in the comparison of groups using development parameters (per capita income and ASK).

QUALITATIVE ASSESSMENT

The qualitative assessment focused on the design features of the three options for a global MBM scheme by identifying and elaborating on the implications of different design choices. Any MBM is designed to achieve a clear environmental objective, which can be established with a baseline or cap on emissions levels. The distribution of the environmental objective among participants establishes individual obligations, which collectively respect the environmental objective. Both Member States and aircraft operators would have important roles to play in a global MBM scheme. It will be important to distinguish between the compliance obligations placed on participants in a scheme and on the implementation responsibilities, such as administration and enforcement obligations, for Member States.

COUNCIL – 197TH SESSION – SIXTH MEETING (9 NOVEMBER 2012)

COUNCIL DECISION – C-DEC 197/6

"…recognized that the results of the qualitative and quantitative analysis of the three options for a global MBM scheme evaluated by the Secretariat with the support of the Experts demonstrated that all three options were technically feasible and had the capacity to contribute to achieving ICAO's environmental goals..."

Compliance obligations could generally be tracked through a registry, which at a minimum, would record the environmental objective of a scheme, emissions of each participant, obligation of each participant to surrender emissions units, and tracking of emissions units to ensure that participant obligations are met. A robust monitoring, reporting and verification (MRV) system is key to any MBM, as it ensures that one unit of emissions emitted and recorded in one jurisdiction is directly comparable to a unit in another jurisdiction. This also protects fair market competition and avoids market distortion.

Three main differences in the design features of the three options for a global MBM scheme (global mandatory offsetting, global mandatory offsetting with revenue and global emissions trading) were identified as follows:

1. use of different emissions units;
2. differences in the allocation of obligations to individual participants; and
3. different accounting requirements to ensure compliance under the two systems.

These design differences were assessed for the complexity of administrative steps that would likely be involved in implementing the three options, as follows:

A global mandatory offsetting scheme: could be less complex since existing emissions units can be used and tracked through a simple registry.

A global mandatory offsetting scheme complemented by a revenue generation mechanism: could be more complex due to the need to determine how revenues will be collected and used.

A global emissions trading scheme: could increase complexity and have higher upfront costs due to the need to administer specific aviation allowances (however, it should offer more flexibility for participants due to the creation of emissions units, which can be traded in the marketplace).

CONCLUSION

Overall, the results of the qualitative and quantitative assessments of the three options for a global MBM scheme demonstrated that they were technically feasible and have the capacity to contribute to achieving ICAO's environmental goals. (See **Box** on Council - 197th Session - Sixth meeting, 9 November 2012). ■

REFERENCES

1 CAEP/5 Working paper: *Economic Analysis of Potential Market-based Options for Reduction of CO_2 Emissions from Aviation* (CAEP/5-WP/24).

2 ICAO Assembly Resolution A37-19: *Consolidated statement of continuing ICAO policies and practices related to environmental protection—Climate change*, (http://legacy.icao.int/env/A37_Res19_en.pdf).

3 International Energy Agency, *World Energy Outlook 2011*. To be consistent with modeling data, 2010 dollars were converted to 2006 dollars.

4 International Energy Agency, *World Energy Outlook 2011*. To be consistent with modeling data, 2010 USD were converted to 2006 USD. Fuel prices were converted to annual prices until the year 2036.

MARKET-BASED MEASURES

IATA AGREEMENT ON CARBON NEUTRAL GROWTH

BY INTERNATIONAL AIR TRANSPORT ASSOCIATION

The International Air Transport Association (IATA) represents 240 airlines that carry over 84% of global air traffic. In June 2013, IATA overwhelmingly endorsed a resolution on the "Implementation of the Aviation Carbon-Neutral Growth (CNG2020) Strategy". Member airlines agreed that a single global mandatory carbon offsetting scheme would be the simplest and most effective option for an MBM designed to address climate change.

The resolution provides governments with a set of principles on how they could establish procedures for the development and implementation of a single market-based measure that is integrated into an overall package of measures to achieve CNG2020. The intention of such an MBM would be to deliver real emissions reductions, not revenue generation for governments. The agreed principles apply to emissions growth post-2020.

The sector has already agreed on global targets for greenhouse gas (GHG) emissions, as follow:

- Improving fuel efficiency by 1.5% annually to 2020;
- Capping net emissions from 2020 onward;
- Cutting emissions in half by 2050, compared to 2005.

Aviation was the first sector to agree on a global strategy to achieve climate change goals. An MBM is one of the four pillars of the aviation industry's united strategy on climate change. The three remaining pillars, improvements in technology, operations, and infrastructure will deliver the long-term solutions for aviation's sustainability.

A summary of the main principles of the resolution follows:

- Setting the industry and individual carrier baselines, using the average annual total emissions over the period 2018–2020.

- Agreeing to provisions and/or adjustments for:
  - Early movers-benchmarked between 2005–2020 with a sunset by 2025;
  - New market entrants for their initial years of operation;
  - Fast growing carriers.

- Adopting an equitable balance for determining individual carrier responsibilities that consider:
  - An "emissions share" element (reflecting the carrier's share of total industry emissions);
  - A post-2020 "growth" element (reflecting the carrier's growth above baseline emissions).

- Reporting and verification of carbon emissions that are:
  - Based on a global standard to be developed by ICAO;
  - Simple and scalable, based on the size and complexity of the operator.

- Instituting a periodic CNG2020 performance review cycle that revises individual elements and parameters as appropriate. ■

MARKET-BASED MEASURES

OFFSET CREDITS AS AN OPTION FOR "DESTINATION GREEN"

BY TAKASHI HONGO

TAKASHI HONGO

He is a Senior Fellow at Mitsui Global Strategic Studies Institute. Mr. Hongo served in the Japan Bank for International cooperation (JBIC). He led the drafting the Environment Guideline for JBIC's financing which was renowned as the most advance and practical environment guideline for public finance. He also initiated various carbon related financial instruments such the "GREEN + J-MRV". By using these experiences, he recently focused on harmonization of the decentralized Asian Carbon Market including Bilateral Carbon Offset Mechanism (BOCM) and reforms of financing for the low carbon economy using MRV such as the Performance Base Incentive Scheme. He has contributed to the International Energy Agency (IEA), International Renewable Agency (IRENA), IPCC, UNEP and UNEP FI, OECD, ICAO, GLOBE International, ADB and APEC in addition to the Japanese government and local authorities through various committees.

Environment and climate change are serious global issues. Worldwide greenhouse gas (GHG) emission reductions will be necessary and unavoidable for sustainable industry and societal growth and international aviation is no exception to this. The following article looks at the progress that has been made to date in developing and implementing emissions trading systems. It also discusses the possibility of developing an ICAO carbon emissions trading scheme, and what the criteria and attributes of such a system would be.

FLEXIBILITY IS KEY

Generally speaking, it is better to develop a wide variety of measures to achieve reduction targets effectively and efficiently. This is because there are many ever-changing variables in the mix, including the business environment, available technology, evolving technological innovations and changing investment strategies. Accordingly, the "flexibility of reduction measures" is crucial.

Four primary options are considered for reducing emissions in the aviation sector:

1. Replacement of existing fleet with more efficient aircraft.
2. Route optimization and improvement of ground services.
3. Use of bio fuels as a zero emissions alternative energy source.
4. Offset credit mechanisms.

Each of the above options has pros and cons. Design and commissioning of more efficient aircraft, as well as implementation of route optimization and ground system improvements are essential measures that are already ongoing, and reductions achieved through them will continue for many years. However, it takes a long time to deliver new aircraft and to change over to the most optimal aviation routes. Furthermore, the costs of these measures are quite high. Drop-in type bio fuels have become almost a proven technology. However, further technology innovation is needed to improve their cost competitiveness and to avoid potential conflicts with food and water supplies.

Offset mechanisms reduce emissions indirectly by supporting GHG emission reduction activities through the purchase of offsetting "reductions". For instance, biomass can be used for renewable energy (and reduce CO_2 emission by reducing fossil fuel) but it requires investment for installing equipment. Offset mechanisms support the investment by funding a part of investment cost through purchasing "reductions". When costs are high to achieve abatement reductions by introducing new aircraft or using bio fuels, an offset mechanism can be a reasonable cost option and can work as a bridge towards eventual direct reductions in airline services. Offset mechanisms tend to increase the flexibility of investment timing and reduce investment costs.

INTERNATIONAL EMISSION TRADING AND POSSIBLE OFFSET CREDITS FOR AVIATION

The carbon market is shifting from the two dominant market systems, Kyoto Credit and EU Allowance, to a fragmented markets regime. Following this structural change, various types of credits, both national and sub-national schemes, as well as project base emission reduction credits and allowances under ETS will soon be available for offsetting purposes. **Figure 1** summarizes the current carbon offset credit systems that have been implemented.

Type of Credits	Administration	Source of Reductions	Remarks
CER	UNFCCC	Six Green House Gasses reduction in developing countries.	• Biggest project base reduction market and 2,371 million ton issued. • Uncertainty after 2023
Voluntary Credits • VCS • Gold Standard (GS) • Others like J-VER	• Association and NGO • VCS (alliance by IETA, WBCSD, etc.) • WWF	• Six GHG gasses but uncovered potential like forest. • Additional value such as social and biodiversity.	• 125 million ton VCS and 43 million ton GS are issued. • Used for voluntary offset or sub-national scheme but volume is limited.
Allowance • National Scheme: EU, Australia, Korea • California and Quebec, Chinese Provincial, Tokyo	• National government • Local authority	• Installations covered by ETS. Mostly power and industry. Tokyo ETS covers offices. • Offset credits such as CER, VCS are allowed. California use REDD.	• Domestic operation of aviation are under domestic regulations and easy to access.
New Credits • REDD+ • CCS • HCFC	-	• Varieties of sources such as forest and CCS (Carbon Capture Storage). • HCFC and CFC are GHG but not covered by CDM.	• Forest is a target for voluntary credits. 1,600 million a year is emitted by land use change. • Stock of HCFC and CFC in 2020 is 8,700 million ton.

Figure 1: *Types of Offset Credit Schemes.*

Project based credits are represented by Certified Emission Reductions (CER) that were implemented by United Nations Framework Convention on Climate Change (UNFCCC). By April 2013, 1,308 million tonne credits have been issued. Various "Clean Development Mechanisms (CDM) Reforms", such as simplifying the process and improving the predictability, are being implemented. CER is the most common and widely used credit type and sufficient amounts of credits can be supplied depending on the price. This scheme will be continued until at least 2023.

Voluntary standard credits are developed and implemented by mostly non-government entities. VCS (Verified Carbon Standard) and Gold Standard are the leading voluntary standards. VCS is supported by business groups including the International Emission Trading Association (IETA) and the World Business Council for Sustainable Development (WBCSD). The Gold Standard was initiated by World Wildlife Fund. By June 2013, 125.4 million tonnes of VCS credits had been issued, with 43 million tonnes of Gold Standard credits issued by March 2013. These credits are used mostly for voluntary offsets of the carbon footprint but not limited to voluntary purposes. For instance, California's Emissions Trading System (ETS) is considering adopting VCS as a standard for evaluating its Reduction of Emission from Deforestation and forest Degradation (REDD+) program.

Australia and Korea have decided to start national ETS programs beginning in 2015, and Brazil and Chile are studying the adoption of national ETS programs. Sub-national governments, such as California, New York and Tokyo, have already started ETS, and Beijing, Shanghai and other cities will start soon. In addition, new project-based credit schemes, like Japan's Joint Credit Mechanism (JCM), are under development. The carbon market is spreading globally and more than 30% of CO_2 emissions are currently covered by ETS or carbon taxes. The World Bank has stated that some 60 carbon regulations have been implemented worldwide. Airlines are affected by various regulations and it would be convenient for them to use the credits which are applicable under these regulations. Credits issued under national and sub-national schemes could also be an option to offset credits.

Carbon Capture and Storage (CCS) and Reduction of Emission from Deforestation and forest Degradation (REDD+) have significant reduction potential. Destruction of HCFC (Hydro Chlorofluorocarbons)and CFC (Chlorofluorocarbons) also have plenty of reduction potential. These gases are regulated to phase out under the Montreal Protocol (adopted in 1987) but are not eligible for CDM. It is estimated that 8.7 billion tonnes of emissions will be released from refrigerated or insulated buildings by the year 2020. The reduction potential from this source alone is more than 10 times what the estimated emissions will be from international aviation by 2020, and its cost is estimated around US$ 5 per ton CO_2 equivalent. Clearly the reduction potential is significant.

The price of credits is determined by demand and supply, and also influenced by emission regulations and economic activities. Currently, the price is very low due to the low demand for credits caused by the sluggish economy, coupled with the uncertainty of future carbon regulation. The current CER price is €0.3-0.5 and the EU allowance is €4-5. Based on a market survey conducted by IETA, 67% of market players think that the CER price in 2020 will be less than € 5, while 56% believe that the EU allowance in 2020 will be between € 5 and 10. So, the belief is that the price is going to increase but not as high as the peak price reached in 2008. Also, it is important to note that the price of credits varies from system to system.

POSSIBLE ICAO SCHEME

Should ICAO decide to develop its own aviation scheme, there are three important issues in particular that need to be considered: credit eligibility criteria, scheme governance and management, and how costs are transferred.

Eligible Credits

Credit schemes and measures need to be flexible in defining what types of credits could be accepted, in order to avoid uncertainty in the availability and cost of credits in the future market. Therefore, it is better to allow the use of several different types of credits and to construct offset credits which utilize undeveloped reduction space such as: CCS, REDD+ and HCFC/CFC. However, quality control is crucial for contributing positively to global emission reductions and safeguarding ICAO's reputation. Eligibility criteria for offset credits need to be agreed upon and fully disclosed. Following are some guidelines that should be applied:

- Emissions reductions should be confirmed objectively and practically.
- Heavy administration burden should not impede reliable implementation.
- Double counting should be avoided.
- Credits should come from socially acceptable projects.

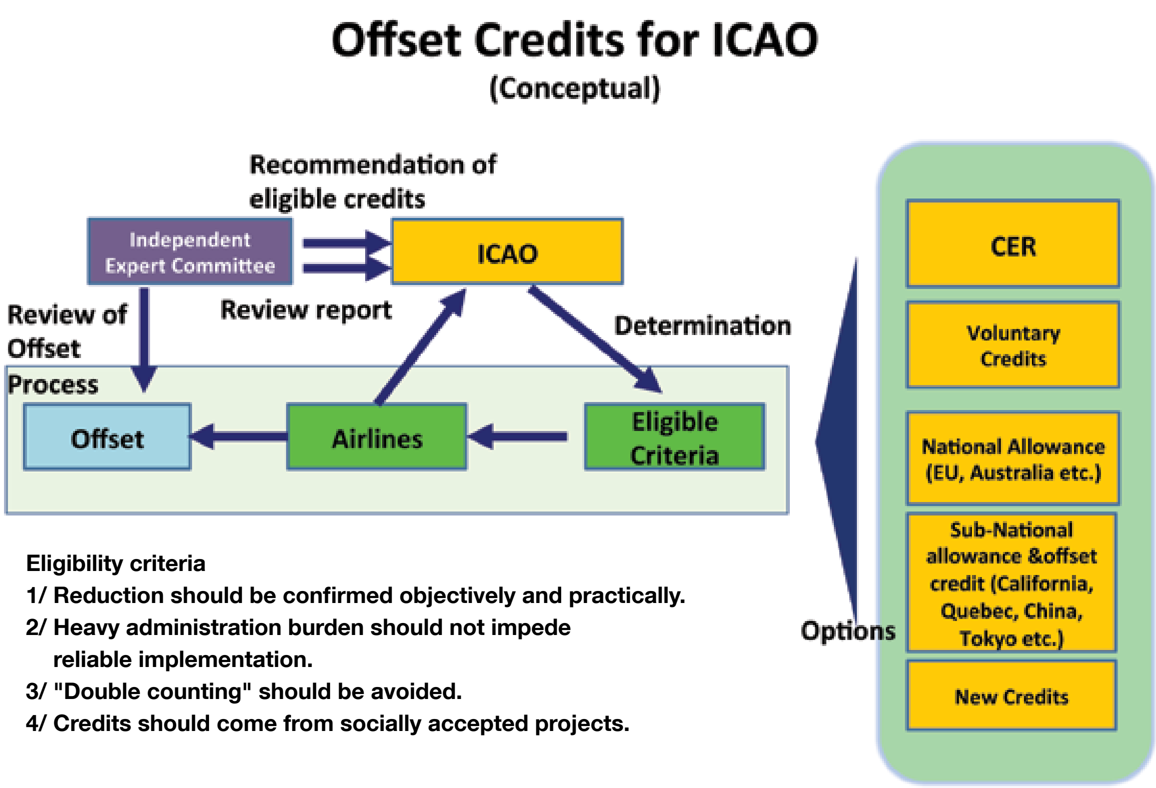


Figure 2: *Proposed ICAO Offset Credit Scheme.*

Governance

Governance of the offset credit mechanism is also crucial. Conflicts among members based on differing points of view may arise during the design and implementation of the mechanism. Experience and know-how are necessary to construct and implement an effective mechanism. A practical solution would be to set up a committee of experts. When doing so, neutrality and expertise will be essential criteria for participation. This Experts Committee should be independent of ICAO and its members should be specialists in their fields, including: carbon markets, finance and investment, technology, and energy and legal issues. They should not represent any interested parties and need to participate only in their personal and professional capacities as experts in their field. A major task of the Independent Experts Committee would be to submit its expert views and recommendations to ICAO for consideration on such issues as, the eligibility criteria of credits and the review of the offset by airlines. ICAO should use the committee's submission to guide its decision making.

Cost Transfer

The cost of offset credits is also a crucial issue. Carbon costs are caused by the creation of external carbon emissions when fuel is burned, and are therefore theoretically part of the fuel cost. Accordingly, these additional costs should be passed on to passengers. Using ICAO's carbon calculator, per passenger emissions from a return flight from Tokyo to New York (business and first class) is 3.1 tonnes, which is US$ 0.8 per pax, when half of the emissions are offset by using the current CER. The economic burden is actually not that large, but awareness of carbon costs is important. One of the practical options for collecting carbon costs is by way of a "carbon surcharge". It shows the carbon cost explicitly and is therefore transparent.

Because international aviation is indispensable for world economic growth, it needs to be fully sustainable. The flexibility of all options developed to manage and offset carbon emissions from international aviation operations will be key to ICAO's ongoing pursuit of "Destination Green". ■

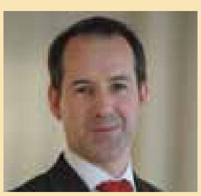
MARKET-BASED MEASURES

ACHIEVING CARBON NEUTRAL GROWTH FROM 2020

BY ANNIE PETSONK AND GUY TURNER

ANNIE PETSONK

She is International Counsel at the Environmental Defense Fund (EDF), an 800,000-member advocacy organization that develops innovative, economically sensible solutions to environmental problems. Annie focuses on creating markets that provide incentives for people to protect the environment, and that foster innovation. She has published extensively on economic incentives to tackle climate change, including for the aviation sector. She teaches as a member of the adjunct faculty at the George Washington University Law School. Prior to coming to EDF, Annie served in the U.S. government, including the Executive Office of the President; in the United Nations; and in the private sector. She is a graduate of Harvard Law School and the Colorado College, which awarded her an honorary degree.



GUY TURNER

He is Chief Economist and Director of Commodity Research in Bloomberg New Energy Finance. In this capacity he is responsible for global analysis and business performance across power, gas and carbon markets as well as economic forecasting for all markets and geographies. Mr. Turner also manages the company's global consulting business. He joined New Energy Finance in 2006 to set up New Carbon Finance – the business dedicated to forecasting the world's carbon markets and now absorbed into Bloomberg New Energy Finance – and he was part of the management that sold the company to Bloomberg in 2009. He has over 22 years experience as a consultant and business manager in the fields of environmental economics, clean energy and climate change.

INTRODUCTION

In 1997, the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) acknowledged the responsibility of the International Civil Aviation Organization (ICAO) for addressing greenhouse gas (GHG) emissions from international aviation[1]. After years of consideration, in 2010 the 37th ICAO Assembly adopted a resolution including, *inter alia*, a goal of improving fuel efficiency 2% per year through 2020; aspirational goals for improving fuel efficiency 2% per year through 2050 and stabilizing international aviation's net carbon emissions by 2020; and requested that the ICAO Council explore the feasibility of a global market-based measure (MBMs) to achieve the stabilization goal.

In June 2013, the International Air Transport Association (IATA) passed a resolution supporting a mandatory global carbon offsetting programme to achieve carbon neutral growth from 2020. Against this backdrop, we address four questions below:

- How big is the emissions gap?
- Where might carbon units come from to offset that gap?
- How much might that cost?
- What are the environmental integrity and administrative issues of various types of offsets?

HOW BIG IS THE GAP?

Any estimate of the emissions gap first requires a projection of international aviation emissions absent an MBM. This in turn depends on many factors including: growth in demand for international air travel, the number and type of planes used to meet this demand, technical improvements in aircraft efficiency, fleet replacement phasing, improvements to air traffic management systems, and fuel mix, including biofuels.

Uncertainties in these factors generate a wide range of projections for the cumulative emissions gap. The latest estimate for the "central" scenario from ICAO's Committee on Aviation and Environmental Protection (CAEP) shows a gap ranging between 14 and 21bnt[2] (billion tonne) over the 30 years from 2020 to 2050. Assuming a conservative potential contribution from alternative fuels the range would be 13bnt to 20bnt[3].

Analytical scenarios can generate estimates of the potential cost and carbon market implications of addressing this gap via a global MBM. Of course, these scenarios depend on, among other things, estimates of the marginal abatement cost (MAC) for in-sector emission reductions, assumptions about sources of carbon units, changes to existing carbon markets, whether tonnes of allowable emissions can be banked or saved from one year to future years, the possibility of forward purchases of carbon units, the availability of option contracts (acquiring the right to purchase carbon units in the future at a price agreed in advance), and other factors.

Factors Affecting Demand, Supply, and Cost

Carefully structured, market tools like banking and credit for early movers can reduce costs while safeguarding environmental integrity. Moreover, environmental integrity and administrative complexity may vary significantly across different types of carbon units:

- In general, units with the highest environmental integrity and least administrative burden come from programmes that place tough caps on emitters, ensure that emissions are accurately reported, and penalize non-compliance, as do the EU and California trading programmes.
- Units for which environmental integrity is subject to question and/or involve greater administrative burden, usually come from programmes that lack a cap on emissions. These programmes allow projects to earn credits if they reduce emissions below what would have otherwise occurred in the project's absence. Proving the environmental integrity of such units is difficult. Regulators, for example, must determine whether emissions would have declined without the project, and must account for "leakage" (*i.e.* reducing emissions in one place increases emissions elsewhere). These issues have led regulators to place quantitative and qualitative restrictions on such credits[4].

SOURCES OF CARBON UNITS TO OFFSET THE GAP

From a macro perspective, the global aviation sector currently accounts for about 2% of world CO_2 emissions. Growth in air travel is expected to double by around 2040[5]. International aviation comprises about two thirds of the total. Offsetting this growth is not expected to pose a problem for the industry.

In theory, to offset international aviation's emissions growth, emissions could be reduced anywhere else. Units from any of the world's existing emissions cap and trade programmes, or those under development[6], could be used. In addition, the UN and other bodies recognize over a hundred categories of carbon credits-producing projects in sectors where there is no cap on emissions. These projects range from domestic and industrial energy efficiency, to renewable energy to forestry and land use. Many more categories are expected to be recognized. Supplying the aviation industry with carbon units to offset the industry's post-2020 growth thus seems eminently feasible.

Potential Supply

Four main sources of supply could provide emissions units to meet the aviation industry's goals:

1. Emissions allowances from national or regional cap and trade programmes.
2. Emissions allowances created under the Kyoto Protocol.
3. Credits from UN registered emission reduction projects.
4. Credits from voluntary offset projects.

Whether, and to what extent, these could be counted as "supply" is unclear, given that some were developed in the absence of an emissions cap, or are subject to uncertainties about the future regulatory framework under which they might be accepted.

1. Emissions Allowances From National or Regional Cap and Trade Programs

These include the European Union's emissions trading system (EU ETS), New Zealand's programme, the U.S. State of California's programme, and the Canadian Province of Quebec's provincial programme.

The EU ETS is the largest system in operation. It has a large surplus of allowances that could potentially be used by the aviation industry. The EU ETS caps GHG emissions (mostly CO_2, but also N2O and PFCs) from more than 11,000 power generating and industrial facilities in 31 countries. As of mid-2013, aircraft within-EU travel are also covered. In total, the system covers about 50% of EU CO_2 emissions. This system, combined with the economic downturn in Europe, has resulted in emissions substantially below the cap for the last five years[7], and a substantial "bank" of unused allowances.

Analysis by Bloomberg New Energy Finance (BNEF) indicates that withdrawals from the "bank" may begin starting in 2018, but will still leave a potential pool of banked allowances of about 1.7bnt by the year 2020. These would be available to aviation sector buyers if EU ETS allowances were deemed eligible in a future global MBM. Allowances from the New Zealand, California, and Quebec programmes might also be deemed eligible in a future aviation MBM. Allowances from programmes under development could provide further supply. China, for example, recently launched the first of seven pilot emissions trading programmes, and Korea is consulting on design options for its proposed system. Others currently considering such programmes include Mexico, Kazakhstan, South Africa, Australia and Brazil. While it is difficult to estimate the potential of these programmes, one in the Brazilian state of Acre estimates that it will reduce emissions by as much as 164mt during the period 2006 to 2020[8].

2. Kyoto Protocol Emissions Allowances

The Kyoto Protocol was established under the auspices of the UNFCCC in 1997. It imposes GHG emission limits on, and issues emissions allowances to, some 35+ countries for the period 2008 to 2012. Although the US did not participate, and Canada withdrew, the targets were accepted by the EU, Japan, New Zealand, Australia, Russia and the Ukraine, among others.

Among the Protocol's primary flexibility mechanisms are emissions trading and banking: a Party with an emissions limit may transfer surplus allowances to another such Party and/or save surplus allowances for use in future years. Included in this trading are allowances registered with the UNFCCC as representing emission reduction units (ERUs) from joint implementation (JI) projects in Parties with emissions caps (see below). Parties with emissions caps may also use certified emission reductions (CERs) from the Protocol's Clean Development Mechanism, which approves projects in Parties without emissions caps, provided that the projects and CERs meet various criteria (see below).

Many Protocol Parties have met their targets through a range of domestic measures and trading. Some countries' emissions dropped well below their caps as a result of economic restructuring in the early 1990s, and have banked or saved large stocks of allowances. BNEF figures show that Russia has the largest bank of allowances, at 8.8bnt, followed by Ukraine at 2.8bnt, Poland at 0.89bnt, and Romania at 0.78bnt. Other EU countries collectively account for around 1.4bnt of banked allowances. In total, Kyoto Parties currently hold around 14bnt of banked allowances.

Whether these allowances, as a practical matter, will come into future emissions trading programmes is unclear. Consequently, with the possible exception of allowances rendered surplus through JI projects, it is prudent to exclude these when calculating potential supply available to the aviation sector[9].

3. UN Registered Emission Reduction Projects
This source of supply includes the JI projects and CDM projects, noted above. Offsets from these projects are calculated as the difference between the actual emissions from a project and what would have happened in the project's absence. Projects are subject to a series of validation and verification steps before they can be approved by the UN. Questions have been raised about the environmental integrity of some CDM and JI credits, although ERUs generated by JI projects are transacted by subtracting allowances from the host country's pool of Kyoto allowances, thereby providing a greater measure of environmental certainty. The EU ETS and the future Australia programme allow private entities to meet part of their compliance obligations using ERUs and CERs; California does not.

By mid-2013 some 6,750 CDM and 600 JI projects had been registered with the UN. BNEF calculates that together, both sources are capable of issuing around 5,500 Mt of offset credits between 2008 and 2020, with actual volumes depending on price.

Of the 1.3bnt CERs and 730 Mt ERUs already issued, not all will be available to the aviation sector. BNEF estimates that between 2008 and 2020, companies and governments in the EU, Australia, and Japan will purchase around 3bnt, to offset domestic emissions. In addition, credits from certain industrial processes cannot be used in the EU and Australia. This leaves a net surplus of about 2.3bnt of CERs and ERUs up to the year 2020 that could be used by the aviation sector post-2020.

4. Voluntary Offsets
In addition to the national/regional and Kyoto compliance-driven markets, there are also voluntary offsets via projects under the auspices of the Verified Carbon Standard, Climate Action Reserve, and the Gold Standard, which are not accredited by the UN[10] but have their own quality assurance processes. Companies or individuals voluntarily purchase these to offset their emissions, or as pre-compliance instruments with the intention that the credits may be used in some future legally mandated programme. Similar to some other emissions markets, supply in the voluntary sector is currently running ahead of demand. Based on recent data from BNEF and Forest Trends[11], by the end of 2011 only about a quarter of the 280 Mt of voluntary credits accumulated had actually been used to offset emissions. This proportion is however increasing, and in 2011 just under 50% of verified credits had been used.

With the voluntary supply growing at about 90 Mt a year, and an increasing share being retired each year, BNEF estimates that by 2020 around 360 Mt of voluntary offsets could be available to aviation.

"Supply" Summary
BNEF estimates that if environmental integrity concerns can be addressed, the above units present a maximum available supply of up to 4.4bnt by the year 2020. This supply is only what is likely to be left unused, based on historic and expected credit generation activities in existing programmes and voluntary markets. It does not include the potentially substantial new supply that could be brought to market to meet additional demand.

COSTS

Taking ICAO's CAEP 2013 figures, along with an assumption for alternative fuel reductions, the international aviation sector could face a shortfall of between 13bnt and 20bnt of CO_2 offsets over the 30 years from 2020 to 2050. On the basis of a central estimate of around 16.5bnt, the ***currently identifiable*** surpluses of 4.4bnt could meet around a quarter of this demand. Beyond this, additional investment would be needed to reduce emissions from sources outside the international aviation sector.

Ultimately what matters is the price paid for these offsets. Today, different types of carbon allowances and credits have different prices and these are likely to change over time. Currently, allowances in the EU ETS trade at around \$6/t, CERs and ERUs are less than \$1/t, and voluntary offsets are about \$6/t. Across all offset types, prices are likely to rise over time.

To model costs, Environmental Defense Fund (EDF) prepared conservative estimates of offset "supply" and "demand"; the price at which the intersection of those two curves

S/tCO_2	2015	2020	2025	2030	2035	2040	2045	2050
Scenario #1	7	9	12	15	19	24	31	39
Scenario #2	6	7	8	11	14	18	23	29

Table 1: *International Civil Aviation CNG2020 – Offset Costs (\$/tCO_2) (Real USD 2010). Source: EDF.*

would provide an estimate of the potential cost outlay of airlines. EDF's demand curve assumes that aviation will grow according to the central scenario based on the latest CAEP estimates, and will reduce emissions by a central amount via technology, operations, infrastructure, and alternative fuels. EDF's supply curves are also based on a number of assumptions. Two scenarios are created on the emissions reduction requirements for existing and newly formed cap and trade schemes outside the aviation sector: Scenario 1 assumes these schemes require a 50% cut in emissions by 2050 and Scenario 2 a 25% cut. It is also assumed that these schemes will limit the use of offsets to some extent and that offsets used in the aviation sector must meet strict environmental integrity criteria. The resulting modelled offset prices for international aviation are shown in **Table 1**.

The analysis shows the unit cost of offsets increasing from about \$6-7/t in 2015 to around \$29-39/t by 2050. These prices imply annualized estimated costs through 2050 of \$4.3-\$7.8 billion per year under Scenario 1, and \$3.3-\$6.1 billion per year under Scenario 2.

To put this in context, these costs will represent less than 0.5% of international airline revenues on average over this period. With all major airlines participating, there will be little risk of competitive distortions, so nearly all could be passed through to consumers. The net cost to industry would therefore be trivial.

CONCLUSIONS

International aviation's goal of carbon neutral growth from 2020 is realistic. Starting with in-sector reductions, and moving up the marginal abatement cost curve to out-of-sector reductions, available carbon units, by 2020, could provide around a quarter of the industry's offset requirements through 2050.

Offset prices are currently low. Although prices will likely rise over time, they will remain significantly below the cost of reducing emissions within the international aviation sector. Even if offset prices rise, the net cost to the aviation sector of achieving carbon neutral growth by 2020 (CNG2020) will be trivial and nearly all the additional costs will be passed through to customers. The industry should therefore have few concerns about the implications of CNG2020, and should consider more aggressive targets aligned with long term climate goals.

REFERENCES

1 See Kyoto Protocol on Climate Change (1997) at Article 2.2; and see "A New Flightplan: Getting Climate Measures for Aviation off the Ground," Transport & Environment, Environmental Defense Fund, The International Council on Clean Transportation and the Aviation Environment Federation (2012), text available at www.transportenvironment.org/sites/te/files/media/Aviation%20Conference%20Background%20Report.pdf; see also H. Miller, "Civil Aircraft Emissions and International Treaty Law," 63 J. of Air and Commerce 698 (1998).

2 ICAO Doc 10012, *Report of the Ninth Meeting of the ICAO Committee on Aviation Environmental Protection (CAEP/9)*.

3 Source Lee D.S., L. L. Lim and B. Owen (2013), "Bridging the aviation CO_2 emissions gap: why emissions trading is needed", Dalton Research Institute, Dept. of Environmental And Geographical Sciences, Manchester Metropolitan University, Manchester, UK.

4 For example, the EU ETS has a maximum import quota of around 11% of allocated emissions over the period 2008 to 2012, and has restricted the use of carbon offsets from projects that destroy certain industrial gases with high global warming potentials (HFCs).

5 Extrapolated from IATA Economics, 2013, which shows global aviation emissions increasing from 677Mt in 2012 to 1011 Mt in 2030.

6 See, *e.g.*, www.ieta.org/worldscarbonmarkets

7 See "The European Union Emissions Trading System: Results and Lessons Learned," Environmental Defense Fund (2012), text available at www.edf.org/sites/default/files/EU_ETS_Lessons_Learned_Report_EDF.pdf

8 See, *e.g.*, www.ipam.org.br/download/livro/Subsidio-para-a-Adocao-de-meta-de-reducao-de-desmatamento-no-ambito-do-PPCD-Acre/227

9 That said, it is important for governments to keep in mind that if jurisdictions with emissions caps under the Kyoto Protocol choose to allow emissions units from their domestic emissions trading programs to be used in an MBM for international aviation, they will need to subtract from their Kyoto allowance accounts an amount of Kyoto allowances equal to the domestic emissions units transferred to the aviation scheme.

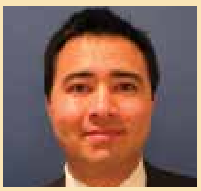
10 This could be for a range of reasons including different project types, such as types of land use activities, or because the start dates don't exactly coincide with the requirements of the UN validation processes.

11 Bloomberg New Energy Finance, Forest Trends, 2012, "Developing Dimension – State of the Voluntary Carbon Markets 2012".

MARKET-BASED MEASURES AND THE UNITED NATIONS

BY ROBIN RIX

This article provides an overview of market-based measures that have been established under the United Nations Framework Convention on Climate Change (UNFCCC). It outlines the origins of these measures, assesses current trends, and offers views on the likely direction for these measures in the coming decade.



ROBIN RIX

He is the lead officer for strategy development relating to market-based mechanisms at the United Nations Climate Change Secretariat. Since 2009 he has serviced the intergovernmental negotiations on the future role of carbon markets and worked on initiatives to strengthen and improve the existing international mechanisms. He was previously a lawyer at Clifford Chance in London, and holds law and undergraduate degrees from the University of Toronto and a master's degree in political science from the University of Oxford.

BACKGROUND AND ORIGINS

Convention

The overarching international agreement on climate change, the United Nations Framework Convention on Climate Change (UNFCCC), was adopted in 1992 and entered into force in 1994. Its ultimate objective is the stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous human-induced interference with the climate system. The Convention has been ratified by almost all countries (195 Parties at the time of writing), which meet annually to review the implementation of the Convention.

At their first meeting (COP1, 1995), Parties agreed that the commitments under the Convention were inadequate for addressing climate change, and they launched a process to strengthen them. To guide this process, they agreed that developed countries should take the lead in reducing emissions, calling upon them to accept quantified targets for their domestic emissions and to elaborate policies and measures to meet those targets.

Kyoto Protocol

The outcome of the above process was the Kyoto Protocol, which was adopted at the third meeting of the Parties to the Convention (COP3, 1997) and entered into force in 2005. The Kyoto Protocol establishes a legal framework by which developed countries accept emission targets for their domestic emissions for periods of time, known as commitment periods. The Kyoto Protocol does not prescribe emission targets for developing countries. Two commitment periods have been agreed to date: a first commitment period from 2008 to 2012, and a second commitment period from 2013 to 2020.

Of the 195 Parties to the Convention, 193 are also Parties to the Kyoto Protocol, the exceptions being Canada and the United States. These Parties meet annually, concurrently with the COP, to review the implementation of the Kyoto Protocol.

Market-based Measures

Three market-based measures were established under the Kyoto Protocol.

The largest and best known of these measures is the clean development mechanism (CDM), which provides for, first, the registration of projects that reduce emissions in a developing country and, second, the issuance of units equivalent to the emission reductions achieved by these projects.

These reductions are measured as the difference between (i) baseline emissions (*i.e.* what emissions would have been in the absence of the project), and (ii) actual emissions (*i.e.* what emissions actually were). These units may then be transferred to other entities, most commonly to counterbalance, or offset, their emissions. Units may be issued for a crediting period of ten years, or for seven years that may be renewed twice.

In addition to reducing emissions, the CDM was also designed to assist developing countries in achieving sustainable development. To confirm this, each project must receive a letter of approval from its host country confirming that the project helps it to achieve sustainable development.

Governance of the CDM is the responsibility of an international regulatory body known as the Executive Board. Its key duties include: the consideration of requests for registration and issuance, the design and approval of methodologies for determining baselines and measuring emission reductions, and the accreditation of third-party auditors who perform delegated functions such as reviewing requests for registering projects and issuing units.

To date, the CDM has registered approximately 7,000 projects and issued almost 1.4 billion units, known as certified emission reductions (CERs).

The second market-based measure established under the Kyoto Protocol is joint implementation (JI), which operates similarly to the CDM but with two notable differences. First, JI focuses on projects in developed countries, rather than developing countries. Second, JI has two tracks; its first track allows an individual developed country to set its own standards for measuring emission reductions and issuing units, while its second track operates much like the CDM in being governed by an international regulatory body. The first track is by far the larger of the two, with approximately 98% of units under JI being issued under this track.

The third market-based measure is international emissions trading (IET), which involves the transfer of emissions units between developed countries, usually between governments.

CURRENT QUESTIONS

Negotiations Under the Kyoto Protocol

The three Kyoto market-based measures, particularly the CDM, have been the subject of intense scrutiny over the past few years with a view to reforming and strengthening them. Reforms fall broadly into seven categories:

1. **Environmental integrity:** As units correspond to the difference between baseline emissions (which are, by definition, hypothetical) and actual emissions, baselines must be properly set to prevent the issuance of non-additional units. While the CDM has historically used project-specific baselines, a growing trend has been the use of standardized baselines, set conservatively, that promote greater objectivity and certainty. The first two standardized baselines were approved in early June 2013, and more are expected to be approved in the coming years.

2. **Sustainable development:** As explained above, a condition of registration is that a host country provides a letter confirming that the CDM project helps it achieve sustainable development. Several stakeholder groups have suggested that the criteria used by governments to provide such letters should be more widely publicized, and also that the letters should be revocable if a CDM project is found not to help a host country in achieving sustainable development any longer. The UNFCCC produces an annual report on the sustainable development benefits of the CDM and has called for greater transparency in this area.

3. **Regional distribution:** The geographic imbalance of the CDM is a frequent source of concern, with over two-thirds of registered projects (and over three-quarters of all issued CERs) originating from China and India. That said, current trends suggest a growing number of projects in other countries, most notably in Africa. The UNFCCC has recently opened four regional collaboration centres – in Colombia, Grenada, Togo, and Uganda – with a view to building capacity and promoting more diverse participation in the CDM.

4. **Operational efficiency:** In its initial years, the timelines for registering projects and issuing CERs were protracted, taking several months and at times up to and exceeding one year. Allegations of complex, non-user-friendly guidance were also made. That said, internal operational reforms and an increased quality of submissions have led to significant streamlining, and criticisms of this nature are now almost non-existent.

5. **Level of aggregation:** The CDM traditionally assessed emission reductions on a facility-by-facility basis. This has prompted claims that much broader coverage is needed, whereby emissions are measured and then reduced at broader levels of aggregation (*e.g.* an entire industrial sector). The response of the CDM has been the growth of "programmatic CDM", in which a bundle of similar projects can be considered as a single project, thereby allowing for greater coverage and reducing transaction costs.

6. **Net decrease in emissions:** A commonly voiced concern about the CDM is that it is generally used as an offsetting mechanism, whereby emissions reduced in one location simply entitle emissions to be increased elsewhere. While true, several attributes enable the CDM to achieve a net decrease in emissions, among them the use of conservatively set baselines, time-bound crediting periods, and lower default factors.

7. **Governance:** The CDM is governed by a ten-person executive body. Various reforms have been undertaken to make its operations more transparent, although further initiatives are under consideration (*e.g.* clear criteria for appointment, objective code of conduct).

These reforms are being considered as part of the review of the CDM rules, which the Parties to the Kyoto Protocol are expected to resolve at their year-end meeting in Warsaw. These reforms have also been informed by the findings of the High-level Panel on the CDM Policy Dialogue, a blue-ribbon group which released a comprehensive report in 2012 on means to reform the CDM.

Negotiations Under the Convention

In parallel with the negotiations under the Kyoto Protocol on existing market-based measures, the Parties to the Convention are engaged in negotiations under the Convention on new measures.

At their meeting in Bali (COP13, 2007), Parties agreed to consider "various approaches, including opportunities for using markets" as tools to enhance emission reductions. These were elaborated in a series of negotiations that produced, at the meeting in Cancun (COP16, 2010), a list of seven guiding elements for new market instruments, including: the stimulation of emission reductions across broad segments of national economies, environmental integrity, a net decrease of emissions, good governance, and robust market functioning and regulation.

A breakthrough was achieved at the meeting in Durban (COP 17, 2011), when a "new market-based mechanism" (NMM) was established and an agreement was reached to consider a "framework for various approaches" (FVA) – covering market-based measures administered at the domestic level, such as emissions trading systems or country specific offset programmes. At the meeting in Doha (COP18, 2012), Parties established two work programmes; one on the new NMM and another on the FVA. These work programmes are expected to lead to modalities for the operation of the NMM as well as further guidance, if not modalities, on the FVA.

FUTURE PATHWAYS

While the precise outcomes of the negotiation processes are unlikely to be known for several years, the following considerations may apply.

First, **there is a growing sense that the CDM is a useful tool that is worth preserving and strengthening**. Despite a rocky few years in which the CDM was the object of intense criticism and slated for replacement by new market-based measures, its worth in assessing the quality and quantity of emission reductions is becoming increasingly appreciated. Further, when one considers what Parties hoped that new market-based measures would achieve – namely broader coverage within national economies, stronger environmental integrity, a net decrease in emissions, and better governance – are all compatible with the existing mechanism, and reflect the current direction of CDM reform.

Second, **accessibility to the CDM is being broadened**. Although the first use of the CDM was as a tool to help developed countries meet their emission reduction targets under the Kyoto Protocal, its use is not limited to that purpose. Units may also be "cancelled", via established procedures that are administered by the United Nations Climate Change Secretariat, in order to meet the emission reduction targets of individuals, companies, or industry sectors that seek to carbon-neutralize their emissions. Such a method of offsetting is trusted, reliable, and easy to apply, particularly as the CDM is a centrally administered mechanism that enjoys a high level of international legitimacy, particularly among developing countries. It may therefore be of interest to the aviation sector.

Third, **there is an appetite for focusing on the appropriate role of domestic market-based measures**. Parties explicitly recognize that countries have the sovereign right to develop and implement their own measures to reach their emission reduction targets, and that these can include market-based measures. The current debate revolves around how the quality of these measures can be assured if they are used to meet compliance or voluntary targets, with various models under discussion.

REFERENCES

Decisions by the Conference of the Parties, including 1/CP.1, 1/CP.3, 1/CP.13, 1.CP.16, 2/CP.17, 1/CP.18.

Decisions by the Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol, including 2-3-7-9-11-13/CMP.1, 1/CMP.2, 2/CMP.3, 2/CMP.4, 2/CMP.5, 3/CMP.6, 8/CMP.7, and 5/CMP.8.

"Climate Change, Carbon Markets, and the CDM: A Call to Action." Report of the High-level Panel on the CDM Policy Dialogue (2012). <www.cdmpolicydialogue.org>

"Mapping Climate Pricing Initiatives: Developments and Prospects" (World Bank, 2013).

CHAPTER 5

STATE ACTION PLANS

STATE ACTION PLANS TO REDUCE AVIATION CO_2 EMISSIONS

BY ICAO SECRETARIAT

During the 37th Session of the ICAO Assembly, held in October 2010, ICAO Member States adopted a comprehensive, global policy to address greenhouse gas (GHG) emissions from international aviation. This policy, as enshrined in Resolution A37-19, reflects the commitment of ICAO to lead the aviation sector's collective efforts to address climate change and to identify global solutions.

As part of this policy, the Assembly invited each State to voluntarily develop and submit an action plan outlining the policies and activities being undertaken to reduce CO_2 emissions generated by international aviation activities.

STATE ACTION PLANS INITIATIVE

Since October 2010, ICAO has developed a robust capacity building strategy to assist States in developing action plans to reduce CO_2 emissions from international aviation.

During this initial phase, ICAO developed an action plan template, as well as a web interface for national action plan focal points, which uses a step-by-step approach to facilitate the development and online submission of action plans to ICAO. In addition, with the support of experts from the Committee on Aviation Environmental Protection (CAEP), ICAO also developed a guidance document on action plans, Doc 9988, *Guidance on the Development of States' Action Plans on CO_2 Emissions Reduction Activities*.

Between 2011 and 2012, ICAO organized several regional training workshops, during which 91 States representing 93% of global international air traffic were trained (see **Figures 1** and **3** to **8**). During these workshops, focal points were trained to use the action plan template and the Web interface, and were asked to provide feedback on Doc 9988. ICAO also worked directly with individual States and national action plan focal points to assist in the development of action plans.

These efforts paid off and, by mid-August 2013, 63 States had submitted action plans to ICAO, representing around 80% of international revenue tonne-kilometres (RTKs). Of the plans submitted thus far, more than 22 are available on the ICAO public website[1]. A further 20 States expressed their intent to submit action plans by the end of 2013.

WHAT IS AN ACTION PLAN?

Action plans are a planning and reporting tool for States to communicate information on their activities to address CO_2 emissions from international civil aviation to ICAO. The level of detail of the information contained in an action plan will ultimately enable ICAO to compile global progress towards meeting the goals set by Assembly Resolution A37-19.

The aviation sector plays an important role in the national economy of any country and contributes toward its further socio-economic

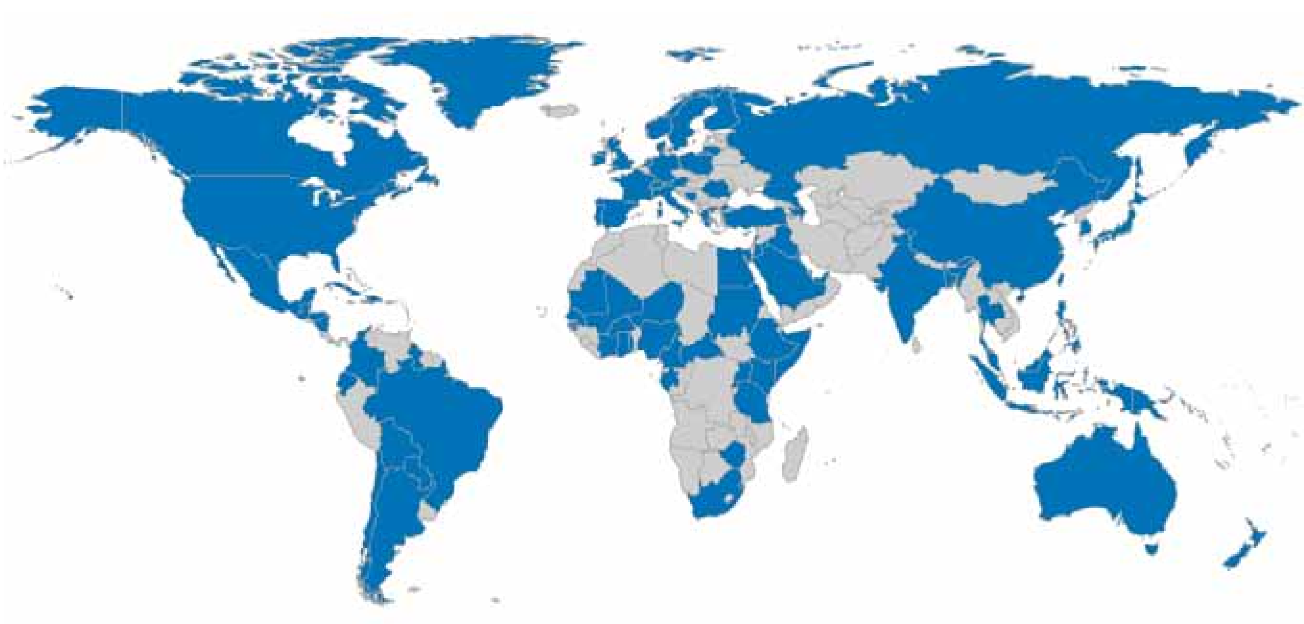


Figure 1: *Global Coverage of States Trained During the ICAO Hands-on Training Workshops. In Blue are the States Trained.*

development. Improving environmental performance will promote the sustainable growth of international civil aviation, while ensuring consistency with any overarching CO_2 emissions limitation or reduction efforts already being undertaken by the State.

In addition, action plans give ICAO Member States the ability to: establish partnerships; promote cooperation and capacity building; facilitate technology transfer; and provide assistance.

Action plans allow States to showcase the specific voluntary measures they intend to undertake to improve fuel efficiency and/or reduce their carbon footprint, thereby contributing to the global environmental aspirational goals established by the 37th ICAO Assembly.

A key aspect of successfully developing and implementing an action plan is the degree and nature of collaboration among different stakeholders within a State. These can include, among others, aviation and environmental authorities, airlines and airports, air navigation service providers, statistical departments and fuel providers. Collecting information from these stakeholders and consolidating this input into an action plan ensures that the development of the plan is based on a cooperative process and that the measures contained therein are accurate, comprehensive, and feasible to implement.

Example of Cooperation and Engagement of All Stakeholders – Korea Action Plan

"Korea established an aviation climate change response group that involved all of the stakeholders from the aviation sector: government; airlines; airport operators; air traffic control authorities; and research institutes.

Part of this group's role was to review the government's research on effective international aviation climate response. Based on the group's recommendations, voluntary GHG reduction agreements between the government and airlines were signed in 2010, and are currently being implemented.

The collaborative efforts undertaken by all stakeholders resulted in the establishment of the aviation GHG database, dubbed the National Aviation Resource Management Information System, which plays an important role in relevant research and policy-making in the country."

BASKET OF MEASURES

A wide variety of possible measures can be taken by States, air carriers, airport authorities and air navigation service providers to reduce emissions from civil aviation.

Through their action plans, States outline the various policies and activities that they have selected from a "basket of measures" in their jurisdiction to limit or reduce CO_2 emissions from international aviation (see **Figure 2**). This "basket" contains measures such as:

- aircraft-related technology development;
- alternative fuels;
- improved air traffic management and infrastructure use;
- more efficient operations;
- economic or market-based measures; and
- regulatory measures.

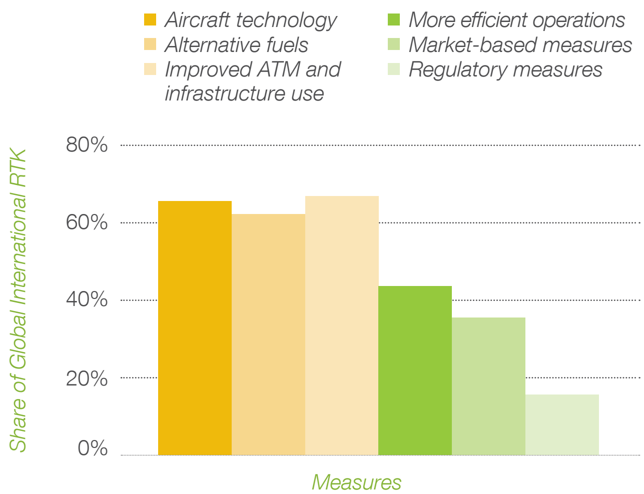


***Figure 2:** Measures Selected by States in the Action Plan Submitted to ICAO.*

Figure 2 depicts the distribution of the six categories of measures addressed in State Action Plans. The remainder of this article discusses and elaborates on each of these common emission reduction measures.

***Figure 3:** ICAO Regional Hands-on Training Workshop for States' Action Plans on CO_2 Emissions Reduction Activities, Bangkok, Thailand, 25 to 27 May 2011.*

AIRCRAFT-RELATED TECHNOLOGY DEVELOPMENT

The implementation of the latest available emissions reduction technologies for aircraft have significant benefits. Some measures in this category, such as the introduction of winglets or the purchase of new aircraft, are not only justified on the grounds of environmental benefits, but also in light of economic and strategic considerations.

Retrofitting and Upgrade Improvements To Existing Aircraft – Federal Republic of Germany Action Plan
"Retrofit of Air Berlin's Boeing B73N fleet with Blended Winglets.

The wing tips of the B737 (-700/-800) fleet were retrofitted with Blended Wings. The measure increases the aspect ratio of the wing, thus reducing lift-induced drag and increasing performance.

Due to the implementation of this measure, 337,500 l/plane p.a. were reduced. This represented a 3% fuel reduction per flight, the equivalent of 85,000 kg/plane of CO_2 reduction (representing 3% per flight). Implementation of these measures began in 2002, and the Stakeholders involved were the airlines and the Boeing Company.

The anticipated co-benefits of this measure are better climb performance and a noise reduction by about 6.5%."

For more information on the Germany Action Plan, please visit: www.icao.int/environmental-protection/Pages/action-plan.aspx

ALTERNATIVE FUELS

The anticipated gains in efficiency from technological and operational measures will not completely offset the overall emissions that are 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.

Drop-in fuels are substitutes for conventional jet fuel and 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 the combined 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 GHG emissions and therefore reduce aviation's contribution to global climate change.

Over the short and medium-term horizon, aviation will be heavily dependent on drop-in liquid fuels 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.

Information on the use of alternative fuels for civil aviation, as well as the document, *ICAO Review: Sustainable Alternative Fuels for Aviation*[2] are available in the ICAO Global Framework for Alternative Aviation Fuels (GFAAF)[3]. Information regarding worldwide initiatives on the development and deployment of sustainable alternative fuels for aviation is also available through the GFAAF.

Alternative Fuels Measure – Development – Argentina Action Plan
"A multidisciplinary group has been set up in Argentina with participants from government authorities, regulatory agencies, technological and agricultural institutes, oil companies, air operators and chambers, in order to find the best alternative, which will allow a comprehensive analysis of the different alternatives, advantages and disadvantages for the production in Argentina of biojet fuel in line with international quality standards. The stakeholders involved are ANAC, Aerolineas Argentinas, YPF, INTI, INTA, CARBIO, SSTA and the Ministry of Interior and Transport."

Developing Alternative Fuels Measures – United States Action Plan
"The United States Government has taken significant steps during the last five years to facilitate the development and deployment of "drop-in" alternative aviation fuels. Some of the progress and successes in the development of sustainable alternative fuels for aviation conducted by the USA are mentioned below:

- *On 1 July 2011, the standard-setting organization ASTM International approved a bio-derived sustainable alternative jet fuel known as HEFA, for commercial use up to a 50% blend level.*
- *In late 2011 two US commercial airlines flew their first domestic flights powered by HEFA biofuels.*
- *Research projects are conducted focusing on using sustainably grown wood energy crops for transportation fuels (University of Washington).*
- *In April 2012, the Air Force completed testing and certification of the entire fleet on Fischer-Tropsch synthetic fuel and continues to certify the fleet on hydro-processed renewable jet (HRJ) and alcohol-to-jet (ATJ biofuel blends)"*

For more information on the USA Action Plan, please visit: www.icao.int/environmental-protection/Pages/action-plan.aspx

***Figure 4:** ICAO Regional Hands-on Training Workshop for States' Action Plans on CO_2 Emissions Reduction Activities, ICAO European and North Atlantic Office, Paris, France, 11 to 13 July 2011.*

***Figure 5:** ICAO Regional Hands-on Training Workshop for States' Action Plans on CO_2 Emissions Reduction Activities, ICAO Headquarter, Montreal, Canada, 21 to 23 November 2011.*

European Advanced Biofuels Flightpath – United Kingdom Action Plan

"In March 2011, the European Commission published a White Paper on transport. In the context of an overall goal of achieving a reduction of at least 60% in greenhouse gas emissions from transport by 2050 with respect to 1990, The White Paper established a goal of low-carbon sustainable fuels in aviation reaching 40% by 2050.

As a first step towards delivering this goal, in June, the European Commission, in close coordination with Airbus, leading European airlines (Lufthansa, Air France/KLM, & British Airways) and key European biofuel producers (Choren Industries, Neste Oil, Biomass Technology Group and UOP), launched the European Advanced Biofuels Flightpath. This industry-wide initiative aims to speed up the commercialisation of aviation biofuels in Europe, with the objective of achieving the commercialisation of sustainably produced paraffinic biofuels in the aviation sector by reaching a two million tons consumption by 2020."

For more information on the UK Action Plan, please visit: www.icao.int/environmental-protection/Pages/action-plan.aspx

IMPROVED AIR TRAFFIC MANAGEMENT AND INFRASTRUCTURE USE

ICAO has a strategy to improve the use of communication, navigation and surveillance/air traffic management (CNS/ATM) systems. A main objective of the strategy is to improve the efficiency of air traffic management which will lead to reductions in fuel burn and emissions. Problems associated with the provision of air navigation services using conventional CNS systems include airspace fragmentation and lack of homogeneity, as well as inefficient routing and ATM planning. These issues could potentially result in congestion and related fuel-burn penalties.

In the process of developing national and regional plans for the implementation of CNS/ATM systems, most States have conducted research, studies, and analyses to select what they believe to be the most effective system(s) components which will offer benefits when implemented. However, environmental benefits such as emissions reduction potential, may not have been included in such analyses. In these cases, a complementary analysis may be needed to cover the estimation of environmental benefits from more direct routing, reduced congestion, and improved response to airspace user operational preferences.

Such analyses would also account for the impact of more efficient air traffic management, ground operations, terminal operations (departure, approach and arrival), en route operations, airspace design and usage, and aircraft equipment and capabilities. These are all documented in detail in various ICAO Manuals: *Air Traffic Services Planning Manual* (Doc 9426), *Manual on Airspace Planning Methodology for the Determination of Separation Minima* (Doc 9689), *Global Navigation Satellite System (GNSS) Manual* (Doc 9849), *Global Air Navigation Plan* (Doc 9750), *Performance-based Navigation Manual* (Doc 9613), *Global Air Traffic Management Operational Concept* (Doc 9854), *Manual on Global Performance of the Air Navigation System* (Doc 9883) and *Manual on Air Traffic Management System Requirements* (Doc 9882).

Airport infrastructure measures related to reducing aircraft emissions at airports include: improving the efficient use and planning of airport capacities; installation and use of terminal support facilities (such as fixed electrical ground power and pre-conditioned air) to reduce aircraft APU usage; and the construction of additional taxiways and runways to provide direct terminal access and reduce congestion. These are detailed in the following ICAO Manuals: *Airport Planning Manual* (Doc 9184); *Aerodrome Design Manual* (Doc 9157); *Airport Air Quality Manual* (Doc 9889).

More Efficient Operations – Tanzania Action Plan

- *"The mitigation measure adopted by the State at current capacity is operational. The measure involves the implementation of several sub-measures, concurrently. The measure which has been adopted contains the following sub-measures: Arrivals Management, Taxiing Management, Reduced Vertical Separation Minima, and Departure Management.*
- *It has been estimated that when the total implementation of the measure is achieved, there will be an annual savings in fuel burn and CO_2 emissions of 34.4% for total fuel burn and emissions and savings of 17.2% for international fuel burn and emissions. It is estimated that total benefits of the measures will be achieved by 2050. The implementation process started in 2001, and the realization of the benefits started to be accrued from 2005."*

ATM and Infrastructure Use Measures – Jamaica and Trinidad and Tobago Action Plan (for the KINGSTON FIR and PIARCO FIR respectively)

By using the IFSET tool, Jamaica and Trinidad and Tobago's State Action Plans showcase the fuel efficiency within PIARCO FIR and the Kingston FIR.

"Based on the IFSET estimations for Sangster International Airport, and by Jamaica using the CDO, the fuel savings are estimated to be 21.5% and 44,415 kg of CO_2 emissions each month.

RNAV routes used in the PIARCO FIR reduced mileage and reduced fuel emissionsexample: 2% and 5% fuel savings (based on the selected for RNAV route) and a reduction of CO_2 of 334 and 550 kg (based on the selected RNAV route)."

For more information on the Trinidad and Tobago Action Plan, please visit: http://www.icao.int/environmental-protection/Pages/action-plan.aspx

MORE EFFICIENT OPERATIONS

Emissions reductions may be achieved in the short term and with minimum investment through improved aircraft operations and management. Improvements can be introduced to pre-flight procedures (*i.e.* centre of gravity, take-off mass, flight planning, taxiing, APU), as well as in-flight procedures (*i.e.* take-off and climb, cruise, descent, holding and approach), and post-flight maintenance procedures (*i.e.* airframe and engine maintenance and aerodynamic deterioration). These measures are detailed in the following ICAO Manuals: *Procedures for Air Navigation Services—Aircraft Operations* (Doc 8168); *Environmental Assessment Guidance for Proposed Air Traffic Management Operational Changes, Operational Opportunities to Reduce Fuel Burn and Emissions* (see article *Two New ICAO Manuals on Reducing Emissions Using Enhanced Aircraft Operations*, Chapter 4 in this report).

More Efficient Operations Measures – Canada Action Plan

"Reducing GHG Emissions at the Gate and on the Ground—Airlines and airports are working together to reduce emissions from APUs and ground support equipment (such as baggage tugs and tractors). For example, in Canada, airports are pursuing opportunities to supply their loading gates with preconditioned air, which helps to minimize the use of APUs.

Taxi Operations: The Canadian aviation industry (airports, airlines, and NAV CANADA) will continue to work together to reduce GHG emissions by reducing airport aircraft ground emissions through improved taxi and queuing procedures. The CAC, NACC and NAV CANADA will establish an average baseline for taxi times at the four major airports (Vancouver, Calgary, Toronto, and Montreal)."

For more information on the Canadian Action Plan, please visit: www.icao.int/environmental-protection/Pages/action-plan.aspx

More Efficient Operations, best practices in operations – United Arab Emirates Action Plan

"In 2011, Etihad Airways, embarked on a programme to replace 3,000 containers from the original aluminium containers with environmentally friendly lightweight versions. It is estimated that the implementation of the new containers will cut emissions by approximately 5,000 tons in 2012.

Emirates had replaced 40% of the heavier aluminium unit load device (ULDs) with lightweight units, saving 23 kilograms over the aluminium model. Over the 2011 to 2012 reporting year, using the lightweight ULDs saved 4,207 tonnes of fuel and almost 19,000 tonnes of CO_2 emissions. When complete in 2013, the full upgrade will save Emirates 14,475 tonnes of fuel and 45,595 tonnes of CO_2 emissions per year (based on 2011 to 2012 fleet size)."

ECONOMIC AND MARKET-BASED MEASURES

Economic and market-based measures are policy tools designed to achieve environmental goals at a lower cost and in a more flexible manner than traditional regulatory measures. ICAO has been developing various policies, guidance material and studies on this subject, including: *Guidance on the Use* *of Emissions Trading for Aviation* (Doc 9885), *A Scoping Study of Issues Related to Linking "Open" Emissions Trading Systems Involving International Aviation* (Doc 9949) and *Offsetting Emissions from the Aviation Sector* (Doc 9951).

MBM – Switzerland Action Plan

The Swiss Action Plan is a combination of European-wide supranational measures with the participation of Switzerland, as well as genuine Swiss national measures undertaken by various actors of the Swiss aviation system.

Some of the national activities reported are:

a) *Carbon offset – SWISS Int. Air Lines offers its customers to offset the CO_2 emissions generated each time they travel by air. SWISS Int. Air Lines and Lufthansa have entered into a partnership with the non-profit foundation myclimate, a Swiss-based charitable foundation, which provides carbon offsetting measures. This "carbon offset" amount will be invested by myclimate in climate protection projects selected by SWISS Int. Air Lines. The foundation assures that this will save the same amount of CO_2 as was generated by the passenger's flight.*
b) *The Swiss ETS – On 23 December 2011 the Swiss parliament passed the CO_2 act. This legal framework allows the Federal Council to define sectors, for example that of civil aviation, which will be included in the Swiss emission trading system (ETS). Negotiations with the EU about linking the Swiss ETS and the EU ETS are currently being conducted.*

For more information on the Switzerland Action Plan, please visit: www.icao.int/environmental-protection/Pages/action-plan.aspx

REGULATORY MEASURES/OTHER

These measures could include airport movement caps/slot management policy, requirements for the use of sustainable alternative fuels, and enhancing weather forecasting services, among others. Proper assessment would be needed to address the feasibility and emissions reduction potential of each measure.

The voluntary preparation of their action plans will assist States in identifying the basket of measures to be implemented to limit or reduce CO_2 emissions from international aviation, as well as the specific assistance needs to implement such measures, including financing, technical assistance, and training/capacity-building. In turn, it will allow ICAO to address the specific needs of States in terms of facilitating access to the required assistance.

Figure 6: *ICAO Regional Hands-on Training Workshop for States' Action Plans on CO_2 Emissions Reduction Activities, Nairobi, Kenya, 4 to 6 July 2011.*

Regulatory Measures – China Action Plan

The CAAC, in accordance with the "Guidelines" that were released "…is going to materialize its emissions reduction objectives into three phases and therefore a target benchmark has been set for each Phase: Phase I, to strengthen the foundation (2011 to 2012), Phase II, to scale up the promotion (2013 to 2015) and Phase III, analysis, innovation and optimization (2016 to 2020). By the end of each phase, a reduction of 11%, 15% and 22% respectively, is expected to be achieved in fuel consumption per RTK with the year 2005 as baseline."

Efforts have been made by the CAAC to explore a system of "Data – Collecting, Monitoring and Evaluating", aiming at a more accurate understanding of energy consumption by the sector, promote the establishment of an industry-wide energy conservation and emissions reduction scheme, and accelerate the development of a long term mechanism to address energy conservation and emissions reduction, as well as climate change in the sector so as to meet the industry's needs for its future sustainable development."

For more information on China's Action Plan, please visit: www.icao.int/environmental-protection/Pages/action-plan.aspx

Creation of an Environmental Management Unit within the Civil Aviation Authority Structure – Venezuela Action Plan

"The National Civil Aviation Institute, through its Planning and Budgetary Office, is currently working on a project to create the structure for a unit designed to deal with matters related to the environment within the Aviation Authority.

The overall purpose for creating the unit is to implement the national government's policies related to this subject and to provide environmental management services to the aviation community".

ASSISTANCE TO STATES TO DEVELOP ACTION PLANS

In addition to requesting the ICAO Council to provide guidance and other technical assistance for the preparation of States' action plans, Assembly Resolution A37-19 also requested the Council to study, identify and develop processes and mechanisms to facilitate the provision of technical and financial assistance. The Council was also asked to work to facilitate access to existing and new financial resources, technology transfer and capacity building for developing countries, and to initiate specific measures to assist developing States as well as to facilitate access to financial resources, technology transfer and capacity building. (see article *Assistance and Financing Opportunities for Emissions Reduction Measures*, Chapter 6 in this report).

ICAO has since developed and implemented a robust capacity building programme to assist States, in particular, with the preparation and submission of action plans within the 2010 to 2013 timeframe. The programme components include:

- development of a detailed guidance manual;
- development of a web interface for States' action plans;
- convening seven hands-on training workshops for States action plans, worldwide;
- development of the *Strategic Plan for the Provision of Assistance for States' Action Plans* with the ICAO Technical Cooperation Bureau (TCB) in order to assist States develop their action plans;
- provision of assistance through 200 conference calls, to identify and respond to specific requests from States;
- development of appropriate tools (ICAO Fuel Savings Estimation Tool (IFSET)[4], ICAO Carbon Emissions Calculator) (see article *ICAO Environmental Tools*, Chapter 1 in this report);
- assistance to various Air Navigation Service Providers in quantifying emissions reductions accrued through navigational measures. For example, assistance provided to ASECNA in quantifying emissions was presented by ASECNA during the ICAO Regional Hands-on Training Workshop for States' Action Plans on CO_2 Emissions Reduction Activities, held in Dakar, Senegal, from 24 to 26 September 2012 (see article *Case Study: ASECNA Fuel Savings Using IFSET*, Chapter 1 in this report);
- development of various information sharing web-based portals, including the ICAO Global Framework on Aviation Alternative Fuels (GFAAF);
- publication of special editions of the ICAO Journal and ICAO Environmental Report covering the latest developments and technical issues related to aviation and the environment;
- convening ICAO events (*e.g.* workshops, symposia), to facilitate information sharing and to initiate discussion with ICAO Member States and other stakeholders on key areas related to aviation and the environment.

Figure 7: *ICAO Regional Hands-on Training Workshop for States' Action Plans on CO_2 Emissions Reduction Activities, Dubai, United Arab Emirates, 14 to 16 June 2011.*

ICAO Technical Cooperation – Implementation Measures – Indonesia Action Plan

ICAO-TCB will be working directly on the new large-scale environmental measures project with the Directorate General of Civil Aviation (DGCA) of Indonesia. The agreed objective is to assist in developing measures such as: Indonesian Implementation Master Plan, including the Institutional and management aspects, legislative and capacity improvement, as appropriate, to support implementation measures of the State Action Plan on carbon emissions reduction, Green Flights and Green Airports operational programmes, more efficient airspace design utilizing performance-based navigation guidelines, advice on appropriate market-based measures, initiatives related to alternative fuels, the development of a comprehensive emissions inventory, as well as a database system that includes oversight programme measures.

Moreover, in order to fulfill the Assembly's request to facilitate the provision of technical and financial assistance, as well as to facilitate access to existing and new financial mechanisms, ICAO organized the "Assistance for Action – Aviation and Climate Change" (ACLI) Seminar, in October 2012 in Montreal[5].

The ACLI Seminar provided States and other stakeholders with essential information on a range of assistance projects, including: capacity building; new technologies; financing for emissions reduction activities; technology transfer; and technical support. In particular, it highlighted the synergies and constructive engagement among ICAO, its Member States, stakeholders, and other international organizations during the first phase of the initiatives related to State Action Plans.

Currently, consistent with the *Strategic Plan for the Provision of Assistance for States' Action Plans*, ICAO TCB is involved in a number of large scale projects (*e.g.* in Indonesia) and offers technical support to States to develop their respective action plans.

NEXT STEPS

Based on the States' action plans received to date, ICAO has identified how action plans could be improved upon, and is looking ahead to further enhancement activities to be undertaken over the next triennium.

Areas where further development is required include more robust data reporting on CO_2 emissions by States, and more detailed information on the specific measures selected along with their corresponding environmental benefits. ICAO is also looking for more widespread use of tools such as the ICAO Fuels Savings Estimation Tool (IFSET), and the ICAO Carbon Emissions Calculator[6] (see article *ICAO Environmental Tools*, Chapter 1 in this report). In their submissions, States should clearly identify exactly where technical assistance and financial support are needed.

Nevertheless, the significant amount of good work undertaken in connection with the development of action plans and the level of support and commitment to the process by States has been impressive. In an effort to maintain the momentum of the first phase of this initiative, and to keep States engaged and actively involved in the action plan process, it is necessary for ICAO to open a new dialogue with States to exchange perspectives on how ICAO could better assist States to improve their action plans and support the implementation of the selected measures. This will constitute the second phase of this initiative.

As described above, ICAO developed a comprehensive strategy to further support States in preparing and/or updating their action plans, as well as to support those States that require assistance in implementing the measures identified in their action plans. In this regard, additional regional training seminars will be planned across the ICAO Regions, in collaboration with the ICAO Regional Offices, Member States, and international and regional organizations. These seminars will focus on the improvement of data collection and the use of tools in the action plans already submitted. States are encouraged to submit and update their action plans by mid-2015, in order to enable the global data compilation by ICAO.

Moreover, ICAO is currently exploring the establishment of new partnerships with other international organizations for State Action Plan funding and to secure financing to facilitate the implementation of the measures selected by States for inclusion in their action plans. (see article *Assistance and Financing Opportunities for Emissions Reduction Measures*, Chapter 6 in this report).

The overarching objective of this project is to contribute to international and regional efforts to address growing CO_2 emissions from international aviation toward the development of a low carbon air transport sector. ■

REFERENCES

1 www.icao.int/environmental-protection/Pages/action-plan.aspx

2 www.icao.int/environmental-protection/Documents/SUSTAF%20Review[2].pdf

3 www.icao.int/environmental-protection/GFAAF/Pages/default.aspx

4 www.icao.int/environmental-protection/Pages/Tools.aspx

5 www.icao.int/meetings/acli

6 www.icao.int/environmental-protection/Pages/Tools.aspx

Figure 8: *ICAO Regional Hands-on Training Workshop for States' Action Plans on CO_2 Emissions Reduction Activities, Mexico City, Mexico, 2 to 4 May 2011.*

CHAPTER 6
ASSISTANCE AND FINANCING

ASSISTANCE AND FINANCING FOR INTERNATIONAL AVIATION EMISSIONS REDUCTION

BY ICAO SECRETARIAT

OVERVIEW

Assembly Resolution A37-19 requested the ICAO Council to study, identify and develop processes and mechanisms to facilitate the provision of technical and financial assistance, as well as facilitate access to existing and new financial resources, technology transfer, and capacity building for developing countries. It also requested the initiation of specific measures to assist developing States, as well as to facilitate access to financial resources, technology transfer, and capacity building.

To fulfill the request of the Assembly, ICAO has developed and implemented a robust capacity building programme to assist Member States in the preparation and submission of their action plans within the 2010 to 2013 timeframe (see Chapter 5 *State Action Plans To Reduce Aviation CO_2 Emissions*, in this report). ICAO also organized the "Assistance for Action – Aviation and Climate Change" (ACLI) Seminar which addressed, among other things, the needs identified by States in their respective action plans (see **Figure 1**).

The ACLI Seminar highlighted the synergies and constructive engagement among ICAO, its Member States, stakeholders, and other international organizations during the action plan initiative. It also showcased the possible financial mechanisms related to climate change to which the international aviation sector could gain access.

CHALLENGES AND OPPORTUNITIES FOR FINANCING THE AVIATION SECTOR

Currently, international aviation has no dedicated financial mechanism related to climate change, such as the Climate Investment Fund (CIF)[1] or Clean Development Mechanism (CDM)[2] of the Kyoto Protocol. However, the current absence of such a mechanism does not mean that there are no initiatives or specific examples of financial contributions to support aviation-related climate change mitigation measures.

Financial support for mitigation measures can be originated from public, private, and public-private sectors, and can be channelled through various intermediaries. These channels include bilateral financing institutions (BFIs), multilateral financing institutions (MFIs), development cooperation agencies, the United Nations Framework Convention on Climate Change (UNFCCC) process, as well as various funds, such as those managed by the Global Environment Facility (GEF), non-governmental organizations and the private sector directly[3]. Currently, private financing sources from foreign direct investment provide a large part of the total funding. Most of the public international financing for mitigation measures is provided through BFIs and MFIs.

The major sources of multilateral financing include the Global Environment Facility (GEF)[3], World Bank (WB)[4], European Bank for Reconstruction and Development (EBRD)[5], Asian Development Bank (ADB)[6], European Investment Bank (EIB)[7], African Development Bank (AfDB)[8], and Inter-American Development Bank (IDB)[9]. These funding bodies, among others, have allocated resources to emission mitigation measures.

A number of concrete opportunities were identified during the ICAO ACLI Seminar including possible partnerships that will provide the financial assistance required to implement the measures selected. This Chapter will showcase a number of opportunities identified for financing through various sources, to assist States in the development and implementation of different mitigation measures, as identified in the State action plans.

For example, the Inter-American Development Bank (IDB) is the leading source of development financing for Latin America and the Caribbean (LAC), with local offices in all its 26 borrowing Member Countries. In early 2011, it launched the Regional LAC Aviation Biofuels Initiative to help public and private institutions develop a sustainable biojet fuel industry in LAC employing different kinds of local feedstocks. This initiative involved a variety of start-up activities, all with the goal of demonstrating their feasibility for the local aviation sector, and as a potential export. (see article *Financing the Development of Aviation Biofuels in Latin America and the Caribbean*, Chapter 6 in this report).

At the ICAO ACLI Seminar, the United Nations Development Programme (UNDP), the implementing agency for the GEF, expressed its support for potential projects under ICAO, using as a reference case the project which was implemented in conjunction with the International Maritime Organization (IMO) and financed by GEF. The "GloBallast" programme aimed at the maritime shipping industry's handling of ballast water, and can be used as a model for the aviation sector (see article *UNDP: Leveraging Climate Finance for Sustainable Future*, Chapter 6 in this report).

Recognizing the urgent need to address the impact of international aviation on climate change and acknowledging that to do so effectively will necessitate undertaking meaningful mitigation actions, the European Commission is also engaged in potential support for measures to address CO_2 emissions and established the following key areas as financing priorities: supporting the preparation or further elaboration of States' action plans; assisting the improvement of CO_2 environmental system tools and processes for compiling national inventories in the aviation sector; and financing country-specific pilot measures to reduce aviation fuel consumption and to improve airspace usage. (see article *The EU As A Partner for Low Carbon Development – Prospects For the Aviation Sector*, Chapter 6 in this report).

In addition, the ICAO Technical Cooperation Bureau (ICAO–TCB) is reinforcing the wide-ranging series of concrete programmes and measures that ICAO has been pursuing to help its Member States mitigate their international aviation carbon emissions. ICAO–TCB is involved in offering technical support to States to develop and implement their action plans.

For example, a large-scale environmental measures project to implement the measures identified in the Indonesian State Action Plan is currently underway, involving the government of Indonesia and ICAO–TCB. This initiative reflects the determination of Indonesia to meaningfully address the environmental performance of its air transport sector, over both the near- and longer-term, while also supporting recent presidential decrees on greenhouse gas emissions.

***Figure 1:** Opening Session by Dr. Kandeh K. Yumkella, Director-General of the United Nations Industrial Development Organisation (UNIDO), ICAO "Assistance for Action – Aviation and Climate Change" (ACLI) Seminar, Montreal, Canada, 23 to 24 October 2012.*

ICAO–TCB is working directly on the new project with the Directorate General of Civil Aviation (DGCA) of Indonesia. The agreed objectives include a master plan for legislative improvements on emissions including Green Flights and Green Airports operational programmes, more efficient airspace design utilizing performance-based navigation guidelines, advice on appropriate market-based measures, as well as initiatives relating to alternative fuels, and the development of a comprehensive emissions inventory (see article *State Action Plans To Reduce Aviation CO_2 Emissions*, Chapter 5 in this report).

FINANCING – NEXT STEPS

ICAO will continue to assist States in developing and improving the action plans which have already been submitted. ICAO is also collaborating with Member States that have requested assistance in implementing measures to reduce CO_2 emissions from international aviation operations (see article *State Action Plans To Reduce Aviation CO_2 Emissions*, Chapter 5 in this report), and will continue to explore concrete processes and mechanisms for the provision of such assistance.

A series of articles in this chapter cover examples and possibilities for climate financing, through various sources, to assist States in the development and implementation of their action plans. ■

REFERENCES

1 **Climate Investment Funds (CIF)** was established in 2008 by several multilateral development banks. The CIF has balanced and equitable governance with equal representation from developed and developing countries. (www.climateinvestmentfunds.org/cif/)

2 **Clean Development Mechanism (CDM)** 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. (cdm.unfccc.int)

3 www.thegef.org

4 www.worldbank.org

5 www.ebrd.com/pages/homepage.shtml

6 www.adb.org/themes/climate-change/main

7 www.eib.org/projects/priorities/climate-action/index.htm

8 www.afdb.org/en/topics-and-sectors

9 www.iadb.org/en/inter-american-development-bank,2837.html

FINANCING THE DEVELOPMENT OF AVIATION BIOFUELS IN LATIN AMERICA AND THE CARIBBEAN

BY ARNALDO VIEIRA DE CARVALHO

ARNALDO VIEIRA DE CARVALHO

He is Lead Sustainable Energy Specialist with the Energy Division of the Inter-American Development Bank (IDB) in Washington, DC, USA. He has been working with biofuels since the seventies. Mr. Vieira de Carvalho has worked for the IDB since 1997 on financing and implementing sustainable energy projects, including biofuels, throughout Latin America and the Caribbean. He was Director of the Latin American Energy Organization (OLADE) in Ecuador and occupied several positions in the private sector, including General Manager and Department Head.

INTRODUCTION

The Latin America and the Caribbean (LAC) region has one of the cleanest energy matrices in the world. In fact, 31% of the region's total energy demand is satisfied by renewable energy, compared with a figure of 13% for the world and 8% for OECD countries[1]. This is due to a huge hydroelectricity and bioenergy infrastructure already in place.

The Inter-American Development Bank (IDB) is the leading source of development financing for Latin America and the Caribbean (LAC), with local offices in all its 26 borrowing Member Countries. The IDB Group, the world's oldest regional development bank, is composed of the Inter-American Development Bank itself, the Inter-American Investment Corporation (IIC)[2] and the Multilateral Investment Fund (MIF)[3], financing both private and public sector projects, with or without sovereign guarantees. Over the past 50 years the IDB has contributed more than US$ 30 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 (US$ 216 billion cumulative as of July 10, 2013).

As a multilateral development bank, IDB has a mandate to support investment programmes in LAC that:

- Contribute in a relevant way to sustainable social and economic development of its Member Countries;
- Reduce poverty and create jobs;
- Provide longer-term environmental benefits and mitigate climate change;
- Promote sustainable rural development;
- Improve competitiveness, foster capacity-building, technology development, and innovation;
- Optimize the use of human and natural resources of its Member Countries;
- Stimulate public-private partnerships, among others.

When produced in a sustainable way, biofuel production and utilization can comply with all of these conditions and contribute to the LAC's social and economic sustainable development. 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[4].

In addition to financing the private sector in building the biofuels production infrastructure, such as the Brazilian CNAA ethanol plants project[5], 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, environment, and agriculture ministries of the various LAC countries, so that they can make informed decisions about the preparation and implementation of their sustainable biofuels programmes. For this reason, the IDB has been financing studies and programmes for more than half of its borrowing Member Countries: Argentina, Brazil, Mexico, Colombia, Chile, El Salvador, Honduras, Guatemala, Dominican Republic, Haiti, Guyana, Suriname, and Paraguay. The Bank has also been collaborating on other initiatives such as the US-Brazil Memorandum of Understanding on Biofuels, and its component to support third countries, which specifically benefits countries in Central America and the Caribbean.

AVIATION BIOFUEL BENEFITS

In comparison with ethanol and biodiesel, the aviation biofuels market is expected to encounter fewer technical and market obstacles due to the "drop-in" fuel approach being adopted by the aviation industry, which does not require adaptation of engines or storage/distribution infrastructure. Also, jet fuel is much less likely to receive government subsidies than gasoline and diesel, which frequently creates great barriers for ethanol and biodiesel programs to compete in the marketplace. All this should make it easier to introduce biojet fuels in LAC.

Most importantly, this new biofuel market niche clearly recognizes the value of biofuels with respect to their carbon emission reduction benefits, and the market appears to have a much better integrated and coordinated stakeholder support structure than the traditional ethanol and biodiesel sectors. With its strong environmental component, the biojet fuel sector is expected to encounter fewer barriers, making it a candidate for rapid development in LAC and elsewhere.

IDB AVIATION BIOFUELS INITIATIVE FOR LAC

In early 2011 the IDB launched the *Regional LAC Aviation Biofuels Initiative* to help public and private institutions develop a sustainable biojet fuel industry in LAC employing different kinds of local feedstock. This initiative was motivated by several factors including: the above-mentioned benefits, requests received from the region, the LAC's leading role on ethanol and biodiesel production and utilization, and by international initiatives such as the Commercial Aviation Alternative Fuels Initiative (CAAFI) to promote the development of greener aviation fuels[6]. This initiative involved a variety of start-up activities such as funding consultancy services, knowledge development, and dissemination of material and the conduct of workshops on the sustainable use and production of biojet fuels; all with the goal of demonstrating their feasibility for the local aviation sector, and as a potential export.

Under this initiative, IDB is partnering with major aviation industry stakeholders that are leading the development of alternative aviation fuels worldwide, and particularly in LAC. These companies and organizations include Embraer, Boeing, GOL, Azul, Amyris, ASA of Mexico, GE, the International Civil Aviation Organization (ICAO), CAAFI, the World Economic Forum (WEF), as well as other airlines, aircraft manufacturers, and biofuel technology providers. These institutions and companies are working together on regulations and targets for carbon emission reductions with the industry's goal of replacing as much as 50% of jet fuel worldwide by alternative sources by 2050. A strong motivation for this transition is the pressure for the sector to reduce its carbon emissions that could otherwise limit the sector's growth.

The first activity supported by this initiative was the preparation of the *Brazil Action Plan for FIFA World Cup 2014 and Rio 2016*

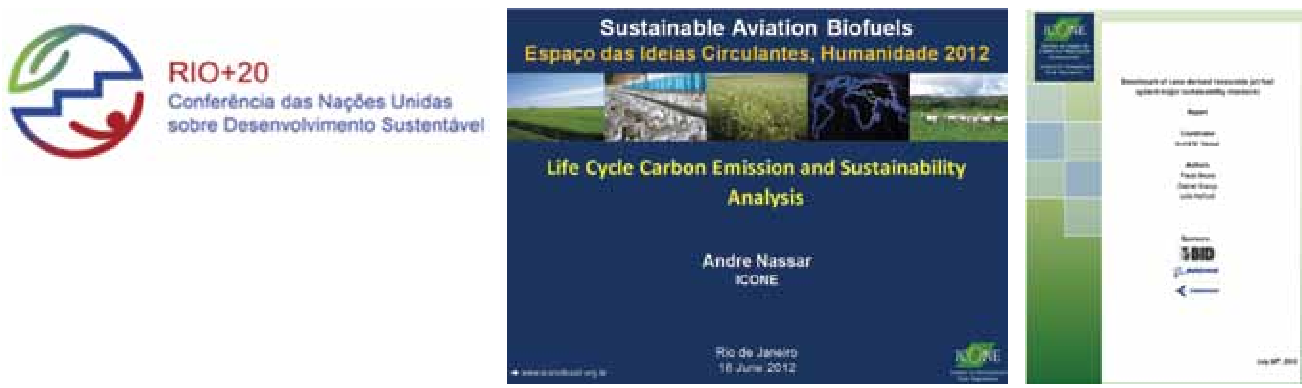


Figure 1: *Documents Presenting First Results of the IDB-funded Regional LAC Aviation Biofuels Initiative, Co-financed by Major Aviation Sector Stakeholders, during Rio+20 Conference, Rio de Janeiro.*

Figure 2: *First-ever DSHC Biojet Fuel Flight by Azul Airlines, Amyris, Embraer, GE on June 19th, 2012 during Rio+20 Conference, Rio de Janeiro.*

Figure 3: *Brazilian Portion of the ICAO Rio+20 Flightpath by GOL Flight on June 19th, 2012, Rio de Janeiro, Supported by the IDB-funded Regional LAC Aviation Biofuels Initiative and Partners.*

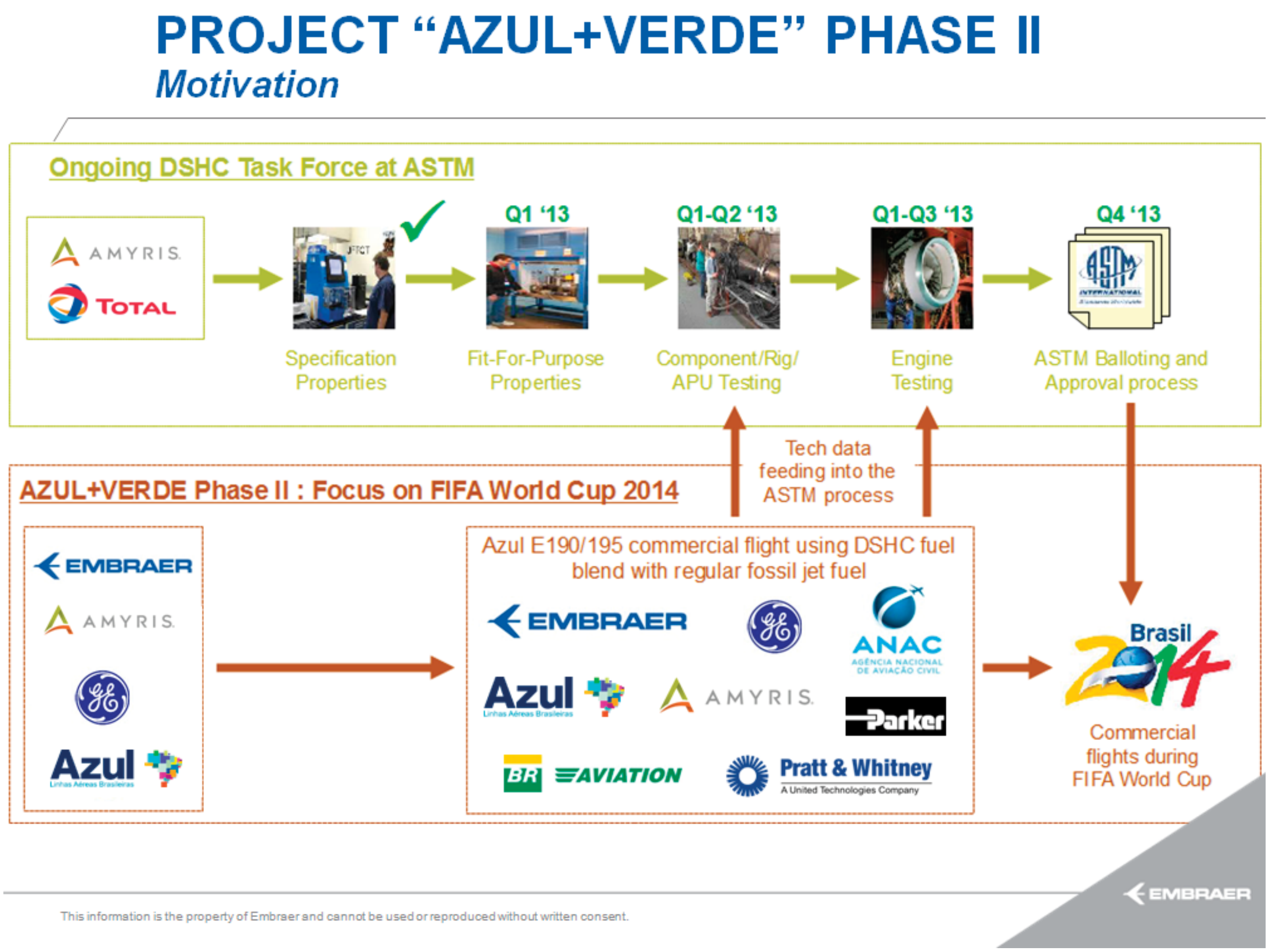


Figure 4: *Certification Compliance Plan (STC process) to Help Put in Place Regulations for DSHC Biojet Fuels to Allow Commercial Flights in Brazil.*

Figure 5: *Camelina Cultivation Ready for Harvesting; and Fructification (Source: Mauro Knudsen).*

Olympics (December 2011) which aims to reduce/offset the carbon footprint of international and domestic flights through the use of biojet fuel. The next supported study was the *Life Cycle Carbon Emission and Sustainability Analysis* of biojet fuel from sugar cane (DSHC), which indicated over 82% carbon emissions reduction in comparison to conventional jet fuel. These results were presented during a dedicated event at Rio+20, just before the first-ever DSHC demonstration flight. A study on the *Benchmark of Cane-derived Renewable Jet Fuel Against Major Sustainability Standards* followed. Also, the IDB LAC initiative supported the Brazilian portion of the ICAO Rio+20 "*Flightpath to a Sustainable Future*" Initiative, with GOL Airlines, that demonstrated that it is already possible to have connecting flights across the Americas with different airlines and aircraft types, using biojet fuels from different feed stocks — see **Figures 1** to **3** (see article *Flightpath to a Sustainable Future: The ICAO Rio+20 Global Biofuels Initiative*, Chapter 8 in this report).

Work is continuing on the plan to make biojet-fueled commercial flights possible in Brazil during the 2014 FIFA World Cup soccer games. This IDB initiative also supports the effort led by Embraer to prepare a certification compliance plan (STC process) to help put in place regulations for DSHC biojet fuels specifically for Embraer E-jets family of aircrafts, as depicted in **Figure 4**.

In addition to these activities in Brazil, other studies have been supported by a number of LAC countries. For example, a feasibility study for the first LAC biojet fuel production plant was financed for Aeropuertos y Servicios Auxiliares (ASA) of Mexico. The key objective of the study was to assist ASA to evaluate the feasibility of installing renewable jet process units of two sizes, processing 2,000 barrels per stream day (bpsd) and 6,500 bpsd of refined vegetable oils respectively, to produce a renewable jet product at locations in Mexico. It was envisioned that the unit would be integrated into an existing industrial facility (such as an oil refinery) in order to minimize the total cost of the project and achieve cost savings over a Greenfield facility. The study was carried out by UOP, with the assistance of an external contractor.

Also, a study into the possibility of using camelina sativa (see **Figure 5**) as feedstock for the production of biojet fuel was sponsored by Argentina. The study examined the feasibility of camelina cultivation in marginal areas in the south of the country, including the analysis of economic, social and environmental issues. This feedstock has been successfully used in North America, but the experience in South America has been limited thus far. Nevertheless, this feedstock is promising, especially if the large land areas currently used for soybeans in Argentina could be used annually in rotation with camelina plantation. ■

REFERENCES

1 International Energy Agency (IEA), World Energy Outlook 2012 (WEO-2012).

2 Inter-American Investment Corporation (IIC).

3 Multilateral Investment Fund (MIF).

4 www.iadb.org/biofuelsscorecard

5 www.iadb.org/en/projects/project-description-title,1303.html?id=BR-L1107; 1108 and 1170

6 www.caafi.org

UNDP: LEVERAGING CLIMATE FINANCE FOR A SUSTAINABLE FUTURE

BY **OLIVER PAGE**

OLIVER PAGE

He is the Climate Change Regional Technical Advisor for the United Nations Development Programme (UNDP) in Latin America and the Caribbean. He is responsible for the implementation of UNDP's Climate Finance Readiness activities and has leveraged financing from numerous sources for strategic climate change mitigation and adaptation interventions throughout the region. Mr. Page has represented UNDP in numerous speaking and lecturing engagements and has repeatedly been a guest lecturer for the Climate Change Master's program at the University of Bilbao, Spain. He has also contributed to several UNDP publications on energy and climate change, including "Transforming On-Grid Renewable Energy Markets" (2012), and "Derisking Renewable Energy Investment" (2013).

THE CLIMATE FINANCE CHALLENGE

Holding global temperatures at no more than 2°C above pre-industrial levels is the global challenge of the 21st century. Stabilizing the atmospheric CO_2 concentration at 450 parts per million requires a transformation in production and consumption processes across all countries. This transformation must involve a country-driven shift toward policies and technologies that leverage new investments and mainstream climate change into existing systems. In addition, significant support must be provided to build resilience into these systems, particularly for the poorest and most vulnerable of developing countries which have contributed least to the build-up of greenhouse gases in the atmosphere.

The scale of the financial challenge to achieve this transformation is in the order of hundreds of billions of US dollars. Moreover, the sources of such funding are multiple, including national and international public financing, private sector investment, capital markets, and international cooperation resources. The financing available and the capacities to absorb resources vary across different countries; whereas developed countries have internal capacities to generate and use climate finance, many developing countries lack the financial resources necessary or the institutional, policy, and skills systems to leverage and use climate finance effectively. The impacts of these barriers are heightened for vulnerable groups, such as the poor and women, threatening the achievement of poverty reduction goals and the Millennium Development Goals (MDGs).

The international community has responded to this scarcity by increasing public financing of climate change activities over recent years. For example, governments have established and/or repurposed institutions such as the Global Environment Facility, the Adaptation Fund, the Climate Investment Funds, and most recently the Green Climate Fund. Some have also set up new evolving financial mechanisms such as performance-based payments for clean energy, increased efficiency, and emissions reduction from deforestation, degradation, and forest conservation (REDD+). In addition, developing countries have increased their own public spending on climate change activities. However, while extremely important, increasing supply of public finance alone will not promote transformations in the production and consumption processes. The scale of the financing required and the cross-sectoral nature of the climate challenge means that countries have to integrate climate change into their development planning processes and ensure that public and private investments contribute to a low emission, climate resilient future.

SUPPORTING CLIMATE FINANCE READINESS

The United Nations Development Programme (UNDP) supports its partner countries in climate finance readiness, which is the process of planning for, accessing, delivering, monitoring and reporting on climate finance. This applies both internationally and domestically, in ways that are transformative and fully integrated with national development priorities and achievement of the MDGs. Within this framework, UNDP supports countries in the following areas of work.

Strengthening National Capacities to Plan for Finance

UNDP supports governments in preparing low-emissions, climate-resilient sustainable development strategies. Planning for climate actions must be based on overarching development priorities at the national level. The capacities required to assess needs and define priorities are complex to build and the process for strengthening these capacities is iterative. This is particularly important given that climate finance flows are neither purely public, nor purely private. This varied landscape requires specific national mechanisms for coordinating relevant government ministries and agencies around climate priorities, as well as key economic and social players, including international and domestic private sector stakeholders.

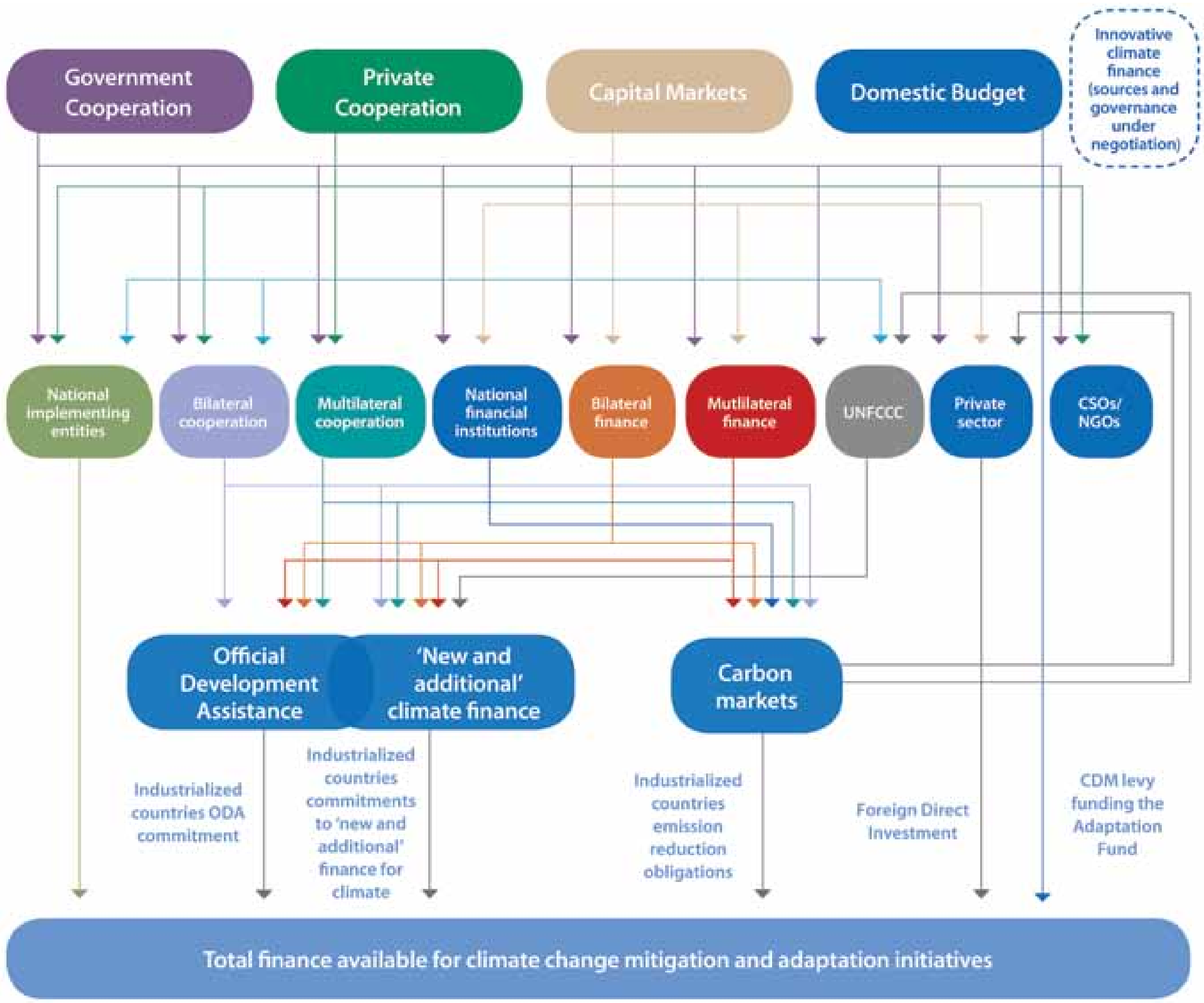


Figure 1: *Existing Climate Change Finance Flows (Source: UNDP, 2011a).*

Strengthening Capacities to Access Different Forms and Types of Finance

In the context of myriad financing options, it is increasingly important for countries to be able to directly access funding from different sources. This includes formulating projects, programmes, and sector-wide approaches that attract and catalyse further public and private financing. Likewise, the capacity to blend and combine those resources at the national level is important to achieve maximum impact and leverage a wider range of financial instruments[1]. UNDP supports countries in accessing, combining, and sequencing multiple sources of financing to best respond to national needs, including multilateral and bilateral funds, international carbon markets, private investments, and domestic public funds. Accessing finance requires a range of different institutional tools, mechanisms, and modalities; specific capacities are needed at the national level to institute and operate such financing platforms.

Strengthening Capacities to Deliver Finance — and Implement/Execute Activities

Delivering financing involves the implementation and execution of activities at the regional, national, or local level and ensures that climate finance contributes to effective and transformative actions on the ground. UNDP is a key partner to over 100 countries in implementing climate finance initiatives from multiple sources of financing, ranging from targeted technical support interventions to widespread initiatives that transform renewable energy markets at the country level. Delivering resources requires key national financial management capacities to meet international fiduciary standards, as well as a local supply of expertise from which to procure skills to undertake project activities. Furthermore, coordination among entities is essential to ensure that project-level activities are in line with national development planning and strategies at the macro level.

Figure 2: *Components of Climate Finance Readiness.*

Strengthening Capacities to Monitor, Report, and Verify on Financial Expenditures and Associated Results/Transformative Impacts

Monitoring, reporting, and verifying (MRV) financial flows, expenditures, and results are key aspects of climate finance readiness. Countries must develop national capacities to track domestic and international climate change expenditures and link them to direct results, in particular to greenhouse gas (GHG) emission reductions. Payment-for-results systems require an explicit attribution of GHG reductions ("results") in order to access financial flows ("payments") and so necessitate integrated national reporting mechanisms. Nationally Appropriate Mitigation Actions (NAMAs) are based on the premise that countries will be able to report on domestic mitigation activities, ranging from unilateral domestically-funded actions to measures fully supported by international sources of finance. Thus, UNDP works with countries in developing flexible and robust MRV systems that maintain a consistent level of transparency and accuracy and are consistent with domestic and international standards.

It is important to note that, while these core elements are almost always present in some form at the national, sub-regional, or local levels, this does not translate into a one-size-fits-all model. Different configurations of these four components can exist within institutions, between institutions, or across national or sectoral systems. UNDP's approach acknowledges that the needs of countries are different and evolve over time, and it works with national stakeholders to develop and implement a climate finance strategy that responds to a country's specific needs and opportunities.

CLIMATE FINANCE AND INTERNATIONAL AVIATION

The international aviation emission reduction goals expressed in the ICAO Resolution on International Aviation and Climate Change will trigger a widespread transformation of the industry's energy consumption patterns. As an emblematic sector of international connectivity with a truly global presence, international aviation's greening efforts will engage all countries and lead to profound change. The emission reduction potential is vast, ranging from cutting edge design of highly efficient technology to development of sustainable second and third generation biofuels, deployment of innovative air traffic management systems, and revamped airport designs and ground operations.

All of these changes will be stimulated by an array of existing and forthcoming climate finance instruments that can be applied to the aviation sector's needs. Public research and development (R&D) funding, and private venture capital, must be strategically deployed to further low-carbon technology innovation, both in aviation infrastructure and in sustainable biofuel production. Market-based measures may be applied to ensure that emission reduction efforts are distributed in a cost effective manner across the industry. Policy and financial de-risking measures, which address underlying technical, policy and institutional barriers, and providing public loans and guarantees, can lower risk perceptions and the cost of capital for investments in clean technologies, thus enticing private capital. The limited sources of available grant financing can also be applied to remove barriers and increase national capacities to engage in the sector's emission reduction efforts.

With its presence in 177 countries and over 20 years' experience in working on climate change mitigation, UNDP is well positioned to support ICAO Member States in reducing their emissions from the international aviation sector. The combination of ICAO's aviation expertise and UNDP's ability to implement specialized climate change projects at the country level can enhance the technical support provided to States working on low emissions aviation plans and ensure that these efforts are mainstreamed into the country's broader development planning process. Upon identification of an optimal set of measures to be applied in individual countries, UNDP can support the identification of policy, finance, and technical support tools to support the greening of the aviation sector. National climate finance roadmaps should be developed to identify the most appropriate sources of finance, seeking to stimulate investment, increase the competitiveness of the industry, and foster green growth at the national level.

The widespread transformation of a global sector to address an environmental concern is both possible and feasible. For example, just in the past decade the GloBallast programme, financed by the Global Environment Facility (GEF) and implemented by UNDP in partnership with the International Maritime Organization (IMO), radically transformed the maritime shipping industry's handling of ballast water. As a result, invasive species pollution has been drastically reduced and a governance framework to minimize ballast water pollution has been put in place through the International Ballast Water Convention. This was achieved through a process that engaged all countries by providing technical assistance, transferring and applying new technologies and practices, supporting the development of national policy frameworks, and leveraging investments.

The international aviation sector can be inspired by this type of success. The climate change challenge is daunting, but a strong start has been made by establishing clear, ambitious emission reduction goals for international aviation and defining a sector wide basket of measures for reducing the industry's carbon footprint. UNDP is fully prepared to support this effort and contribute in making the transformation to green aviation a reality, working on the ground and catalysing change, together with our partner countries, ICAO, and the international community. ■

REFERENCE

1 The joint UNDP/World Bank Climate Finance Options Platform (www.climatefinanceoptions.org) provides a comprehensive overview of current climate finance sources, including resource availability, access mechanisms, and eligibility criteria.

THE EU AS A PARTNER FOR LOW CARBON DEVELOPMENT – PROSPECTS FOR THE AVIATION SECTOR

BY ELINA BARDRAM

ELINA BARDRAM

She is the Head of Unit, for International Carbon Markets, Aviation and Maritime Unit in European Commission's Directorate-General for Climate Action. Prior to this Ms. Bardram served as a Deputy Head of Unit for Climate Finance and Deforestation. Between 2003-2010, Ms. Bardram worked in the policy coordination and strategy directorate of the External Relations Directorate-General, where she led a team developing EU outreach capacities, presence and campaigning in third countries. Before joining the European Commission, Ms. Bardram served at the UN country office in Nigeria and was employed in the business consulting sector in Europe. Ms. Bardram holds a Ph.D. in economics from Vienna University of Economics and Business.

EU DEVELOPMENT AND CLIMATE FINANCE

The European Union (EU) has long been the world's most generous Official Development Assistance (ODA) donor. In fact, the EU and its Member States collectively provide more than half of global ODA funding which exceeds US$ 100 billion on annual basis[1]. A significant and continuously increasing part of this assistance is dedicated to climate change-related action. Following the voluntary pledges undertaken at the Copenhagen climate conference in 2009, the EU, together with its Member States, has been the greatest contributor to Fast Start Finance, spending a total EUR €7.34 billion during the period 2010 to 2012[2] in support of climate action in developing countries (**Figures 1** and **2**). Within this context, the European Commission as the executive of the European Union, is also a major source of climate finance, providing more than €3.7 billion for climate change-related ODA[3] since 2002.

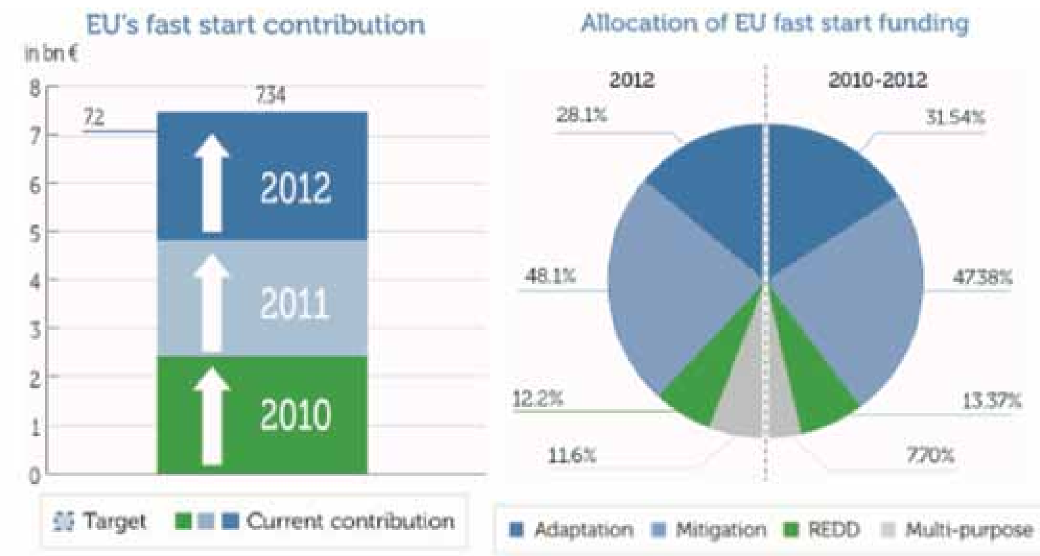
The EU does not consider climate action and financing as "stand-alone" issues. Rather, they are part of a wider sustainable development cooperation model, and need to be incorporated into the broader national plans, as well as in the sector specific strategies of countries. Our objective is to work with partner countries to integrate climate change into their domestic policies in a way that mirrors the country's specific circumstances. One flagship initiative promoting this approach is the Low Emission Capacity Building Programme (LECBP)[4]. As a joint collaboration between the EU, Germany, Australia and the United Nations Development Programme (UNDP), the LECBP helps formulate and implement nationally appropriate mitigation actions and low emission development strategies. Among other things, it is aimed at building private and public sector capacity for mitigation action and supporting the improvement of national greenhouse gas (GHG) inventories in the 25 current LECBP partner countries.

EU PRIORITIES FOR MITIGATION ASSISTANCE RELATED TO INTERNATIONAL AVIATION

There are already a number of climate change-relevant projects in the field of aviation. Examples include the initiative to compile a report on the carbon footprint of the civil aviation sector in India[5], and the environmental components of the ASEAN Air Transport Integration Project[6].

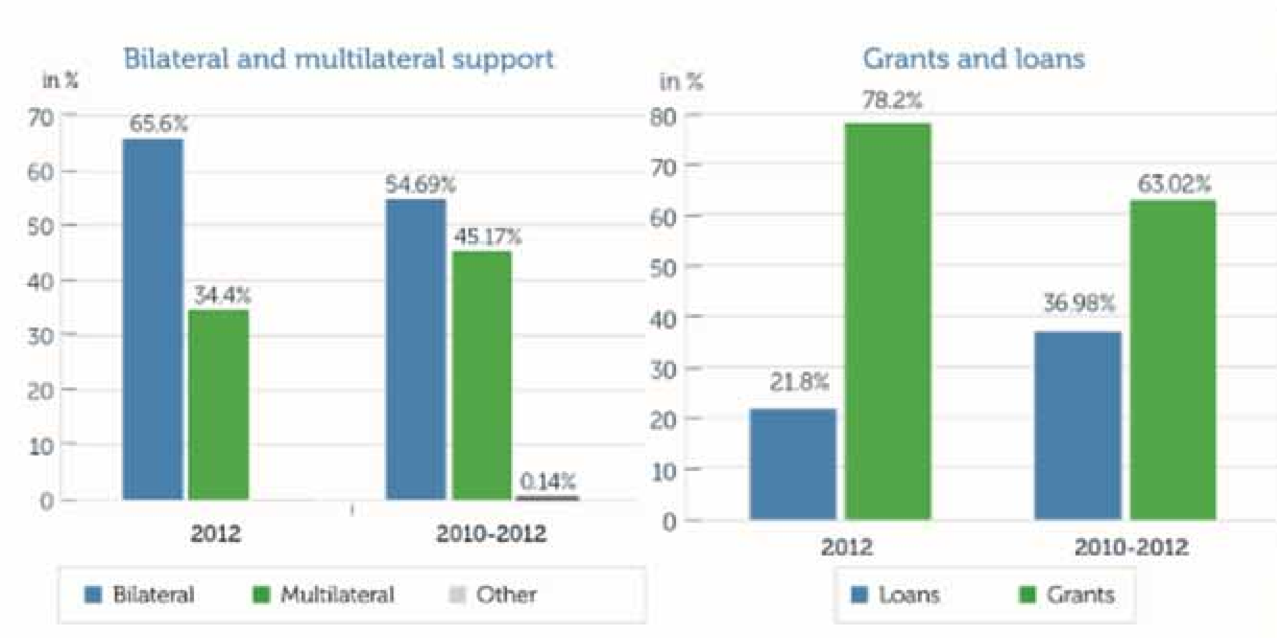
Interest in mitigation projects relating to aviation is likely to increase. Bearing in mind the need to keep global warming below 2ºC compared to the temperature in pre-industrial times which translates into the goal of limiting global annual emissions below 20 gigatons (**Figure 3**) there is an urgent need to address aviation emissions globally. In 2010, approximately 65% of global aviation fuel consumption was from international aviation. Based on CAEP/MDG's analysis, this proportion is expected to grow to nearly 70% by 2050 (see article *Environmental Trends in Aviation to 2050*, **Figure 3**, Chapter 1 in this report). Furthermore, the overall climate impact factor of aviation could be larger than the impact of aircraft carbon dioxide (CO_2) emissions alone[7].

Through tourism and the export of goods and services, many developing countries have become key stakeholders in international aviation. Air transport has a significant role in facilitating economic development and connecting countries to the global marketplace. In the coming decades, demand for aviation services will be especially strong in China, India, and the Middle East[8]. Aviation-related emissions are expected to grow at a much faster rate in emerging economies and developing countries than in industrialized countries, as growth in aviation is closely linked to growth in GDP. According to ICAO passenger traffic forecasts, between 2010 and 2030, growth rates in the Asia/Pacific, Latin American, Caribbean and African statistical regions will exceed those in Europe and North-America[9].



http://ec.europa.eu/clima/policies/finance/international/faststart/index_en.htm

***Figure 1:** EU Fast Start Funding – Distribution According to Years and Purpose.*



http://ec.europa.eu/clima/policies/finance/international/faststart/index_en.htm

***Figure 2:** EU Fast Start Funding – Distribution According to Support Type.*

Financing of climate-related projects and initiatives could assist developing countries with limited resources to identify emission abatement or avoidance opportunities and extend low carbon development planning to the aviation sector. In this context, State Action Plans, as called for by the 2010 ICAO Assembly Resolution A37-19, provide a useful tool for monitoring, planning and managing aviation emissions, as well as for identifying country specific priorities for action. The EU strongly believes that comprehensive, high quality action plans could play an important role in mid- and long-term planning, as well as increase ownership and involvement of national authorities in the field of managing aviation emissions (see article *State Action Plans To Reduce Aviation CO_2 Emissions*, Chapter 5 in this report).

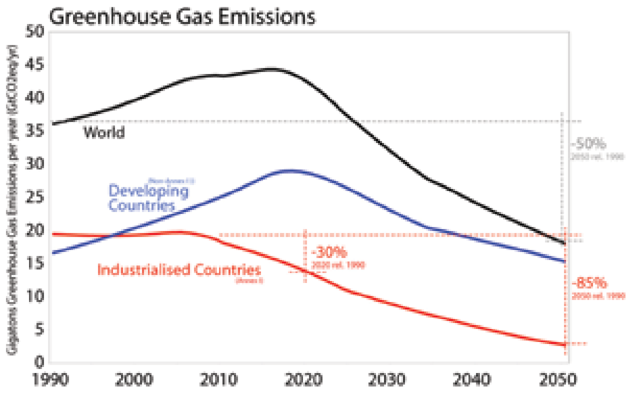


Figure 3: *EU Global Vision for Emissions Reduction.*

EXPLORING A PROJECT OPPORTUNITY FOR CO_2 REDUCTION IN AVIATION

The European Commission is currently exploring an opportunity to develop a project in cooperation with international partners to support capacity building for CO_2 mitigation from international aviation. According to the initial project concept, which is currently under elaboration with the ICAO Secretariat, financing would focus on three activity areas:

- Supporting the preparation or further elaboration of State's action plans;
- Assisting the improvement of CO_2 environmental system tools and processes for compiling national inventories in the aviation sector;
- Financing country-specific pilot measures to reduce aviation fuel consumption and to improve airspace usage.

The activities outlined above would be mutually supportive and aim at maximizing synergies. For example, improved environmental system and management would facilitate the preparation of robust projections to support strategic planning for future action. Possible emission reductions and limitation measures identified in the action plans would be tested for feasibility and cost effectiveness. Good quality data on historical and current emissions would help to validate the impact of the pilot measures foreseen by the project, and would prepare the groundwork for further policy planning and enhanced financing opportunities.

The EU strongly supports stakeholder involvement as well as project transparency throughout all phases of the project. Action plans should go through country-relevant, extensive consultation procedures, and should be made public. To ensure coherence, the improvement of aviation environmental system should facilitate reporting, not only to ICAO, but also under the United Nations Framework Convention on Climate Change (UNFCCC), using existing and widely accepted methodologies[10] developed by the Intergovernmental Panel on Climate Change (IPCC).

Though the project is primarily aimed at country-level action, regional adoption and cooperation may be a significant spin-off benefit. The EU plans to explore the possibility of preparing action plans and undertaking capacity building and strategic planning activities at the regional level.

The European Commission hopes to announce further details of this multi-million dollar project over the course of Fall 2013, and it looks forward to reinforced cooperation with its international partners in promoting climate compatible and energy efficient aviation policies and practices. ■

REFERENCES

1 http://ec.europa.eu/europeaid/what/development-policies/financing_for_development/index_en.htm

2 http://ec.europa.eu/clima/policies/finance/international/faststart/index_en.htm

3 http://ec.europa.eu/clima/policies/finance/international/other/index_en.htm

4 www.lowemissiondevelopment.org

5 http://pib.nic.in/newsite/erelease.aspx?relid=88278 http://eeas.europa.eu/delegations/india/eu_india/trade_relation/index_en.htm

6 http://ec.europa.eu/europeaid/work/funding/awp2008/documents/asia/awp_grants_thailand_aatip_en.pdf

7 IPCC Special Report "Aviation and the Global Atmosphere", 1999.

8 Green Growth and the Future of Aviation, OECD, 2012.

9 ICAO Environmental Report, 2010.

10 See ICAO Guidance Material for the Development of States Action Plans, Appendix G and 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2, Energy.

CHAPTER 7

ADAPTATION

OVERVIEW

ADAPTATION

BY ICAO SECRETARIAT

Impacts on the climate as a result of increasing levels of anthropogenic greenhouse gas (GHG) emissions are now considered a significant threat to sustainable development. The negative impact of climate change on health, food security, and economic activities are well documented and highlight the importance of addressing climate change. From an aviation perspective, this is of particular relevance as the aviation industry expects significant growth over the coming decades.

The ICAO Committee on Aviation Environmental Protection (CAEP) estimates that by 2040, fuel consumption, and hence CO_2 emissions, from international aviation is projected to increase by 2.8 to 3.9 times compared to the 2010 value.

The physical risks associated with climate change include: rising water levels and temperatures; changes in moisture content in the atmosphere; increasing wind speeds; and increasing severity and frequency of storm activity[1]. In addition, these physical risks could exacerbate social, economic and political risks, which could increase operating costs and potentially impact the sustainable growth of aviation.

The articles in this chapter focus on the possible adverse impacts on aviation activity due to climate change and the adaptation measures that the aviation industry could adopt in conjunction with its ongoing mitigation activities. This chapter also addresses the challenges and opportunities associated with financing climate change adaptation activities from multiple sources.

ADAPTATION AND MITIGATION

Aviation stakeholders are already taking action to reduce GHG emissions from aviation. Chapter 4 *Global Emissions* in this report deals with mitigation measures. A detailed list of the basket of mitigation measures that can be taken by the aviation stakeholders can be found on the ICAO public website.

On the other hand, adaptation measures are those activities undertaken by stakeholders to manage the consequences of climate change on aviation. According to scientists, possible consequences as a result of high accumulation of GHG emissions in the atmosphere include sea level rise, temperature changes, changes in precipitation and increased storms. Some examples of tangible adaptation measures that can be implemented to counter the effects of climate change in aviation operations include: improving the coastal defences of an existing airport; relocating coastal airports further inland; and using modern technology like Light Detection and Ranging (LIDAR) to manage clear air turbulence.

Creation of a disaster operations group that provides airport operators, with a formal reference framework to establish and apply mutual assistance programmes, during the occurrence of regional catastrophes is an example of the types of initiatives that could be implemented to integrate adaptation activities into the overall environment planning activities of the States.

The 37th Session of the ICAO Assembly in 2010 requested the monitoring and dissemination of relevant information on the potential impacts of climate change on international aviation operations and related infrastructure, in cooperation with other relevant international organizations and the industry. ICAO and its Member States, as well as other stakeholders have been sharing this type of information through CAEP. For example, ICAO has worked with the World Meteorological Organization (WMO) to establish a global programme that enables commercial aircraft to take inflight meteorological measurements. This collaboration provides invaluable data that contributes to a better understanding of the global climate. In addition, WMO provides valuable information on the potential risk of climate change on aviation (see article *Leading the Way Toward Mitigating the Effects of Climate Change of WMO*, Chapter 7 in this report).

According to the *Stern Review on Economics of Climate Change*[2], it is suggested that it is much more cost-effective to take preventive and adaptive action earlier on, than it is to try to mitigate the consequences of the adverse impact of climate change later.

While drastic mitigation measures could reduce and stabilize atmospheric GHG concentrations, emissions are still expected to be higher than current levels in the coming years, making it imperative to anticipate and adapt to the impacts from climate change, as indicated in **Figure 1**.

The major risks to aviation from these impacts, and potential adaptation measures are shown in **Table 1**.

ADAPTATION FINANCING

Financing is often a significant obstacle to States when planning to undertake climate change adaptation measures. Higher costs and financing needs will be required for those measures involving modifications to existing airport infrastructures and improving protection to installations in coastal areas. The greater the number of airports that will be exposed to expected climate change impacts, the higher the financing envelope that may be required by States.

Major Risk	Level of Uncertainty	Probability of Occurrence
Sea level rise	Virtually certain	≥ 99%
Temperature changes		
Decreases in very cold days	Virtually certain	≥ 99%
Increases in Artic 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: *Major Weather Events – Level of Uncertainty and Probability of Occurrence.*

Major Risk	Potential Adaptation Measures
Property Damage to Airport Infrastructure and Aircraft from extreme weather	• Infrastructure reinforcement. • Sea walls, natural or artificial barriers to provide improved coastal protection. • Improvements to storm water management. • Possible relocation of coastal airports in cities identified as most vulnerable[3]. • Constructing new airports further inland. • Focus on infrastructure design for new and existing installations.
Adaptation costs could impact sustainable aviation	• Amortize the adaptation costs over the long term associated with the benefit period from the adaptation activities. • Make regulatory changes to allow access to adaptation financing at very competitive rates from governments, as well as multilateral and bilateral financing institutions.

Table 1: *Major Risks to Aviation and Potential Adaptation Measures.*

States could generate financing by channelling resources from government budgets earmarked for the environment. Private sector investments could also be the source of financing. Funding of adaptation measures could come from multiple sources and dedicated funds for adaptation are currently under consideration.

The challenges in locating funding sources for adaptation are greater for poor and vulnerable States. In 2009, the 15th Session of the Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC COP15) adopted the Copenhagen Accord, which stated that adaptation funding needs to be prioritized for the most vulnerable countries, including Least Developed Countries (LDC) and small-island developing States. In 2010 at UNFCCC COP16, parties adopted the Cancun Adaptation Framework, which committed support to developing countries for adaptation action.

Estimates of financing needs for adaptation vary greatly. An initial World Bank study report estimated that the cost would be between US$70 to $100 billion a year[4] between 2010 and 2050 for adapting to an approximately 2°C warmer world by the year 2050. The UNFCCC has estimated that by 2030 additional investments and financial flows of between US$8 to $140 billion are needed for adapting infrastructure vulnerable to climate change globally[5]. The funds that are needed for adaptation that could specifically address the needs of the aviation sector are currently unavailable. However, aviation

Fund	Purpose	Administered by
Least Developed Countries Fund (LDCF)	Support the preparation and implementation of NAPAs (National Adaptation Program of Actions).	Global Environment Facility (GEF)
Special Climate Change Fund (SCCF)	Support long term adaptation measures to impacts of climate change.	Global Environment Facility (GEF)
Adaptation Fund (AF)	Established under Kyoto Protocol financed by 2% of proceeds from CER issued for a CDM Project and used to fund programs and projects dedicated to adaptation in developing countries.	Adaptation Fund Board
Global Climate Change Alliance (GCCA)	Bilateral initiative of the European Union to support most vulnerable countries to adapt to the effects of climate change.	European Commission (EC)
Green Climate Fund (GCF)	Mechanism to transfer money from the developed to developing countries to assist them in their adaptation and mitigation measures.	UNFCCC

Table 2: *Funding Sources for Climate Adaptation Projects in Developing Countries.*

infrastructure could benefit from global adaptation financing mechanisms, as well as from the implementation of holistic adaptation measures.

Adaptation financing as a percentage of total climate financial needs has increased from approximately 8% in 2010 (US$ 587 million) to around 21% in 2011 (US$ 957 million)[6]. Some of the climate funds that could respond to the adaptation needs of developing countries are indicated in **Table 2**.

ICAO recognizes the importance of both mitigation and adaptation measures as effective means for the sustainability of aviation operations. The ICAO State Action Plans process provides a forum for States to indicate their mitigation projects and identify their assistance needs. ICAO is actively collaborating with multilateral development agencies and donor institutions to facilitate the provision of technical and financial assistance to Member States to address the impacts of international aviation on climate change. ICAO will continue to monitor, collect and disseminate information on the potential risks of climate change on aviation operations and infrastructure, as well as on adaptation measures and financing sources that could minimize these risks. ■

REFERENCES

1 See IPCC 2007 Summary for Policymakers. In Climate Change 2007: The Physical Science Basis.

2 Is a report released for the British government by economist Nicholas Stern, chair of the Grantham Research Institute on Climate Change and the Environment at the London School of Economics and also chair of the Centre for Climate Change Economics and Policy (CCCEP) at Leeds University and London School of Economics.

3 Ranking Port Cities with High Exposure and Vulnerability to Climate Extremes: Interim Analysis: Exposure Estimates", OECD 2007. The full report can be accessed from: www.oecd.org/env/workingpapers

4 World Bank Report – Economics of Adaptation to Climate Change – (www.worldbank.org/en/news/feature/2011/06/06/economics-adaptation-climate-change).

5 Investments and Financial Flows to Address Climate Change – unfccc.int/resource/docs/publications/financial_flows.pdf

6 www.odi.org.uk/resources/docs/7469.pdf

LEADING THE WAY TOWARD MITIGATING THE EFFECTS OF CLIMATE CHANGE

BY HERBERT PÜMPEL

HERBERT PÜMPEL

He is currently the Officer in Charge of the Meteorological Applications Branch, Weather and 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. Pümpel 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. Pümpel obtained his Ph.D. in Meteorology and Physics from the University of Innsbruck in 1978, undertaking his studies in the fields of theoretical physics and dynamical meteorology.

IDENTIFYING THE PROBLEM

For more than 15 years, the two UN scientific organizations, the World Meteorological Organization (WMO) and ICAO, have been cooperating to study and minimize the impact of aviation on climate change. These efforts have also been coordinated with the Intergovernmental Panel on Climate Change (IPCC), which had prepared a special report on aviation and climate change, and provides regular updates on aviation-related greenhouse gas (GHG) production and emissions.

At the same time, improved weather information, in terms of better forecasts of upper level winds and temperatures and the location and intensity of aviation weather hazards, has contributed significantly to a number of operational measures designed to reduce not only fuel burn and CO_2 emissions, but also to decrease noise levels in the approach areas of airports. Combined with technological measures, such improvements have helped to control the growth of emissions in terms of passenger kilometres flown and freight tonnes delivered to industry and consumers.

Nevertheless, despite all of these efforts, it is a fact that global civil aviation, while only contributing a small percentage of global GHG emissions (about 2%), is an essential factor in economic development and experiences steady growth rates, even during regional economic downturns.

RISK MITIGATION

Aviation is one of the pioneer industry sectors involved in developing mature safety risk management approaches and programmes. Safety risk management helps to mitigate any emerging challenges and risks that may affect the future development of the industry. Since 2007, WMO and the ICAO Environment Branch have cooperated in conducting early assessments concerning the emerging potential risks to the aviation industry caused by the increasingly visible effects of climate change and weather variability.

In summary, these risks fall into three broad categories:

1. Societal impacts affecting demand for aviation
2. Sustainability of infrastructure and energy supply
3. Operational risks and hazards

The following paragraphs provide some additional background and information on these risk factors in the context of the global aviation industry.

Societal Impacts of Climate Change

The general consensus in the latest reports emerging from the scientific community is that, although it may vary somewhat from region to region, climate change and variability will affect the developing world and poorer countries most, thus hampering their economic development.

Human health is profoundly affected by weather and climate. For this reason, WMO is collaborating closely with the World Health Organization (WHO) in order to improve predictions and develop mitigating measures to deal with outbreaks of weather and climate related illnesses and airborne diseases. Indeed, aviation was severely affected in past pandemic health crises such as the avian flu and SARS outbreaks. The interdisciplinary cooperation between WMO and WHO will certainly help aviation to better assess and mitigate such risks in the future when more such events are likely to occur in some world regions.

Risks To Sustainability of Energy Infrastructure and Supply

Infrastructure decisions and investments in aviation typically have a 30 to 60 year time horizon. Such decisions range from those about an optimized aircraft fleet, to the planning of airports and supporting infrastructure. Currently, the major issues with respect to fleet decisions are fuel burn and emissions concerns. The support infrastructure decisions usually involve public/road transport systems that serve the airports. Finally, there is the question as to how the availability and cost of alternative fuels will reflect on the sustainability of aviation growth potential.

Recent scientific work seems to indicate an increased frequency of en route turbulence events on some aircraft routes. If this is found to be substantiated by empirical data, it may have an influence on route selection. It could even affect aircraft design. For example, design configurations optimized for minimum fuel consumption may not be the ideal ones for maintaining stability and comfort in frequent turbulent situations.

Scarcity of large areas of level ground near population centres is a main concern for the development of new airports. In many cases, this pressure has led to the location of new hub airports close to the seashore on artificially created islands, or in semi-protected floodplains. With climate change, such installations are likely to become vulnerable to sea level rise, storm surges, and tropical cyclones.

Researchers and organizations studying the complex issues related to the sufficient availability of alternative fuels as a measure to limit GHG net increases by aviation will be able to benefit from the collaboration between WMO and the Food and Agricultural Organization. Among other things, climate outlooks will help to determine the likely availability of biomass-based energy sources that depend on climate-related agricultural yields.

Operational Risks and Hazards

These risk factors are largely directly related to airline operations as follows:

- Impacts on the efficiency and reliability of flights. Knowing that 70% of all traffic delays in the U.S. are attributed to weather, the U.S. Federal Aviation Administration (FAA) has determined that two thirds of these could be prevented with better weather information. Increased confidence in weather information can lead to more accurate flight planning operations and, as a result, improved service levels to customers.

Improved, timely warnings of severe weather phenomena such as thunderstorms, windstorms, and rainstorms are needed to reduce incidence of damage to aircraft and injury to customers and/or employees.

- The ICAO Global Air Navigation Plan foresees several steps of Aviation System Block Upgrades (ASBUs), moving towards a performance-based air navigation system (see article *Minimizing the Adverse Environmental Effects of Civil Aviation Activities through the ICAO Block Upgrades*, in Chapter 4 in this report). Precise knowledge of current and forecast weather conditions is paramount for ensuring smooth and efficient traffic flow control and management.
- All indications are that in the future there will be increased frequency, amplitude, duration and severity of high-impact weather events due to climate change and increased variability. Accordingly, the need for improved and more timely weather information is becoming even stronger.
- Many parameters used in flight planning depend on weather and climate; ranging from the temperature-dependence of the maximum take-off weight, climb performance (*i.e.* important for obstacle clearance), to maximum cross winds and tail winds. All of these variables are expected to be subject to significant changes with a more volatile climate.

UNDERSTANDING AND ASSESSING THE RISKS

In order to understand and quantitatively predict the current and future states of the Atmosphere-Ocean-Biosphere System, the WMO is establishing a globally integrated observing system for atmospheric and oceanic parameters called the WMO Integrated Global Observing System (WIGOS), which is closely linked to the co-sponsored Global Climate Observing System (GCOS). Biosphere data and other geo-referenced datasets are obtained in close cooperation the Group on Earth Observations (GEO).

While data for the earth's surface is collected mainly by national and regional observing networks, many essential processes of the atmosphere can only be understood, modelled and predicted based on vertical profile information collected from the surface to very high levels of the atmosphere.

Such profile data can be obtained globally by using both polar orbiting meteorological satellites and so-called geostationary satellites. The first type of satellite orbits typically between 300 and 800 km above the surface, and crosses over a specific point of the earth always at the same time of the day. The geostationary satellites are placed on a geo-synchronous orbit about 36,000 km above the earth. These are able to provide regular scans over a 24 hour period.

While this data is very valuable and forms the "backbone" of daily forecast operations, the data does not provide very detailed vertical profiles of winds, temperature, and humidity. Such detailed profiles are necessary to grasp the vertical structure and stability of the atmosphere, which is a determining factor in the formation of clouds, thunderstorms, and low-level temperature inversions, for example.

So, for this type of information, so-called "radio sondes" are released at specific sites and carried to the stratosphere by hydrogen-filled balloons, where they take measurements at very close intervals and transmit them to a ground station by short wave communication.

Such data is very precise and valuable, but its cost can be prohibitive for many developing countries, leading to large data gaps (both spatially and temporally) over most of the developing world, and over the oceans.

In seeking solutions for this serious problem, it was discovered that commercial aircraft are taking most of the required measurements anyway, as part of their normal operations, and additional sensors for humidity could easily be added to the range of currently available sensors. Establishing such a data link between aircraft operations centres and meteorological services, has proven to be an excellent way to make this data available to the meteorological community.

Thus, WMO in cooperation with aviation partners, created the Aircraft Meteorological Data Relay (AMDAR) Programme about 20 years ago. This eventually led to the development of the AMDAR observing system. The AMDAR observing system is a sub-system of the WIGOS and the Global Observing System, which are defined and maintained under the WMO World Weather Watch Programme.

USING AVIATION-GENERATED WEATHER DATA TO IMPROVE WEATHER AND CLIMATE ANALYSES

The AMDAR system predominantly utilizes existing aircraft on-board sensors, computers, and communications systems, to collect, process, format, and transmit meteorological data to ground stations via satellite or radio links. The data is collected and processed in accordance with WMO requirements and standards. Once on the ground, the data is relayed to National Meteorological and Hydrological Services, where it is processed, verified for quality control, and transmitted on the WMO Global Telecommunications System (GTS).

AMDAR Status

More than 3,000 aircraft from 38 airlines worldwide participate in the WMO global AMDAR programme, producing over 300,000 high-quality observations per day. These observations include air temperature, wind speed, and wind direction; together with the required positional and temporal information. An increasing number of humidity and turbulence measurements are also being made.

Benefits and Impacts

The data collected using AMDAR is used for a range of meteorological applications, including, public weather forecasting, climate monitoring and prediction, early warning systems for weather hazards and, importantly, weather monitoring and prediction in support of the aviation industry.

The introduction of AMDAR has proven beneficial in two particular ways.

AMDAR data has proven useful to several levels of meteorology, from operational forecasts and numerical weather prediction (NWP), to climate and atmospheric constituents monitoring and modelling. All of these activities combined, contribute to the provision of a number of very important weather services including public weather service; severe weather predictions, and warnings; all based on near real-time weather updates.

The data obtained through AMDAR is also useful for local weather forecasts which provide information about surface winds and temperatures. This data can also be used to detect and quantify the strength of an inversion. Also, the improved prediction of cloud development and forecasts of warm and cold fronts are direct, short-term benefits that result from the availability of AMDAR information. Data relating to such phenomena as vertical stability, deep convection, water vapour content, and upper-wind observations, can be used to predict the strength and movement of weather fronts and tropical cyclones; although it isn't quite as useful for detecting and predicting some local weather phenomena such as low-level wind shear, turbulence, and thunderstorms. On the other hand, AMDAR data is very useful for detecting weather conditions conducive to drought and wild fires, such as high temperatures, low humidity, and strong winds.

Benefits to Aviation

AMDAR data has also proven to be beneficial to the aviation industry. Much like the benefits that permeate through several levels of meteorological studies, the benefits to the aviation industry are numerous. Cumulatively they can aid in improved operations throughout the entire aviation spectrum. Below are some of the main benefits that accrue to the aviation industry through its participation in AMDAR:

- Ultimately, better planning leads to better efficiency. With the availability of AMDAR data, airlines can plan more accurately which can result in significant cost savings.
- The aviation industry also benefits from improvements to Air Traffic Control (ATC) management of airport facilities and operations associated with departure and arrival management, avoidance of holdings and re-routings (accurate wind information needed), runway management and changes to conditions affecting runway management (wind, fog conditions, etc), and other aspects affected by weather-related phenomena.
- Many of the high-impact weather events expected to become more frequent in the future are of a smaller scale, and the high resolution of AMDAR data will be instrumental for better predictions of these high-impact events.
- The improved quality of meteorological information for aviation forecasting provides support for ATC en route operations in such a way that more detailed and more accurate guidance can be provided to aircraft. Activities like flight pattern management (*i.e.* horizontal and vertical separation), online flight plan updating, and altitude change procedures (*i.e.* turbulence, icing avoidance) all benefit from the use of AMDAR information.

Going Forward

While the benefits and impact of AMDAR as a global upper air observing system have been demonstrated to be significant and profoundly positive for both meteorological and aviation applications, it is very evident that this system has reached only a fraction of its coverage and full potential.

WMO recently completed a study and produced a report titled "*AMDAR Coverage & Targeting for Future Airline Recruitment*"[1], which, among other things, found that "There are over 1,300 airlines worldwide that fly to 1,700 destinations, carrying 5.1 Billion passengers and carrying 200 Billion Revenue Tonne-Kilometers (RTKs)". Also, "a little over 500 of these airlines represent the significant scheduled carriers on the planet that have significant route structure…".

The study undertook an analysis of the current AMDAR programme coverage and identified seven data-sparse areas of the globe. **Figure 1** shows the improved coverage possible by utilizing those airlines and aircraft operating within the data-sparse areas that are best suited to AMDAR programme participation. The study identified 128 airlines consisting of 2,514 aircraft that have the potential to dramatically improve global upper air coverage at a fraction of the cost of the satellite or radio sonde development that would be necessary to derive a similar improvement in upper-air monitoring capability.

WMO and its members want to work together with ICAO towards realizing this very achievable and beneficial AMDAR programme expansion in partnership with the aviation industry. This activity would help to demonstrate that, while aviation is an emitter of GHG, it also has the potential to become a large part of the solution for mitigation by providing more of this unique and valuable data for use in climate and weather monitoring. ■

REFERENCE

1 www.wmo.int/pages/prog/www/GOS/ABO/AMDAR/resources/AMDAR_Coverage_Recruitment_Study.html

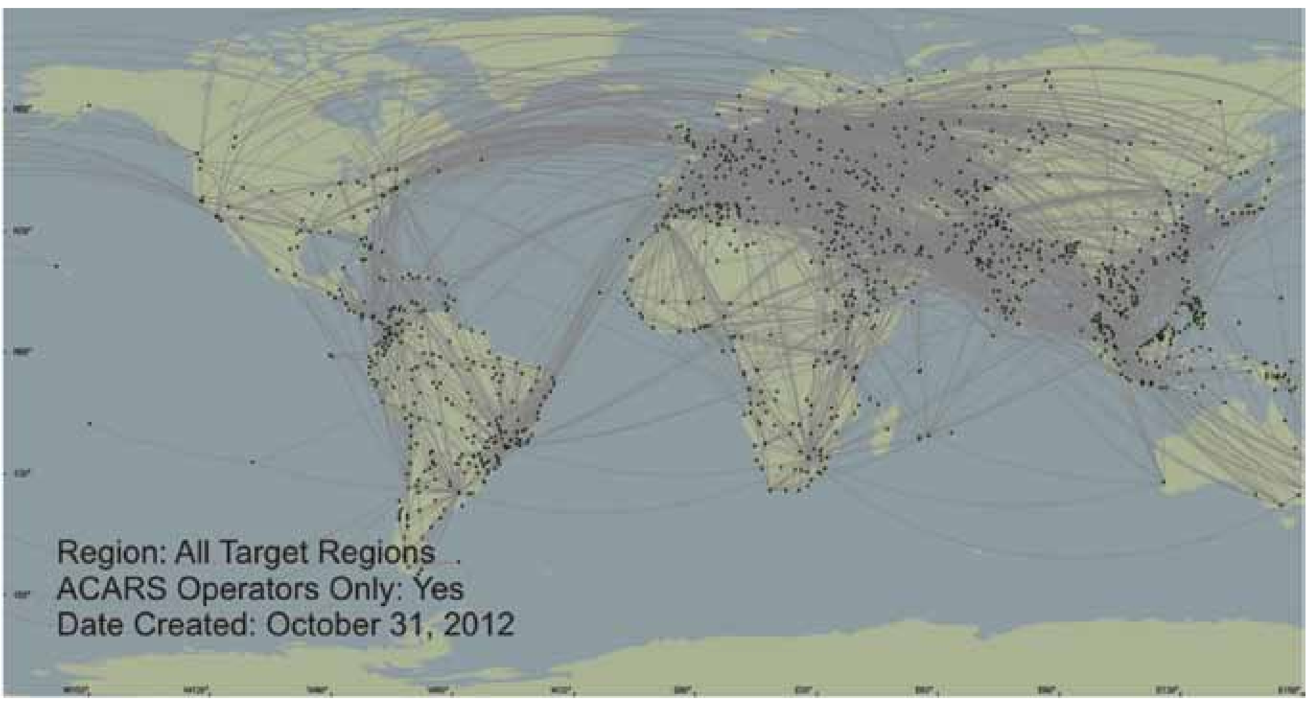


Figure 1: *Routes Coverage of Airlines Capable of Improving Coverage Over Data-sparse Target Areas.*

ADAPTING TO CLIMATE CHANGE – THE TIME TO ACT IS NOW

BY RACHEL BURBIDGE

This article is based on work carried out for the EUROCONTROL "Challenges of Growth 2013" report. Challenges of Growth is a series of studies intended to provide decision-makers with the best-achievable set of information to support long-term planning decisions for aviation in Europe, with a particular focus on the capacity of the air transport network. Studies were completed in 2001, 2004, 2008 and 2013. They are available at: www.eurocontrol.int/articles/challenges-growth BOX 1

RACHEL BURBIDGE

She joined EUROCONTROL in 2005. She has been leading Eurocontrol's work on climate change adaptation since 2009. She also currently works on aviation market-based measures policy and contributes to the SESAR Single European Sky ATM Research Programme, where she leads the environmental risk and regulation work. She has a degree in Environmental Studies and a Masters degree in Sustainable Development.

The climate is changing. Many parts of the world are already experiencing increasing temperatures, altered precipitation patterns, and more frequent and intense extreme weather events. Scientific evidence suggests that without significant reductions in global carbon dioxide (CO_2) emissions such changes will become more severe. All sectors of global society will be affected, including the aviation industry.

POTENTIAL CLIMATE IMPACTS ON AVIATION IN EUROPE

Impacts of climate change on aviation in Europe will vary depending on current regional climate, geographical location, and scale of operation. These impacts will affect infrastructure, operations and operating costs (see **Figure 1**). Changes to temperature, precipitation and storm patterns are expected in the near-term, and certainly by 2030. The impacts of sea level rise will be more gradual and are not expected to be a factor until later in the century. However, more frequent and intense storm surges will have earlier impacts, reducing capacity and increasing delays in the shorter term (see **Table 1**). Some impacts, such as changes to aircraft performance due to increased temperatures, or changes in procedures due to shifts in local wind direction, may incur additional environmental risks due to the redistribution of noise impact around airports, possibly constraining their ability to grow.

Heavy precipitation events and more powerful and frequent storms can lead to temporary loss of capacity and increased delays, especially if multiple hub airports in a region are affected. Heavy snow in unexpected locations can have a particularly large effect on airport operations due to the relative lack of preparedness. Moreover, the impact of disruptive weather can be exacerbated when airports are operating close to capacity. Consequently, busier airports may experience more significant disruption. As well as shifts in average climatic conditions, extreme conditions, such as very hot or very cold temperatures, can be expected to become more frequent and last longer, increasing operational challenges.

Changes in air traffic demand patterns may be triggered by climate-related changes, both in terms of tourist destination preferences and global supply chains. Although such issues will seldom be isolated from other factors affecting demand, it is important to understand the potential impacts of climate change, particularly when investing in long-term infrastructure projects. Moreover, despite the current global economic crisis, overall aviation demand is expected to continue to grow in the coming years, putting increased pressure on operations in both emerging and established markets. The impacts of disruptive events such as convective weather or heavy precipitation can be exacerbated when capacity at an airport is constrained. Therefore, it is essential to identify locations which may experience both high growth in demand and significant impacts from climate change.

BUILDING CLIMATE RESILIENCE

Despite geographical variations in impacts, there is now broad agreement as to the challenges which will be faced due to climate change. This knowledge should be used as the basis to take action to identify adaptation measures which will help develop resilience to those impacts. Risk assessment and resilience planning are required at both network and local levels.

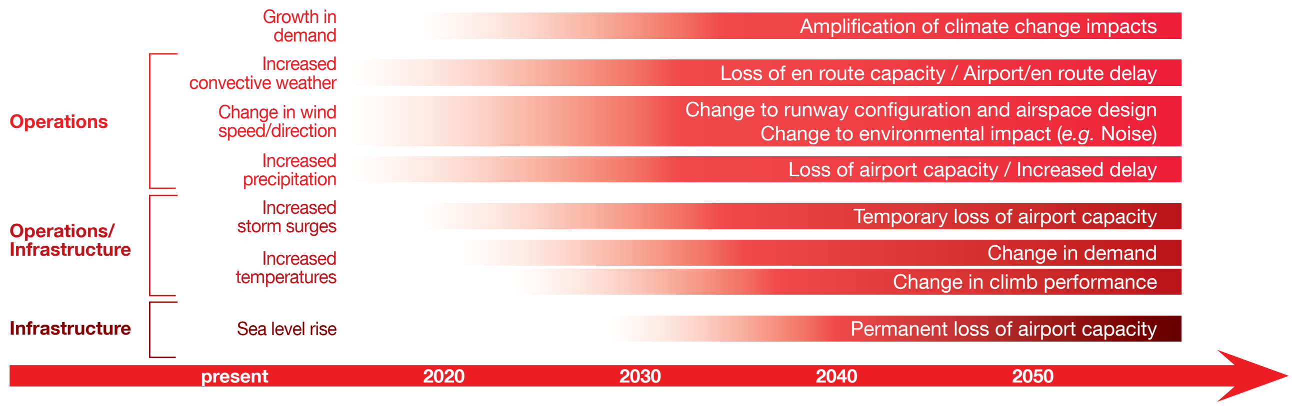
While this will undoubtedly entail further research, particularly to better understand the potential impacts on capacity and demand, it is also necessary to progress with implementation, particularly since early action can be cost-effective. In particular, "no-regrets" or "win-win' measures can contribute to reducing the costs of building long-term climate resilience. For example, measures which are intended to build greater weather resilience and facilitate operations in adverse conditions, and address issues such as capacity, or improve infrastructure, can be cost and resource efficient solutions. Moreover, some of the least expensive and potentially most effective ways to build resilience are: staff training, sharing of

ACTIONS TO BUILD AVIATION'S CLIMATE RESILIENCE

- Assessment of gaps and vulnerabilities for the sector at local, regional and global levels;
- Identification and implementation of local, regional and global resilience measures, particularly no-regrets measures such as operational improvements;
- Identification and implementation of cost-effective measures such as training;
- Increased collaboration with MET Services to better exploit advanced forecasting techniques;
- Analysis of the potential impacts of climate change on air traffic demand to inform medium and long-term operational and business planning.

Impact				
Temperature increase	**Changes to precipitation (rain and snow)**	**Increase in intensity and frequency of convective weather**	**Changes in Wind patterns**	**Sea level rise**
Potential impact for aviation				
Changes in demand. Changes in climb performance. Redistribution of noise impact. Heat damage to tarmac surfaces.	Operational impacts: loss of capacity and efficiency. Increased delay. Increased de-icing requirements. Increased pressure on drainage systems. Structural issues due to changes in ground frost depth and duration.	Operational impacts: loss of capacity and efficiency. Increased delay.	Increased crosswinds and loss of runway capacity. Redistribution of noise impact due to procedural changes.	Loss of network capacity, increased delays, network disruption. Temporary or permanent airport closure.
Type of impact				
Persistent	Intermittent	Intermittent	Intermittent	Persistent
Approximate timescales				
> 20 years before impacts become serious	< 20 years but potentially much sooner	< 20 years but potentially much sooner	< 20 years but potentially much sooner	> 40 years before impacts become serious
Potential resilience measures required				
Research to understand potential demand shifts. Review of infrastructure and personnel requirements (+/-). Airspace redesign. Community engagement.	Operational improvements to increase robustness and flexibility. Improved use of MET forecasting. Information sharing (SWIM). Training. A-CDM.	Operational improvements to increase robustness and flexibility. Onboard technology for weather detection. Improved use of MET forecasting. Information sharing (SWIM). Training. A-CDM.	Local risk assessments. Operational improvements to increase robustness and flexibility.	Operational improvements to increase robustness and flexibility. Sea defences. Development of secondary airports.
EUROCONTROL, Challenges of Growth 2013. ***Timescales are based on analysis for Europe and may vary for other regions***				

Table 1: *Overview of Key Climate Change Impacts and Resilience Measures Identified.*



Note: This is a broad indication which does not account for regional differences nor future emissions trajectories/climate sensitivity. Timescales are based on analysis for Europe and may vary for other regions. **Sources:** IPCC 2007b; Thomas *et al.* 2008; Thomas and Drew *(eds.)* 2010; SESAR 2012. **Analysis:** EUROCONTROL, Challenges of Growth, 2013.

***Figure 1:** AEM Fuel Burn and Emissions Calculation.*

best practices, experiences and solutions, and the implementation of processes which facilitate collaborative responses to climate change challenges. Therefore, although the potential impacts of climate change are numerous and will vary according to climate zone, many solutions are either already being implemented, or at least have been identified. Nevertheless, there are financial implications to this preparedness; cost-benefit analyses will be required to determine what level of impact it is feasible to cope with.

Some stakeholders are already taking comprehensive action. For example, the US Federal Aviation Administration (FAA) has developed a programme to build infrastructural and operational climate resilience. On the other side of the Atlantic, EUROCONTROL has been working in partnership with air navigation service providers, airports, and airlines to improve the operational management of adverse weather conditions, both en route and at airports. This has involved measures such as the implementation of procedures to facilitate planning, coordination, and communication during disruptive events, as well as ways to proactively manage demand.

Yet, a recent consultation carried out by EUROCONTROL as part of the "2013 Challenges of Growth" work (see **Box 1**) suggests that, while a growing number of European airport operators and air navigation service providers are now developing climate adaptation plans and implementing resilience measures, many organizations have either yet to consider this issue, or do not have the knowledge and resources to act. This suggests that more data, information and guidance are required, and that climate adaptation needs to be addressed collaboratively as an industry.

Indeed, due to the interconnectedness of the regional and global aviation systems, an integrated approach to building resilience is essential to ensure that vulnerabilities in one part of the network don't exacerbate impacts in other parts. In fact, during the peak of Hurricane Sandy's onslaught in 2012, it is estimated that 8% to 9% of global airline capacity was grounded, resulting in lost revenues conservatively estimated at around US$0.5 billion[1]. An increase in such events will have a significant operational and financial impact. Therefore, even if one part of the global integrated transport system is fully protected against such risks, the overall network is still vulnerable if another vital part does not take the necessary action. This suggests that a holistic approach which integrates local and regional impact assessments and resilience planning may be required. Resilience measures should also be coordinated with other parts of the transport network, including ground transport access to airports, so as to reduce overall vulnerability to the maximum extent possible.

SUMMARY

The potential impacts of climate change on the aviation industry will vary according to location and scale of operation, and may be further exacerbated by the challenge of accommodating increased growth in demand. However, at a high level, many of the solutions have already been identified. Cost-effective climate adaptation relies on building resilience into current infrastructure and operations planning, and by identifying low cost and no-regrets measures such as training.

As aviation is a global industry, vulnerabilities in one part of the network can translate into costs and operational impacts in other parts. Therefore, we need to communicate and collaborate at all levels in order to implement resilience measures as efficiently and effectively as possible. Overall, climate change is a risk management issue. Early action is the key to cost-effective adaptation. Therefore, the time to act is now. ■

REFERENCE

1 IATA (2012), Hurricane Sandy added to Industry Challenges in October, IATA Press Release No. 48, 29 November 2012 [online] www.iata.org/pressroom/pr/pages/2012-11-29-01.aspx (Accessed 25/01/2013).

CASE STUDY: CLIMATE CHANGE ADAPTATION PLAN AT HEATHROW

BY XAVIER OH

XAVIER OH

He is the Senior Manager Environmental Protection at Airports Council International (ACI). He has been with ACI since September 2005 and is based in the ACI Headquarters in Montreal. As an industry association, ACI is an official Observer at ICAO's Committee on Aviation Environment Protection (CAEP), represented by Mr. Oh. 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.

Changes to the global climate are becoming increasingly observable, and airports need to start preparing themselves for the consequences. In May 2011, London Heathrow Airport (LHR) published a report[1] on its climate change adaptation plan. The report provides a case study of one airport's adaptation plan, which can be used as an example for other airports.

The LHR approach was based on a risk management approach similar to that used for safety issues. Hazards are identified and rated on both their likelihood and the potential severity of the outcome. These are combined to provide a level of risk priority. Risk mitigation measures already in place are assessed, along with the uncertainty or confidence associated with the projections. Finally, the process defines what adaptation responses need to be acted upon.

In three sections, this article examines the risk management process used at LHR, provides some specific illustrations of how this was implemented, and gives an overview of the outcome.

LHR CLIMATE RISK MANAGEMENT IN SEVEN STEPS

The following paragraphs provide a step-by-step summary of exactly what was involved in the London Heathrow Airport risk management project:

1. **Identify Climate Hazards and Potential Consequences**
   Analysis at LHR identified 34 climate hazards in the following categories: temperature (11), precipitation (7), storms (5), winter conditions (4), off-site impacts (4), sea level rise (2) and fog (1). The main sources of data included UK government climate research, an existing risk register, and airport development plans.

2. **Evaluate the Likelihood of the Consequence (Short Term and Medium/Long Term)**
   For each of the 34 hazards, "Likelihood" was evaluated on a scale of 1 to 5: (1) Improbable, (2) Unlikely, (3) Less than Likely, (4) More than Likely, and (5) Probable. Different ratings were made for the short term (ST – 2020) and the medium/long terms (M/LT – 2020 to 2050). Analysis of evidence and processing of data involved climate change modelling, the LHR risk management process, and expert judgement.

3. **Evaluate the Severity of the Consequence (ST and M/LT)**
   Severity of each "Consequence" was rated for the ST and M/LT also on a scale of 1 to 5: (1) Minor, (2) Moderate, (3) Significant, (4) Substantial and (5) Grave.

4. **Establish the Risk Priority (ST and M/LT)**
   A Risk Assessment Matrix (**Figure 1**) was used to combine the Likelihood and Severity, and thus rate each Consequence as either Green, Amber or Red, for Low, Moderate and Significant Risk, respectively.

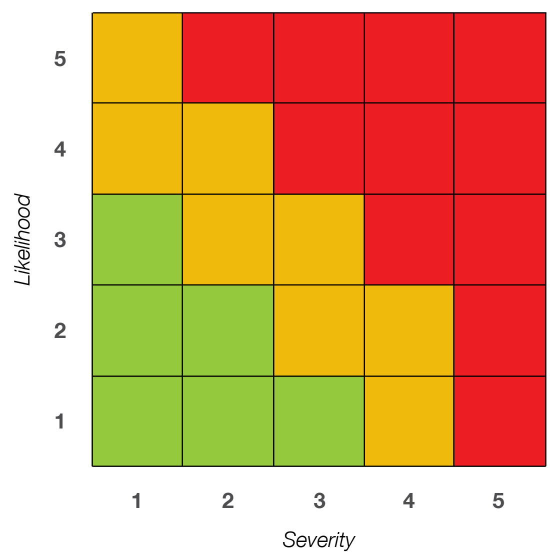


Figure 1: *Risk Assessment Matrix.*

5. **Establish Control Rating of Current Risk Control Measures**
   For most climate hazards at LHR some mitigation measures are already in place. Examples include storm-

water management systems and winter operations procedures. An assessment was made of the suitability of the existing control measures for managing and mitigating each hazard or consequence in each of the time frames. LHR rated the adequacy of its existing control measures using a scale of 1 to 4: (1) Excessive, (2) Optimal, (3) Adequate, and (4) Inadequate.

6. **Consider Uncertainty or Confidence of Projections**
   This step involved grading the overall uncertainty of the projections and the level of confidence in the conclusions. Uncertainty was graded as Low, Moderate or Significant based on: climate change research, regional and company development plans, and expert judgement.

7. **Define Required Adaptation Response**
   Finally, for each item for each period, a response was identified. "Action" meant that specific actions were required in the short term, or that the issue needed to be included in long term planning. "Prepare" meant that additional research was needed before action and "Watching Brief" meant that risks were longer term and there was a need to monitor the science and effects of climate change.

TWO EXAMPLES OF RISK ITEMS ANALYSED

The first example, of the 34 items identified at LHR, was the "increased risk of schedule interruption due to stormy conditions". In the short term, this was assessed with a Likelihood of 3 (Less than likely) and a Severity of 1 (Minor), which when combined give a Low (green) Risk. In the medium/long term, Likelihood increased to 4 (More than Likely), so the risk increased to Moderate (amber). The existing air traffic control (ATC) procedures such as separation distances and contingency plans for disruption, were assessed to be Optimal. Although there was High Uncertainty in the storm projections, the final conclusion was that for this item the airport should maintain a Watching Brief and no immediate action is required.

Storms interruption to schedule	**ST Low Risk**	**M/LT Moderate Risk**	**Existing Measures – Optimal**	**Action Status – Watching Brief**

The second illustrative example is "the risk of localized flooding in the case of heavy rainfall events". In the short term, this was assessed with a Likelihood of 2 (Unlikely) and a Severity of 2 (Moderate), which combined to give a Low (green) Risk. In the medium/long term, Likelihood increased to 3 (Less than Likely), so the risk increased to Moderate (amber). The existing storm-water control infrastructure was assessed to be Adequate. With a Moderate Uncertainty in the rainfall projections, the conclusion was that an Action was attached to this item: the engineering department should conduct sensitivity tests of the airport drainage infrastructure to ensure that it is as robust as practicable, and to investigate and address risks of flooding to existing critical assets.

Localized flooding	**ST Low Risk**	**M/LT Moderate Risk**	**Existing Measures Adequate**	**Action item**

OVERALL OUTCOMES OF THE LHR PLAN

Of the 34 climate hazards identified in the LHR study, 29 were categorized as Low Risk and five as Moderate Risk in the short term. In the medium/long term to the year 2050, 24 items were Moderate Risk and two were Significant Risk. Clearly the risks will increase over the decades as climate change is expected to progress. The two M/LT Significant Risk items were the overload of the pollution control system during hot weather, and a fire hazard when ambient temperatures exceed the 38°C fuel flash point.

The resulting actions in the Adaptation Plan included a majority (20 of 34 items) with a "Watching Brief". Eight (8) items were labelled "Prepare" which specifies further research before actions. The remaining six items called for "Action": tasks include reviewing building design standards for flooding, reviewing the pollution control system for hot weather operations, and continuing to implement the recommendations of the Heathrow Winter Resilience Enquiry.

OBSERVATIONS

This study at Heathrow (and those at eight other UK airports) demonstrated that airports can start developing risk management adaptation plans and can produce a set of concrete actions. The work is reliant on climate modelling and the forecasting of what can be expected in terms of temperature, rainfall, storms, wind, winter conditions, and other weather patterns. For LHR the information came mainly from UK government sources. Other input and processes were mostly based on risk management processes that are well established at the airport, and the use of best available and/or expert judgement.

In summary, an Airport Climate Change Adaptation Plan, with its "issues to watch" and "items requiring action", provides a basis for the airport operator to understand the expected impacts of climate change on the infrastructure and operation of the airport, and to be prepared for the most critical eventualities. ■

REFERENCE

1 http://archive.defra.gov.uk/environment/climate/documents/adapt-reports/08aviation/heathrow-airport.pdf (Accessed 20/5/2013).

CHAPTER 8

PARTNERSHIPS AND COOPERATION WITH OTHER ORGANIZATIONS

OVERVIEW

ICAO'S COOPERATION WITH OTHER UN BODIES AND INTERNATIONAL ORGANIZATIONS

BY ICAO SECRETARIAT

INTRODUCTION

As part of the broader United Nations family, ICAO maintains a close relationship with other UN bodies and international organizations (see **Figures 1** and **2**). The main purpose of maintaining this cooperation is to obtain a better technical, scientific and socio-economic understanding of aviation's impact on the environment, to exchange views and information, build synergies for policy-making, and to facilitate the implementation of measures to limit or reduce aviation's adverse impacts on the environment, with a view to ensuring the sustainability of its operations.

ICAO maintains a close relationship with the United Nations Framework Convention on Climate Change (UNFCCC), by closely following the development of the discussions within this forum, and by regularly providing information and perspectives on issues related to international aviation and on those matters considered by the various UNFCCC deliberative bodies that may have an impact on the aviation sector (see article *Negotiations on a Future Global Climate Change Agreement*, Chapter 8 in this report).

In addition, ICAO has also continued to cooperate with other organizations, such as: the Intergovernmental Panel on Climate Change (IPCC), the World Meteorological Organization (WMO), the United Nations Conference on Sustainable Development (UNCSD), the International Maritime Organization (IMO), the United Nations Development Programme (UNDP), the Global Environment Facility (GEF) and the World Tourism Organization (UNWTO).

As part of the UN system, ICAO, along with other UN agencies, funds, and programmes, is a member of the UN Environment Management Group (EMG), which was established to coordinate environmental issues throughout the UN system. ICAO has been actively involved in the EMG work on the UN climate neutral initiative, and the ICAO Carbon Emissions Calculator was officially approved by the EMG to calculate CO_2 emissions from air travel (see article *ICAO Contribution to Environmental Sustainability in the United Nations System*, Chapter 8 in this report).

ICAO also cooperates with the UN High-level Committee on Programmes (HLCP) Working Group on Climate Change in order to promote programmatic coherence through information and knowledge sharing, and to foster concrete initiatives aimed at assisting Member States in implementing the climate change agenda and streamlining climate-related issues into individual programmes of United Nations system organizations.

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC)

ICAO's collaboration with the IPCC resulted in the IPCC *Special Report on Aviation and the Global Atmosphere* in 1999, the first sectoral report from IPCC providing consolidated scientific information on aviation's climate impact, briefing policymakers on the challenges ahead and highlighting key mitigation options.

ICAO also provided substantial input and actively supported the IPCC in the development of the *Guidelines for National Greenhouse Gas (GHG) Inventories*[1] by providing the necessary expertise for the development and refinement of a methodology for the calculation of aviation emissions.

ICAO has also collaborated with the IPCC on the assessment reports on climate change, in particular the Fourth Assessment Report (AR4) and on the preparation of the Fifth Assessment Report (AR5), which is scheduled to be completed in 2014. ICAO cooperates with the IPCC to ensure that issues related to aviation and climate change are covered in the AR5. ICAO particularly requested that the AR5 further explore the effects of non-CO_2 aviation emissions, update the trends of aviation GHG emissions and include the latest ICAO work on mitigation measures.

WORLD METEOROLOGICAL ORGANIZATION (WMO)

WMO and ICAO cooperate closely through the ongoing review of the requirements of meteorological services for aviation, in the adoption of procedures for the provision of these services, and in keeping them up to date. In addition, ICAO has been working with WMO to establish a global programme enabling commercial aircraft to take meteorological measurements. This collaboration is a vital part of the global atmospheric observing system, with approximately 250,000 observations per day being made available to scientists, researchers and weather forecasters. These observations provide invaluable data that contributes

UN Framework Convention on Climate Change **(UNFCCC)**	• Implementation of the Convention and Kyoto Protocol (Art 2.2) • Post-2012 Negotiation on Climate Change • Coordinate Activities and Inputs to SBI, SBSTA, ADP • Aviation Emissions Data and Methodological Issues • Flexible Mechanisms – Aviation Projects for CDM

Intergovernmental Panel on Climate Change **(IPCC)**	• Special Report on Aviation and the Global Atmosphere – 1999
	• IPCC 4th and 5th Assessment Reports
	• Coordination on Methodologies
	  • IPCC Guidelines for National Greenhouse Gas Inventories
	  • IPCC Emissions Factors Database
	• IPCC Emissions Scenarios – Aviation Scenarios Inputs

UN Environment 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)**	• Participation on High Level Meetings • Statements on Climate Change Mitigation
UN Industrial Development Organization **(UNIDO)**	• Participation on High Level Meetings • Cooperation on Climate Change
UN Commission on Sustainable Development **(UN CSD)**	• Agenda 21 and Further Developments • Rio+12 • MDG • SDG
UN World Health Organization **(WHO)**	Coordination on Noise and Health Legislation/Research Regarding Aviation
International Maritime Organization **(IMO)**	Cooperation on climate change regarding sectoral approaches (bunkers)
UN World Tourism Organization **(UNWTO)**	Aviation Environmental Policies and Tourism
High level Commitee on Programmes **(HLCP)**	• UN System Coordination • Climate Change • UNFCCC COP/CMP
Food and Agriculture Organization **(FAO)**	Agricultural aspects of Sustainable Alternative Fuels
UN Economic Commission for Europe **(UNECE)**	Conference on Transport and Environment
UNECE Convention on Long-Range Transboundary Pollution **(CLRTAP)**	Protocols on Substances – NO_x, Volatile Organic Compounds (VOCs)
Ozone Secretariat **(Montreal Protocol)**	• Updates/guidance Regarding Montreal Protocol for the Depletion of Ozone • Scientific Assessment Panel • ANB in Charge of Use of Halons for Aircraft Fire-fighting
International Standards Organization **(ISO)**	• TC20 – Aircraft and Space Vehicles • TC70 – Internal Combustion Engines* • TC146 – Air Quality • TC207 – Environmental Management* *Indirectly
Society of Automotive Engineers **(SAE International)**	• Aircraft Exhaust Emissions measurement (E-31) • Aircraft Noise Measure & Noise Aviation Emission Modeling (E-21) • Ac-9 Aircraft Environmental Systems Commitee
International Electrotechnical Commission **(IEC)**	• Noise Measurement Instruments (Electroacoustic, Instrument Specifications, Performance Requirements) • IEC Publication Nos 179, 225, 651 and 804 • IEC 60942; 61094 (Parts 3 and 4); 61260/61672-1
International Chamber of Commerce – Commission on Transport and Logistics **(ICC CST)**	Cooperation on Air Transport and Environment
World Economic Forum **(WEF)**	Cooperation on Climate Change Projects
International Energy Agency **(IEA)**	Data Sharing on Related Issues (Fuel, CO_2)
International Renewable Energy Agency **(IRENA)**	• Renewable Energies • Aviation Biofuels

***Figure 1:** ICAO's Cooperation with UN Bodies and International Organizations on Aviation and Environment.*

to a better understanding of weather, volcanic ash dispersion and global climate (see article *Cooperation Between WMO and ICAO: Leading the Way Toward Mitigating the Effects of Climate Change*, Chapter 7 in this report).

UNITED NATIONS CONFERENCE ON SUSTAINABLE DEVELOPMENT (UNCSD)

The UNCSD (also known as the Rio+20 Conference) was held in June 2012 in Rio de Janeiro, Brazil, marking the 20th anniversary of the 1992 United Nations Conference on Environment and Development (UNCED), in Rio de Janeiro, Brazil and the 10th anniversary of the 2002 World Summit on Sustainable Development (WSSD) in Johannesburg, South Africa. Rio+20 was the biggest UN conference ever held, with approximately 44,000 badges issued for the official meetings and a broad participation of leaders from governments, business and civil society, as well as UN officials, academics, journalists and the general public. Representatives from 191 UN Member States and observers, including 79 Heads of State or Government, addressed the general debate.

Among the themes of the Conference, the most relevant theme for ICAO was renewable energy, and in particular, sustainable alternative fuels for aviation. During the Rio+20

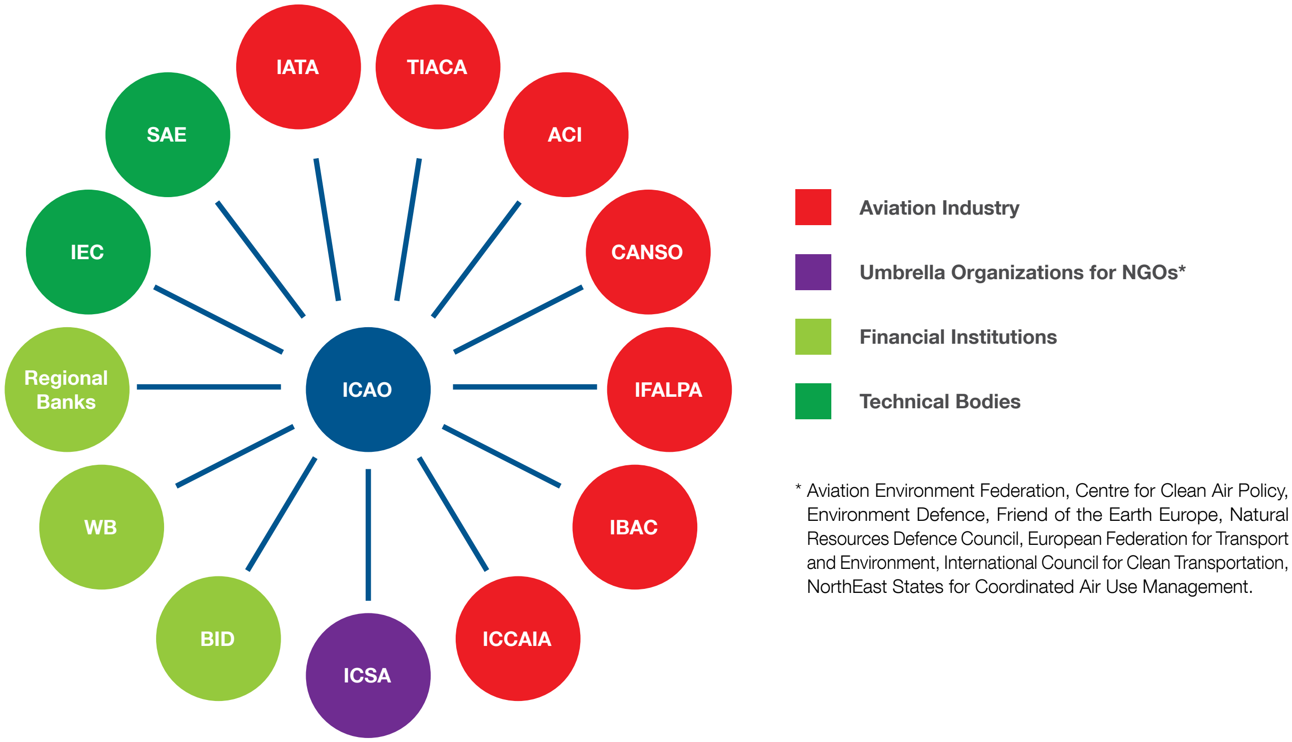


Figure 2: *Cooperation with Other International Organizations.*

Conference, ICAO organized, in close cooperation with industry partners, a series of four connecting commercial flights from Montréal, Canada to Rio de Janeiro, Brazil, which were all powered by sustainable alternative fuels (see article *Flightpath to a Sustainable Future*, Chapter 8 in this report). The initiative was extremely successful and, one year later, the Rio+20 "Flightpath to a Sustainable Future" initiative partners came together at the Le Bourget Paris Air show to celebrate the first anniversary of this event.

Following the outcome of the Rio+20 Conference[2], the UN Secretary General issued an implementation framework which maps the updates of all the major initiatives and actions related to the outcome of the Rio+20 Conference in various areas, such as energy and sustainable transport. ICAO is engaged in this process and will continue to work with the UN Secretariat on new initiatives and partnerships that will be launched in response to the Rio+20 outcome and follow-up process.

INTERNATIONAL MARITIME ORGANIZATION (IMO)

IMO is the UN specialized agency responsible for the prevention of marine pollution from international shipping. ICAO and IMO cooperate and share best practices in developing climate policies, including GHG mitigation measures and actions, in connection with the ongoing UNFCCC negotiation process.

In 2011, IMO adopted technical and operational measures for international shipping. Technical guidelines to support the implementation of these measures, as well as a resolution on technical cooperation and technology transfer that would facilitate the implementation of these measures were also agreed.

UNITED NATIONS DEVELOPMENT PROGRAMME (UNDP) AND GLOBAL ENVIRONMENT FACILITY (GEF)

In an effort to facilitate the provision of financial assistance for actions on climate change, and in particular for the preparation and implementation of States' action plans on CO_2 emissions reduction activities, ICAO is currently developing a programme with the UNDP and GEF. The UNDP is the authorized implementing agency of GEF, which was established as a programme within the World Bank to assist in the protection of the global environment and to promote environmental sustainable development (see article *UNDP: Leveraging Climate Finance for a Sustainable Future, The Climate Finance Challenge*, Chapter 6 in this report).

WORLD TOURISM ORGANIZATION (UNWTO)

ICAO collaborates with UNWTO in several areas of strategic importance to air transport and tourism with the aim of maximizing synergies when dealing with cross-sectoral policy issues. In particular, on the occasion of the Sixth Worldwide Air Transport Conference (ATConf/6) in March 2013, ICAO and UNWTO signed a Joint Statement, acknowledging the intention of the two UN agencies to begin cooperating more closely on areas of common interest, including the reduction of GHG emissions from aviation and tourism (see article *UNWTO and ICAO: A Collaborative Approach on Tourism, Air Transport and Climate Change*, Chapter 8 in this report).

INDUSTRY GROUPS

ICAO works with industry groups to help guide policymaking, provide support to its Member States, and coordinate actions across the environment agenda. These groups include Air Transport Action Group (ATAG), Airports Council International (ACI), Civil Air Navigation Services Organization (CANSO), International Air Transport Association (IATA), International Coordinating Council of Aerospace Industries Associations (ICCAIA), and The International Air Cargo Association (TIACA). These industry groups help ICAO promote aviation's sustainable growth for the benefit of the international community by investing in technology, improving operational efficiency, and building and using efficient infrastructures.

On the occasion of the ICAO Symposium on Aviation and Climate Change held in May 2013, ICAO and ATAG signed a Joint Statement to strengthen their collaboration to better promote and communicate to governments and the aviation industry on all developments and initiatives related to the sustainable development of global air transport[3]. Also in 2013, ICAO and TIACA signed a Declaration of Intent to strengthen their cooperation on technical matters, including environmental practices.

NON-GOVERNMENTAL ORGANIZATIONS

The International Coalition for Sustainable Aviation (ICSA) is a structured network of environmental non-governmental organizations (NGOs) which share common concerns with civil aviation's contribution to air quality, climate change and noise issues. As an observer to ICAO's Committee on Aviation Environmental Protection (CAEP), ICSA provides technical expertise and brings an NGO perspective to developing policies and strategies to reduce emissions and noise from the aviation sector. ■

REFERENCES

1 *IPCC Guidelines for National Greenhouse Gas Inventories* and the *Good Practice Guidance*, www.ipcc-nggip.iges.or.jp/public/2006gl/index.html

2 http://sustainabledevelopment.un.org/futurewewant.html

3 www.icao.int/Newsroom/Pages/ICAO-and-ATAG-sign-joint-statement.aspx

FLIGHTPATH TO A SUSTAINABLE FUTURE THE ICAO RIO+20 GLOBAL BIOFUELS INITIATIVE

BY ICAO SECRETARIAT

The United Nations Conference on Sustainable Development (UNCSD), also known as the Rio+20 Conference, took place in Rio de Janeiro, Brazil in June 2012. It marked the 20th anniversary of the 1992 United Nations Conference on Environment and Development (UNCED), which was also held in Rio. The objectives of the Rio+20 Conference were to: secure renewed political commitment for sustainable development; assess the progress made to date; identify the remaining gaps in the implementation of the outcomes of the major summits on sustainable development; and address new and emerging challenges.

The outcome of the Conference, a report titled *The Future We Want*[1], focuses on a number of important subjects, including: access to renewable energy, sustainable transport, poverty eradication, finance, and sustainable development goals. All of these issues play a central role with respect to international aviation[2].

To highlight the importance of the sustainable energy debate for aviation, and to mark its participation at the UNCSD for the first time in history, ICAO brought together aviation and biofuel industry stakeholders to conduct a series of connecting commercial flights powered by alternative fuels. The ICAO Secretary General, Mr. Raymond Benjamin travelled to Rio on four separate, connecting flights operated respectively, by Porter Airlines, Air Canada, Aeroméxico, and GOL, each one using a different type of sustainable biofuel (see **Figure 1** and **Table 1**). The first flight departed from Montreal on 18 June 2012 and the final leg arrived in Rio the following day, 19 June 2012, which was designated as "Aviation Day at Rio+20".

A group of approximately 400 people contributed to the "Flightpath to a Sustainable Future" initiative by providing support in: planning; logistics; coordination; fuels; flight operations; media presence; and local liaison. In addition to saving

Figure 1: *Mr. Raymond Benjamin, ICAO Secretary General – Flightpath to a Sustainable Future.*

Figure 2: *Partners from the Rio+20 Initiative and Mr. Brice Lalonde, Special Advisor on Sustainable Development to the UN Global Compact, at the 2013 Le Bourget Paris Air Show.*

Leg	Airline	Aircraft	Route lenght (km)	Biofuel Blend
Montreal – Toronto	Porter Airlines	Bombardier Q400	494	Camelina
Toronto – Mexico City	Air Canada	Airbus A319	3,243	Used cooking oil
Mexico City – São Paulo	Aeromexico	Boeing 777	7,423	Used cooking oil, jatropha and camalina
São Paulo – Rio de Janeiro	GOL	Boeing 737-800	366	Inedible corn oil and used cooking oil

Table 1: *Flightpath to a Sustainable Future – Biofuels Flights Details.*

ICAO Rio+20 Video
ICAO produced a powerful video highlighting aviation's contribution across the economic, environment, and social pillars of sustainable development. This video was showcased at the ICAO Rio+20 side event and exhibition booth. It can be downloaded from this link: www.youtube.com/watch?v=wFO94zMhEYo

***Figure 3:** Flightpath to a Sustainable Future – Biofuel Flights Partners.*

47 tonnes of CO_2, or an overall 20% reduction in emissions, these biofuel flights set a series of breakthrough records:

- First biofuel flights by Air Canada and GOL.
- First series of connecting international biofuel flights by multiple aircraft.
- First North American commercial biofuel flight using optimized air traffic management.
- First South American biofuel flight using optimized air traffic management.
- First flight using biofuel derived from sugar cane (parallel Azul test flight).
- Greatest number of passengers carried on commercial biofuel flights in 24 hours (388).
- Longest international itinerary using biofuels between Montreal–Rio (11,525 km great circle).

The scale of this effort was matched only by its ambitious goal – reaching out to 50,000 participants at Rio+20 and showcasing what can be achieved by the aviation sector through technological improvement, cooperation, and determination.

The 2013 Le Bourget Paris Air show coincided with the first anniversary of the launch of the Rio+20 "Flightpath to a Sustainable Future" initiative. The partners in this Rio+20 initiative came together in Paris to commemorate the series of landmark biofuel flights. ■

***Figure 4:** Sculpture inspired by a turbine fan, with four leaves representing each "Flightpath" leg. ICAO Secretary General Invited the partners to Place a leaf in the sculpture at each point of the journey.*

REFERENCES

1 http://sustainabledevelopment.un.org/futurewewant.html
2 www.icao.int/environmental-protection/Documents/RIO+20_booklet.pdf
3 www.icao.int/environmental-protection/Documents/RIO+20_Flightpath_Review.pdf

NEGOTIATIONS ON A FUTURE GLOBAL CLIMATE CHANGE AGREEMENT

BY ICAO SECRETARIAT

In 1992, the international community agreed on a framework for addressing global warming 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. It is the ultimate objective of the Convention to stabilize greenhouse gas concentrations "at a level that would prevent dangerous anthropogenic (human induced) interference with the climate system." The UNFCCC entered into force in 1994; today, 195 Parties having ratified it.

The Kyoto Protocol to the UNFCCC, adopted in 1997, shares the Convention's objective, principles and institutions and sets legally-binding GHG emissions limitation and reduction commitments for 37 industrialized countries and the European Union. The resulting emissions reductions amount to an average of 5% below 1990 levels over the five-year first commitment period 2008-2012.

Emissions from international aviation include over-flight of 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 Kyoto Protocol excluded them from the national totals of individual countries and from their 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, working through ICAO.

MOVING TOWARD A FUTURE GLOBAL CLIMATE CHANGE AGREEMENT

At the climate change conference in Montreal in 2005, Parties to the Kyoto Protocol initiated a process to consider further commitments of industrialized 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).

Two years later, at the UN climate change conference in Bali in December 2007, Parties adopted the Bali Roadmap, that established a process to enable the full, effective and sustained implementation of the Convention through long-term cooperative action up to and beyond 2012. Discussions following the mandate of the Bali Roadmap took place under the "Ad-hoc Working Group on Long-term Cooperative Action under the Convention" (AWG-LCA) and focused 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.

Following the climate change conference in Bali, Indonesia in 2007, AWG-LCA and AWG-KP continued their work in accordance with relevant mandates. Since the last ICAO Assembly in 2010, the major climate change conferences under the UNFCCC and Kyoto Protocol were the Cancun conference in December 2010 in Mexico, the Durban conference in December 2011 in South Africa, and the Doha conference in December 2012 in Qatar.

At the 2010 climate conference in Cancun, Mexico, Parties agreed on broad issues to help developing nations deal with climate change. It encompassed finance, technology and capacity-building support to help such countries meet urgent needs to adapt to climate change, and to speed up their plans to adopt sustainable paths to low emission economies that could also mitigate the negative impacts of climate change.

At the 2011 climate change conference in Durban, South Africa, Parties launched the work towards the adoption of a global and legally-binding agreement on climate change by 2015, for implementation from 2020. This work takes place under the "Ad-hoc Working Group on the Durban Platform for Enhanced Action" (ADP). Under the ADP process, two streams of work were initiated: 1) on development of an agreement applicable to all Parties in 2015, to come into effect from 2020; and 2) on consideration of the options and ways for increasing the levels of ambition to close the gap between the current pledges of Parties and those required by 2020 to achieve the 2°C target.

DOHA CLIMATE GATEWAY

The most recent climate conference was held in Doha, Qatar, where Parties concluded the work of both AWG-LCA and AWG-KP and adopted a series of decisions, referred to as the "Doha Climate Gateway", which include:

- Amendment to the Kyoto Protocol. The eight-year second commitment period from 2013 to 2020; review of commitments by Annex I Parties by 2014; and continuation of flexible mechanisms under the Kyoto Protocol.
- Extension of the work programme on long-term climate finance for one year by the end of 2013 to further analyse options for the mobilization of US$ 100 billion per year by 2020 from a wide variety of potential sources.
- An elaborated work plan for the ADP process, which covers: the elements of a negotiating text to be available by December 2014; the negotiation text to be available prior to May 2015; and a legally-binding agreement on climate change to be adopted at the Paris conference in December 2015 for implementation from 2020.
- The final outcome of the AWG-LCA does not contains decision text in on matters related to international aviation and maritime transport.

ICAO AND THE UNFCCC PROCESS

Since the last Assembly, ICAO has continued to provide the conferences under the UNFCCC with regular statements[1] on recent ICAO developments related to international aviation and climate change. During these negotiations several Parties expressed support for further work to be undertaken by ICAO and the International Maritime Organization (IMO) to address GHG emissions from the international aviation and maritime sectors, respectively. Other Parties suggested that the work of ICAO and IMO should be guided by the principle of common but differentiated responsibilities (CBDR) under the UNFCCC. Divergent views were expressed, including the need for a general framework that could commonly be applied to international transport (aviation and maritime) and other sectors, as well as the appropriateness and need for the UNFCCC to give specific guidance to the work of ICAO and IMO.

With respect to "long-term climate finance", some Parties expressed concern about the options proposed by other Parties for using the international aviation and maritime sectors as one of the sources for mobilizing US$ 100 billion per year by 2020. However, it should be highlighted that ICAO's global aspirational goals for the international aviation sector will require adequate financial resources within the sector itself, enabling it to effectively respond to the global climate change challenge. Some studies of climate change finance have suggested international aviation as a source of funding at levels that are disproportionate to the sector's contribution to global emissions. Such an approach would limit the ability of the sector to address its own emissions, and in addition, could have an adverse effect on demand, thereby reducing the economic benefits that aviation delivers.

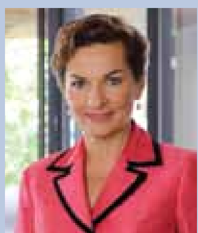
Several Parties identified further progress of work under ICAO and IMO as one of the international cooperative initiatives for increasing the level of ambition. ICAO and its Member States need to closely follow up if, and how, the issues related to international aviation would be undertaken in the ADP process. The next major UNFCCC conference will be held from 11 to 22 November 2013 in Warsaw, Poland. ■

REFERENCE

1 ICAO statements to UNFCCC are available at: www.icao.int/environmental-protection/Pages/statements.aspx

INTERNATIONAL AIR TRANSPORT - KEY TO CLIMATE CHANGE RESPONSE

BY CHRISTIANA FIGUERES



CHRISTIANA FIGUERES

She was appointed Executive Secretary of the United Nations Framework Convention on Climate Change (UNFCCC) by UN Secretary-General Ban Ki-moon on 17 May 2010.

It seems like the world is getting smaller as the flow of people and information across the globe increases. Rapid development and technological advances have ushered in an era of heightened connectivity that relies heavily on air transport for mobility.

However, this development has come with an unexpected price. Science now clearly shows that climate change threatens both the natural environment and business-as-usual growth. Overcoming climate change will require an interconnected and collaborative response that builds a new development model, while continuing to meet mobility needs.

The International Civil Aviation Organization has a history of collaborating to address climate change related to aviation. The Organization has long worked closely with the United Nations Framework Convention on Climate Change (UNFCCC) to minimize the environmental impacts of international air transport. The adoption of Resolution A37-19 in 2010 further clarifies sector-wide action to curb aviation greenhouse gas emissions and strengthened collaborative response.

The resulting progress has been positive. Clear global aspirational goals to reduce emissions and increase efficiency have been established. States have been invited to submit action plans and outline their assistance needs. Sustainable alternative fuels for aviation have been recognized as a real alternative for significantly curbing future aviation-generated carbon emissions. And, market-based measures have been explored as a way to achieve further emission reductions and efficiency goals.

While this progress is promising, aggregate global action is not enough to achieve the internationally agreed goal of limiting warming to 2°C. We must do more.

This Environmental Report precedes the 2013 ICAO Assembly, and I urge the Assembly to remember that action taken under the auspices of ICAO represents crucial global response and complements UNFCCC action. I therefore encourage ICAO to build on its strong foundation and dynamically turn policy into environmental stewardship, sustainable development, and climate change action.

The Assembly convenes at an important moment in history. Work this year will inform the UNFCCC negotiations to achieve a new universal agreement in 2015, to come into force in 2020, and to raise more immediate ambition to curb greenhouse gas emissions. ICAO implementation has great potential to support the 2015 universal agreement by increasing the options to raise ambition.

A sustainable future requires balancing increased mobility needs with the need for low-carbon growth. The work of ICAO is creating the framework needed to strike that balance. ■

ICAO CONTRIBUTION TO ENVIRONMENTAL SUSTAINABILITY IN THE UNITED NATIONS SYSTEM

BY ISABELLA MARRAS

ISABELLA MARRAS

She is the Coordinator of the Sustainable UN Facility, an initiative hosted by UNEP to help UN system organisations to move the UN system towards corporate environmental management. She has a legal background and has worked on matters related to sustainable consumption, education and sustainable procurement for 15 years. Facilitating change towards sustainability within organizations or in people's personal lives is her strong interest and professional focus.

The Sustainable UN facility (SUN) was created in 2008 by The United Nations Environment Programme (UNEP) with the explicit goal to support the commitment made by the UN heads of agencies, funds and programmes in 2007 to implement the UN Climate Neutral Strategy, which asks UN entities to measure and reduce their own GHG emissions and consider common options to offset them. SUN activities take place in three primary focus areas: 1) management (including procurement and travel), 2) buildings, and 3) organizational culture (staff behaviour). Gradually the SUN facility has expanded its portfolio of advice to promote a systematic approach to environmental management in support of the recent decision by the UN heads of agency to implement environment management systems (EMS) in all UN entities.

In June 2013 the SUN facility published the fourth edition of the report "Moving Towards A Climate Neutral UN" which contained GHG emissions data for the UN system in 2011 and documented efforts to reduce them in 2012. Total emissions for 2011 were 1,751,534 CO_2 equivalents.

The report is the result of a very close and positive collaboration between the SUN facility and a network of 63 UN system reporting entities. Such important work would not be possible without the collaboration of ICAO and its carbon emissions calculator (see article *ICAO Environmental Tools*, Chapter 1 in this report), and the expertise that ICAO makes available to ensure that travel data is accurate and easy to report (see **box** on *Environmental Sustainability Management Within ICAO*).

Air travel is consistently reported to be one of the largest sources of greenhouse gas emissions for many UN organizations, representing slightly more than 50% of total GHG emissions on average. Consequently, these organizations are focusing efforts on reducing the number of flights undertaken and are introducing e-communications as alternative solutions to air travel.

Number of UN staff (including peacekeeping operations)	221,258
Number of reporting institutions	63
Total emissions	1,751,534 tCO_2eq
Emissions per capita	7.9 tCO_2eq
Air travel per capita	4.0 tCO_2eq

Table 1: *UN System Carbon Footprint in 2011.*

The operation of physical facilities such as offices and other buildings are also major contributors to greenhouse gas emissions. A number of energy management strategies are being applied, including: Leadership in Energy and Environmental Design (LEED) certification, production of renewable energy on site, and energy efficient technologies such as LED lights and control systems. As a result, the carbon footprints of many UN facilities are reducing.

The contribution of ICAO to "greener" decision-making in the UN system goes beyond the ICAO carbon emissions calculator. In 2011, ICAO made its "green meetings calculator" available to all UN agencies and provided training on its use. This software works by generating an optimal location for a meeting in terms of lower CO_2 emissions, taking into consideration the city of origin and the number of participants, as well as other parameters. While many factors may affect the decision for where a meeting should be held, the calculator helps facilitate the planning process.

ICAO has also demonstrated its commitment to the wider-reaching sustainability management initiatives by providing substantial inputs to the SUN reports "Sustainable Procurement Guidelines for Freight Forwarding" and "Sustainable Events Guide".

At the UN system level, the Chief Executives Board for Coordination agreed in April 2013 that UN organizations will gradually implement Environment Management Systems, focusing on cost efficiencies and short term returns. A number of organizations are moving towards such an approach. Some have taken a few very prudent steps, whereas others have moved more boldly, already obtaining, or are working towards, ISO certification for their facilities and operations. Such certification will allow them to establish a baseline, record progress and savings, and enable them to be transparent and clear in their communications.

Despite the limited resources available, the joint work done so far between UNEP-SUN and ICAO is a demonstration of how, by combining their expertise, UN system organizations can multiply their skills and obtain significant results. In that context, the SUN facility, very much appreciates the work and assistance of ICAO for its support and contribution in tracking and reducing the aviation GHG emissions from the UN system operations.

Because the work is done on a system-wide basis, and the sustainability of individual agencies is only possible through close interagency cooperation, should ICAO be willing to move towards a more systematic approach to emissions and footprint reduction, support from the SUN facility and sharing of experiences with other organizations will be there to assist them. ■

ENVIRONMENTAL SUSTAINABILITY MANAGEMENT WITHIN ICAO

ICAO monitors its carbon emissions and annually updates its greenhouse gas (GHG) inventory by estimating the Secretariat's carbon footprint using the ICAO Carbon Emissions Calculator (see article *ICAO Environmental Tools*, Chapter 1 in this report) and the United Nations Environment Programme (UNEP) GHG emissions calculator. The total ICAO carbon footprint in 2012 was 6,177 tonnes of CO_2 emissions, with staff air travel accounting for almost 50% of the total inventory. The ICAO per capita GHG emissions were 8.6 tCO_2/staff.

Through formalized policies regarding its operations, the Organization continues to work to further reduce its environmental impact and improve its sustainability management.

For example, ICAO has recently adopted a number of measures across the Organization that are generating financial savings while contributing to efforts to lower the Organization's carbon emissions. These efforts include the adoption of measures to achieve a paperless environment, such as the implementation of an integrated print-on-demand (and reprint-on demand) system, which thus far has reduced the inventory of printed documents by 65%, and the establishment of a "paperless" process to distribute documents to ICAO bodies, which has resulted in a 90% reduction in the reproduction and distribution of documentation. Office space has been reallocated to maximize efficiency, reduce energy consumption and improve access to natural light, and a policy to procure office furnishings made of recycled materials has also been implemented. In addition, between 2010 and 2011 ICAO achieved a reduction of approximately 5% in flight-related GHG emissions per staff member per kilometre. To achieve this, ICAO revised internal policies and restricted eligibility for business class tickets so that only staff travelling for over nine hours are eligible for business class travel.

ICAO will continue to lead by example in support of the implementation of sustainability management practices within the UN system through the quantification of its climate footprint, by actively taking steps toward reducing its footprint and by providing other sister Organizations the best available information and tools to enable the accurate quantification of emissions reductions from air travel.

ICAO Secretariat

UNWTO AND ICAO: A COLLABORATIVE APPROACH ON TOURISM, AIR TRANSPORT AND CLIMATE CHANGE

BY **TALEB RIFAI**

TALEB RIFAI

He was elected as Secretary-General of the World Tourism Organization (UNWTO) in October 2009 and begun his four-year term on 1 January 2010.

Tourism and air transport have a symbiotic relationship. In 2012, there were over one billion international tourists travelling the world in one single year, spending as much as US$ 1.3 trillion in the countries they visited. Over 50% of them reached their destinations by air. On the other hand, international air passengers, both business and leisure travellers, are predominantly tourists.

The World Tourism Organization (UNWTO) counts climate change as a top priority among the many issues requiring collaboration and coordination between tourism and air transport. Greenhouse gas emissions (GHG) from travel and tourism are estimated to contribute about 5% of global CO_2 emissions, of which air transport accounts for an estimated 40%.

With this background, UNWTO and ICAO have long been working together to tackle climate change. This work has gained particular relevance since 2007 when UNWTO, along with the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO), convened the Second International Conference on Climate Change and Tourism in Davos, to which key input on aviation was provided by ICAO. The resulting *Davos Declaration* included, as a priority, the need to "mitigate emissions in transport, in cooperation with ICAO and other aviation organizations".

Yet, this objective can only be met if we address the issue of climate change and air transport in the broader context of tourism development. The 2010 UNWTO "*Statement regarding mitigation of greenhouse gas emissions from air passenger transport*" that was presented to the 37th session of the ICAO Assembly called for an assessment of mitigation measures in the context of broad-spectrum tourism, rather than of air transport in isolation, considering the social and economic costs and benefits of travel and tourism in cohesion with climate change mitigation impacts. It particularly highlighted the importance of alleviating the impacts that these measures might have on tourism destinations, notably long-haul developing, and particularly, least-developed and island countries where tourism depends on air transport. UNWTO also calls for a non-duplication of emissions levies on transport and other tourism activities. For example, as a result of the application by more than one authority, or through different overlapping regimes such as taxation and emissions trading.

Climate change is one of the key issues included in the 2010 UNWTO/ICAO Memorandum of Cooperation and in the recently released Joint Statement in which the two organizations agreed to work together with the aim of "Contributing to the reduction of greenhouse gas emissions from aviation and tourism". It is in this framework that UNWTO remains fully committed to providing a tourism perspective to ICAO's ongoing policy making and the continuing debate on air transport and climate change. ■

ACKNOWLEDGEMENTS

This report was coordinated and prepared by the ICAO Environment Branch with contributions from many experts within ICAO, CAEP and other international organizations.

Jane Hupe
Chief, Environment Branch
Coordinator and Lead Author

Blandine Ferrier
Associate Environment Officer
Report Project Manager
Chapter 4 – Global Emissions – Operations
Chapter 5 – State Action Plans
Chapter 7 – Adaptation

Theodore Thrasher
Environment Officer
Chapter 1 – Aviation and Environment Outlook

Chaouki Mustapha
Environment Officer
Chapter 1 – Aviation and Environment Outlook – Air Traffic and Fleet Forecasts

Neil Dickson
Environment Officer
Chapter 2 – Aircraft Noise
Chapter 3 – Local Air Quality
Chapter 4 – Global Emissions – Technology

Tetsuya Tanaka
Environment Officer
Chapter 4 – Global Emissions
Chapter 8 – Partnerships and Cooperation with Other Organizations

Philippe Novelli
Environment Officer
Chapter 4 – Global Emissions – Sustainable Alternative Fuels

Sam Brand
Rasa Sceponaviciute
Environment Officers
Chapter 4 – Global Emissions – Market-based Measures

Sainarayan Ananthanarayan
Environment Officer
Chapter 6 – Assistance and Financing

Lorenzo Gavilli
Environment Officer
Chapter 8 – Partnerships and Cooperation with Other Organizations

Iulia Bogatu
Consultant
Assistant Coordinator of the Report
Chapter 7 – Adaptation

Vanessa Muraca
Report editing and revision

Angelika Fuchs-Ledingham
Loise Karanja-Fry
Report revision

ICAO Support
Anthony Philibin, Communications Office
Martin Maurino, Air Navigation Bureau
Michael DeLeon, Air Navigation Bureau
Susan Joseph, Air Transport Bureau

Printing Services
ICAO Reproduction,
Sales and External Distribution Services

Editorial Services
Shaun Fawcett, Text editing Final Draft Publishing

Graphic Design Services
Bang Marketing

ICAO wishes to thank those individuals who have made valuable contributions to this Environmental Report.

CHAPTER 1 - AVIATION AND ENVIRONMENT OUTLOOK

Authors and Contributors: Gregg Fleming (Volpe Center, FAA, U.S.), Urs Ziegler (FOCA, Switzerland), Andrew Watt, (EUROCONTROL), Christopher Roof (Volpe Center, FAA, U.S.), Fabio Grandi (FAA, U.S.), Yury Medvedev (TsAGI, Russian Federation), Agence pour la Sécurité de la Navigation Aérienne en Afrique et à Madagascar (ASECNA), Xavier Oh (ACI), Chrystelle Damar (ACI EUROPE), D. W. Fahey (NOAA Earth System Research Laboratory, U.S.), S. L. Baughcum (Boeing Company, U.S.), M. Gupta (FAA, U.S.), D. S. Lee (Manchester Metropolitan University, U.K.), R. Sausen (DLR, Germany), P. F. J. van Velthoven (KNMI, The Netherlands), Sylvie Mallet (Transport Canada, Canada), and Kevin Guittet (DGAC, France). **Reviewer:** ICAO Secretariat

CHAPTER 2 - AIRCRAFT NOISE

Authors and Contributors: Dennis Huff (NASA Glenn Research Center, U.S.), Ulf Michel (DLR, Germany), Brian Tester (ISVR, U.K.), Dominique Collin (SNECMA Moteurs, France), Sandy Liu (FAA, U.S.), Victor Sparrow (Pennsylvania State University Graduate Program in Acoustics, U.S.) Yoshikazu Makino (Japan Aerospace Exploration Agency, Japan) Willem Franken (EASA), James Skalecky (FAA, U.S.), Rhett Jefferies (FAA, U.S.), Fay Collier (NASA, U.S.), Ruben Del Rosario (NASA, U.S.), Andrew Kempton (Rolls-Royce), Pierre Lempereur (Airbus), Tatsuya Iishi (JAXA, Japan), Tsutomu Oishi (IHI), Benny Pang (Bombardier), Mark Huising (Bombardier), Victor Kopiev (TsAGI, Russian Federation), Yuri Khaletskiy (CIAM, Russian Federation), Carlos Grandi (Embraer), and Micael Do Carmo (Embraer). **Reviewer:** ICAO Secretariat

CHAPTER 3 - LOCAL AIR QUALITY

Authors and Contributors: Theo Rindlisbacher (FOCA, Switzerland), S. Daniel Jacob (FAA, U.S.), Rick Miake-Lye (Aerodyne Research, Inc. U.S.), Paul Madden (ICCAIA), Dom Sepulveda (ICCAIA), Joe Zelina (ICCAIA), Rudy Dudebout (ICCAIA), Kian McCaldon (ICCAIA), and Olivier Penanhoat (ICCAIA). **Reviewer:** ICAO Secretariat

CHAPTER 4 - GLOBAL EMISSIONS

Authors and Contributors: *Technology*: Leslie Riegle (ICCAIA), Muni Majjigi (ICCAIA), Olivier Husse, Thierry Nowaczyk, Sarah Le Brocq, Kevin Goddard (all Airbus), Kevin Morris (ADS), and Dan Allyn, Sean Newsum, Steven Baughcum, Douglas DuBois, David Forsyth, Mike Garrison, Ricky Mack, Matthew Muehlhausen, Robert Peterson, Robert Solaimani (all Boeing), Lourdes Maurice (U.S.), Nick Cumpsty, (U.K.), Juan J. Alonso (U.S.), Serge Eury (France), Bengt-Olov Nas (IATA), Malcolm Ralph (U.K.), Steve Arrowsmith (EASA), Mike Samulski (EPA, U.S.), Roger Worth (DfT, U.K.) and Ralph Iovinelli (FAA, U.S.). **Reviewer:** ICAO Secretariat

Operations: Kevin Morris (ICCAIA, U.K.), Shannon Scott (CAA New Zealand), Dirk Kügler (Germany), Lee Merry Brown (U.S.) Teresa Di Lallo (Italy), Daniel McGregor (ICCAIA), Michael Owen Ball (U.S.), Dick Marchi (ACI), and Grady P. Boyce (IATA). **Reviewer:** ICAO Secretariat

Sustainable Alternative Fuels: Jan Bode (Germany), Barbara Bramble (RSB), Tania Buenrostro (Mexico), Delia Dimitriu (Manchester Metropolitan University, U.K.), Frédéric Eychenne (ICCAIA), Thimothy Fenouhlet (EC), Johnston Glenn (Gevo), James Hileman (U.S.), Nicolas Jeuland (France), Christopher Jessberger (AIREG), Virpi Kröger (Neste Oil), Michael Lunter (The Netherlands), Chris Malins (ICCT), Philippe Marchand (Total), Bruno Miller (Metron Aviation), Shumani Mugeri (South Africa), Xavier Oh (ACI), Martina Otto (UNEP), John Plaza (Imperium Renewables), Gerard Ostheimer (U.S.), James Rekoske (ICCAIA), Thomas Roetger (IATA), Shona Rosengren (Australia), Andrea Rossi (FAO), Arne Roth (Bauhaus Luftfahrt), Marcelo Saito (Brazil), Alfredo Iglesias Sastre (Spain), Andreas Sizmann (Bauhaus Luftfahrt), Laurens Van Sterkenburg (The Netherlands), Michael Sicard (France), Cindy Thyfault (Westar Trade Resources), Terry Thompson (Metron Aviation), Cesar Velarde Catolfi-Salvoni (Spain), Arnaldo Vieira de Carvalho (IDB), Hoang Vu Duc (EC), Kevin Welsh (U.S.), David White (Australia), Zheng Xingwu (China), Nancy Young (A4A) Christoph Jessberger (AIREG), Leigh Hudson (British Airways, U.K.), Inmaculada Gomez, (ITAKA, Spain), Fokko Kroesen (KLM, The Netherlands), Jimmy Samartzis (United Airlines, U.S.), Martin Porsgaard (Scandinavian Airlines), and Luis Augusto Barbosa Cortez (SABB, Brazil). **Reviewer:** ICAO Secretariat

Market-based Measures: Scott Stone (Australia), Shona Rosengren (Australia), Adriano Santhiago de Oliveira (Brazil), Luiz Brettas (Brazil), Leigh Mazany (Canada), Stephen Hairsine (Canada), Yue Huang (China), Zheng Xingwu (China), Wang Ren (China), Amit Garg (India), Shigehiko Yamaguchi (Japan), Peter Alawani (Nigeria), Junhaeng Jo (Republic of Korea), Weijen Leow (Singapore), Lee Chee Tong (Singapore), Jacky Chong (Singapore), Urs Ziegler (Switzerland), Alejandro Piera (UAE), Maryalice Locke (U.S.), Kim Carnahan (U.S.), Kevin Welsh (U.S.), Timothy Fenoulhet (EC), Philip Good (EC), David Batchelor (EC), Paul Steele (ATAG), Brian Pearce (IATA), Tim Johnson (ICSA), Paul Steele (IATA), Chris Goater (IATA), Takashi Hongo (Mitsui Global Strategic Studies Institute), Annie Petsonk (EDF), Guy Turner (BNEF), and Robin Rix (United Nations Climate Change Secretariat). **Reviewer:** ICAO Secretariat

CHAPTER 5 - STATE ACTION PLANS

Extracts from the State Action Plans from Korea, Federal Republic of Germany, Argentina, United States, United Kingdom, Tanzania, Jamaica and Trinidad and Tobago, Canada, United Arab Emirates, Switzerland, China, and Venezuela. **Reviewer:** ICAO Secretariat

CHAPTER 6 - ASSISTANCE AND FINANCING

Authors and Contributors: Arnaldo Vieira de Carvalho (IDB), Oliver Page (UNDP), and Elina Bardram (EC). **Reviewer:** ICAO Secretariat

CHAPTER 7 - ADAPTATION

Authors and Contributors: Herbert Pümpel (WMO), Rachel Burbidge (EUROCONTROL), and Xavier Oh (ACI). **Reviewer:** ICAO Secretariat

CHAPTER 8 - PARTNERSHIPS AND COOPERATION WITH OTHER ORGANIZATIONS

Authors and Contributors: Isabella Marras (SUN UNEP). **Reviewer:** ICAO Secretariat

Special thanks to
Christiana Figueres, Executive Secretary, United Nations Framework Convention on Climate Change (UNFCCC) and **Taleb Rifai**, Secretary-General, World Tourism Organization (UNWTO).

ICAO ENVIRONMENTAL PUBLICATIONS

Noise
- *Annex 16 to the Convention on International Civil Aviation – Environmental Protection*, Volume I – Aircraft Noise
- Noise Abatement Procedures: Review of Research, Development and Implementation Projects – Discussion of Survey Results, 2010 (Doc 9888)
- *Airport Planning Manual*, Part 2 – Land Use and Environmental Control (Doc 9184)
- Recommended Method for Computing Noise Contours around Airports (Doc 9911)
- Environmental Technical Manual Volume I – Procedures for the Noise Certification of Aircraft (Doc 9501)
- Guidance on the Balanced Approach to Aircraft Noise Management (Doc 9829)
- Report of the Second Independent Experts on Noise Reduction Technologies Review and the Associated Medium and Long Term Goals**

Aviation Alternative Fuels
- ICAO Review: Sustainable Alternative Fuels for Sustainable Aviation, October 2011

Operations
- Continuous Descent Operations (CDO) Manual (Doc 9931)
- Procedures for Air Navigation Services – Aircraft Operations (OPS) (Doc 8168)
- Review of Noise Abatement Procedure Research and Development and Implementation Results (Doc 9888)
- Environmental Management System (EMS) Practices in the Aviation Sector (Doc 9968)
- Operational Opportunities to Reduce Fuel Burn and Emissions**
- Environmental Assessment Guidance for Proposed Air Traffic Management Operational Changes**
- Operational Fuel Burn Goals**

Aircraft Engine Emissions
- *Annex 16 to the Convention on International Civil Aviation – Environmental Protection*, Volume II – Aircraft Engine Emissions
- Environmental Technical Manual Volume II – Procedures for the Emissions Certification of Aircraft Engines (Doc 9501)
- Report of the Independent Experts on the Medium and Long Term Goals for Aviation Fuel Burn Reduction From Technology (Doc 9963)
- Report of the Independent Experts to CAEP/8 on the Second NO_x
- Review and the Establishment of Medium and Long Term Technology Goals for NO_x (Doc 9953)
- Offsetting Emissions from the Aviation Sector (Doc 9951)
- Report on Voluntary Emissions Trading for Aviation (VETS Report) (Doc 9950)
- Scoping Study of Issues Related to Linking "Open" Emissions Trading Systems Involving International Aviation (Doc 9949)
- Scoping Study on the Application of Emissions Trading and Offsets for Local Air Quality in Aviation, First Edition (Doc 9948)
- Guidance on Aircraft Emission Charges Related to Local Air Quality (Doc 9884)
- Draft Guidance on the use of Emissions Trading for Aviation (Doc 9885)
- Independent Experts NO_x Review and the Establishment of Medium and Long Term Technology Goals for NO_x (Doc 9887)
- Airport Air Quality Manual (Doc 9889)
- ICAO's Policies on Charges for Airports and Air Navigation Services (Doc 9082)
- Circular on the CO_2 Standard Certification Requirement (Circ.337)**
- Report on the Assessment of Market-based Measures (Doc 10018)

*** Agreed at the ninth meeting of the ICAO Committee on Aviation Environmental Protection (CAEP/9). Publication of these documents is in progress.*

http://www.icao.int/environmental-protection/Pages/environment-publications.aspx

ICAO Environmental Tools
http://www.icao.int/environmental-protection/Pages/Tools.aspx

ICAO WISHES TO THANK ALL THOSE WHO CONTRIBUTED TO
THIS 2013 ICAO ENVIRONMENTAL REPORT FOR THEIR SUPPORT

ICAO

International Civil Aviation Organization
999 University
Montréal, QC, Canada
H3C 5H7

Tel.: +1 (514) 954-8219
Fax: +1 (514) 954-6077
Email: info@icao.int

www.icao.int