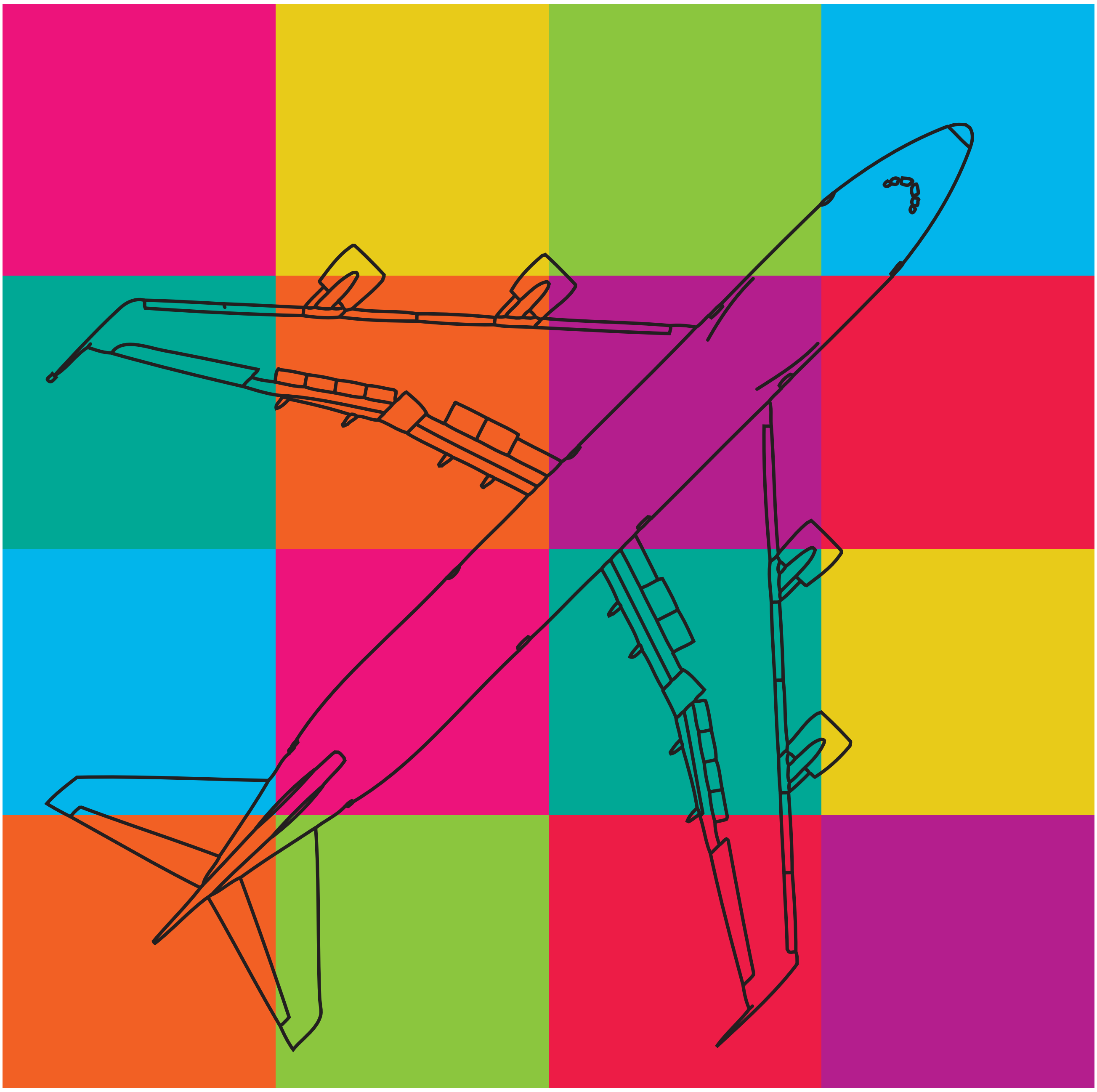
ON BOARD
A SUSTAINABLE FUTURE



ICAO

2016 ENVIRONMENTAL REPORT

ICAO ENVIRONMENTAL REPORT 2016

AVIATION AND CLIMATE CHANGE

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

DEMONSTRATING LEADERSHIP

In 2013, the 38th Session of the ICAO Assembly acknowledged our substantial progress in all areas of environmental action. In the field of aviation and climate change, it reaffirmed the collective aspirational goals of two per cent fuel efficiency improvement annually, and carbon neutral growth from 2020. To progress towards these goals, ICAO elaborated a comprehensive 'basket' of mitigation measures, namely innovative aircraft technologies, more efficient operations, sustainable alternative fuels, and market-based measures (MBMs).

With respect to the MBM, the 39th ICAO Assembly, taking place at our Montréal Headquarters this fall, will consider a detailed recommendation addressing the key design elements of a global MBM and the mechanisms for its implementation from 2020.

These achievements bolster ICAO's leadership role in limiting and reducing emissions from international civil aviation, and as President of the ICAO Council I can testify to our Member States' commitment to ensuring that leadership doesn't falter. This is particularly relevant following the historic agreement reached during the 21st United Nations Framework Convention on Climate Change (UNFCCC) Conference of the Parties, held in Paris in December 2015, and ICAO is now driving the actions needed from international aviation to help complement the ambitious objectives set out in the Paris Agreement.

This triennium has also seen ICAO and its Member States multiplying our partnerships with leading governmental and non-governmental organizations, industry bodies, and research institutes. These initiatives have already begun to bear fruit, and many meaningful CO_2 emissions reductions are being realized as a result. Some of these have been featured in this Report, which serves to demonstrate how States and international aviation are truly getting On Board a Sustainable Future.

Cooperation was also clearly on display in the important work undertaken of late by our Committee on Aviation Environmental Protection (CAEP), a key contributor to our technical achievements in the Environmental domain. The CAEP brings together more than 600 international experts, from all fields related to aviation and the environment, and its recent work has helped us to recommend the first-ever CO_2 certification Standard for aircraft. More generally, intensified cooperation is helping us to define new operational improvements, and to support the development and deployment of sustainable alternative fuels at an unprecedented pace.

ICAO's leadership role on the environment relies in part on our historic ability to guide and assist those who wish to act to protect the environment, but who may not have the means to do so. In the spirit of our ongoing No Country Left Behind initiative, we will continue to pursue capacity-building and assistance measures towards the more effective implementation of ICAO's global Standards and Policies, a critical enabler of our broader environmental goals.

Dr. Olumuyiwa Benard Aliu
President of the Council

NOW BOARDING

For almost five decades now, the International Civil Aviation Organization (ICAO) has been at the forefront of aviation environmental issues. During this time, we have worked cooperatively with a wide variety of stakeholders, driving positive progress on emissions reduction and assisting States to address aviation's environmental impacts through globally-harmonized approaches.

Delivering on an ambitious environmental agenda in response to the mandate received from its Member States, ICAO has evolved its environmental activities into a broader, truly global vision for greener air transport. Sustainable development is at the heart of our strategy, and serves to ensure that future generations will continue to enjoy the wide-ranging benefits of safe and secure air transport on an environmentally responsible basis.

Turning this vision into action, ICAO's current Strategic Objectives contribute to 13 out of the 17 United Nations Sustainable Development Goals (UN SDGs), and our Environmental work programme alone contributes to ten of them. Adopted by world leaders in September 2015, the UN SDGs are our common roadmap to transform our world beyond 2030, and global air transport connectivity is an essential enabler for many of them.
ICAO is committed to leading international aviation efforts towards the attainment of the UN SDGs, and this 2016 ICAO Environmental Report is a clear reflection of our dedication to delivering tangible results. On-Board a Sustainable Future sets a strong foundation for more forward-looking policies and better preparedness on our environmental challenges, while helping to increase awareness globally of how aviation's benefits are essential to the realization of truly sustainable civil societies.

An important part of my mission as Secretary General of ICAO is to convey this message to our partners, within and outside the United Nations family, in order to help inspire others and demonstrate how tangible solutions to our environmental challenges can be successfully implemented, provided the right framework for action is set. This framework should undoubtedly facilitate partnerships and pave the way for future innovation – key priorities on our shared path to a more sustainable future and the full realization of the UN SDGs.

ICAO is proud to be playing an important part in this endeavour, and we are grateful to the many partners who are cooperating with us on this journey.

Dr. Fang Liu
Secretary General

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THE TRIENNUM IN REVIEW: TOWARDS ENVIRONMENTAL SUSTAINABILITY

The 38th Session of the ICAO Assembly raised expectations for the environmental work of the Organization, emphasizing "the importance of ICAO continuing to demonstrate its leadership role on all international civil aviation matters related to the environment"[1].

On climate change, the "basket of measures" is the pathway which was agreed by our Member States to meet our aspirational goals of a two per cent per annum fuel efficiency improvement, and carbon neutral growth from 2020. Significant progress has been achieved on the implementation of all the basket of measures elements during the past three years, namely innovative technologies, more efficient operational procedures, sustainable alternative fuels, and a global market-based measure suitable to international flight emissions.

A new CO_2 emissions Standard for aeroplanes was recommended earlier this year which should eventually promote a cleaner, more sustainable aviation sector. It will do so by preventing future backsliding and ensuring that enhancements in aircraft environmental performance are implemented by States and the aviation industry.

The new emissions Standard will be complemented by more efficient flight operations, and in this regard ICAO Member States adopted a Global Air Navigation Plan, which outlines a performance improvement and technology roadmap towards shorter routes and less emissions-intensive take offs and landings, through Performance-based Navigation (PBN) and the ICAO Aviation System Block Upgrades (ASBUs).

While technical and operational improvements are therefore well under way, cleaner and more sustainable energy sources could be the real game-changer for aviation emissions reduction.

Alternative fuels are essential to ICAO's environmental strategy and are an integral part of airlines' environmental strategies. Indeed, sustainable alternative drop-in fuels are the only practical renewable energy option available for aircraft today. While the technical feasibility, environmental impacts and safety of biofuels have been well-demonstrated, integrated thinking is now required to accompany their large-scale deployment. But the realization of this potential tomorrow is highly dependent on the policies we put in place today.

Another important element of our environmental work involves the assistance and capacity-building we engage in on our Member States' Action Plans outlining their aviation emissions mitigation actions. ICAO has implemented dedicated Action Plan assistance projects, in partnership with the European Union (EU), the United Nations Development Programme (UNDP) and Global Environment Facility (GEF). This has allowed, among other recent benefits, for the installation of solar panels at airports to supply international aviation gate operations with renewable energy.

In 2013, the 38th Session of the ICAO Assembly "*decided to develop a global Market-Based Measure [MBM] scheme for international aviation*"[2] which would be implemented from 2020.

A number of actions have been taken by ICAO in order to fulfill this mandate, including raising awareness of the key principles underpinning the functioning and design of a global MBM scheme. To achieve this objective, ICAO organized a series of Global Aviation Dialogues (GLADs) on MBMs in 2015 and 2016, which educated and informed States on the MBM issues and permitted well-informed deliberations on the global MBM's design. An essential element of our work going forward will be to support States in building the necessary Monitoring, Reporting and Verification (MRV) capacities they will need to implement the Global MBM, should it be adopted by our 39th Assembly this autumn.

ICAO is working hard to be the next global climate success story, and to achieve carbon neutral growth from 2020, and we are striving to foster stronger cooperation with our partners in order to do so.

Mr. Boubacar Djibo
Director, Air Transport Bureau

1. Assembly Resolution A38-17
2. Assembly Resolution A38-18

OUR FLIGHT PLAN

The ICAO Environmental Report 2016 is the Organization's opportunity to share information on the progress made over the last three years across key areas of ICAO's environmental protection activities. This compendium of scientific articles informs the public of the work of the ICAO Secretariat, ICAO Member States and the many other stakeholders involved.

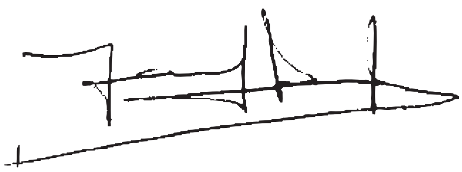
In this edition, concrete case studies have been added to illustrate the quantified benefits of the mitigation actions developed and supported by ICAO. Major steps have been taken since the 38th Session of the ICAO Assembly in 2013 to equip States with the tools needed to pave the way for an environmentally sustainable future, and some initiatives are already bearing fruit.

The 2016 ICAO Environmental Report provides a comprehensive overview of our work relating to noise (Chapter 2), air quality (Chapter 3), and CO_2 emissions (Chapter 4). Emerging topics have proven to be of increasing interest to ICAO Member States, leading to intensification of ICAO's work on the environmental management of aircraft life-cycle processes, respecting the guiding principles of "reduce, reuse, recycle" (Chapter 6), and climate change adaptation (Chapter 7).

All of ICAO's work is data-driven, and an important pillar of ICAO's decision-making on environment are the ICAO trends we develop for traffic, noise and emissions (Chapter 1).

The last three years have also seen the proliferation and strengthening of ICAO partnerships on the environment (Chapter 8). These lay the foundation for robust objectives and multiply the effects of our actions, a point which is particularly true in the area of climate change mitigation (Chapter 5). Here, the assistance projects implemented by ICAO in the context of its States' Action Plan initiative have led to the implementation of targeted CO_2 emissions reduction measures.

Readers may further wish to note that each of these chapters clearly identifies how the work being described in them contributes to the UN Sustainable Development Goals (SDGs), thereby illustrating and reinforcing the relevance of ICAO's environmental strategy and actions to the overall attainment of the UN 2030 Agenda for Sustainable Development.



Ms. Jane Hupe
Deputy Director Environment

COMMITTEE ON AVIATION ENVIRONMENTAL PROTECTION (CAEP)

BY JANE HUPE, CAEP SECRETARY

The Committee on Aviation Environmental Protection (CAEP) is the only 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 24 Members from all regions of the world, and 15 Observers (see **Table 1**). Over 600 internationally-renowned experts are involved in CAEP activities and working groups (see **Figure 1**). All of its proposals for example, measures to minimize noise and emissions, are assessed on the basis of four criteria: technical feasibility, environmental benefit, economic reasonableness, and interdependencies. The CAEP held three Steering Group meetings to guide the work programme during the three-year period leading up to the tenth meeting of CAEP in February 2016 (CAEP/10).

The ICAO Council reviews and adopts CAEP recommendations, including amendments to the Standards and Recommended Practices (SARPs) on aircraft noise (Annex 16, Volume I), engine emissions (Annex 16, Volume II), and the recently recommended Annex 16, Volume III on aeroplane CO_2 emissions. In turn, the Council reports to the ICAO Assembly (191 States plus international organizations) where the main policies on environmental protection are ultimately adopted and translated into Assembly Resolutions.

CAEP/10 Achievements

The Tenth meeting of the Committee on Aviation Environmental Protection (CAEP/10) was held at ICAO headquarters in Montréal, Canada in February 2016. The meeting was attended by approximately 200 participants. This meeting marked the culmination of three intense years of activity by the CAEP working groups looking into aircraft noise, operations, and emissions. It involved more than 600 experts from different States and organizations around the world.

Based on the work of the Committee's technical experts, the CAEP/10 meeting agreed on a comprehensive set of 17 recommendations that will help ICAO fulfill its mandate on aviation environmental protection. Key areas of progress and focus during CAEP/10 included:

- an agreement on a new aeroplane CO_2 emissions Standard;
- an agreement on a new non-volatile Particulate Matter (nvPM) engine emission Standard;
- review of the significant technical work completed so far on a Global Market Based Measure (GMBM);
- tabling of updated trends for CO_2, noise and engine emissions;
- recommendation of a new Circular on "Community Engagement on Aviation Environmental Management"; and
- establishing priorities and work programmes for the CAEP/11 work cycle (2016-2019).

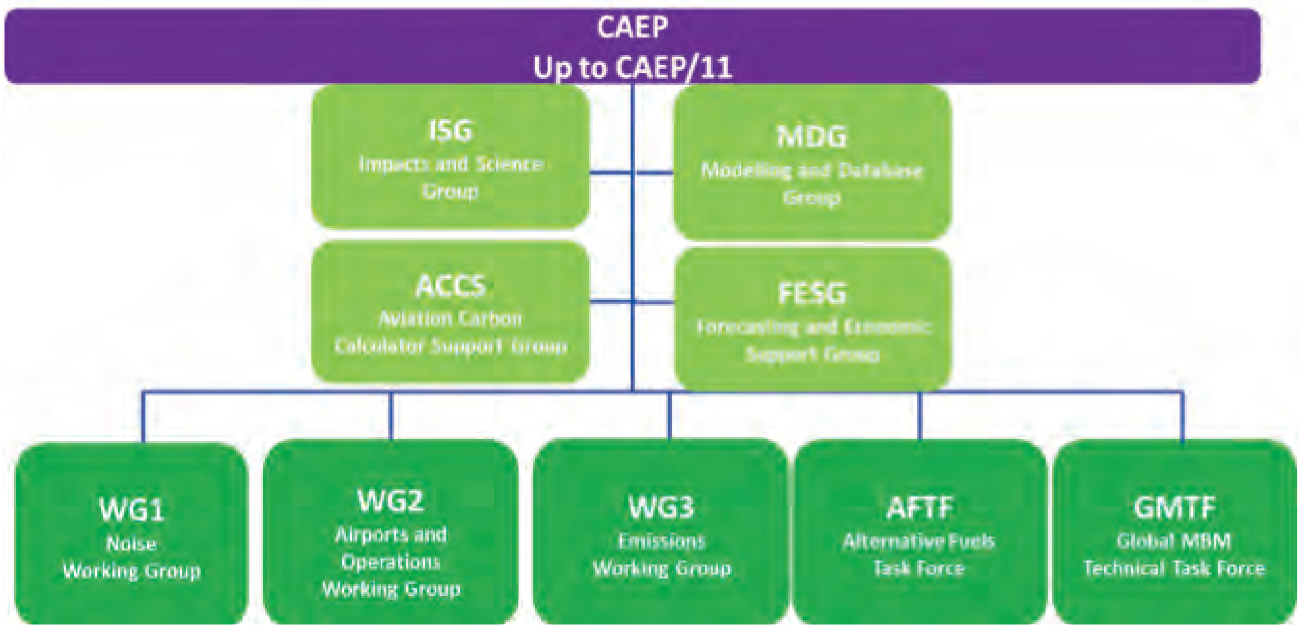


Figure 1. CAEP working groups and structure approved at CAEP/10 (2016)

Members (24 States)		
Argentina	Australia	Brazil
Canada	China	Egypt
France	Germany	India
Indonesia	Italy	Japan
Netherlands	Poland	Russian Federation
Singapore	South Africa	Spain
Sweden	Switzerland	Ukraine
United Arab Emirates	United Kingdom	United States

Observers (5 States and 10 Organizations)		
Greece	Norway	Peru
Saudi Arabia	Turkey	ACAC
ACI	CANSO	EU
IATA	IBAC	ICCAIA
ICSA	IFALPA	UNFCCC

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

New Standards on CO_2 emissions and nvPM

The results of the CAEP/10 meeting were unprecedented, because it was the first time CAEP had been able to recommend two completely new standards in one meeting, on Carbon Dioxide (CO_2) and non-volatile particulate matter (nvPM) emissions.

The recommended Aeroplane CO_2 Emissions Certification Standard is a technology standard with the aim of encouraging more fuel efficient technologies into aeroplane designs. This technology-based approach is similar to the current ICAO engine emissions standards for Local Air Quality (LAQ) and the aircraft noise standards. The recommended CO_2 standard has been developed at the aeroplane level, and therefore has considered all technologies associated with the aeroplane design (e.g. propulsion, aerodynamics and structures). This approach is similar to the current ICAO aircraft noise standards. The CO_2 standard will apply to subsonic jet and turboprop aeroplanes that are new type (NT) designs from 2020, as well as to those aeroplane type designs that are in-production (InP) in 2023 and undergo a change. Regarding the latter, if after 2023 any InP aeroplane type design that is changed to the extent that it triggers applicability, it would then need to be made compliant with the standard. In 2028, there is a production cut-off. This means that InP aeroplanes that do not meet the standard can no longer be produced from 2028, unless the designs are modified to comply with the standard. The recommendation on the CO_2 emissions standard was supported by a significant data driven process and the cost-benefit modelling analysis of several different CO_2 stringency options. The new CO_2 emissions Standard is recommended as being included in an entirely new Volume to Annex 16 (Volume III).

The recommended new nvPM standard has been developed for the certification of aircraft engines emissions and is set at the engine level, in a similar way to the current ICAO engine emission standards. The recommended new nvPM standard will apply to engines manufactured from 1 January 2020, and is for the certification of aircraft engines with rated thrust greater than 26.7kN. The new nvPM standard is the first of its kind, and it includes a full standardized certification procedure for the measurement of nvPM, and the regulatory limit for the nvPM mass concentration set at the current ICAO smoke visibility limit. The new nvPM standard is recommended as a new Chapter to Annex 16, Volume II. The agreement on the new nvPM standard will set the basis for a more stringent nvPM standard during CAEP/11.

The aeroplane CO_2 and engine nvPM standards will be subject to final review and adoption by the ICAO Council during 2017. Further information on the nvPM and CO_2 standards can be found in Chapters 3 and 4 of this Environmental Report.

Global Market-Based Measure (MBM) Scheme

During the 38th session of the Assembly, the ICAO Council was requested to finalize the work on the technical aspects, environmental and economic impacts and modalities of the possible options for a global MBM scheme, including on its feasibility and practicability, taking into account the need for development of international aviation, the proposal of the aviation industry and other international developments, as appropriate, and without prejudice to the negotiations under the UNFCCC." The mandate included making "a recommendation on a global MBM scheme that appropriately addresses them and key design elements, including a means to take into account special circumstances and respective capabilities […], and the mechanisms for the implementation of the scheme from 2020 as part of a basket of measures which also include technologies, operational improvements and sustainable alternative fuels to achieve ICAO's global aspirational goals." The Council's first action following the 2013 Assembly was to establish the EAG, mandated to oversee all work related to the global MBM scheme and make recommendations to the Council. The EAG started with a "strawman" approach, a basic proposal with a view to generating discussion and analysis. As part of the assessment process, the EAG called on CAEP for a series of analyses, including:

- future CO_2 emissions volumes from international aviation and cost impacts to achieve carbon-neutral growth from 2020;
- approaches for distribution of offsetting requirements to individual aircraft operators;
- cost impacts using various combinations for operator and international aviation growth factors; and
- comparison of approaches to offsetting requirements

CAEP undertook additional work on technical aspects of the global MBM scheme, such as monitoring, reporting and verification (MRV), emissions unit criteria (EUC), and registries.
The CAEP/10 meeting reviewed the significant technical work completed so far, and agreed on recommendations related to MRV, EUC, and registries. CAEP recommended that the technical reports submitted to the meeting be used as the basis for further work, pending future decisions by the Council and Assembly. The meeting also recognized the analytical work undertaken by CAEP on various approaches for a global MBM scheme to support the work of the Council and its Environment Advisory Group (EAG). The work continues leading up to the 39th Assembly and further information on MBMs can be found in Chapter 4 of this Environmental Report.

Sustainable Alternative Fuels

The use of sustainable alternative fuels is an important element of the basket of measures for reducing aviation's impact on the global climate and also on air quality. CAEP has carried out a substantial amount of work related to developing a projection for the possible availability of sustainable alternative fuels in 2020 and 2050, along with their potential to reduce net CO_2 emissions. The analysis showed that in 2020, a reduction of 1.3 per cent of international aviation CO_2 emissions could be possible from the use of sustainable alternative fuels. By 2050, 100 per cent of international aviation jet fuel demand could be met with alternative fuels. However, such a scenario is highly dependent on policy decisions that are taken. CAEP also carried out a considerable amount of work on the life-cycle analysis methodology for sustainable alternative fuels for use in a global MBM scheme. Further information on Alternative Fuels can be found in Chapter 4 of this Environmental Report.

New Air Cargo CO_2 EmissionsTool

The current ICAO Carbon Calculator for passenger air travel emissions is one of the most popular tools developed by ICAO. It allows passengers to estimate the emissions attributed to their air travel. It is simple to use and only requires a limited amount of information from the user. To complement the ICAO Carbon Calculator for passenger air travel emissions, during the CAEP/10 meeting, a methodology to quantify air cargo CO_2 emissions was recommended by CAEP. This new methodology will predict the CO_2 emissions from cargo shipped on board both passenger and dedicated cargo aircraft. This tool will only require information such as origin and destination. The ICAO Carbon Calculator is available for use on the ICAO website and on mobile applications (see http://www.icao.int/environmental-protection/carbonoffset/pages/default.aspx and Chapter 4 of this Environmental Report).

Environmental Trends

Every three years, CAEP develops an analysis of environmental trends in aviation to include: Aircraft Emissions that affect the Global Climate; Aircraft Noise; and Aircraft Emissions that affect Local Air Quality (LAQ). CAEP uses 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 CAEP/10 meeting, CAEP developed an updated set of trends and it was recommended that these be the basis for decision-making on matters related to the environment during the 39th ICAO Assembly. Further information on the Environmental Trends in Aviation to 2050 can be found in Chapter 1 of this Environmental Report.

Aircraft Noise

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. CAEP continued its important work of ensuring that the ICAO noise standards are up to date and relevant. CAEP also continued the important work of monitoring noise technology and understanding the progress towards the use of these technologies on-board aircraft. This is part of the continued efforts to ensure that the latest available noise reduction technology is incorporated into aircraft designs.

Supersonic Noise Standard

CAEP also continued its work on the development of a new supersonic noise standard for future aircraft, and understanding the current state of sonic boom knowledge, research and supersonic aeroplane projects. It is anticipated that the certification of a supersonic aeroplane could occur in the 2020-2025 timeframe.

It was also recognized that based on the CAEP trends work, for the first time, ICAO and its Member States may be able to consider the possibility that, under an advanced technology improvements scenario, an increase in aircraft operations may no longer result in an increase in noise contour area after 2030. This demonstrates how ICAO Standards for aircraft noise are working, and of the possibility of decoupling of air traffic growth and noise growth.

Further information on Aircraft Noise can be found in Chapter 2 of this Environmental Report.

Airports and Operations

The ICAO Global Air Navigation Plan (GANP) offers the potential to deliver fuel and CO_2 emissions reductions. Recognizing this, an analysis of environmental benefits from the implementation of the Aviation System Block Upgrade (ASBU) Block 0 was conducted by CAEP. The analysis showed that the full implementation of the aviation system block upgrade (ASBU) Block 0 could achieve 0.7 to 1.4 per cent fuel saving in 2018 compared to 2013.

CAEP continued its work on assisting states with developing guidance material on airport planning. The CAEP/10 meeting recommended an update to the Airport Planning Manual, Part 2, to include climate change considerations and to meet the direct needs for guidance of States facing environmental challenges at and around airports. CAEP also recommended a new Circular on "Community Engagement on Aviation Environmental Management", which identifies key principles for stakeholders communication.

State of the Science

During the CAEP/10 meeting a set of White Papers were presented which provided the summary of a scientific literature review on a number of areas associated with aviation and environment. This summary was developed during an ICAO CAEP Aviation Environmental Impacts Seminar, which involved designated internationally-recognized experts to inform the process of writing the White Papers. The following three White Papers are published as articles within this Environmental Report, and these report the State of Science on:

- **Aviation Noise Impacts:** This article summarizes the state of knowledge on noise measurement and prediction and the relationship between aviation noise and community annoyance, children's learning, sleep disturbance and health impacts. Further information can be found in Chapter 2 of this Environmental Report.
- **Aviation Impacts on Air Quality:** This article includes an update to the aircraft Particulate Matter (PM) emissions State of the Science, with a particular focus on PM caused by aircraft and their impacts on surface air quality. Information is also presented on measuring and modelling emissions, PM emissions from alternative fuel combustion, modelling emissions dispersion and concentrations, and cruise emissions impacts on air quality. Further information can be found in Chapter 3 of this Environmental Report.
- **Aviation and Climate:** This article provides a summary of recent progress on the state of the science since 2012, especially related to contrails and induced cloudiness, aerosol and NOx effects, and emissions from alternative aviation fuels. Further information can be found in Chapter 4 of this Environmental Report.

Future Work and Meetings

The meeting developed the future work programme for CAEP/11, and the three top priorities are the collection of data and further consideration of stringency levels for the nvPM Standard, completion of remaining technical work related to a global MBM scheme, and support for the implementation of the CO_2 emissions Standard. In addition, a number of emerging issues were highlighted, namely:

1) synthesis report on adaptation to climate change;
2) report on aircraft recycling; and
3) placing international aviation into context with a 1.5°C/2.0°C temperature increase scenario. These new areas are addressed further within this Environmental Report.

Figure 2. The CAEP/10 meeting, ICAO Headquarters, Montreal, Canada, 1 to 12 February 2016

CHAPTER 1

AVIATION AND ENVIRONMENTAL OUTLOOK

OVERVIEW
BY ICAO SECRETERIAT

ICAO first initiated the development of Standards and Recommended Practices related to aircraft noise in the 1960s with similar work on smoke emissions from aircraft engine following shortly thereafter. These efforts were aimed to limit the adverse impact of international civil aviation on the environment becoming a strategic objective of the Organization. To ensure a sound basis for policy decisions to achieve this objective, since 2010, the Assembly has agreed that the environmental trends projections prepared by the ICAO Committee on Aviation Environmental Protection (CAEP) be the basis for their decision-making on matters related to the environment. Today, ICAO has agreed a comprehensive set of environmental aircraft design Standards that cover noise, five pollutants that affect local air quality, and CO_2 emissions to protect the global climate.

ICAO's policies are established by its 191 member States, who meet normally every three years at the ICAO Assembly. Given that decisions taken by ICAO are international in nature, a solid and common basis for its consensus-based decision-making is needed, and ICAO is quite unique as it develops these trends assessments in-house.

CAEP brings together the most comprehensive set of data on aircraft performance and operations available and a cadre of experts from all regions of the world to apply a state-of-the-art modelling framework in order to prepare the trends. The scenarios presented for the consideration of the Assembly reflect the inputs of all relevant stakeholders, including aircraft and engine manufacturers, airlines, air navigation service providers and non-governmental organizations. In addition, panels of independent experts provide unbiased input related to noise, emissions, and operational changes. The involvement of this broad range of expertise allows the effects of traffic growth, fleet turnover, technology improvement, and operational enhancements to be accurately captured. The end result of these efforts is the globally recognized trends that are described in this chapter.

The trends that were presented to the ICAO Assembly in 2010 provided insights into the future contributions of aircraft technology and operational changes to aircraft noise, emissions that affect local air quality and emissions that affect the global climate. Updates were made to the trends presented to the ICAO Assembly in 2013, including updated traffic and fleet forecasts and the ability to understand the contributions that aircraft technology and operational changes can make independently. The trends presented in 2010 only showed the combined effects of technology and operational improvements.

Of course, the needs and priorities of the Organization evolve over time and while the trends cover a period of 40 years, they require regular update. One of the most rapidly evolving areas in the field of aviation environmental protection is the development of sustainable alternative fuels. As discussed in Chapter 4, Global Emissions, with five approved pathways to date for producing alternative jet fuel, their technical feasibility of proven. It is, therefore, now appropriate to begin developing scenarios that reflect their possible contribution toward reducing lifecycle CO_2 emissions. The inclusion of these scenarios represents the most significant update to the trends, thereby supporting discussions related to not only alternative fuels, but also in the context of the basket of measures for reducing international aviation's impact on the global climate.

This chapter describes the set of trends that are presented to the Assembly for their decision-making, complete with descriptions of the scenarios in order to provide the reader with insight into the future evolution of international civil aviation noise and emissions. The effectiveness of ICAO's Standards is clear, with aircraft noise and emissions both growing at a rate slower than the increase in air traffic, including the possibility that within 15 years, under advanced technology scenarios, aircraft noise may no longer grow at all. All indications are that the future is brighter… and quieter!

Sustainable Development Goals

ENVIRONMENTAL TRENDS IN AVIATION TO 2050

BY GREGG G. FLEMING (UNITED STATES DEPARTMENT OF TRANSPORTATION VOLPE NATIONAL TRANSPORTATION SYSTEMS CENTER) AND URS ZIEGLER (FEDERAL OFFICE OF CIVIL AVIATION, SWITZERLAND)

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

- **Aircraft Emissions that affect the Global Climate;**
- **Aircraft Noise; and**
- **Aircraft Emissions that affect Local Air Quality (LAQ).**

CAEP 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.

Trends in Aviation Emissions that affect the Global Climate

The assessment of GHG trends is based on the latest CAEP central demand forecast using a base year of 2010; the validity of which was assessed in the CAEP/10 (2016) cycle. Forecasted years included 2020 and 2030 with an extension to 2040 and results extrapolated to 2050. Data presented for 2005 and 2006 are reproduced from prior trends assessments.

Three models contributed results to the GHG trends assessment: US Federal Aviation Administration's (FAA) Aviation Environmental Design Tool (AEDT), EUROCONTROL's IMPACT, 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, the Growth and Replacement Fleet Database, and the Common Operations Database (COD), which are all proprietary databases, including Campbell-Hill which is owned and maintained by Airlines for America (A4A).

Table 1 summarizes the nine full-flight fuel burn and CO_2 emissions scenarios developed for the assessment of trends for aircraft emissions that affect the global climate.

The trends presented were developed in the context of a longer-term view. Short term changes in global fuel efficiency can be affected substantially by a wide range of factors such as fluctuations in fuel prices, and global economic conditions. **Figure 1** provides results for global full-flight fuel burn for international aviation from 2005 to 2040, and then extrapolated to 2050. The fuel burn analysis considers the contribution of aircraft technology, improved air traffic management, and infrastructure use (i.e., operational improvements) to reduce fuel consumption. The figure also illustrates the fuel burn that would be expected if ICAO's 2 per cent annual fuel efficiency aspirational goal were achieved.

Figure 2 puts these contributions in context with the uncertainty associated with the forecasted demand, which is notably larger than the range of potential contributions from technological and operational improvements. Despite this uncertainty, the baseline trends forecast is broadly consistent with other published aviation forecasts. The trends forecast, which is for revenue tonne kilometres (RTK) and international aviation, shows a 20 year (2010-2030) compound average annual growth rate (CAGR) of 5.3 per cent. By way of comparison, using revenue passenger kilometres (RPK) for all traffic as the forecast measurement, Boeing's Airbus' and Embraer's most recent 2015 forecasts have 20 year (2014-2034) CAGRs of 4.9 per cent, 4.6 per cent and 4.9 per cent respectively[1]. The CAEP's RPK 20 year forecast (2010-2030) has a baseline forecast of 4.9 per cent, with a low outlook at 4.2 per cent and high at 5.7 per cent. While acknowledging the different forecast units and coverage, the trends baseline outlook shows reasonable alignment with the aviation industry and the most recent CAEP view of future aviation growth in the early 2010s.

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

Figure 3 presents full-flight CO_2 emissions for international aviation from 2005 to 2040, and then extrapolated to 2050. This figure only considers the CO_2 emissions associated with the combustion of jet fuel, assuming that 1 kg of jet fuel burned generates 3.16 kg of CO_2. As with the fuel burn analysis, this analysis considers the contribution of aircraft technology, improved air traffic management and infrastructure use (i.e., operational improvements). In addition, the range of possible CO_2 emissions in 2020 is displayed for reference to the global aspirational goal of keeping the net CO_2 emissions at this level. Although not displayed in a separate figure, the demand uncertainty effect on the fuel burn calculations shown in Figure 2 has an identical effect on the CO_2 results. Based on the maximum anticipated fuel consumption in 2020 (Scenario 1) and the anticipated Scenario 9 fuel consumption in 2040, a minimum CO_2 emission gap of 523 Mt is projected in 2040. Extrapolating Scenario 9 to 2050 results in a 1,039 Mt gap.

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

Table 1. Full-Flight Fuel Burn and CO_2 Scenarios.

Note: Independent Expert is represented as IE. In CAEP/8 (2010), IEs provided a range of operational improvements in the form of a lower bound and upper bound.

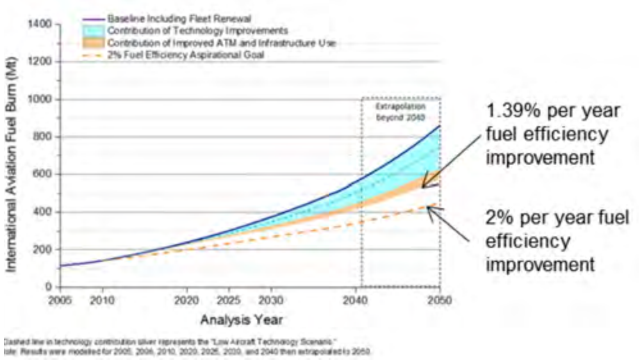


Figure 1. Fuel Burn Trends from International Aviation, 2005 to 2050

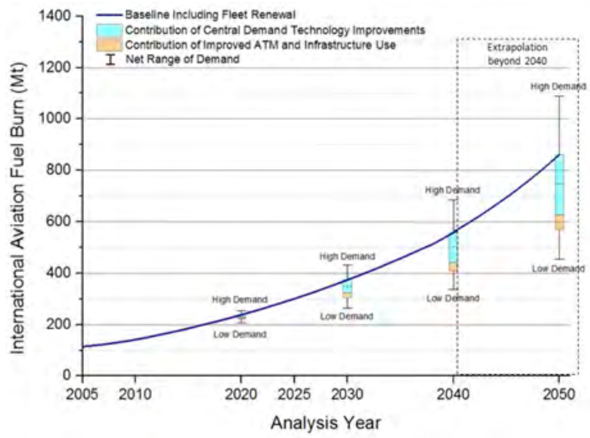


Figure 2. Range of Uncertainties Associated with Demand Forecast, 2005 to 2050

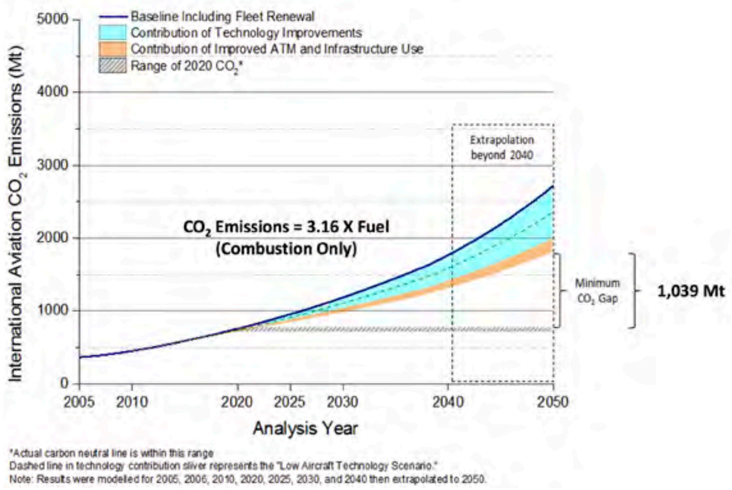


Figure 3. CO_2 Emissions Trends from International Aviation, 2005 to 2050

Contribution of Alternative Fuels to GHG Trends Assessment

CAEP was charged with calculating estimates of alternative jet fuel (AJF) contributions to fuel replacement and life cycle GHG emissions reductions in the Trends Assessment out to 2050. Analyses were performed for 2020 and 2050. The short-term scenarios for AJF availability were established from fuel producers' announcements regarding their production plans from State-sponsored production plans, if associated with ICAO Member State target. For the long-term scenarios, CAEP assessed future jet fuel availability by first estimating the primary bioenergy potential constrained by selected environmental and socio-economic factors; by second estimating the proportion of bioenergy potential that could actually be achieved or produced; and finally by exploring the quantity of AJF that could be produced from the available bioenergy. AJF availability was calculated including 9 different groups of feasible feedstocks (starchy crops; sugary crops; lignocellulosic crops; oily crops; agricultural residues; forestry residues; waste fats, oils and greases; microalgae; municipal solid waste (MSW)). The final values provided by CAEP to MDG include potential total global production and an average Life Cycle Assessment (LCA) value based on the share of different fuel types that contribute to each scenario. The LCA values are not intended to be applied separately to regional forecasts.

For 2020, there were six production estimates and two GHG LCA estimates (low and high), resulting in 12 possible GHG emissions scenarios. The 2020 scenarios provide up to 2 per cent petroleum-based fuel replacement and up to 1.2 per cent GHG emissions reductions.

For 2050, CAEP calculated 60 production achievement scenarios and two GHG emissions scenarios resulting in 120 scenarios. Certain global conditions, economic investments, and policy decisions are assumed as part of each scenario definition and would be necessary to reach the associated outcome of alternative fuel production and GHG reductions.

The trends assessment figures for international aviation shown below include the range of CAEP results and an "illustrative" scenario that achieves 19 per cent net CO_2 emissions reduction assuming significant policy incentives and high biomass availability. Fuel replacement results for international aviation can be found in **Figure 4**. See **Figure 5** for net CO_2 emissions results. The amount of AJF and the associated CO_2 emissions reductions were allocated proportionally between international and domestic use based on projected fuel demand (65 per cent and 35 per cent in 2010, respectively).

For 2020 and 2050, total petroleum-based fuel amounts for the different fuel demand scenarios were multiplied by the specific CO_2 combustion emissions factor of 3.16 to get baseline GHG emissions shown in **Figure 5**. Calculations of GHG emissions reduction were performed according to the following formula provided by the CAEP Market Based Measure Task Group:

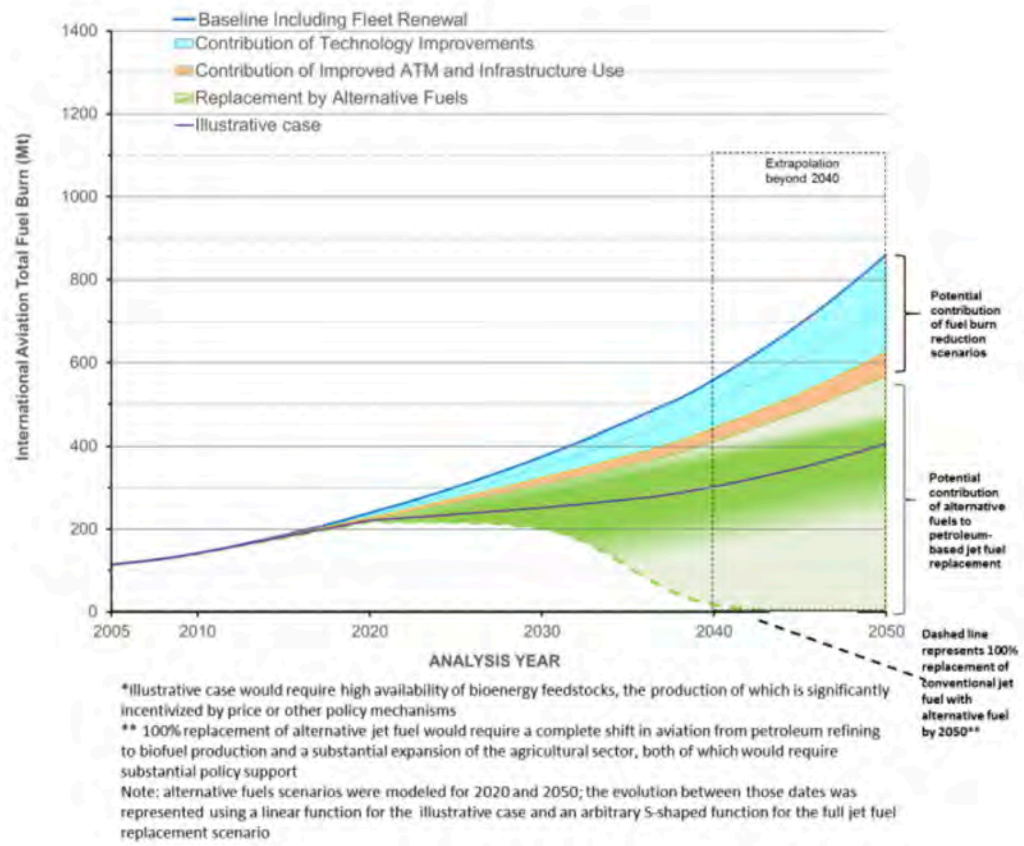


Figure 4. Aircraft Fuel Burn from International Aviation, 2005 to 2050 Updated to Include Potential Replacement of Jet Fuel with Alternative Fuels

Total Emissions = 3.16 x (CJF + AJF*(LCA_AJF/LCA_CJF))
Where CJF = conventional jet fuel, AJF = alternative jet fuel, and **LCA_X** = life cycle CO_2 equivalent emissions of fuel X.[2]

The GHG reduction "wedge" was created by connecting the least contribution scenario values to each other and the greatest contribution values to each other. The 2020 "medium scenario without green diesel" was connected to the 2050 value for the illustrative scenario. CAEP elected to show linear growth for intermediate and high GHG reduction scenarios[3].

Several of the 2050 scenarios that CAEP evaluated resulted in zero alternative jet fuel production and therefore no contribution to GHG emissions reduction[4].

The zero AJF results are equivalent to the line associated with Scenario 9 for technology and operational improvements as described above. The scenario with the greatest contribution to GHG emissions reduction could supply more alternative jet fuel than is anticipated to be used in 2050. For the purposes of this analysis, production for the highest contribution scenario is ramped up to full replacement in 2050 based on Scenario 9.

If industry growth were to follow an s-shaped curve, the highest growth rates would occur around 2035, in which 328 new large biorefineries would need to be built each year at an approximate capital cost of US$ 29 Billion to US$ 115 Billion per year. Lower growth rates would be required in years closer to 2020 and 2050. Achieving this level of emissions reduction would also require the realization of the highest assumed increases in agricultural productivity, highest availability of land for feedstock cultivation, highest residue removal rates, highest conversion efficiency improvements, largest reductions in the GHG emissions of utilities, as well as a strong market or policy emphasis on bioenergy in general, and alternative aviation fuel in particular. This implies that a large share of the globally available bioenergy resource would be devoted to producing aviation fuel, as opposed to other uses.

Achievement of carbon neutral growth at 2020 emissions levels out to 2050 would require nearly complete replacement of petroleum-based jet fuel with sustainable alternative jet fuel besides the implementation of aggressive technological and operational scenarios. The future development and use of alternative fuels will highly depend on the policies and incentives in place for such fuels. Based on the analysis assumptions, if enough alternative jet fuel were produced in 2050 to completely replace petroleum-derived jet fuel, it would reduce net CO_2 emissions by 63 per cent.

Trends in Aircraft Full Flight NO_X Emissions

The following scenarios were assessed for Full Flight NOx:
Scenario 2 is the moderate aircraft technology and CAEP/9 (2013) Independent Expert (IE) Operational Improvement case that assumes aircraft NOx improvement based upon achieving 50 per cent of the reduction from current NOx emission levels

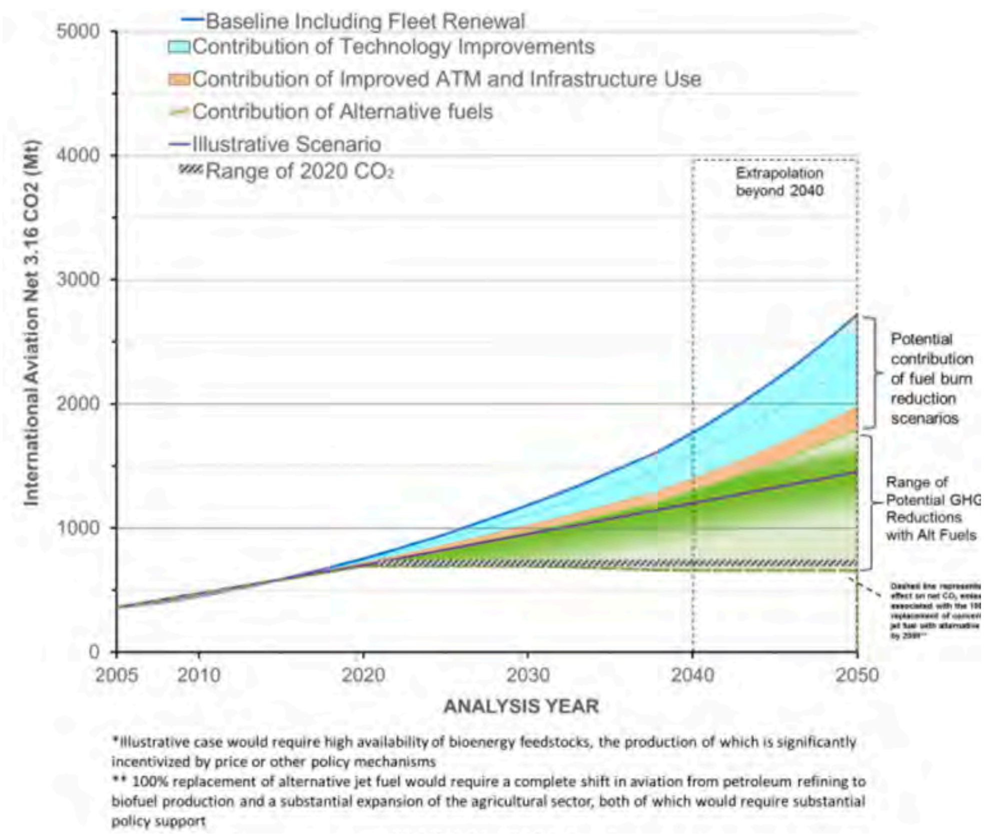


Figure 5. Aircraft CO_2 Emissions from International Aviation, 2005 to 2050, Updated to Include Alternative Fuels Life Cycle Emissions Reductions

to the NOx emissions levels by CAEP/7 (2007) NOx IE goals review (-60 per cent +/- 5 per cent of current CAEP/6 (2004) NOx Standard) for 2030, with no further improvement thereafter.

Scenario 3 is the advanced aircraft technology and CAEP/9 (2013) IE Operational Improvement case that assumes aircraft NOx improvement based upon achieving 100 per cent of the reduction from current NOx emission levels to the NOx emissions levels by CAEP/7 (2007) NOx IE goals review (-60 per cent +/- 5 per cent of current CAEP/6 (2004) NOx Standard) for 2030, with no further improvement thereafter.

Two models contributed results to the full flight NOx trends assessment: (1) FAA's AEDT; and (2) EUROCONTROL's IMPACT. MDG results for international operations are shown in **Figure 6**. The 2010 baseline NOx value is 2.15 MT. In 2040, the NOx value ranges from about 4.81 MT with Scenario 3 to 6.35 MT with Scenario 2.

Interpretation

In 2010, international aviation consumed approximately 142 million metric tonnes of fuel, resulting in 448 million metric tonnes (Mt, 1kg x 10^9) of CO_2 emissions. By 2040, fuel consumption is projected to have increased 2.8 to 3.9 times the 2010 value,

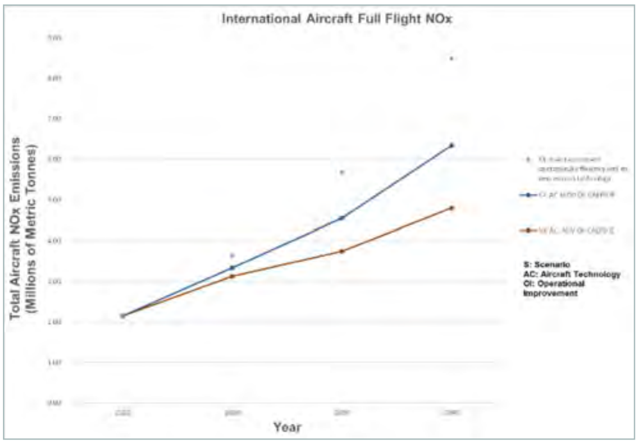


Figure 6. International Aircraft Full Flight NOx

while revenue tonne kilometres are expected to increase 4.2 times under the central demand forecast. By extrapolating to 2050, fuel consumption is projected to have increased 4 to 6 times the 2010 value, while revenue tonne kilometres are expected to increase 7 times under the central demand forecast.

Under Scenario 9 as defined 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 cent per annum to 2040, and at 1.39 per cent per annum, if extrapolated to 2050. While in the near term (2010 to 2020), efficiency improvements from technology and improved ATM and infrastructure use are expected to be moderate, they are projected to accelerate in the mid-term (2020 to 2030). During the 2020 to 2030 period, fuel efficiency is expected to improve at an average rate of 1.76 per cent per annum under Scenario 9. The magnitude of the modelled fuel efficiency improvements is as expected given the 1.5 per cent per annum technology improvement associated with Scenario 9, and the variability of the forecasted RTK. This 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 cent per annum fuel efficiency.

In 2020, it is expected that international aviation will consume between 216 and 239 Mt of fuel, resulting in 682 to 755 Mt of CO_2 emissions. Under the range of 2020 scenarios, it is estimated that up to 2 per cent of this fuel consumption could consist of sustainable alternative fuels in 2020. Significant uncertainties exist in predicting the contribution of sustainable alternative fuels in 2050. Based on scenarios considered by CAEP, it is possible that up to 100 per cent of the CO_2 emissions gap could be closed with sustainable alternative fuels in 2050, but this would require nearly complete replacement of petroleum-based fuels with sustainable alternative jet fuel. Complete replacement would require approximately 170 new large biorefineries to be built every year from 2020 to 2050, at an approximate capital cost of US$15 Billion to US$60 Billion per year if growth occurred linearly.

Achieving this level of emissions reduction would also require the realization of the highest assumed increases in agricultural productivity, highest availability of land for feedstock cultivation, highest residue removal rates, highest conversion efficiency improvements, largest reductions in the GHG emissions of utilities, as well as a strong market or policy emphasis on bioenergy in general, and alternative aviation fuel in particular. This implies that a large share of the globally available bioenergy resource would be devoted to producing aviation fuel, as opposed to other uses.

Even under this scenario, achieving carbon neutral growth exclusively from the use of sustainable alternative fuels is unlikely to happen in 2021 or shortly thereafter as for the production of alternative fuels an initial ramp-up phase is required before production can reach the levels mentioned above.

Trends in Aircraft Noise

A range 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 does not include any aircraft technology improvements beyond those available in 2010 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 in 2010, 2020, 2030, and 2040. The other scenarios assume increased implementation of both operational and technological improvements. Scenarios 2, 3, and 4 are assumed to represent the range of most likely outcomes.

For airports outside the United States (US) and Europe two different population sources were used to count people inside

Scenario	Name	Technology Improvement	Operational Improvement
1	Sensitivity Case	None	None
2	Low Aircraft Technology and Moderate Operational Improvement	0.3 EPNdB/annum, 2011 -2013	2 per cent reduction in contour area shape applied to population exposed.
3	Moderate Aircraft Technology and Operational Improvement	0.3 EPNdB/annum, 2011 -2030 0.1 EPNdB/annum, 2031 -2040	2 per cent reduction in contour area shape applied to population exposed.
4	Advanced Aircraft Technology and Moderate Operational Improvement	0.3 EPNdB/annum, 2011 -2040	2 per cent reduction in contour area shape applied to population exposed.

Table 2. Scenarios Developed for the Assessment of Aircraft Noise Trends
Note: EPNdB means Effective Perceived Noise Level in Decibels.

Scenario	Name	Technology Improvement	Operational Improvement
1	Sensitivity Case	None	None
2	Moderate Aircraft Technology and Operational Improvement	50 % CAEP/7 NOx Independent Expert goals for 2030, nothing thereafter	CAEP/9 IE
3	Advanced Aircraft Technology and Operational Improvement	100 % CAEP/7 NOx Independent Expert goals for 2030, nothing thereafter	CAEP/9 IE

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

of contours (legacy GRUMP and the newer LANDSCAN).[5] Comparisons between GRUMP/LANDSCAN and census sources from the US, United Kingdom, and Mainland Europe yielded mixed results, with some airports having higher and some lower population counts. Consequently, population results were presented as an uncertainty range, showing both low and high values.

Figure 7 provides results for the total global population exposed to aircraft noise above 55 DNL for 2010, 2020, 2030, and 2040. The 2010 baseline value ranges from a low of 21.4 to a high of 34.9. The population results assume 2010 levels throughout the analysis period (2010 to 2040). Of note is that under an advanced aircraft technology and moderate operational improvement scenario, from 2030, aircraft noise exposure may no longer increase with an increase in traffic.

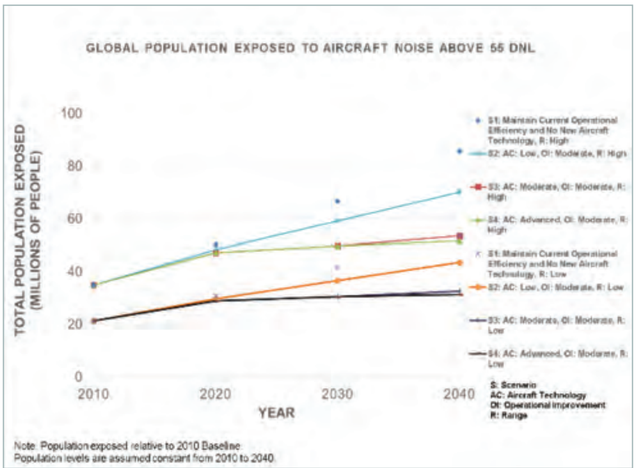


Figure 7. Total Global Population Exposed to Aircraft Noise Above 55 DNL

Trends in Aircraft Emissions that affect Local Air Quality

A range of scenarios have also been developed for the assessment of aircraft emissions trends below 3,000 feet above ground level (AGL) that affect LAQ, particularly NOx, as shown in **Table 3**.

Again, Scenario 1 is the sensitivity case that assumes the operational improvements necessary to maintain current operational efficiency levels, but does not include any aircraft technology improvements beyond those available in 2010 production aircraft. Scenarios 2 and 3 assume aircraft NOx improvements based upon achieving some per cent (50 per cent and 100 per cent, respectively) of the reduction from the current NOx emission levels to the NOx emissions levels by CAEP/7 (2007) NOx Independent Expert goals review (about 60 per cent of the current CAEP/6 (2004) NOx Standard) for 2030, as well as fleet-wide operational improvements by region.

Figure 8 provides results for NOx emissions below 3,000 feet AGL from international operations for 2010, 2020, 2030, and 2040. The 2010 baseline value is about 0.15 million metric tonnes (Mt, 1kg x 10^9). In 2040, total NOx ranges from 0.32 Mt, with Scenario 3, to 0.42 Mt with Scenario 2.

The results for PM emissions from international operations below 3,000 feet AGL follow the same trends as those for NOx. The 2010 baseline PM value is 914 metric tonnes. In 2040, total global PM is projected to be about 3,003 metric tonnes with Scenario 2.

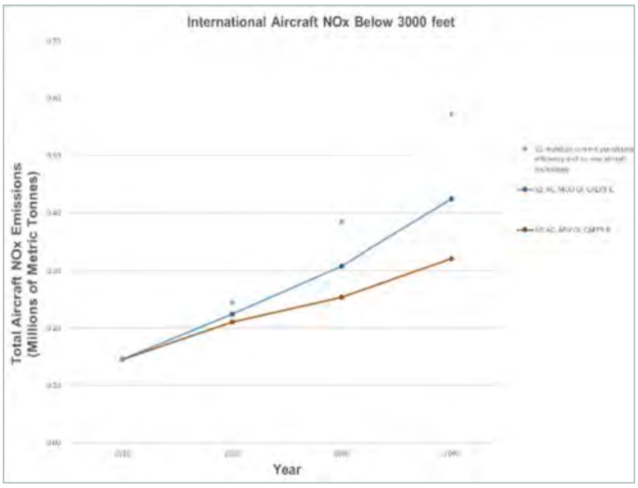


Figure 8. Total International Aircraft NOx Below 3,000 Feet

Conclusion

The CO_2 emissions that affect the global climate, and emissions that affect local air quality are expected to increase through 2050, but at a rate slower than aviation demand. Under an advanced aircraft technology and moderate operational improvement scenario, from 2030, aircraft noise exposure may no longer increase with an increase in traffic. However, it has to be kept in mind that the uncertainty associated with future aviation demand is notably larger than 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 ICAO's 2 per cent annual fuel efficiency aspirational goal. Sustainable alternative fuels have the potential to make a significant contribution, but sufficient data are not available to confidently predict their availability over the long term. Also, considering only aircraft technology and operational improvements, additional measures will be needed to achieve carbon neutral growth relative to 2020.

References

1. http://www.boeing.com/resources/boeingdotcom/commercial/about-our-market/assets/downloads/Boeing_Current_Market_Outlook_2015.pdf;
   http://www.airbus.com/company/market/forecast/;
   http://www.embraermarketoutlook.com/RPK-GPD.html
2. This calculation provides an "in-flight" equivalent of CO_2 emissions reduction based on the life cycle values of the alternative fuels, which are used because reductions in atmospheric carbon from aviation biofuel use occur from feedstock production and fuel conversion and not from fuel combustion.
3. CAEP did not specify a function for connecting the 2020 results to the 2050 results in their outputs. However, CAEP did provide information on the range of options for connecting these results. CAEP anticipates that growth of a new industry such as that for AJF will follow an "S-shaped" trajectory, but it is not clear when investment, and therefore, growth of production capacity of the industry, will ramp up. Ramp up to alternative fuel production in 2050 is anticipated to be somewhere between linear and exponential growth (i.e., the lower end of the S-curve). Linear growth for intermediate and high net CO_2 emissions reduction scenarios is shown. No meaningful data exist in order to calibrate the curve. Therefore, values for intervening years between 2020 and 2050 for the AJF scenarios should be considered illustrative only.
4. These scenarios reflect a lack of bioenergy availability in general or a prioritization of other bioenergy usages over aviation.
5. http://beta.sedac.ciesin.columbia.edu/data/set/grump-v1-population-count
   http://web.ornl.gov/sci/landscan/

EUROPEAN MODELS STRENGTHEN INTEROPERABILITY IN SUPPORT OF CAEP

BY DAVID MARSH (EUROCONTROL), IVAN DE LÉPINAY (EASA), LAURENT CAVADINI (EUROCONTROL) AND LAURENT BOX (EUROCONTROL)

In 2013, IMPACT and AAT were introduced as the new flagship tools within the European aviation environmental modelling tool suite. Both models are based on the experience gained during more than 15 years of environmental model development in support of European environmental assessments, and to support the ICAO Committee on Aviation Environmental Protection (CAEP) assessments.

Impact

AEM is a EUROCONTROL model that can determine the amount of fuel burned by a specific aircraft type equipped with a specific type of engine, flying a specific 4D trajectory. It can also determine the precise by-products of burning that fuel such as: carbon dioxide (CO_2), water vapour (H_2O), oxides of sulphur (SO_X), oxides of nitrogen (NO_X), unburnt hydrocarbons (HC), carbon monoxide (CO), particulate matter (PM), and some volatile organic compounds (VOCs) such as benzene and acetaldehyde.

STAPES is a multi-airport noise model that is the result of successful collaboration by the European Commission (EC), the European Aviation Safety Agency (EASA) and EUROCONTROL. STAPES consists of a noise modelling software, hosted and maintained by EUROCONTROL, which is compliant with the calculation method recommended in ICAO Doc 9911, combined with an airport database that provides information on runway and route layouts, along with statistics on their usage (i.e. distribution of aircraft operations). The STAPES airport database, jointly maintained by EASA and EUROCONTROL, covers 75 European airports that are representative in terms of their noise impact on the surrounding population (i.e. number of people within the L_{den} 55 dB noise contours). EASA and EUROCONTROL continue to work together to expand this database through the inclusion of additional airports, both within the European Union states and other European Civil Aviation Conference (ECAC) Member States. The ultimate goal is to cover 90% of the European population that is significantly exposed to aircraft noise. STAPES is a CAEP-approved noise model that has contributed to CAEP's noise trends assessment and future stringency analyses since 2009.

The introduction of IMPACT constitutes a significant improvement towards achieving robust trade-off assessments between noise and fuel burn and/or gaseous emissions. IMPACT integrates AEM and STAPES into a common modelling platform, with a goal to "feed" these environmental models with common input data in terms of aircraft trajectories (along with other flight parameters of relevance for environmental modelling purposes).

A key component of IMPACT is a new aircraft trajectory calculator, which computes complete aircraft trajectories from the departing airport to the destination point, along with engine thrust and fuel flow information. This common trajectory data is then exported to AEM and the core noise calculation module of STAPES to compute fuel consumption, emissions, and noise contours. With this modelling approach, consistent assessments of trade-offs between noise and fuel burn and/or gaseous emissions are enabled over the portion of the trajectories within the Terminal Manoeuvring Area (TMA). The IMPACT trajectory calculator relies on the Aircraft Noise and Performance (ANP) database and the latest release of EUROCONTROL's Base of Aircraft Data (BADA). The ANP database provides the noise and performance characteristics of a wide range of civil aircraft types, which are required to compute noise contours around civil airports using the calculation method described in ICAO Doc 9911. ANP datasets are supplied by aircraft manufacturers for specific airframe-engine combinations, in accordance with a specific ANP Data Request Form developed and maintained within ICAO. BADA (Base of Aircraft Data) is an aircraft performance model developed and maintained by EUROCONTROL, in cooperation with aircraft manufacturers and operating airlines. BADA is based on a kinetic approach to aircraft performance modelling, which enables the accurate prediction of aircraft trajectories and the associated fuel consumption.

The complete trajectory computed by the IMPACT aircraft trajectory calculator is illustrated in **Figure 1**.

Another key characteristic of IMPACT is that it is a web-based modelling platform remotely accessed by the users, via a dedicated and secured portal. All the calculations are performed on dedicated servers hosted by EUROCONTROL. In particular, users do not need to install any specific software on their machines; they only need a web browser to connect to the IMPACT web portal, upload their input data, launch calculations, visualise, and download the results. This web-based approach

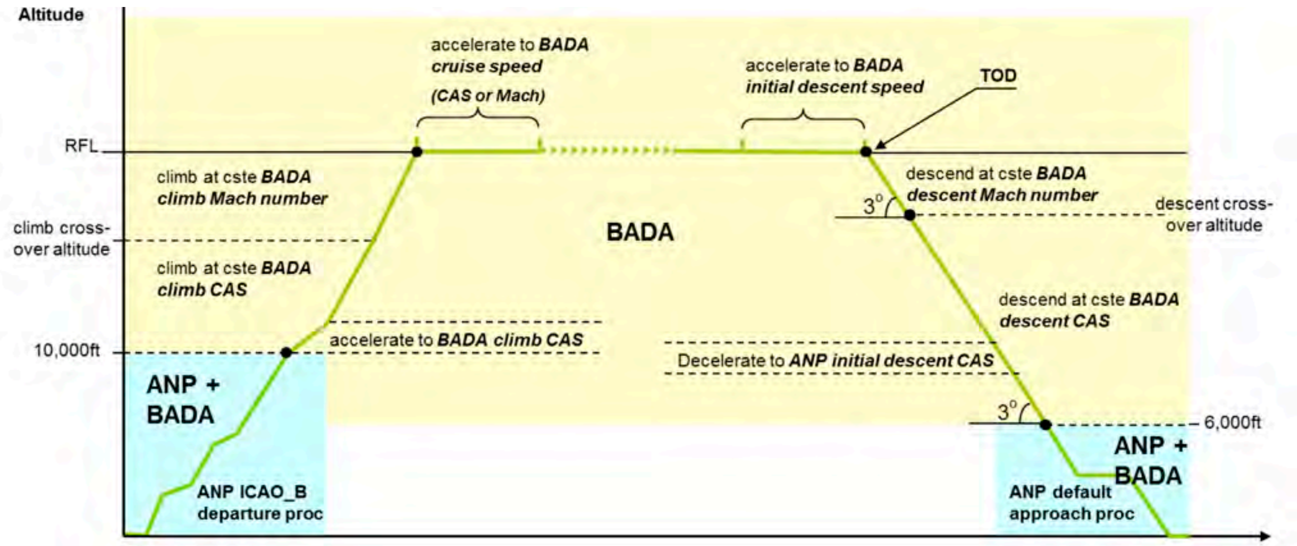


Figure 1. IMPACT full flight procedure used in CAEP[1].

enables easy update of the different databases used by IMPACT, without the need to redistribute a new software package, and provides the flexibility to select the database versions to be used in a study. Another major advantage is that it secures sensitive aircraft reference data such as the BADA data.

IMPACT supports different types of input data, which can be retrieved from various sources (i.e. real-time and arithmetic model-based simulations, real data, or more theoretical definitions of flight procedures). The main results produced by IMPACT include noise contour shapefiles, surface and population count using the European Environment Agency (EEA) population database, fuel burn and emissions of a wide range of pollutants, gridded (i.e. geo-referenced) emission inventories within the LTO portion; as an introduction to further – more detailed – Local Air Quality (LAQ) assessments.

During the CAEP/10 work programme, IMPACT was thoroughly reviewed against other CAEP-approved models and contributed to the CO_2 Standard analysis as well as the greenhouse gas and LAQ trends assessment.

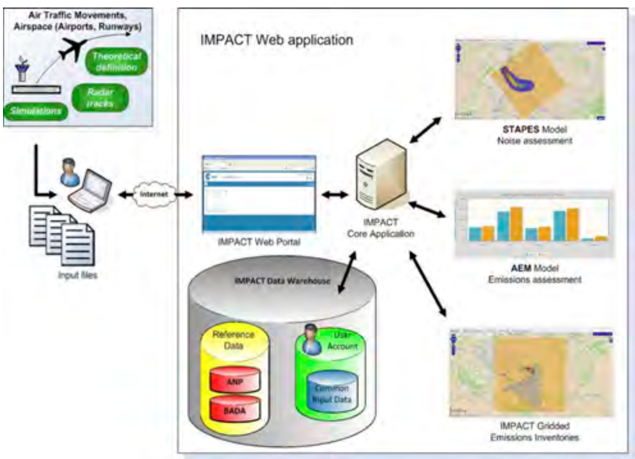


Figure 2. IMPACT Web-based Modelling Platform.

While meeting CAEP assessment needs, IMPACT was also developed to comply with the Single European Sky ATM Research (SESAR) environmental assessment requirements and is the recommended assessment tool for this European ATM research programme.

The Aircraft Assignment Tool (AAT)

To meet European needs and as part of their support of CAEP, the European Commission, EASA and EUROCONTROL have developed a fleet and operations forecasting capability called the Aircraft Assignment Tool (AAT). The AAT is a generic tool that takes as input an existing demand and fleet forecast, such as that from CAEP's Forecasting and Economic Analysis Support Group (FESG), and converts it into a forecast of movements by particular aircraft types on specific airport pairs. The geographical scope is dependent on the forecast, and can range from a single airport pair to full global operations. The output of the AAT can be used as input to environmental models such as IMPACT. Such information can also be used to assess the evolution of the aircraft fleet for future planning and policy purposes.

Aircraft types in AAT are typically grouped by user-defined categories based on their transport and range capability. Within a particular category, each aircraft type is assigned a specific market share. Market shares are specified by the user, which allows the application of various calculation methods including: equal market shares (all aircraft in a bin have the same share); market-driven market shares (shares are derived from the relative operating costs of each aircraft, e.g. using a multinomial logit); and historical market shares (shares are derived from past aircraft deliveries). If the demand forecast is expressed in available seat-kilometres (ASK) or available tonne-kilometres (ATK) for freighters, the AAT adjusts the number of movements on a given route to the size of the aircraft assigned to this route and their respective market shares.

The typical AAT input data consists of: a demand forecast; a set of base year operations (e.g. the Common Operations

Database for CAEP applications); aircraft retirement curves; a set of in-production aircraft over the forecast period (future fleet) along with their respective transport capability (seats/tonnes), maximum range and their market shares in the group they belong to (shares may vary in time). The AAT can also handle user-defined phase-out functions for specific aircraft types.

The AAT was developed following four key non-functional requirements:

Flexibility: With a variety of possible uses, the AAT is flexible enough to process input data from different sources and deliver output data fit for various modelling tools.

Speed: To allow regular updates within strict deadlines and with limited resources (e.g. EUROCONTROL forecasting process), the AAT architecture allows relatively easy operation and fast run-times.

Openness: In order to be transparent, the AAT does not develop its own assumptions (based on historical data patterns or the like). Instead the assumptions are formulated, and the input data constructed, by the user outside the AAT. This allows the AAT to be used for analysis of scenarios and "what-ifs" following different "stories" as defined and specified in the inputs by the user.

Accessibility: The AAT is accessible via a web portal and therefore only requires a web browser and an internet connection to be run.

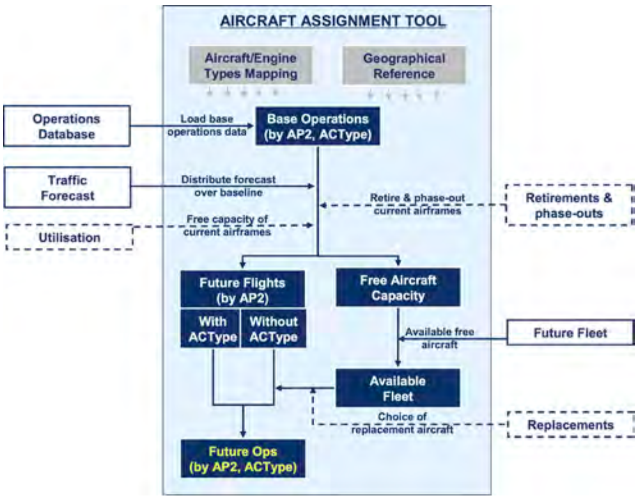
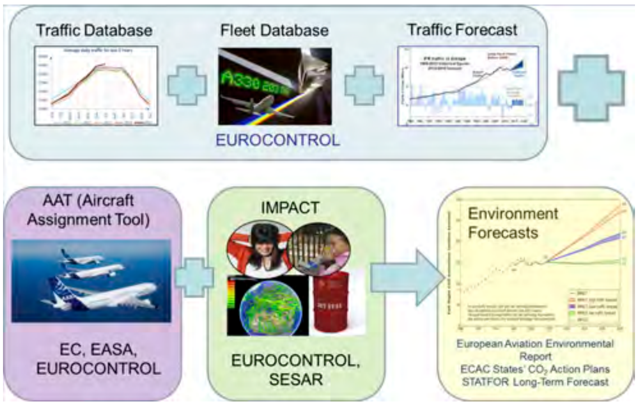


Figure 3. Aircraft Assignment Tool (AAT) design. (AP2 = Airport pair; ACType = Aircraft type)

During the CAEP/10 cycle, the AAT was reviewed by the FESG and was used in the CO_2 standard's cost-effectiveness analysis. During 2015, the focus of work on AAT was on European applications. The tool was integrated into the EUROCONTROL/ STATFOR 20-year forecast toolset for the passenger market segment. Combined with IMPACT, it made it possible to estimate the evolution of noise and emissions in Europe until 2035 under various traffic forecasts and aircraft technology scenarios.

Examples of IMPACT and AAT Benefits:



The combination of AAT and IMPACT enabled to estimate the evolution of noise and emissions in Europe until 2035 under various traffic forecast and aircraft technology scenarios to feed the European Aviation Environmental Report 2016[2].

Future Developments

IMPACT and AAT will continue to be developed in order to meet CAEP/11 and European modelling needs. In particular:

- Additional comparisons between IMPACT and other CAEP models have been initiated, which focus on the calculation of other pollutants such as Particulate Matter (PM), in preparation for the CAEP/11 analyses of the PM Standard.

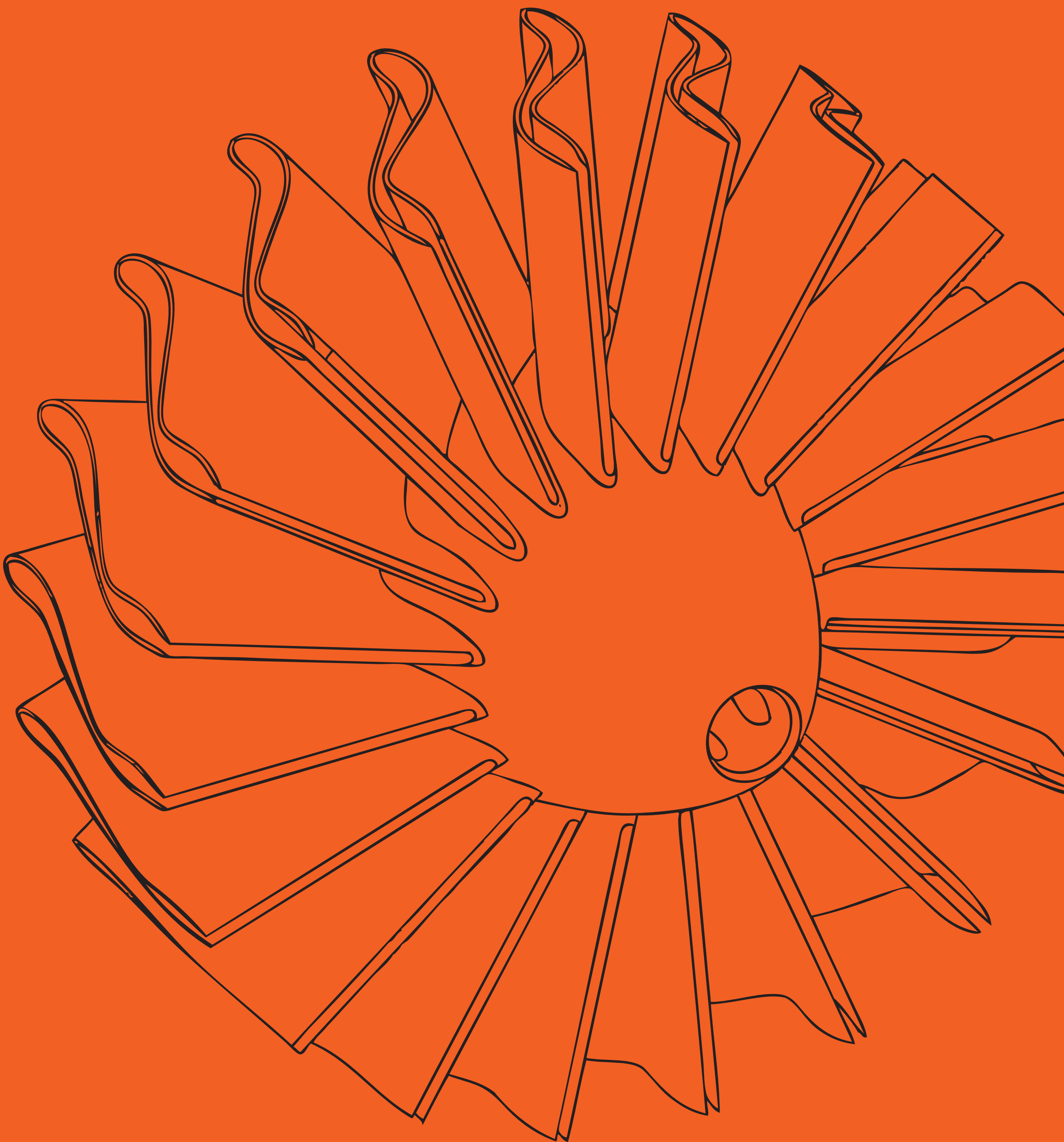
- The integration of AAT with STATFOR will be completed in 2016 with the addition of the business aviation and all-cargo market segments. Begun in late 2015, and continuing into 2016, a number of improvements are being made to this interface, designed to reduce the manual effort required to prepare the inputs, and to analyse the outputs, including a new module to derive year-on-year aircraft deliveries.

References

1. TOD= Top Of Descent ; CAS=Calibrated airspeed ; RFL= Requested Flight Level
2. http://easa.europa.eu/eaer

CHAPTER 2

AIRCRAFT NOISE



REDUCING AIRCRAFT NOISE - OVERVIEW

BY ICAO SECRETERIAT

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 main overarching ICAO policy on aircraft noise, which contains details on all the elements that can be employed to achieve noise reductions, is the Balanced Approach to Aircraft Noise Management. This can be found in the ICAO *Doc 9829, Guidance on the Balanced Approach to Aircraft Noise Management.*

An important pillar of the Balanced Approach to Aircraft Noise Management is the reduction of noise at source. Aircraft noise ("*noise at source*") has been controlled since the 1970s by the setting of noise limits for aircraft in the form 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. 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.

The first noise standard was developed by the ICAO Committee on Aircraft Noise (CAN,1971), 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 recognize 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.

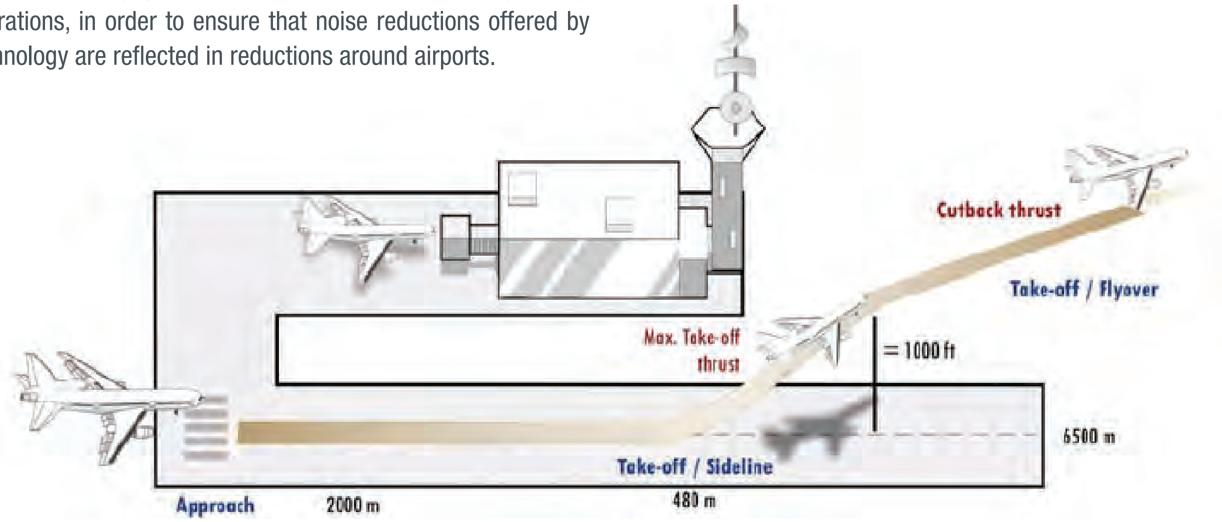


Figure 1. Aircraft noise certification reference points.

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.

ICAO NOISE POLICY

The Balanced Approach to Aircraft Noise Management consists of identifying the noise problem and analyzing various measures available to reduce noise at a specific airport 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 identify the noise-related measures that achieve maximum environmental benefit most cost-effectively using objective and measurable criteria.

Following 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 and this resulted in further stringency increase of the noise standard which is contained in Annex 16, Volume I, Chapter 4.

In the 2013 ICAO Environmental Report it was reported that the CAEP/9 (in February 2013) meeting had recommended an amendment to Annex 16, Volume I involving an increase in stringency of 7 EPNdB (cumulative) relative to the current Chapter 4 levels. In 2014 the ICAO Council adopted the new Chapter 14 noise standard for jet and propeller-driven aeroplanes. This new, more stringent standard is shown in **Figure 2**, (along with the previous ICAO noise standards for reference) and will be the mainstay ICAO Standard for subsonic jet and propeller-driven aeroplane noise for the coming years. It is 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 mass.

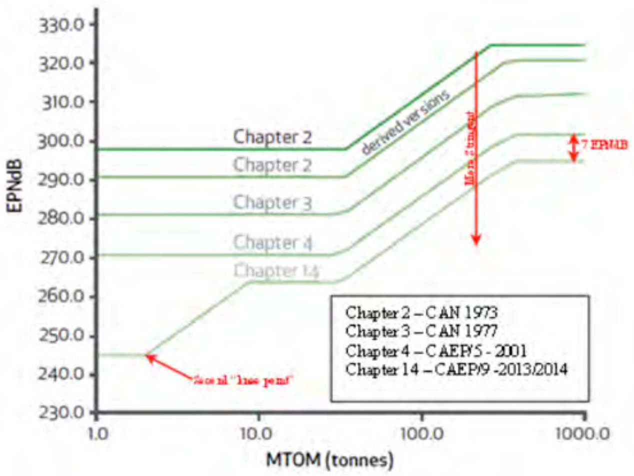


Figure 2. The progression of the ICAO Noise Standard.

Over the past three years (2013-2016), work has been conducted by ICAO to ensure the currency of the technical basis underpinning the ICAO Standards, guidance and policies associated with reducing aircraft noise. This work has included, among several topics, investigations into emerging subsonic aeroplane noise reduction technologies, studies into the status of aeroplane and helicopter noise reduction technology and the continuing development of SARPs for future supersonic aeroplanes. ICAO has also worked on the environmental aspects of airport land-use planning, and airport community engagement good practices. This chapter of the Environmental Report provides more details on the aforementioned topics.

As a result of the new 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.

Noise Reduction Technology

In order to set a new noise Standard in future, an understanding of current research and technology development 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. ICAO continually monitors research and development in noise reduction technology, and this complements the Standard-setting process. As reported in the 2013 Environmental Report, CAEP conducted an independent expert review to evaluate expected commercial aircraft noise levels by 2020 and 2030. The review focused on new novel aircraft and advanced engine concepts. More information on the IE review can be found in ICAO Doc 10017. While a full independent expert review was not conducted during the past three years, CAEP has continued to undertake a comprehensive overview of ongoing worldwide aircraft noise reduction efforts and associated goals (see article page 38).

As part of the technical monitoring effort, CAEP conducted a status review of the noise technology advancements of helicopters between 2000 and 2015 to highlight the developments since the last helicopter noise assessment report conducted in 2001 (during CAEP/5). The review included examining both noise reduction technologies and the costs associated with those technologies. The results of the helicopter status review was published on the ICAO website in 2016. The report includes an overview of international noise technology programmes and research initiatives, key noise reduction technologies of modern helicopters, and the status of advanced noise reduction technologies currently being tested in research programmes. Constraints and challenges to incorporate both current noise reduction technologies and promising new technologies are also considered (see article page 42).

Community engagement for aviation environmental management

As part of proper land-use planning and management, community engagement by airport operators and other aviation stakeholders is the key link between environmental stewardship and mitigating environmental constraints to aviation operation and growth. Recognizing the importance of community engagement, CAEP undertook a task in 2013 to collect case studies of airport outreach programs around the world and developed an ICAO Circular in 2016 highlighting both lessons learned and good practices (See article page 63). The Circular was developed to assist and encourage States and the aviation industry, in particular airports, airlines, and Air Navigation Service Providers, to engage local communities early in airport development projects to address environmental matters.

Supersonic Aircraft Noise Standards Development

ICAO 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. The goal of the procedures formulation effort is to establish technical flight test procedures for supersonic noise certification. These would be in addition to the certification requirements for the subsonic local airport conditions, where the maximum noise levels that would be applicable to subsonic jet aeroplanes would likely be used.

During the CAEP/11 cycle, progress has been made on identifying certification measurement locations for assessing sonic boom noise on the ground; selecting an appropriate noise metric for use in a Standard that assesses sonic boom noise and shows favorable correlation between outdoor measurement and indoor human response; and evaluating the benefits of using sonic boom predictions in supersonic noise certification in addition to physical measurements. Research Focal Points (RFPs) also continue to inform the work of CAEP with details on important research associated with supersonic flight and guide the selection of metrics and measurement locations (see article page 46).

Future ICAO work

ICAO continues to develop measures aimed at mitigating the impact of aircraft noise, and to support this ICAO continues to develop international standards, guidance material, and technical documentation as appropriate for the needs of the international community. This includes the maintenance of Annex 16, the environmental technical manuals, and the ICAO noise databank. Over the next three years the work on noise will focus on:

- monitoring and reporting on the various national and international research programme goals and milestones;
- conducting an integrated aircraft-level technology assessment of aeroplanes that includes both noise and emissions;
- continuing to develop a certification Standard for possible future supersonic aircraft.

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 the ICAO objective of reducing or limiting the number of people affected by aircraft noise.

Sustainable Development Goals

WHITE PAPER ON AIRCRAFT NOISE* AVIATION NOISE IMPACTS: STATE OF THE SCIENCE

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*This White Paper represents the summary of the scientific literature review undertaken by researchers and internationally-recognized experts. It does not represent a consensus view of ICAO.

Noise is defined as "unwanted sound". Aircraft noise is one, if not the most detrimental environmental effect of aviation. It can cause community annoyance, disrupt sleep, adversely affect academic performance of children, and could increase the risk for cardiovascular disease of people living in the vicinity of airports. In some airports, noise constrains air traffic growth. This white paper summarizes the state of the science of noise effects research in the areas noise measurement and prediction, community annoyance, children's learning, sleep disturbance, and health.

Introduction

Purpose: The goal of this paper is to briefly summarize the current state of scientific knowledge regarding the adverse effects of aircraft noise emissions on the public. Every effort has been made to base the findings upon peer-reviewed publications, carefully reviewed by specialists from around the world. The topics addressed here are community annoyance, children's learning, sleep disturbance, health impacts, and the noise of supersonic aircraft. This white paper also provides some background information on noise measurement and prediction, as well as technical definitions for the interested reader.

Task of the panel: Aircraft noise discussions can be very emotional, and politicians and legislators often struggle to define limit values that both protect the population against the adverse effects of aircraft noise but do not restrict the positive societal effects of air traffic. Noise effects researchers have an important advisory role. They derive so-called exposure-response functions that allow health impact assessments and therefore inform political decision-making. The efforts of the Noise Panel were directed at assessing the current state of the science and provide contracting states with a brief overview of the impacts of aircraft noise on communities. This white paper constitutes a consensus among its authors who have considerable experience in noise effects research, and is based on input from an international expert panel workshop held on February 10 and 11, 2015 in Alexandria, VA, USA. Noise effects depend, among others, on housing structure and cultural values, and legislation and limit values accordingly differ considerably between contracting states. Therefore, the authors did not try to suggest specific limit values, but rather pointed to existing exposure-response functions and recommendations of international organizations.

Community Annoyance

Definition of community annoyance: Community annoyance refers to the average evaluation of the disturbing aspects or nuisance of a noise situation by a "community" or group of residents, combined in a single outcome, annoyance. To facilitate inter-study comparisons and data pooling for the development of exposure-response relationships, a standardized annoyance question has been proposed by members of the International Commission on Biological Effects of Noise (ICBEN),[1] and was adopted by ISO TS 15666.[2] The percentage of highly annoyed respondents is considered to be the main indicator of community annoyance. The use of a common question allows for the comparison of studies from around the globe. As such, the ISG encourages States to utilize the ISO TS 15666 survey in their efforts to measure and understand community annoyance.

Moderating non-acoustic variables: Individual annoyance scores are not only related to acoustic variables, but can be importantly moderated by several personal and situational variables. Two meta-analyses on the influence of such non-acoustical factors on annoyance showed the largest effects of age, fear and noise sensitivity.[3,4] Additional moderating variables put forward are beliefs on the necessity of the noise source, the ability to somehow control or cope with noise or its consequences, trust in authorities, and previous experience with or future expectations regarding noise.[5,6]

Exposure-response relationships: Over the years, several attempts have been made to relate the percentage of respondents highly annoyed by a given source to the noise exposure level in L_{DN}. The derivation of exposure-response curves based on data from many individual studies[7] yielded different curves for aircraft, road traffic, and railway noise, with higher annoyance for aircraft noise than for road traffic or railway noise at the same exposure level. However, there is evidence that the annoyance response to aircraft noise has even increased over the years, and that exposure-response curves based on older aircraft noise annoyance data may no longer apply.[8,9] This stresses the need for an update based on more recent studies using standardized methods.

(Inter)national versus local exposure-response relationships: While exposure-response relationships have been recommended for assessing the expected annoyance response in noise situations, they are not applicable to assess the short-term effects of a change in noise climate. There are indications for an temporary overshoot in annoyance response in situations with a high rate of change, for instance where a new runway was opened.[10,11] Also in more or less steady state situations, the annoyance response in specific surveys often differs from the average expected response.[12] Since airports and communities may differ greatly in several variables moderating annoyance, local exposure-response relationships, if available, may be preferred for predicting annoyance. Still, exposure-response relationships describing the average annoyance response are required to allow health impact assessment across communities and to establish preferable limit values for levels of aircraft noise.

Complaints and their relationship to noise and noise effects: Many airports receive and log complaints as part of their noise monitoring and community outreach efforts. Complaints seem to be triggered by unusual events (e.g. louder than normal; unusual aircraft ground track or altitude) and operational changes (changes in runway usage or flight tracks). Annoyance and complaints are different phenomena, the first being a privately held opinion, and the latter being an overt action. Relatively few studies have utilized complaints databases to investigate whether complaints are related to long-term annoyance as measured using social surveys. Rather than monitoring the number of callers, which may be distorted by repeat callers, this approach should preferably be based on the number of individual complainants and the number of specific issues or incidents that cause complaints There is, however, evidence to suggest that complainants do not represent a cross-section of the population at large, both in terms of their demographic characteristics and their annoyance.

Supplementary noise metrics: An important question for aircraft noise annoyance is whether the annoyance due to infrequent high levels of noise events is the same as the annoyance caused by frequent moderate levels at the same L_{DN}. While some data suggest that the trade-off between levels and numbers of overflights in L_{Aeq}-based metrics such as L_{DN} is approximately correct for predicting noise annoyance,[13] there is also data suggesting that a higher weight of the number of flights might be appropriate.[14] However, an examination of 10+ airport surveys did not support a weighting of "number" greater than that implicit in L_{Aeq}.[15] On average, the weighting was less than that.

Noise mitigation: Annoyance due to aircraft noise has been recognized by authorities and policy makers as a harmful effect that should be prevented and reduced. Priority is given to noise reduction at the source (e.g., engine noise, aerodynamic noise) and reducing noise by adjusting take-off and landing procedures, but these measures are not always sufficient or feasible. Sound insulation of dwellings is often applied, but may not reduce annoyance levels when it is associated with poor indoor air quality.[16] In addition, the observed influence on annoyance of several non-acoustical factors such as fear, perceived control and trust in authorities suggests that communication strategies addressing these issues could strongly contribute to the reduction of annoyance, alongside or even in the absence of a noise reduction.

Conclusions: There is substantial evidence that aircraft noise exposure is associated with annoyance indicators, and exposure-response relationships have been derived to estimate the expected percentage of highly annoyed persons at a community level. Still, several personal and situational factors importantly affect the annoyance of individuals. Recent evidence for an increase in the annoyance response at a given exposure level indicates the need for updating exposure-response curves based on recent studies using harmonized methods, as well as verifying the circumstances leading to a heightened community response. This could inform political decision making on managing aircraft noise exposure and on mitigation measures.

Children's Learning

Chronic aircraft noise exposure and children's learning: Recent reviews of how noise, and in particular aircraft noise, affect children's learning have concluded that aircraft noise exposure at school or at home is associated with children having poorer reading and memory skills.[17] There is also an increasing evidence base which suggests that children exposed to chronic aircraft noise at school have poorer performance on standardized achievement tests, compared with children who are not exposed to aircraft noise. In the limited space available here it is only possible to discuss some of the central epidemiological field studies forming the empirical basis of these conclusions. The most recent large scale cross-sectional study, the RANCH study (Road traffic and Aircraft Noise and children's Cognition & Health), of 2844 9-10 year old children from 89 schools around London Heathrow, Amsterdam Schiphol, and Madrid Barajas airports found exposure-response associations between aircraft noise and poorer reading comprehension and poorer recognition memory, after taking social position and road traffic noise, into account.[18] Reading comprehension began to fall below average at around 55dB L_{Aeq},16hours at school but as the association was linear, there is no specific threshold above which noise effects begin, and any reduction in aircraft noise exposure should lead to an improvement in reading comprehension. A 5dB increase in aircraft noise exposure was associated with a 2 month delay in reading age in the UK, and a 1 month delay in the Netherlands.[19] These associations were not explained by air pollution.[20] Children's aircraft noise exposure at school and at home are often highly correlated. In the RANCH study, night-time aircraft noise at the child's home was also associated with impaired reading comprehension and recognition memory, but night-noise did not have an additional effect to that of daytime noise exposure on reading comprehension or recognition memory.[21]

Interventions to reduce aircraft noise exposure at school: Studies have shown that interventions to reduce aircraft noise exposure at school do improve children's learning outcomes. The longitudinal, prospective Munich Airport study[22] found that prior to the relocation of the airport in Munich, high noise exposure was associated with poorer long-term memory and reading comprehension in children aged 10 years. Two years after the airport closed these cognitive impairments were no longer present, suggesting that the effects of aircraft noise on cognitive performance may be reversible if the noise stops. In the cohort of children living near the newly opened Munich airport impairments in memory and reading developed over the two-year period. This study suggests that it takes a couple of years for impairments to develop. A cross-sectional study of 6,000 schools exposed between the years 2000-2009 at the top 46 United States airports (exposed to Day-Night-Average Sound Level of 55 dB or higher) found significant associations between aircraft noise and standardized tests of mathematics and reading, after taking demographic and school factors into account.[23] In a sub-sample of 119 schools, it was found that the effect of aircraft noise on children's learning disappeared once the school had sound insulation installed. These studies suggest that insulation of schools yields improvements in children's learning.

Mechanisms linking chronic aircraft noise exposure and learning: Aircraft noise may directly affect the development of cognitive skills such as reading and memory but a range of pathways and mechanisms for the effects have also been proposed. Effects might be accounted for by communication difficulties, teacher and pupil frustration, reduced morale, impaired attention, increased arousal – which influences task performance, and sleep disturbance from home exposure which might cause performance effects the next day.[24,25] Noise causes annoyance, particularly if an individual feels their activities are being disturbed or if it causes difficulties with communication. In some individuals, annoyance responses may result in physiological and psychological stress responses, which might explain poorer learning outcomes.

Guidelines for children's noise exposure at school: The WHO Community Noise Guidelines[26] suggest that the background sound pressure level in school classrooms should not exceed L_{Aeq} 35dB during teaching sessions to protect from speech intelligibility and disturbance of information extraction. The WHO guidelines also suggest that school playgrounds outdoors should not exceed 55dB L_{Aeq} during the recess period, to protect from annoyance. The American National Standards Institute (ANSI) Standard for School Acoustics (ANSI S12.50-2002/2010), suggests that internal background noise for unoccupied classrooms should be 35dB L_{Aeq}. The ANSI standard is supported by the Acoustical Society of America and INCE-USA. While the WHO and the ANSI guidelines both specify a maximum sound level of 35 dB for classrooms, it should be noted that for ANSI guidelines this is for unoccupied classrooms, while for the WHO guidelines this is for occupied classrooms. It should also be noted that WHO included cognitive impairment of children as one end-point in their publication on *Burden of Disease from Environmental Noise - Quantification of healthy life years lost in Europe,*[27] relying mainly on the results from the Munich study and the RANCH study.

Conclusions: There is sufficient evidence for a negative effect of aircraft noise exposure on children's cognitive skills such as reading and memory, as well as on standardized academic test scores. Evidence is also emerging to support the insulation of schools that may be exposed to high levels of aircraft noise. A range of plausible mechanisms have been proposed to account for aircraft noise effects on children's learning. Further knowledge about exposure-effect relationships in different contexts would further inform decision-making. It may also be informative to derive relationships for a range of additional noise exposure metrics, such as the number of noise events. To date, few studies have evaluated the effects of persistent aircraft noise exposure throughout the child's education and there remains a need for longitudinal studies of aircraft noise exposure at school and educational outcomes.

Sleep Disturbance

Sleep and its importance for health: Sleep is a biological imperative and a very active process that serves several vital functions. Undisturbed sleep of sufficient length is essential for daytime alertness and performance, quality of life, and health.[27,28] The epidemiologic evidence that chronically disturbed or curtailed sleep is associated with negative health outcomes (like obesity, diabetes, and high blood pressure) is overwhelming. For these reasons, noise-induced sleep disturbance is considered the most deleterious non-auditory effect of environmental noise exposure.

Aircraft noise effects on sleep: The auditory system has a watchman function and constantly scans the environment for potential threats. Humans perceive, evaluate and react to environmental sounds while asleep.[29] At the same SPL, meaningful or potentially harmful noise events are more likely to cause arousals from sleep than less meaningful events. As aircraft noise is intermitted noise, its effects on sleep are primarily determined by the number and acoustical properties (e.g., maximum SPL, spectral composition) of single noise events. However, whether or not noise will disturb sleep also depends on situational (e.g., sleep depth[30]) and individual (e.g., noise sensitivity) moderators.[29] Sensitivity to nocturnal noise exposure varies considerably between individuals. The elderly, children, shift-workers, and those at ill health are considered at risk for noise-induced sleep disturbance.[28] Repeated noise-induced arousals impair sleep quality through changes in sleep structure including delayed sleep onset and early awakenings, less deep (slow wave) and rapid eye movement (REM) sleep, and more time spent awake and in superficial sleep stages.[30,31]

ENREF_2 Deep and REM sleep have been shown to be important for sleep recuperation in general and memory consolidation specifically. Non-acoustic factors (e.g., high temperature, nightmares) can also disturb sleep and complicate the unequivocal attribution of arousals to noise.[32] Field studies in the vicinity of airports have shown that most arousals cannot be attributed to aircraft noise, and noise-induced sleep-disturbance is in general less severe than that observed in clinical sleep disorders like obstructive sleep apnea.[33] Short-term effects of noise-induced sleep disturbance include impaired mood, subjectively and objectively increased daytime sleepiness, and impaired cognitive performance.[34,35] It is hypothesized that noise-induced sleep disturbance contributes to the increased risk of cardiovascular disease if individuals are exposed to relevant noise levels over months and years. Recent epidemiologic studies indicate that nocturnal noise exposure may be more relevant for long-term health consequences than daytime noise exposure, probably also because people are at home more consistently during the night.[36]

Noise effects assessment: Exposure-response functions relating a noise indicator (e.g., maximum SPL) to a sleep outcome (e.g. awakening probability) can be used for health impact assessments and inform political decision-making. Subjects exposed to noise typically habituate, and exposure-response functions derived in the field (where subjects have often been exposed to the noise for many years) are much shallower than those derived in unfamiliar laboratory settings.[37,38] Unfortunately, sample sizes and response rates of the studies that are the basis for exposure-response relationships were usually low, which restricts generalizability. Exposure-response functions are typically sigmoidal (s-shaped) and show monotonically increasing effects. Maximum SPLs as low as 33 dB(A) induce physiological reactions during sleep, i.e., once the organism is able to differentiate a noise event from the background, physiologic reactions can be expected (albeit with a low probability at low noise levels).[37] This reaction threshold should not be confused with limit values used in legislative and policy settings, which are usually considerably higher. At the same maximum SPL, aircraft noise has been shown to be less likely to disturb sleep compared to road and rail traffic noise, which was partly explained by the frequency distribution, duration, and rise time of the noise events[31,39] Although equivalent noise levels are correlated with sleep disturbance, there is general agreement that the number and acoustical properties of noise events better reflect the degree of sleep disturbance (especially for intermitted aircraft noise). As exposure-response functions are typically without a clearly discernible sudden increase in sleep disturbance at a specific noise level, defining limit values is not straight forward and remains a political decision weighing the negative consequences of aircraft noise on sleep with the societal benefits of air traffic. Accordingly, nighttime noise legislation differs between contracting states.

Noise mitigation: Mitigating the effects of aircraft noise on sleep is a three-tiered approach. Noise reduction at the source has highest priority. However, as it will take years for new aircraft with reduced noise emissions to penetrate the market (and will thus not solve the problem in the foreseeable future), additional immediate measures are needed. For example, noise-reducing take-off and landing procedures can often be more easily implemented during the low-traffic nighttime. Land-use planning can be used to reduce the number of relevantly exposed subjects. Passive sound insulation (including ventilation) represent mitigation measures that can be effective in reducing sleep disturbance, as subjects usually spend their nights indoors. At some airports nocturnal traffic curfews have been imposed by regulation. They can be very effective, but are also a drastic measure and, according to ICAO's Balanced Approach, should only be implemented as a last resort. It is important to line up the curfew period with the (internationally varying) sleep patterns of the population.

Conclusions: Undisturbed sleep is a prerequisite for high daytime performance, well-being and health. Aircraft noise can disturb sleep and impair sleep recuperation. Further research is needed to (a) derive reliable exposure-response relationships between aircraft noise exposure and sleep disturbance, (b) explore the link between noise-induced sleep disturbance and long-term health consequences, (c) investigate vulnerable populations, and (d) demonstrate the effectiveness of noise mitigation strategies. This research will inform political decision-making and help mitigate the effects of aircraft noise on sleep.

Health Impacts

There are several ways in which noise could affect health,[40] including a physiological response via the autonomic nervous system leading to rises in blood pressure and heart rate, stress potentially mediated by annoyance, and disturbed sleep. However, the number of health studies available to date is limited.

Aircraft noise and cardiovascular disease (CVD) hospitalizations and mortality: Two large studies have found associations between aircraft noise and heart disease and stroke; one of these examined hospitalization rates in 6 million adults aged 65 years and over living near 89 US airports,[41] the second examined hospitalization and mortality in a population of 3.6 million potentially affected by noise from London Heathrow airport.[42] These studies used a small area (ecological) not individual-level design, so may not have fully accounted for confounding factors. Two individual-level studies have found associations between heart disease and stroke in subgroups who had lived in the same place for >15-20 years; one a cross-sectional study of approximately 5000 individuals living near seven European airports,[43] the second a census-based study of 4.6 million individuals in the Swiss National cohort.[44] A further two individual-level studies, of heart disease mortality in adults in Vancouver[45] and stroke mortality in 64,000 adults living in Denmark,[46] did not find associations possibly due to the fact that the study areas had low levels of noise.

Aircraft noise and hypertension: Two meta-analyses[47,48] relating to seven epidemiological studies in total have found associations between chronic aircraft noise exposure and hypertension in adults (meta-analyses combine evidence from several studies and are considered to provide the highest ranked research and to provide stronger evidence than single studies). Results from the meta-analyses are consistent with findings from meta-analyses of studies investigating road noise that have also shown associations with hypertension.[49] Aircraft noise has been associated but not consistently so with raised blood pressure in children in a number of studies, of which the largest involved 62 schools around London Heathrow and Schiphol airport.[50] The findings from epidemiological studies are supported by experimental and field studies that have demonstrated short-term effects of aircraft noise on blood pressure in adults. A field study of 140 individuals living near four European airports found increases in blood pressure measurements during the night sleeping period related to aircraft movements.[51] Short-term experimental studies in healthy adults[52] and those with existing cardiovascular disease[53] have found dose-response associations between aircraft noise at night and next-morning blood pressure and blood vessel functioning.

Aircraft noise and cardiovascular risk factors: Few studies have been conducted looking at cardiovascular risk factors e.g. biomarkers, adiposity and diabetes. Two experimental studies of aircraft noise recordings played at different volumes during sleep did not find associations with inflammatory markers (Interleukin-6, C-Reactive Protein) in the blood the following morning, while findings were inconsistent with adrenaline and cortisol.[52,53] A study of approximately 5,000 individuals in Stockholm followed up for ten years found a Lden 5 dB(A) increase in aircraft noise was associated with a greater increase in waist circumference of 1.5 cm (95% confidence interval (CI): 1.13 to 1.89 cm)[54] but no associations were seen with body mass index (BMI).[55] The authors suggested that increased stress hormones might contribute to central obesity, measured by waist circumference and waist-hip ratio.

Aircraft noise and birth outcomes: There are only a small number of studies available. A recent systematic review[56] found that four of the five studies identified examining birth weight found associations between lower birth weight and higher aircraft noise. The largest study was conducted around a US military airfield in Japan,[57] examining 160,460 birth records from 1974 to 1993. The studies reviewed did not score highly on quality assessment and the authors of the systematic review concluded that more and better designed studies were needed.

Aircraft noise effects on psychological health: The evidence for aircraft noise exposure being linked to poorer wellbeing, lower quality of life, and psychological ill-health is not as strong or consistent as for other health outcomes, such as hypertension. A study of 2,300 residents near Frankfurt airport found that annoyance but not aircraft noise levels per se ($L_{A,eq,16hours}$, L_{night}, L_{den}) was associated with self-reported lower quality of life.[58] The HYpertension and Exposure to Noise near Airports (HYENA) study, found that a 10 dB increase in day-time ($L_{Aeq,16hours}$) or night-time (L_{night}) aircraft noise was associated with a 28% increase in anxiety medication use, but not with sleep medication or anti-depressant medication use.[59] A sub-study of the HYENA study found that salivary cortisol (a stress hormone that is higher in people with depression) was 34% higher for women exposed to aircraft noise above 60 dB $L_{Aeq,24hours}$, compared to women exposed to less than 50 dB $L_{Aeq,24hours}$,[60] but no associations were found for men. Studies in schools around London Heathrow airport found no effect of aircraft noise at school on children's psychological health or cortisol levels.[61-63] However, the West London Schools Study of 451 children aged 8-11 years found higher rates of hyperactivity symptoms for children attending schools exposed to aircraft noise exposure >63 dB $L_{Aeq,16hours}$

compared to children in schools exposed to levels below 57 dB $LA_{eq,16hours}$.62 A similar effect was observed in the RANCH study.[63] These increases in hyperactivity symptoms, whilst statistically significant, were very small and most likely not of clinical relevance.

Conclusions: There is a good biological plausibility by which noise may affect health in terms of impacts on the autonomic system, annoyance and sleep disturbance. Studies are suggestive of impacts on cardiovascular health especially hypertension, but limited and inconclusive with respect to quantification of these, with a relatively small number of studies conducted to date. More studies are needed to better define exposure-response relationships, the relative importance of night versus daytime noise and the best noise metrics for health studies (e.g. number of aircraft noise events versus average noise level).

Civilian Supersonic Aircraft: A Future Source of Aviation Noise

Supersonic aircraft: All of the noise sources described thus far in this report pertain to noise in the vicinity of airports. In the future, however, it may be necessary to account for a new type of noise source that will be heard while the aircraft is in flight. Aircraft manufacturers are currently working on the design of supersonic civilian aircraft that produce a transient noise called a sonic boom. The sonic boom is pulled along with the aircraft analogous to the way a boat on a lake pulls its wake through the water. And just as the boat's wake impinges on the entire shoreline as it travels the lake, a supersonic aircraft's sonic boom impinges on the earth's surface for the entire supersonic journey. Because civilian supersonic aircraft are envisioned flying at altitudes upward of 15 km, the sonic boom noise might be heard within a corridor on the ground having a width of perhaps 100 km, centered on the aircraft's ground track. Fortunately, this noise will likely have a much lower level than traditional supersonic aircraft like Concorde due to the progress of technologists working to reduce the boom.

Noise regulations for sonic booms: Currently the world's noise regulations for supersonic aircraft exist from a time when the Concorde supersonic airliner was flying. The now-retired Concorde had a loud sonic boom, and the ICAO's Assembly Resolution A38-17 Appendix G protects individuals by reaffirming their position that "no unacceptable situation for the public is created by sonic boom from supersonic aircraft in commercial service." But there has been substantial progress during the last few years by industry, academia, and government laboratories developing supersonic aircraft technology, and by regulatory authorities that would certify such low-boom vehicles.[64-66] It is unclear how soon the new supersonic aircraft will be in widespread use, perhaps 20 to 30 years from now.

Conclusions

Noise is considered one, if not the most detrimental environmental effect of aviation. There is abundant evidence that aircraft noise exposure in the vicinity of airports is related to annoyance, and some evidence that the annoyance response has increased in recent years. There is sufficient evidence for a marked negative effect of aircraft noise exposure on children's cognitive skills, with some evidence that insulation of schools could mitigate this. There is also sufficient evidence that aircraft noise disturbs sleep and can impair sleep recuperation, but further research is needed to establish reliable noise exposure-response relationships and best mitigation strategies. Studies are suggestive of impacts of aircraft noise on health, but inconclusive with respect to quantification of exposure-response relationships, with a limited number of studies conducted to date. Mitigation of these various noise effects is necessary to protect the population living in the vicinity of airports and to address potential constraints to air traffic movements

Additional Information: Background, Including Noise Terms and Definitions

Noise definition: Noise is defined as "unwanted sound", and therefore has both an objective and a subjective component. Whether or not a sound is considered as noise depends both on its acoustical properties and its interference with intended activities. For example, attendees of a rock concert likely do not perceive the music as noise despite very high sound pressure levels (SPL). In contrast, residents living in the vicinity of the concert hall may perceive the music as noise despite much lower levels, as it may interfere with activities like reading a book or learning for school.

Aircraft noise characteristics: In contrast to, e.g., continuous road traffic noise from a busy road, aircraft noise is intermitted noise, i.e. consecutive aircraft noise events are usually separated by a noise-free period. During take-off, noise is predominantly generated by aircraft engines, while aerodynamic noise generated at flaps, gears, etc. may be more prominent than engine noise during landing.

Noise mitigation: The best noise mitigation measure is noise reduction at the source. Engineers were able to substantially reduce aircraft noise over the past decades (e.g., through high-bypass engines). Over the same period, air traffic volume increased substantially. Thus, people are exposed to a higher number of less noisy aircraft today. As it takes many years for new quieter aircraft designs to penetrate the market, different solutions are needed to reduce the number of people affected by relevant levels of aircraft noise. Potential measures include restricting how land is used near airports, changing how and where aircraft operate, limiting aircraft operations based on noise levels, limiting the hours that aircraft are allowed to operate, and providing sound insulation of homes and schools.

Noise monetization: Some States monetize the impacts of noise as a part of their policy making process. Within the U.S., the monetization of noise is based on the willingness of individuals to pay to avoid exposure to noise.[67] This method was used instead of observed differences in housing value as it is easier to gather income information than it is housing data. Within the U.K., Interdepartmental Group on Cost and Benefits (noise), IGCB(N), has developed guidance, which includes methods to quantify and monetize adverse health impacts, i.e. sleep disturbance, myocardial infarction, hypertension and dementia. During the ISG workshop, it was noted that even where methods exist to monetize these impacts, there is significant uncertainty in the results.

Noise monitoring: Many airports monitor noise levels on a regular basis. The equipment includes aircraft noise monitors, devices containing sound level meters, computer memory, and possibly communication equipment. The noise monitors are placed at strategic locations in the airport vicinity, often to assess the noise impact on selected neighborhoods or specific noise-sensitive locations such as hospitals or schools. By regular noise monitoring, an airport can ensure that the great majority of aircraft operations are within established noise limits.

Noise prediction: One of the additional tools used by airports and regulatory authorities are sound level contour maps, often just called noise maps. Using a combination of sound level measurements and appropriate sound mapping software, an airport can establish expected noise levels and determine, for example, locations where noise mitigation is needed. Looking down upon a map of the airport, the highest sound levels occur immediately next to the runways and along the primary aircraft takeoff and descent ground tracks. Moving away from these highest levels, decreased noise is found. Such noise maps can be very useful for assessing current and future noise exposure within several kilometers of airports.

Noise levels: This section will only provide the most basic information. For those who wish to dig deeper, there are a number of available references that explain the finer points.[68-70] Noise, or any type of sound, consists of fluctuations in pressure, p, measured in pascals (Pa), which is a force per unit area. Human hearing is extremely sensitive, and people hear very well over a wide range of pressures. Hence, to put this wide range into a more reasonable scale, logarithms are used.

The sound pressure level (SPL) is defined as

$$L_p = SPL = 20\log_{10}(p / p_{ref})$$

As you can see the logarithm to the base 10 is used, and the symbol utilized is L_p, indicating the level of the pressure. The reference pressure p_{ref} is a threshold of human hearing and equals 20 micropascals. A much larger pressure corresponding to a loud sound might correspond to 100 dB or higher. Very often to measure noise, an additional frequency weighting is used. Human hearing is not equally sensitive across all frequencies, and the most popular method to at least partially compensating for this is the A-weighting curve. A-weighting emphasizes the frequencies to which the human ear is most sensitive and attenuates the low frequency and very high frequency components of the sound. The A-weighted sound pressure level is denoted L_A. This metric is used commonly in assessing a wide variety of noise types, and is often described with the unit dB(A) or dBA.

Aviation noise metrics: Specific to aviation noise, a number of additional metrics are widely used. For single events, such as the passage of aircraft overhead, with its characteristic rising and falling of noise level over a minute or so, the A-weighted sound exposure level (ASEL) captures all of the energy of the event, and is given the symbol L_{AE}. The maximum level heard during the passage of the aircraft is denoted $L_{A\text{-}max}$. For multiple events, the average of those events is denoted L_{Aeq}, and sometimes the duration is specified (e.g., $L_{Aeq24hours}$ if the average is over an entire day). Aircraft noise can occur at any time, and sometimes the distinction is made between daytime and nighttime sound levels using the metrics L_{day} and L_{night}. To broadly account for the additional sensitivity to nighttime operations the day-night average level (DNL) is often used, denoted L_{DN}. It includes a 10 dBA penalty for any sounds occurring between the hours of 2200 and 0700. A 5 dBA penalty can be applied to operations in the evening hours, and this is called the day evening night sound level, denoted L_{den}. These metrics are all based on A-weighted noise levels. An alternative approach is to use the effective perceived noise level (EPNL), which has a more complicated definition found in the references.

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OVERVIEW OF AVIATION NOISE RESEARCH EFFORT SUPPORTED BY THE EUROPEAN UNION

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Establishment of 2020 Noise Goals and Associated Research Strategy

Over the last 15 years the European Union has been implementing a consistent research strategy aimed at addressing aviation noise issues on a problem-solving basis. This priority was first identified in the 2001 report of the Group of Personalities "European Aeronautics – a Vision for 2020+", which set the following goals:

- Reduce perceived noise to one-half of current average levels.
- Eliminate noise nuisance outside airport boundaries both day and night by using quieter aircraft, improving land use planning around airports, and systematic use of noise reduction procedures.

Following-up on these goals, the first edition (2002) of the Strategic Research Agenda (SRA) issued by the Advisory Council for Aeronautics Research in Europe (ACARE) promoted the development of an appropriate strategy encompassing:

- Development of technology development strategies aimed at a new generation of noise reduction means, including the adaptation of related research infrastructures (in particular, testing and computing facilities), and utilizing potential synergies at the national level.
- Implementation of an action plan designed to take advantage of technology advances in aircraft and air traffic systems that employ environmentally friendly operational practices such as noise abatement procedures (NAPs).
- Elaboration of a development plan for impact assessment tools and instruments designed to improve airport noise planning and environmental management practices.

The proposed approach for research clearly mirrored the ICAO Balanced Approach and was further substantiated by way of a quantified target addressing the first noise objective of Vision 2020. Translated into quantitative terms, that objective is an average reduction of 10 decibels per aircraft operation (departure or landing), resulting from technology improvements (source noise reduction), as well as operational improvements (noise abatement procedures).

The two contributors identified to achieve the -10 dB reduction target were further defined in terms of associated technical and operational solutions:

- Source Noise Reduction solutions: noise reduction technologies (NRT generation 1 and 2), novel aircraft and engine /power-plant architectures.
- Noise Abatement Procedures solutions: improved operating practices with current concepts, optimized operations with new technology, and ATM-ATC integration.

A phased approach, as shown in **Figure 1**, was then developed to meet an interim 2010 target of -5 dB. This was done with the help of more readily available solutions with a higher technology readiness level (TRL), paving the way for the technology breakthroughs needed to achieve the full target in 2020.

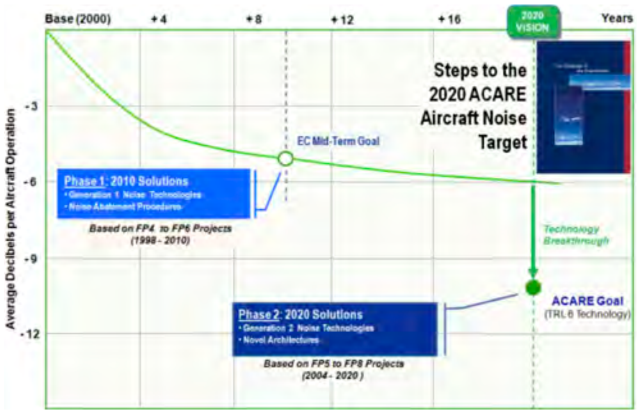

Figure 1. Steps to ACARE 2020 noise target.

A Coordinated European Aviation Noise Research Effort

The basic concept of the European Aviation Noise Research Network (X-NOISE) emerged about the same time as the ACARE SRA. Over the years, the concept of research "network" demonstrated its capacity to accommodate the evolution of the broader research context. It also helped in defining and implementing a robust research strategy with the aim to reduce the impact of noise from air transport. It established well-recognized dissemination and communication protocols and developed an active research community that covered the vast

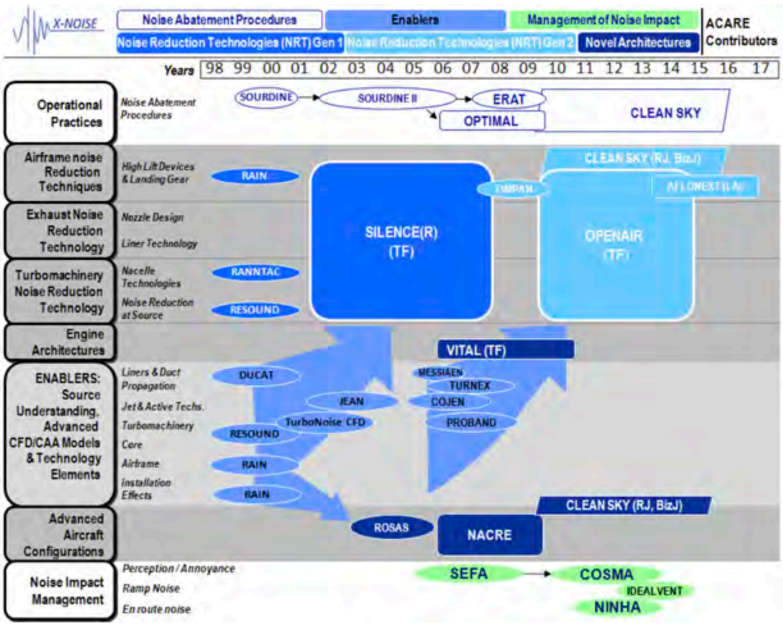

Figure 2. Roadmap of EU funded Aviation Noise Research Projects.

majority of EU Member States. Working with a common set of priorities and objectives, it led to more innovative upstream research developed at a national level, and evolving into larger European projects aimed at downstream research.

Effective strategy implementation is best depicted in the roadmap of European research projects contributing to the 2020 noise target achievement, as shown in **Figure 2**.

A key contributor to the achievement of the mid-term target was the SILENCE(R) project, funded under the EU 5th Framework Programme. Completed in 2007, the 6-year project involved a consortium of 51 partners. Research activities were carried out in various areas, such as engine source noise, nacelle technologies, and airframe source noise. More than 35 NRT Generation 1 prototypes were tested. The project involved two dedicated flight tests and a number of full-scale engine tests, and by the end, ten new technologies were validated from the noise reduction standpoint. They were considered mature enough for further work to address the design tradeoff issues that were identified during the technology evaluation process and through the industrial development work.

The initial research phase is now complete having met the mid-term objective of -5 dB per operation. In line with the described approach establishing operational improvements as an integral part of the solution, this result was achieved by combining the benefits provided by Generation 1 noise reduction technologies with those of the low noise operational procedures validated in the OPTIMAL project.

Initiating the next phase, a significant effort was dedicated to technology enablers throughout the 6th Framework Programme, This focused on advanced methods for predicting fan noise, jet noise, and nacelle liners efficiency, together with low TRL airframe noise reduction concepts. Further maturation of Generation 2 NRT solutions aimed at all significant noise sources was subsequently achieved in the 7th Framework Programme through the project OPENAIR (OPtimisation for low Environmental Noise impact).

Targeting the potential noise benefits expected from novel aircraft configurations, dedicated activity was initiated in ROSAS (Research On Silent Aircraft conceptS), then pursued in a multidisciplinary framework through NACRE (New Aircraft Concepts REsearch). In parallel, work on noise abatement procedures has progressed steadily beyond the initial validation performed in OPTIMAL, also addressing the aircraft systems aspects in CLEAN SKY, while the successive projects SEFA (Sound Engineering For Aircraft) and COSMA (Community Oriented Solutions to Minimise aircraft noise Annoyance) initiated a new approach on annoyance-related issues.

Assessment of Progress Relative to the ACARE 2020 Noise Targets

The methodology established for evaluating progress relative to the fixed-wing aircraft noise target of the SRA is primarily based on a dedicated technology evaluation process, which involves a predictive model that can roll up the benefits of individual technologies for a number of current and advanced aircraft engine configurations. This tool is being used to quantify the progress achieved relative to the ACARE targets, including operational aspects, when applied to operations at a typical airport in 2020. Initiated via the SILENCE(R) project, it has been implemented since 2001 through the string of major EU funded projects that deal with aircraft noise reduction.

Considering further steps towards the -10 dB target (NRT Generation 2, Novel Architectures), the 2015 assessment exercise benefited from the achievements of the OPENAIR project, as depicted in **Figure 3**, as well as from the interim results from CLEAN SKY in specific areas related to business jets and regional aircraft. Generation 2 noise reduction technology activity dedicated to engine noise reduction was mostly performed in the OPENAIR project and includes noise suppression techniques addressing the key sources of fan and jet noise. Through OPENAIR, CLEAN SKY and AFLONEXT, technologies are also being developed to reduce the noise of landing gears and high lift devices. While CLEAN SKY focused on solutions aimed at regional aircraft, OPENAIR and AFLONEXT investigated techniques for larger commercial models. Overall, more than 15 technologies were successfully matured to TRL 4. At last, although not yet quantified, the combined CLEAN SKY-SESAR effort on low noise abatement procedures is expected to provide further consolidation of the benefits registered at TRL 6 by 2010.

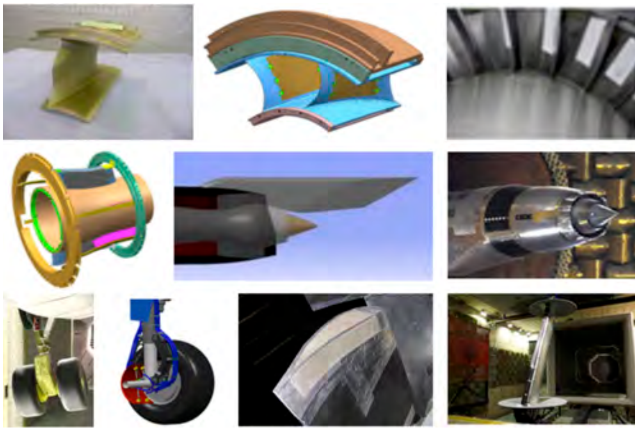

Figure 3. Scope of technologies matured in the OPENAIR project.

Relative to the ACARE noise target of -10 dB per operation, the aircraft noise research effort can be considered generally on track to meet its objective, but it will require significant support in the few years remaining before 2020. Critical actions needed for the ultimate success of the comprehensive overall approach initiated around 2000 can be summarised in the following recommendations:

1. Bring the most promising Generation 2 noise reduction technology to TRL 6, through an appropriately funded full-scale validation effort.
2. Significantly increase the effort dedicated to low noise aircraft configurations.
3. Consolidate wider implementation of low noise operational procedures.

While a significant effort was made towards the achievement of the -10 dB per operation target, a second noise objective defined by the ACARE SRA aims to ensure that benefits from technology and operational solutions effectively lead to reduced noise impacts on people outside airport boundaries, pending appropriate practices and policies are in place. Pan-European research activities have been subsequently initiated in the area related to management of noise impacts.

Supported by a well-balanced partnership, the COSMA project established a unique approach to aviation noise research, by targeting significant progress in the understanding of community noise impacts while consolidating the relationship between the technology optimization process and how the resulting aircraft sound is perceived. COSMA's scientific concept led to innovative ways of combining sound engineering and noise effects analysis to generate low noise impact design recommendations for future aircraft. Extensive field studies around European airports, combined with psychometric laboratory studies formed the basis to establish optimal aircraft noise characteristics regarding lower annoyance levels. Specific sound synthesis techniques re-created a realistic simulation of global airport operations and were then applied to the optimization of flight procedures, when associated with anticipated technology benefits.

Beyond its scientific results, COSMA also left a legacy of harmonized test protocols and innovative simulation tools for future projects to use. In the process, the Annoyance Task Group established within the X-NOISE network proposed a 6-point roadmap for future action, as follows:

1. Review of available aircraft noise annoyance studies in order to update and validate existing dose-response curves.
2. Extended scope of airport community studies.
3. Combined annoyance and sound prediction models.
4. Analysis of complaints due to aircraft noise and development of a standardized noise complaint handling system.
5. Improved dialogue between communities and airports with respect to technical aircraft noise issues.
6. Relevance of non-acoustic variables.

It was also recommended that wider international cooperation be sought in such areas, where knowledge development does not have competitive and industrial property implications.

Addressing the Longer-Term Objectives – Noise and the ACARE SRIA

In 2011, the report "Flightpath 2050 - Europe's Vision for Aviation" issued by the High Level Group on Aviation Research set a new target for 2050, stating that by then "the perceived noise emission of flying aircraft is reduced by 65% relative to the capabilities of typical new aircraft in 2000".

To address the targets set by Flightpath 2050, the 2012 ACARE Strategic Research and Innovation Agenda (SRIA)[1] was developed to cover the 2035 to 2050 timeframe. A complete set of recommendations identified solutions that were capable of reducing noise at departure and arrival by 15 dB per operation by 2050, relative to Year 2000. In addition to expected 2020 achievements, anticipated solutions would involve the development of a 3rd Generation of Noise Reduction Technologies (NRT), relying in particular on active and/or adaptive techniques to reduce the noise of engines, landing gears and high-lift devices. The emergence of novel aircraft configurations was considered an essential factor. In the shorter-term, masking effects from advanced tube and wing concepts associated with ultra-high by-pass ratio propulsion concepts should provide an anticipated 2 dB contribution to the ACARE target. In the longer-term, wider options associated with blended-wing body concepts such as embedded nacelles or distributed propulsion systems should also significantly contribute to further noise reduction.

Moreover, in order to exploit new technology and low noise operations developments, and to enable integrated impact mitigation solutions, it was considered of utmost importance to:

- Improve and continuously update the understanding of how noise from air transport operations affects people, with a significant focus on the influence of non-acoustic factors. **Figure 4** provides a rough survey of the most important non-acoustic variables for long-term annoyance and for annoyance at night.
- Provide the technical support for the successful implementation of planning policies compatible with traffic growth for the long-term benefit of the communities. This will require specific thematic research aimed at better integration of land use planning (LUP) in decision making.

Consistent with this comprehensive strategy, a number of "Enabling Factors" are foreseen as key contributors to the 2050 noise goal achievement, namely:

- Improved numerical simulation capabilities, together with test facilities incorporating advanced measurement techniques, in order to support further noise reduction at source level, and the implementation of multi-disciplinary optimization techniques and aircraft/engine integrated design practices that contribute to lower noise through efficient integration of noise reduction solutions, reduced weight, decreased drag, improved power-plant efficiency, and enhanced flight path design.
- Stimulated advances in related technology areas, such as materials and electronics, to allow the introduction of novel low noise technologies, including active/adaptive techniques.
- Updated, and internationally recognized, annoyance and sleep disturbance models, that take into account the evolution of aircraft noise signatures and traffic conditions (multiple events), and that consider airport specificities.
- Improved tools to support transparent communication policies that cover relevant indices, online forecast and tracking flight path operations, and comprehensive assessment of environmental interdependencies, and the monetization of impacts.

The ACARE SRIA confirmed the importance of addressing the impacts aspects as part of a coordinated research strategy, stating that the targeted 65% noise reduction relative to the 2000 baseline "should be achieved through a significant and balanced research programme aimed at developing novel technologies and enhanced low noise operational procedures, complemented by a coordinated effort providing industry, airports and authorities with better knowledge and impact assessment tools to ensure that the benefits are effectively perceived by the communities exposed to noise from air transport activities".

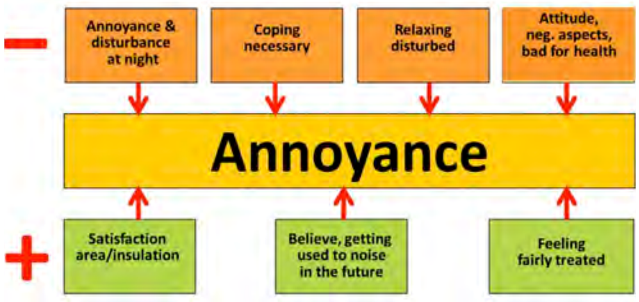

Figure 4. Overview of most important non-acoustic factors contributing to aircraft noise annoyance.

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HELICOPTER NOISE REDUCTION TECHNOLOGY ADVANCEMENTS

BY RAINER HEGER (AIRBUS) AND ERIC JACOBS (SIKORSKY) ON BEHALF OF ICCAIA

The CAEP continually monitors research and development in aircraft noise reduction technology to complement the Standard-setting process. As part of this effort, Working Group 1 of CAEP conducted a status review of the noise technology advancements of helicopters. The review included examining both noise reduction technologies and the costs associated with those technologies, which were treated in a qualitative manner by showing interdependencies and possible detrimental side effects. The Year 2000 was selected as the baseline for this study to highlight the developments since the last helicopter noise assessment report conducted in CAEP/5.

The results of the helicopter status review will be published as an ICAO report in 2016. The report includes an overview of international noise technology programmes and research initiatives, including the major research initiatives conducted in the United States, European Union, and Japan since 2000. The state-of-the-art in helicopter design is examined by reviewing the key noise reduction technologies of several modern helicopters. The status of advanced noise reduction technologies currently being tested in research programmes is reviewed. Finally, the constraints and challenges to design these low-noise helicopters are considered. This article summarizes selected topics from the report.

State-of-the-Art in Helicopter Design

To facilitate an evaluation of the status of helicopter noise reduction technology, a number of recently certificated helicopters were selected as state-of-the-art helicopter designs along with one earlier model deemed representative of a state-of-the-art design. The helicopter models selected were considered to adequately represent the best practices in helicopter design over a wide weight range from 700 to 8600 kg. For the purposes of this selection process, state-of-the-art was defined in the broader sense of aircraft level design, but the selected designs typically incorporate the latest helicopter noise reduction technologies and exhibit very good to the best individual and cumulative margins to the Chapter 8 / Chapter 11 noise limits in Annex 16, Volume 1.

Based on a review of both historic and the state-of-the-art helicopter designs, some key design parameters that affect helicopter external noise levels were categorized into three ratings of Low, Moderate, and High values. Table 1 lists the values that were identified as defining each category.

These parameters provide an insight into identifying low noise helicopter designs. An acoustically optimized helicopter design would ideally incorporate low rotor tip speeds, a low to moderate cruise speed, and a high climb rate.
The dominant acoustic sources of a helicopter include the main and tail rotors and, to a lesser extent, the engine exhaust. Rotor noise control can be accomplished in principal by incorporating the following design measures:

- Reductions in rotor rotational speed
- Increasing the number of rotor blades
- Advanced 3-D rotor blade design (radius, chord, twist, planform, airfoil selection and distribution along radius, anhedral/dihedral tip, and tip shape)
- Active rotor technologies (active flaps, active twist, or higher harmonic control)

Parameter	Low Category	Moderate Category	High Category
Main rotor tip speed	< 215 m/s	215 - 230 m/s	> 230 m/s
Tail rotor tip speed	< 200 m/s	200 - 215 m/s	> 215 m/s
Take-off climb rate	< 1200 ft/min	1200 - 1800 ft/min	> 1800 ft/min
Maximum cruise speed	< 130 kt	130 - 150 kt	> 150 kt

Table 1. Key Helicopter Design Parameters Determining Helicopter Noise Levels

Helicopter Design Process

It is important to note that a proper selection of noise reduction technologies is needed to successfully field a low noise helicopter within the multiple design requirements of a modern helicopter. For example, rotor design features intended to reduce a noise source that is dominant in one flight regime can inadvertently trigger increased noise levels in another flight regime. Similarly, a balanced acoustic design is also required to achieve the lowest noise achievable. For example, a large reduction in tail rotor speed can ultimately result in little to no acoustic benefits if the main rotor speed is set to a high value for performance, handling qualities, or safety reasons.

Decreasing rotational speed, whether by design or operationally, is the main lever for reducing the noise level of a rotor. While historically helicopters have typically operated at one fixed rotor speed, a change in rotor speed can now be implemented automatically in certain regions of the flight envelope to reduce noise using new digital aircraft flight control systems and electronic engine controls. The effect on noise levels is obvious in all certification flight conditions but the method has adverse implications on most other engineering discipline involved in the main rotor design and the full aircraft design.

Figure 1. Prototype 3D blade profile tailoring.

One adverse effect of decreasing the rotor speed is that it also reduces the kinetic energy stored in the rotor. In case of engine failure this energy is essential to a safe autorotation landing. If the rotational speed is designed to be decreased, the inertia of the rotor may have to be increased by adding additional blade mass, which adversely affects aircraft payload. The aircraft certification cost is also significantly increased due to the additional flight test time required. Furthermore helicopters are generally limited by gearbox torque at low altitudes. A reduction of rotational speed thus means less power available for the rotor and therefore deteriorated helicopter performance. Increasing the gearbox torque limits on an in-production design would mean a major redesign of the complete transmission system resulting in additional weight and increased manufacturing cost, which in most cases has been shown to not be economically reasonable. For future designs, advanced gearbox technologies that will enable higher torques at a lighter weight have been tested in the laboratory environment.

Another aspect to be considered is the functionality of passive vibration reduction devices used to ensure an acceptable ride quality. Most vibration reduction devices are effective at only one rotor speed. When designing for multiple rotor speeds, the implementation of an active vibration control (AVC) system capable of multi-frequency response may be required. AVC systems can be effective but do introduce added weight, complexity and cost challenges. However, helicopter AVC is a new technology that is now being implemented on some large helicopters.

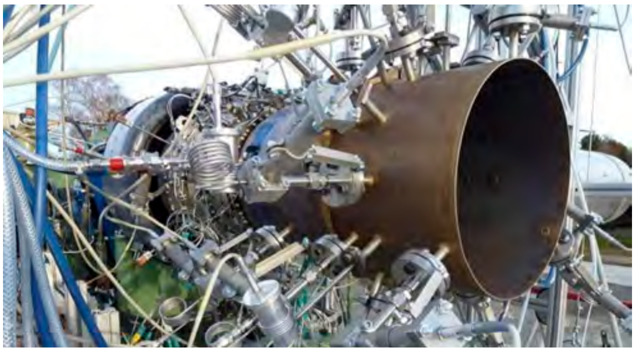

Figure 2. Turboshaft engine exhaust noise identification test

Other rotor design parameters influence the noise to a lesser extent and are oftentimes only effective to mitigate certain phenomenon appearing only in a specific flight condition. In particular, a rotor blade tip shape designed to minimize noise in one flight regime can adversely impact noise levels and aerodynamic performance in other flight regimes. It is now just becoming possible for computational fluid dynamics (CFD) modeling to capture the physics of a rotating rotor in edge-wise flight so that the rotor noise can be predicted and used to make design decisions. Nevertheless, these advanced CFD methods are still too costly to be intensively used for rotor design or optimization. The capability to manufacture advanced blade designs in a production environment must also be considered. An affordable rotor blade design that universally reduces noise emissions can be elusive.

Status of Noise Reduction Technologies

The evaluation of the state-of-the-art helicopter models confirms that available mature noise reduction technologies are being implemented in both new designs and in many new derivative models. These technologies include unequal blade spacing on ducted fans and open tail rotors, new rotor designs and blade planforms, and reduced or even automatically-controlled rotor speeds.

The helicopters included in this study equipped with low-noise tail rotor designs operating at moderate or low blade tip speeds verify the importance of anti-torque related noise in achieving cumulative margins of more than 12 EPNdB below the ICAO noise certification limits. The smaller twin-engine helicopters with alternative anti-torque concepts such as ducted fan or ducted thrust designs achieved even more impressive cumulative margins of more than 17 EPNdB. On one derived version, the replacement of a high tip speed open tail rotor by an acoustically-shielded ducted fan

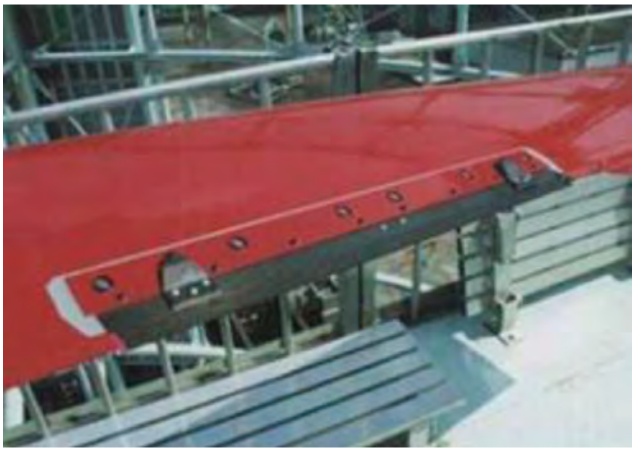

Figure 3. Full-scale rotor blade active flap test

on a helicopter already containing a quiet main rotor provided a cumulative noise benefit of 5 EPNdB for an otherwise acoustically identical configuration. However, the use of a ducted fan system has been limited to date to light to intermediate helicopters weighing less than 6000 kg due to an unfavorable scaling of system weight, efficiency and acoustic benefits.

Active rotor concepts attempt to reduce some inherently contradictive design tradeoffs between flight conditions by allowing an adaptation to the flight condition. Active flaps on rotor blades and individual blade control concepts have progressed to flight test demonstration, and active twist rotor blades have progressed to wind tunnel demonstration. However, the reduction of external noise by active means while maintaining acceptable cabin vibration levels remains a challenging task and system integration, productionization and airworthiness certification all remain significant challenges. The integration of an active rotor technology adds complexity to the design and considerably increases both acquisition costs and direct operating costs. Active rotor systems investigated in research programs to date are not yet reliable enough for product integration.

Noise abatement flight procedures have especially proven to offer noticeable potential to reduce helicopter noise impacts on the ground in specific situations. The implementation of noise optimized procedures is facilitated by comprehensive guidance material published by helicopter manufacturers and promoted by helicopter pilot organizations. New automated approach procedures have been flight test demonstrated and hold even greater promise to reduce the associated pilot workload and encourage regular use.

To address turboshaft engine noise, the testing of inlet and exhaust liners has progressed to the flight test demonstration phase. There has been no activity yet to address core noise. For piston engines, the use of upturned exhausts and new muffler designs has proven effective and both are used in production. Piston engine exhaust resonators have also progressed to the flight test demonstration phase.

Design Tradeoffs and Constraints

Unlike most fixed-wing aircraft, helicopters are designed for multi-purpose usage. The wide range of mission objectives leads to the challenging fact that the typical rotorcraft design requires not one but rather a number of design points for a multitude of missions. Designs therefore have to be evaluated to cover a large flight envelope and a wide range of weather conditions. The respective trade-offs in the design depend heavily on the class (size) of helicopter and the anticipated mission priorities envisaged for this type of helicopter.

Safety or economic considerations for certain helicopter missions obviously can require somewhat different trade-offs leading to certification noise levels closer to the applicable limits in Chapter 8 or Chapter 11 of Annex 16, Volume 1. Though the helicopters examined in the study incorporate most of the latest noise reduction features in terms of rotor blade design, the dimensioning of rotor tip speed and blade loading was typically optimized rather towards a performance to weight ratio needed to have a marketable aircraft.

Low noise design capabilities are inherently impacted by technological feasibility and economical reasonableness issues which often correlate with weight class. For example, some low noise anti-torque technologies are technologically feasible for very small helicopters but may not be economically reasonable to implement in a given design. As gross weight increases to the light-medium weight class, these anti-torque designs become more economically reasonable. As gross weight further increases, however, the technological feasibility disappears with unfavorable scaling of system weight and performance. Hence these anti-torque technologies have yet to be incorporated into medium to heavy weight helicopter designs. However, technologies such as automated rotor speed control, advanced 3D rotor blade designs and active rotor control increasingly become both technologically feasible and economically reasonable with increasing gross weight.

Conclusions and Perspectives

The data presented in the report highlights that significant progress in the reduction of helicopter source noise has been achieved in the last 15 years for both new type designs and some derived versions. Considerable funding has been dedicated to low noise helicopter research particularly in the United States, the European Union, and Japan. The activities focused on the exploration of active and passive rotor technologies, the improvement of numerical acoustic prediction capabilities, the development and operational verification of noise abatement procedures and, to a smaller extent, engine noise reduction concepts.

New noise reduction techniques necessitate extensive interdisciplinary design evaluations. Consequently integration into new products requires considerable time and expense. While new technologies continue to be explored, mature noise

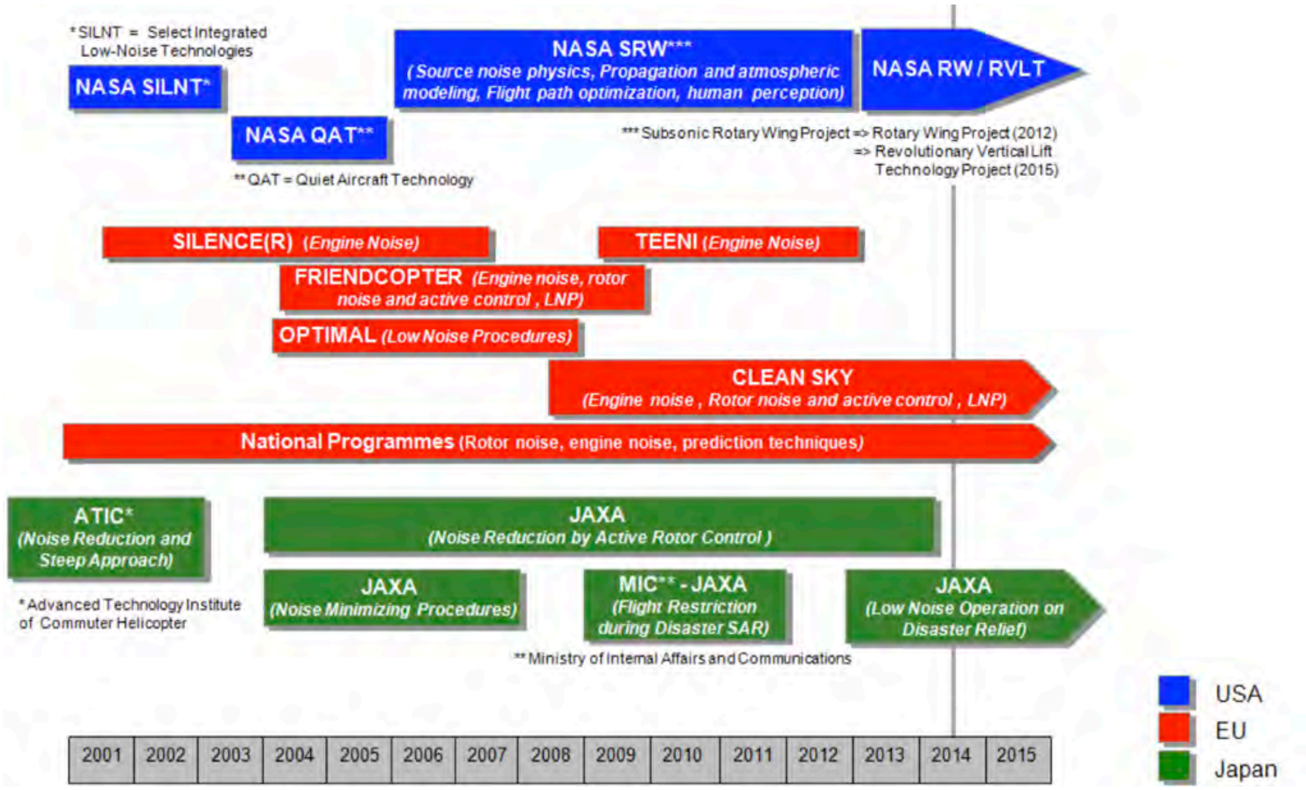

Figure 4. Major Initiatives in Helicopter Noise Research Since 2000.

reduction technologies are being integrated in the designs of all major manufacturers. State-of-the-art helicopter designs achieve cumulative margins of 4 to 17 EPNdB relative to the most stringent maximum permitted noise levels contained in Annex 16, Volume 1.

High margins are achievable for small- and intermediate-sized helicopters partly due to low noise anti-torque concepts and typical mission related design tradeoffs for these weight classes. For certain missions, safety, performance, and economic design tradeoffs may, however, lead to smaller noise certification margins. Special missions that require new hybrid helicopter configurations (for long range and high speed) could face difficulties complying with the applicable noise limits specified for conventional helicopter configurations.

REDUCING SONIC BOOM - A COLLECTIVE EFFORT STATUS REPORT

BY CHARLES ETTER (GULFSTREAM) AND PETER G. COEN (NASA)

Several members of the Aviation Industry believe that a new market segment, and possibly a new era of aviation, could be within reach in the next 15 years or less. This new era will reintroduce civil air travel at supersonic speeds. The technical challenges are significant, and progress is being made on many fronts. The economic impact of a new market segment is global, creating new jobs and new technologies.

Industry views the development of a socially responsible enroute supersonic noise standard as a parallel effort to technology development. This new noise standard, in conjunction with relevant environmental standards is beginning to take shape within the ICAO CAEP (Committee for Aviation Environmental Protection) process.

The new era of supersonic civil flight could be reintroduced in one of two ways. One way would be to operate at supersonic speed over both water and land, utilizing a low boom aircraft design (unrestricted supersonic flight). The other operational scenario would be to fly at design speeds above Mach 1 over water and unrestricted areas, while slowing down to subsonic speeds, or just over Mach 1, in restricted areas. Flying just over Mach 1.0, between Mach 1.0 and 1.15, is referred to as Mach cut-off. Flying below the Mach cut-off speed will result in the sonic boom waveform not reaching the ground. The actual Mach cut-off speed depends on the prevailing atmospheric conditions.

The achievement of commercial supersonic flight will be accomplished via technology breakthroughs developed for smaller aircraft such as business jet aircraft. To date, no purpose-built low boom aircraft has ever been manufactured. The general public has never been exposed to the "softer" overpressure sounds of such a uniquely shaped aircraft.

This article addresses the efforts of Industry and national research organizations to mitigate sonic boom and mature enabling technologies to support the introduction of a low boom aircraft capable of supersonic operation over land. Additionally, the article highlights the accomplishments of CAEP Working Group 1 (Noise) over the last three years, and the interdependence of these efforts.

National Research Organizations

Recently, national research organizations such as National Aeronautics and Space Administration (NASA) in the USA, and the Japanese Aerospace Exploration Agency (JAXA), have increased their investments in supersonic research and development and have plans to continue this effort into the future. Their focus is on developing modern design tools for supersonic aircraft, as well as understanding public response to sonic boom exposure.

National Aeronautics and Space Administration, USA

NASA is a leader in research and technology development for supersonic flight. Recently, NASA published a new strategic plan that includes six thrust areas outlining its investment strategy in the coming years. Strategic Thrust 2 focuses on innovation in commercial supersonic aircraft and near term efforts (2015-25) to support the establishment of a standard for acceptable overland supersonic flight in cooperation with international standards organizations.

NASA will continue validation of analytical tools and technologies to enable the design and development of supersonic aircraft that create minimal sonic boom noise. In the longer term (2025-35), NASA will continue research on technologies required to meet the desired boom level in larger aircraft, in addition to other technical challenges for successful supersonic transports. This research will include reducing propulsion emissions and noise affecting the airport community. NASA will conduct this research in partnership with universities, industry and regulatory organizations.

Low Boom Flight Demonstration

NASA continues to seek support from the U.S. government to design, build, and fly a Low-Boom supersonic Flight Demonstration (LBFD) aircraft (**Figure 1**). NASA has initiated concept studies and project planning to inform the decision-makers regarding a future LBFD. The objectives of LBFD were defined as flight validation of low boom design tools and technologies and creation of community response data to support the development of the above-mentioned supersonic en route noise standard.

The LBFD aircraft is envisioned as a subscale research aircraft that creates a shaped sonic boom signature with a loudness level of 75 PLdB (Stevens Mark VII Perceived Level) or less during supersonic cruise (Mach ≥ 1.4). The LBFD project is envisioned to range from five to seven years in duration.

The LBFD research aircraft, though smaller than future supersonic jets, will serve as a test bed to evaluate the effectiveness of the low-boom design process and accuracy of acoustic propagation codes. Also, by flying LBFD over preapproved populated areas, the reaction of communities can be assessed systematically, providing validation for community response models under development.[1]

Figure 1. Low Boom Flight Demonstrator Concept

Sonic Boom Prediction and Community Response

NASA's work includes the utilization of a unique laboratory that mimics a typical residential living space. This facility, called the Interior Effects Room (IER), provides a controllable environment for subjective testing of indoor effects from sonic booms. Recent results, including the effects of rattle on sonic boom annoyance, were published in 2015.[2]

In 2015, NASA launched two new studies designed to: (1) improve atmospheric turbulence modelling for sonic boom propagation and, (2) develop strategies for future community response testing using an LBFD aircraft. These efforts are expected to continue for two to three years, with results and data publicly available at the conclusion of the work.

Japan Aerospace Exploration Agency

JAXA has been promoting the Silent SuperSonic (S-cube) technology research program for future economical and sustainable supersonic airliners since 2005.

In the S-cube program, a sonic boom test named D-SEND (Drop test for Simplified Evaluation of Non-symmetrically Distributed sonic boom) was conducted to demonstrate advanced low-boom design concepts. One recent completed phase of this program, included dropping an unmanned and non-powered scaled airplane from a stratospheric balloon to demonstrate front and aft shaping of the sonic-boom signatures (**Figure 2**). During that flight test, several sonic-boom signatures at design conditions were measured by airborne and ground microphones.

The Japanese Ministry of Education, Culture, Sports, Science and Technology (MEXT) released its "Next Generation Aircraft Research and Development Vision" in August 2014. A roadmap of this vision established goals to validate new technology for supersonic airplane engines through ground testing and flight tests by 2030. JAXA is expected to play a key role in this program through a close partnership with aerospace companies and academia.

Following this vision, JAXA is considering a new supersonic research program starting in fiscal year 2016 as a successor to its S-cube program. Its main focus will be aircraft noise reduction technologies to accommodate the recent ICAO Chapter 14 noise standard. This program will also include sonic-boom mitigation technology and evaluation research for the ICAO sonic-boom standard development process.

Figure 2. JAXA's Scaled Airplane – Used During Drop Test

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Office National d'Etudes et de Recherches Aérospatiales (ONERA), France

The European Commission 2016-2017 work program, officially released on the 15th of October 2015, has retained a Research and Innovation Action item to contribute to the evolution of the regulation allowing supersonic overland flights, by actively giving support to the ICAO Sonic Boom regulation roadmap.

The RUMBLE (RegUlation and norM for low sonic Boom LEvels) contribution, initiated jointly by Airbus Group Innovation, ONERA and Dassault Aviation, will involve both European and International academic and industrial partners.

The RUMBLE objective is to actively contribute to the ICAO roadmap by bringing complementary scientific knowledge and support to the regulation authorities to prepare for the smooth introduction of low-boom supersonic overland flights with the highest level of worldwide acceptability.[3]

Industry Activity

Several aerospace companies are involved in civil supersonic research. In some cases, this work is funded by, or in partnership with, their respective national research centers; others are funded internally.

Engine and airframe manufacturers have engaged in aircraft and propulsion conceptual design studies for several years, including the NASA Quiet Supersonic Vehicle study of 2003/4 and the EU Framework 5 HISAC program.More recently, some engine and airframe manufacturers have been exploring a wide range of propulsion cycles. (**Figures 3 and 4**) These studies include the relevant requirements for payload, range, and community noise (such as ICAO, Annex 16, Volume I, Chapter 4 or 14).

Some aircraft manufacturers continue to invest in supersonic technology that mitigates the effects of traditional sonic booms. Their approach includes design requirements for unrestricted supersonic flight over land to enable the same operational flexibility of existing subsonic fleets. Sonic boom minimization is the largest technical barrier to achieving this objective.

Figure 3 & 4. Examples of Boeing and Lockheed Martin Entry Level Supersonic Commercial Concepts.

Additionally, industry is engaged with NASA on its Commercial Supersonic Technology program.

Aerion Corporation, based in Reno, Nevada, anticipates program launch of its AS2 business jet in 2016, first flight in 2021, and certification in 2023 (Figure 5). Aerion intends for the AS2 to cruise at Mach 1.4 over oceans and uninhabited areas, and operate at "Mach Cut-off" over populated areas (see Mach Cut-off in introduction). In areas prohibiting cruise above Mach 1, the AS2 can cruise at Mach 0.95 with full range capability. Aerion is considering a family of aircraft, including small supersonic airliners, and has secured firm orders for twenty AS2 aircraft from Flexjet with deliveries as early as 2023.

Figure 5. Aerion AS2 Supersonic Aeroplane.

CAEP Related Activities

Since 2004, ICAO's Committee on Aviation for Environmental Protection (CAEP), Working Group 1 (WG1) has monitored the scientific progress toward supersonic flight of low boom aircraft and has worked to develop the framework for a new boom noise standard.

The primary focus since 2013 has been defining applicable noise metrics for sonic boom and developing certification test procedures for a future supersonic aircraft noise certification standard. These aspects of a new noise standard were considered by the group to be the most reasonable elements of a standard that could be addressed prior to the availability of a LBFD.

The efforts to develop an appropriate metric for a future en route sonic boom standard started with assembling all noise metrics that might be a good candidate for sonic boom measurement. A group of technical specialists from around the globe then began the selection process. As a result of their efforts, the list has been narrowed to a few options that provide a good, but generally similar measure of response to sonic boom. A better understanding of some of the more subtle aspects of community response, such as rattle, vibration, and indoor noise, will likely be needed to shorten the list further.

Additionally, the group has been working on the development of flight test procedures for supersonic noise certification. Three initial priority tasks were identified to: 1) determine measurement locations for assessing sonic boom noise, 2) evaluate the benefits of using sonic boom predictions in supersonic noise certification, and, 3) define instrumentation system requirements. A typical ground exposure is illustrated in **Figure 6**.

It is envisioned that a future low boom noise standard will need to cover more than just the cruise condition, so WG1 is also considering flight conditions such as climb. Additionally, certain unique challenges will exist during noise testing an aircraft that is passing overhead at very high altitudes, where both the noise and the atmospheric conditions need to be measured. The group will be evaluating possible technical solution to address these new challenges.

Research and Future Plans

Due to advancements in high performance computing tools, aerodynamic drag is being significantly reduced using the improved capability to analyze complex flows and aircraft configurations.

Engine manufacturers are working to improve fuel burn, NOx, and jet noise. There may be interdependent and viable trades on environmental design objectives as technologies mature. Avionics and cockpit systems already provide the capabilities needed for civil supersonic operations. Additional work continues to enhance these systems.

Enabling supersonic technologies are converging to produce viable and efficient aircraft configurations, but civil supersonic operations may come in two main phases – supersonic operations over water, followed by supersonic operations over land.

Industry sees the development of both noise and emissions standards by CAEP over the course of the next few years as a vital step in reintroducing the public to civil supersonic flight.

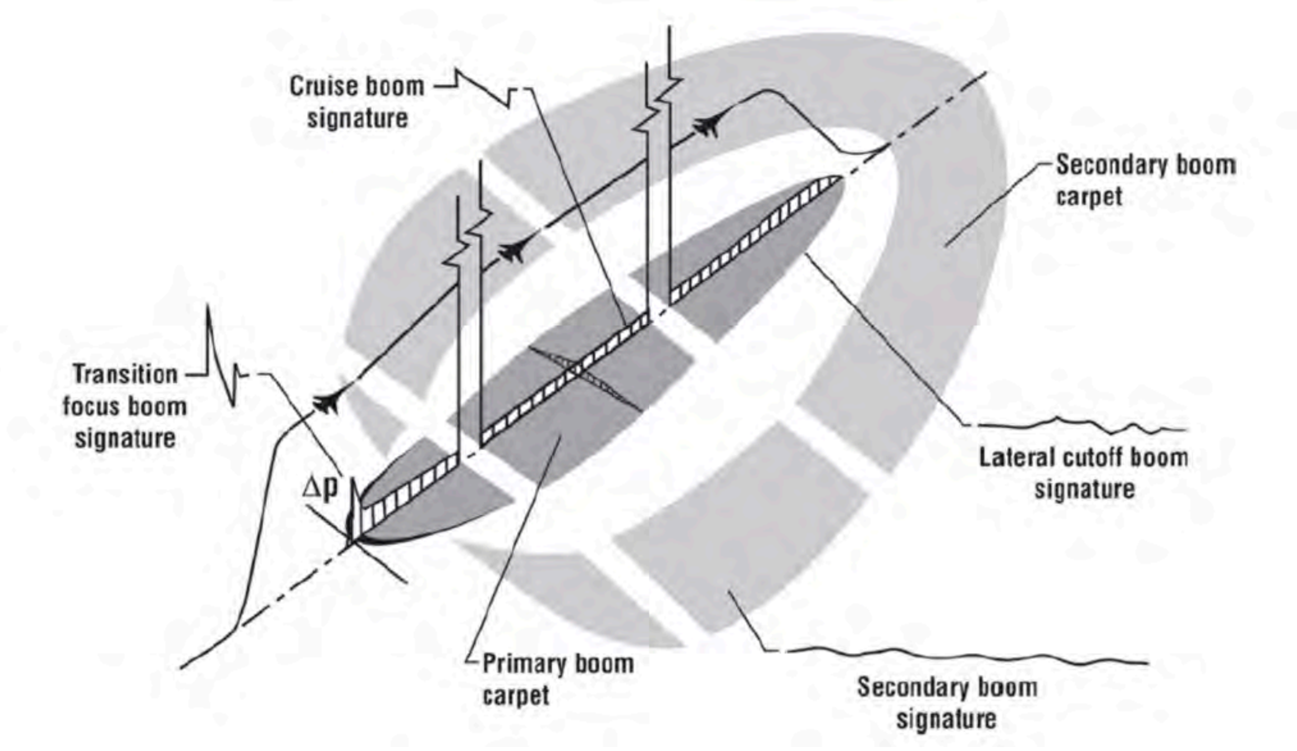

Figure 6. Schematic of Sonic Boom Ground Exposures.[4]

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AIRCRAFT NOISE MODELS FOR ASSESSMENT OF NOISE AROUND AIRPORTS – IMPROVEMENTS AND LIMITATIONS

BY OLEKSANDR ZAPOROZHETS (ENVIRONMENTAL SAFETY INSTITUTE OF THE NATIONAL AVIATION UNIVERSITY, KIEV, UKRAINE)

Noise pollution around airports continues to be the most significant cause of adverse community reaction towards airports[1]. Fifteen years ago, aircraft noise assessment and management was focused on so called "close in" areas around airports; those that were exposed to the highest levels of aircraft noise, typically exceeding 55 dB(A)L_{DN}. Today, community opposition to airport growth is increasingly coming from residents living in areas outside of the traditional "close in" noise contour areas[2]. This has happened because of a fundamental change in the public reaction to aircraft noise. Evidence shows that increased annoyance levels have been measured in the last decade at European airports. For example, recent studies of the airports in Manchester, Paris, Amsterdam, and Frankfurt have shown that public reaction to noise is much higher than that predicted by the conventional noise indices.

The ICAO goal in aircraft noise control is to limit or reduce the number of people affected by significant aircraft noise. ICAO Document 9829, *Guidance on the Balanced Approach to Aircraft Noise Management*, was developed for this purpose. It covers four elements, namely: land-use planning, reduction of noise at source, noise abatement measures, and as a last resort, aircraft operating restrictions. The decision on the choice of noise mitigation measure or the combination of measures to be used is based on a robust data set, including the calculated number of people exposed to aircraft noise for any possible flight scenarios using sophisticated software installed on GIS (Geographic Information System) platform, which helps focus mitigation actions on the highest priority zones.

Two different approaches to aircraft noise modelling exist. Both ICAO[3] and the European Civil Aviation Conference[4] documents provide recommendations for aircraft noise calculations. Their methodologies apply to long-term average noise exposure only. Current versions of noise modelling software (INM, SONDEO, ANCON, IsoBella, AcousticLab, etc.) are consistent with these recommendations. However, a number of States require single noise event measurement or indicator via L_{Amax}, or SEL (single Event Noise Exposure Level), or other noise descriptors.

Aircraft Noise Modelling Characterization

Aircraft noise modelling around airports serves multiple purposes. The models can estimate cumulative noise exposure, or they can identify and describe the size of annoyed population in certain areas; all of which can be used to identify dose-response relationships[5]. ICAO provides guidance on the use of these types of models and provides methods for assessing the acoustical characteristics of the various sources associated with aircraft noise events[6].

The models differ in terms of structure, the number of required parameters, and the initial information necessary to implement each one. The simplest type of model structure includes the definitions of noise footprints (contours for specified values of noise indices and areas bounded by these contours) for any type of the aircraft and particular flight mode.

Two approaches to analysis of aircraft noise phenomena have been defined and computerized. The first approach is based on I/3-octave band spectra noise analysis of any type of aircraft, in any phase of flight in the vicinity of, or inside an airport. In this case, the assumption is that sound waves spread along the shortest distance between the aircraft and the point of noise control. The second approach is based on the concept of "noise-power-distance" (NPD) or "noise radius" (Rn)[5] and provides calculations of aircraft noise maximum and/or exposure levels around the airport, or at any noise monitoring point.

With the second approach, the resulting predictions are location-specific and are not only dependent on flight parameters. It has been utilized in computer programs like ANCON (UK), Fanomous (Netherlands), INM, NOISEMAP (both USA), IsoBella (Ukraine), and AcousticLab (Russian Federation), among others.

Prediction of Noise in the Vicinity of an Airport

Airport noise maps that result from complete airport noise modelling are an essential noise management tool. For example, they form the basis for noise zoning policies and land-use planning decisions. They also contribute to the performance of Environmental Impact Assessments at airports. Such modelling combines the specific features of both flight path and ground aircraft noise models. Important input parameters are the atmospheric temperature, pressure and humidity, all of which may influence both the flight performances of the aircraft and the sound propagation. In addition, aircraft specific data and airport operational information are required to compute the noise of each individual operation.

Typically, the final results of these computations are presented as noise contour diagrams. Noise contours illustrate how the specific noise index varies from location to location as the result of a given aircraft traffic pattern at an airport.

When analyzing the noise situation around an airport in a particular region, or to compare noise exposure from several noise sources in the region, non-acoustical parameters are also taken into account. A widely used such indicator is the amount of population exposed to noise. This can be calculated by counting the number of dwellings exposed to a certain noise level (inside the zone between two specified noise contours) and multiplying that by the average number of inhabitants per dwelling. Often, these data are grouped into classes of 5 dB(A); that is the difference between the noise indictor values on the outer and inner noise contours of the zone under consideration is equal to 5 dB(A).

Measurements of aircraft noise levels or specific noise indicators around airports are the result of many factors including:

- acoustical characteristics of the aircraft;
- intensity of flight traffic around the airport;
- scheme of routes and tracks (both on the airfield and for departure and arrival);
- distribution of aircraft between routes;
- recommended operational procedures used on various routes for each type of aircraft;
- operational factors including the in-flight mass of the aircraft;
- meteorological characteristics;
- runway characteristics;
- presence of acoustic screens;
- topographic conditions at the airport location; and
- any other factors that might cause diffraction and interference between propagated and reflected sound waves.

The main factors that affect the accuracy of the modelling are wind and temperature, as well as variability in the operational procedures employed during take-off. The existing models do not include any corrective factors for wind and temperature, even though these can cause significant changes in ground-to-ground attenuation, and can even result in so called shadow zones, where the noise cannot be observed because the sound waves are refracting upward in some specific wind and temperature conditions.

In view of the large number of variables and the necessary simplifications due to absence of initial data for some significant variables it is desirable to standardize procedures for computing airport noise contours. There is a need to provide guidelines for such a standard method, to identify the major aspects and to supply specifications in respect of each of these.

For an airport noise study, the calculations methodology includes the following steps:

a) Determination of the noise levels from individual aircraft movements at observation points around the airport.
b) Addition or combination of the individual noise levels at the respective points, according to the formulation of the chosen noise index.
c) Interpolation and plotting of contours of selected index values.

Calculations are usually repeated at a series of points around the airport and then interpolations are made between those points of equal noise index values (i.e. noise “contours”).

The noise levels for individual movements are calculated assuming flat terrain from noise-power-distance and aircraft performance data for given atmospheric conditions, based on the yearly averages observed at a range of world airports. However, ambient parameter values have an impact on the flight mode parameters, thus affecting the noise emitted by aircraft. Specifically, atmospheric conditions tend to influence aircraft noise levels, in particular, air temperature causes changes in flight path parameters, sound absorption parameters, and noise generation characteristics.

This confirms the necessity to account for certain operational factors when calculating noise levels around airports. If these calculations are connected with noise zoning and land-use planning, the worst possible operational conditions (from the noise point of view) must be considered. If models are used for monitoring purposes, NPD-relationships must be derived in accordance with actual values of meteorological parameters in the routine mode. This requires use of specific calculation modules (for example a module RADIUS in designed software tool IsoBella) including application of basic acoustic models of the aircraft of particular types with identified transfer functions. The software module is called the NPD-generator (or RADIUS-generator). Flight paths for the aircraft under consideration are built with the so called FLIGHTPATH-generator, which assumes the common flight dynamics models (e.g. as in the INM model).

Similarly, modelling of noise at ground locations near the airport runway during the take-off roll requires several modifications of the basic noise-power-distance data. The modifications result from the fact that the aircraft is on the ground accelerating from essentially zero velocity to its initial climb speed, whereas the basic data are representative of overflight operations at constant airspeed. To accommodate these differences, consideration must be given to: changes in generated sound resulting from jet relative-velocity effects, varying directivity patterns from the moving aircraft, the modified effective duration with increased speed, and the extra attenuation of sound during over-ground propagation at near-zero elevation angles. The directivity patterns are necessary for both taxiing aircraft and engine testing. As one can see from **Figure 2**, the directivity patterns of noise generation are specific to each engine type. Differences between these specific directivity patterns and the generalized relationship proposed by ICAO or ECAC guidances[3,4] may be as large as 10 dB(A) in certain directions.

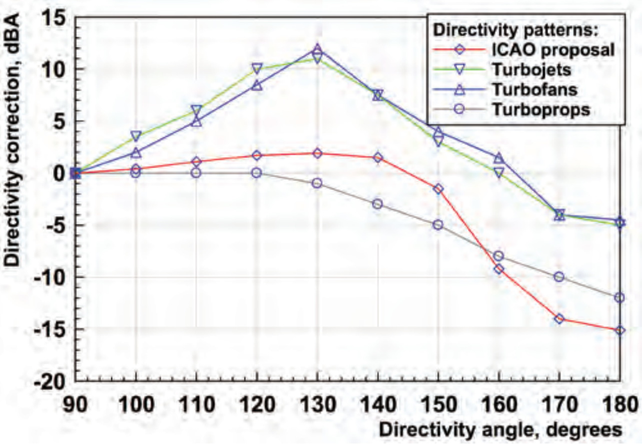


Figure 1. Generalized Directivity Corrections for Characteristic Engine Types.

Excess attenuation due to ground effect is not constant for every condition like it is defined by ICAO or ECAC guidances[3,4], but it is dependent from a locally reacting plane surface. In fact, differences between the predicted attenuation effects on overall A-weighted levels L_A can be as much as 12 dB(A) due to the spectrum variations between aircraft engine types, or even for one type of the engine, but in various directions (see **Figure 2**). The magnitude of the predicted variation is the same, or even greater, as that for NPD variations due to temperature of the air.

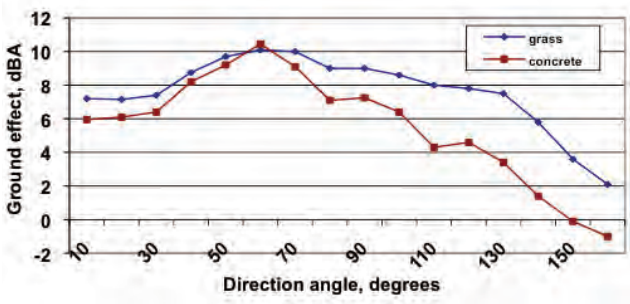


Figure 2. Ground Effect as a Function of The Angle of Engine Noise Radiation.

Examples of noise contour predictions are shown in **Figures 3 and 4**. The calculations use identical initial operating conditions to enable better comparison. **Figure 3** shows the results without any of those changes or improvements. **Figure 4** shows the results obtained with the factors and improvements mentioned above.

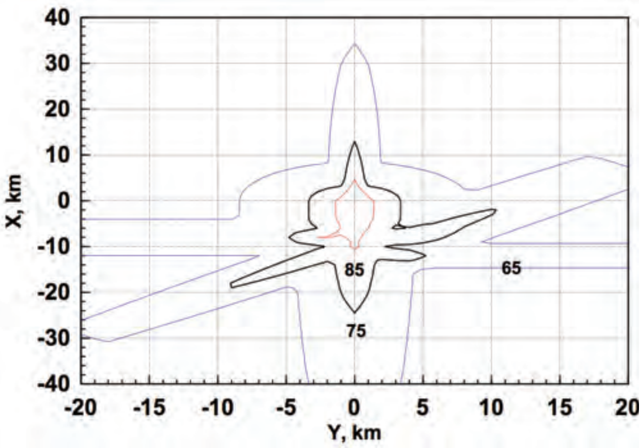


Figure 3. Noise Contours Predicted By Means of an Existing Calculation Method.

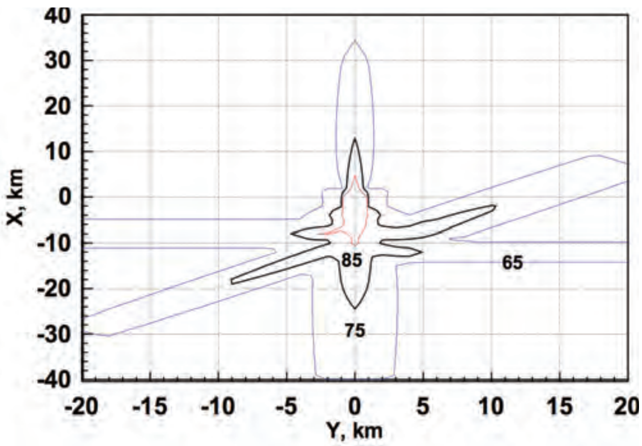


Figure 4. Noise Contours Predicted By Means of the Improved Calculation Method.

Single Aircraft Noise Event Prediction

It is well-known that calculation results for single events differ from actual measurements. On average, mentioned before integrated models provide predictions about 5-10 dB(A) lower than measured values SEL (less inaccuracy closer to runway, larger - far from runway). Such patterns are typical for most analyses, because an acoustical base consists of line sources representing the time-integrated noise from a complete flyover. Noise data are generally supplied by the aircraft manufacturers in the form of NPD curves, which are fixed to standard temperature and humidity. Such models account for geometric spreading, air absorption and ground effect. All existing models represent the same physical phenomena, but do so with different levels of detail and some different choices in particular algorithms. Flight profiles are defined by software via solutions of equations for aircraft balanced motion (in real practice aircraft flight is slightly unbalanced usually), which are recommended by existing methods [3,4], using the data for necessary coefficients from the ANP database, which is supported by Eurocontrol (www.aircraftnoisemodel.com).

As shown in **Figure 6**, flight profiles of real-life operations tend to differ greatly from predictions for balanced motion[7].

The differences are observed not only for the height-distance, but for the flight speeds and thrust settings, which also contribute significantly to the predicted levels of noise. The same is observed for arrivals [3,4], where the thrust setting is usually higher than in the balanced motion predictions.

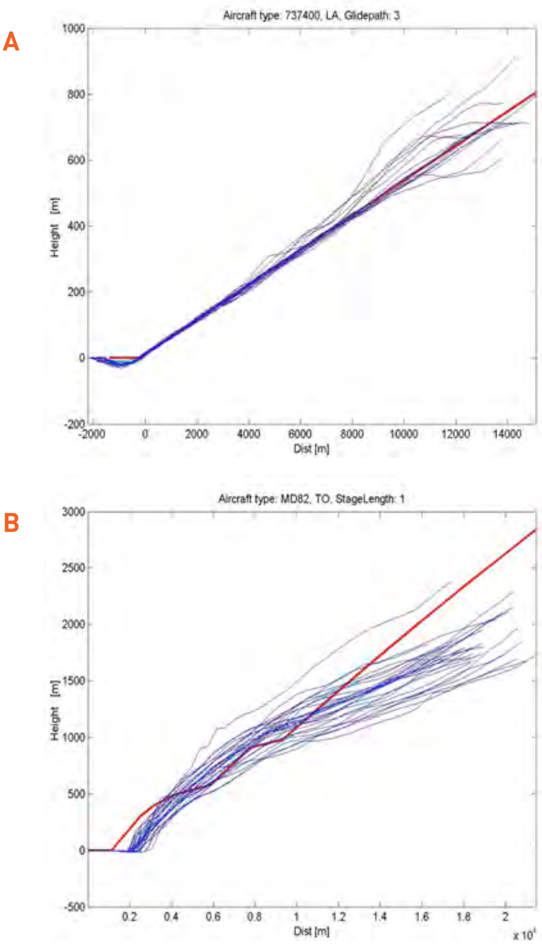


Figure 6. Flight Profiles (Height Via Distance) Observed In Operation (blue lines) In Comparison With Balanced Prediction (red lines): A – Arrival; B – Departure.[10]

There were many results obtained when comparing measurement data with calculated data[11]. It is possible to show large amounts of measured noise data in noise contour presentations and compare those with calculated values. **Figure 9** presents these results using data for A-320 and B-737-400 aircraft. It shows that the measured contour for the maximum level 75 dB(A) is up to the 4 km longer than the calculated contour!

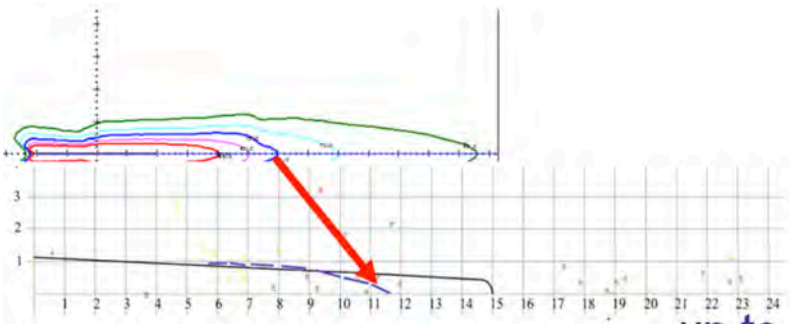
During the arrival phase of a flight, the difference between results observed during operations and the balanced data for flight parameters (See **Figure 8a**) is 2-3 dB(A) higher than the maximum levels calculated by models in accordance with current requirements [3,4]. The same differences may be found for contours produced by the IsoBella model, as shown in **Figure 8b**. Results based on flight input data parameters observed in operation approach/landing contours are longer than for balanced flight data, with an appropriate difference of L_{Amax} ~2 dB(A) at a distance of 1,000 m from the runway end.

For the take-off/climbing phase of flight noise contour for L_{Amax}= 75 dB(A), which is derived from input data for flight parameters observed during actual operations, the difference in contour length is more than 1.5 km than those calculated (see in **Figure 8b**).

Noise Impact Management

Reduction of noise at the receiver point is not an end in itself, but a means to reduce the effects of noise. For ICAO, this translates into limiting or reducing the number of people affected by significant aircraft noise.

There is a difference of around 5-6 dB(A) between the average annoyance curves of recent studies and those using older data. As **Figure 9** depicts, the newer studies indicate that a higher number of people exposed to given noise levels are considered annoyed, compared with a few decades ago[8]. These results are critical for determining the relevance of the of current exposure-annoyance relationships for aircraft noise, and whether these need to be updated.



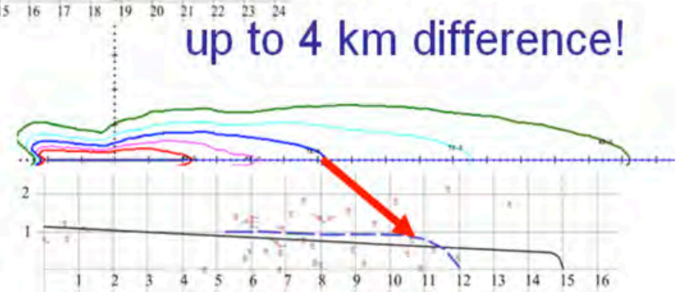


Figure 7. Comparison of Measured and Calculated Noise Contours for A-320 and B-737-400Aircraft In Take-off/Climbing Phases.

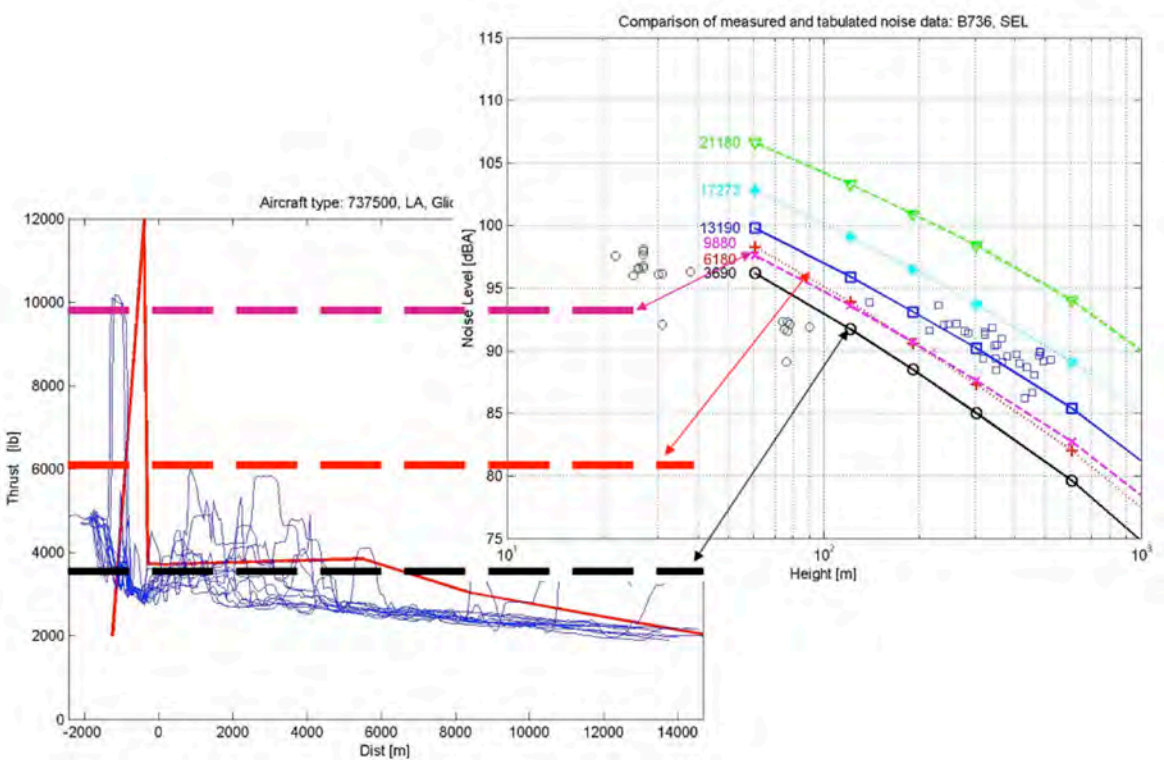


Figure 8a. Comparison of Observed in Operation (magenta) and Balanced (black) NPD curves for B-737-400/500/600 at glideslope.

Aircraft noise management policies need to take into account the evolution of annoyance curves. This is especially important because these show that, for the same noise levels, annoyance is higher for aircraft noise than noise from other sources. It is clear that annoyance levels that exceed the tolerance threshold for a specific nuisance lead individuals to complain.

It is recognized today that annoyance from noise is not exclusively correlated with noise levels. Non-auditory effects of noise give the rise to annoyance and are more complex to describe and measure. Among the non-acoustical factors the mostly contributing (with high correlation with final effect) are the following: negative expectations toward noise development; perceived control and coping capacity; Concern about negative health effects of noise and pollution, etc. There is no agreed methodology to combine all factors of annoyance into a single explanatory model, even if some social and economic factors have been identified as influencing community response to noise. Approximately one-third of the variation (only one-fifth by some estimates) in noise annoyance can be explained by acoustical factors.

As a result, noise management policies should be understood as a dynamic process, meaning that they should be assessed regularly and adapted when necessary in the light of new scientific findings. A truly effective model to measure annoyance still needs to be designed. That should be done in a manner similar to what was done to develop the appropriate models to measure the impacts of all of the elements identified in ICAO's Balanced Approach to aircraft noise management. Nonetheless, the level of noise exposure does determine perceived disturbance. Thus, the effective management and control of aircraft noise should minimize adverse impacts of aircraft noise on health and quality of life. However, investigating the relationship between actual sound levels and perceived noise levels should be a primary objective of future research. New and additional policy measures to mitigate noise impact may result as the focus shifts from noise to annoyance. For that the better communications with communities surrounding airports should improve mutual understanding and contribute to more positive responses to aircraft operations and the associated noise levels.

Conclusions

Aircraft noise modelling is being continuously improved. Early models and software were based on measured data. Current methods are based on more analytical models. However, due to the simplified assumptions used in those models, there are a number of differences between calculated and measured results, especially for single noise events. This analytical method could be complemented with a set of more practical approaches, in order to provide more accurate assessments of noise indices for both separate points and footprints.

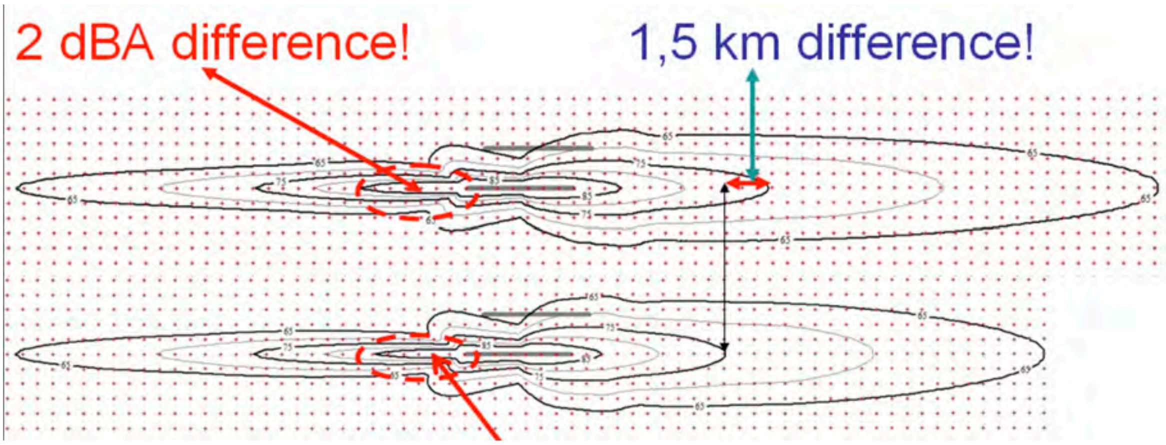


Figure 8b. IsoBellaResults for B-737-400Noise Contours (approach/landing and take-off/climbing) are Higher When Using Input Data for Flight Parameters Observed in Operations; and Lower for Balanced Input Data for Flight Parameters

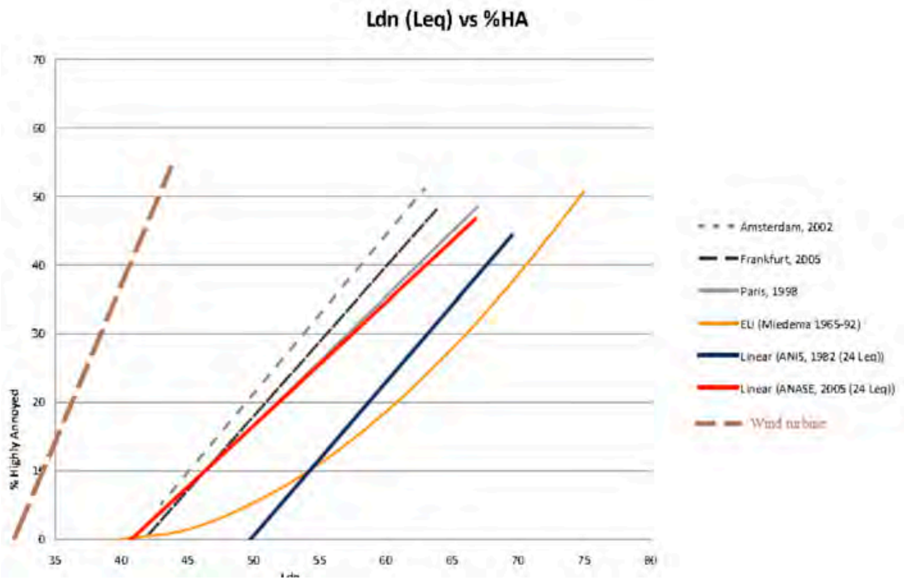


Figure 9. Annoyance Curves for Available and Comparable Survey Data Collected in 20 Different Research Studies Conducted in Europe, North America and Australia.

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USING ECOFLIGHT BUILDING SOFTWARE SUITE FOR PREDICTIVE ASSESSMENT AND DEVELOPMENT OF COMPENSATION MEASURES TO MITIGATE IMPACTS OF AIRCRAFT NOISE IN AREAS NEAR AIRPORTS

BY OLEG A. KARTYSHEV (AVIATION ENVIRONMENT SCIENCE INSTITUTE, MOSCOW) AND MICHAEL O. KARTYSHEV (PHD CANDIDATE, STATE AVIATION UNIVERSITY, MOSCOW)

Urban encroachment into airport areas and changing noise zoning policies in the vicinity of airports make it ever more challenging for airport administrations and local governments to manage noise around airports.

An element of the ICAO Balanced Approach to aircraft noise management is land-use planning and management in noise-sensitive areas[1]. These days, land-use planning and the adoption of noise mitigation measures often involve the definition of noise zones. Various noise zones are defined on the basis of noise exposure levels, both through measurement and computer modelling. As a result, the application of appropriate architectural planning techniques, as well as construction, acoustic engineering, and other methods will ensure that noise protection is in-place in areas of urban development. The Ecoflight Building Software was created to assist in identifying the measures required to compensate for noise exposure, so as to meet specific noise level inside dwellings.

Traditionally, zoning procedures consist of establishing noise maps along aircraft flight paths, more rarely of establishing gradual construction restriction zones. Depending on the classification of a noise zone and its noise exposure, newly constructed buildings are subject to specific requirements regarding soundproofing. In such cases, the real estate developer is responsible for the engineering and implementation of soundproofing solutions. This entails a few challenges for local governments, including: the difficulty of developing noise maps, the large number of necessary noise measurements, and ongoing monitoring to ensure the developer's compliance with the soundproofing requirements at the design and construction stages. Another issue is the lack of a predictable description of aircraft noise impacts after the construction is finished, so that potential real estate buyers can be fully informed about the noise situation of the property they are considering.

New Approach

The assessment of the current acoustic situation at the monitored facilities is usually carried out by onsite measurement campaigns. However, these measurement campaigns are of limited use for predicting the future noise climate around airports. In practice, the data obtained from measurements are highly error-prone for a number of reasons, including: the influence of weather conditions, acoustic background, differences in location of moving noise sources, and variability of engine operating modes during measurements. These factors will all come into play to one degree or another at the location considered for the development of new facilities.

Therefore, the prediction of expected noise levels in areas adjacent to the flight path and inside buildings should be based on noise models, which take into account changes in noise spectral characteristics and the effect of building structures on the reflection and absorption of sound.

Ecoflight Building ensures the high quality analysis of the noise situation of the facility under study. Its acoustic assessment error margins are similar to the results of the other noise assessment models it was compared with. It forms the foundation of a reliable forecast of the noise situation in relation to existing or expected sound levels for investigated facilities[2].

The acoustic characteristics of noise exposure are normally calculated at up to 2 meters from facades, roofs and other enclosure elements of buildings, as well as in the adjacent areas at the specified distance from the ground along the entire height of the building. The characteristics specified can be used to assess the level of acoustic impact on the building, or as source data for subsequent calculations of acoustic characteristics inside protected buildings. These calculations can also be used to compare acoustic characteristics of alternative architecture design and layout, structural and technical components, and other decisions made at the various design and development stages of new dwellings.

The calculation of aircraft noise levels that penetrate inside dwellings is more complicated than the calculation of noise levels from stationary sources. Such calculations are based on the assumption that an aircraft flight path can be broken down into a series of simultaneously radiating acoustic source points, which form an aircraft noise source. These are then represented as a set of aircraft systems and mechanisms with linear dimensions comparable with the length of sound waves radiated by them. This allows them to be analyzed as simulation models of linear sources, which consist of separate sound sources points.

This approach allows the assessment at the pre-engineering stage of: the suitability for construction of investigated areas, the validity of corresponding layouts, and the appropriateness of the construction methods chosen. At the design stage, it is possible to forecast and propose in advance an optimal solution for soundproofing of premises to avoid unreasonably high costs.

Software Design and Features

The Ecoflight Building software suite is designed for modelling and calculating sound levels in specified locations including built-up areas, construction-free zones and buildings. It enables to visualize the sound field attributes of aircraft noise sources in any of those types of locations.

The Ecoflight suite allows the modelling of point, linear, planar, and spatial sound sources. It also covers their other acoustic, spatial and time parameters, taking into account the directionality of acoustic radiation of the sources, their spectral parameters, and the nature of sound emission. The software uses various acoustic and time correction scales; and takes into account the geometrical shapes and sizes of the sources.

The results of the calculations can be displayed in the form of 2D or 3D noise maps for equivalent, maximum, SEL, LDEN, octave (third octave) sound frequencies, linear or A-weighted sound exposure levels (sound pressure). **Figure 1** shows a 3D model of a residential area being designed near Vnukovo International Airport. Also, if needed, the user can change the altitude of the horizontal slice in the calculated model, as shown in **Figure 2**.

The designer can choose intermediate or final calculation results, visualize acoustic pictures (displaying isolines and labels, with or without noise numeric values), and forecast the expected acoustic characteristics of the facilities being designed, constructed, or reconstructed. It is recommended that modelling results be checked against on-site measurements, and the source data be adjusted before the final calculations.

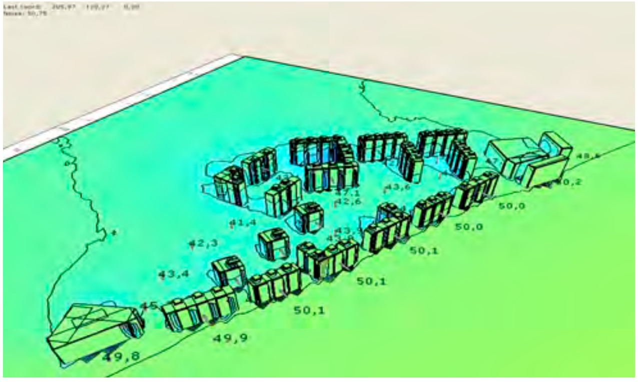

Figure 1. Visualization of Aircraft Noise Impact at Night (L_{eq}).

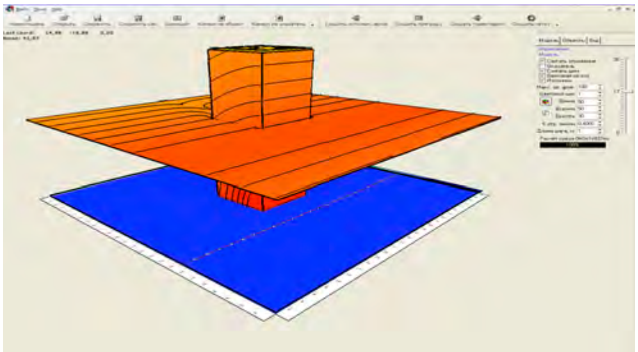

Figure 2. An Example of a 3D Model Visualizing Sound Fields Appearing at the Outside Surfaces of Buildings and in the Adjacent Areas.

This approach ensures the robustness of the forecast.

AcousticLab aircraft noise contour calculation software developed by CA ESC Ltd. (Civil Aviation Environmental Safety Center) was improved as part of the ICAO CAEP/10 cycle and was approved at the 10th meeting of ICAO CAEP. The CAEP Modelling and Database Group played an important role in assessing the robustness of AcousticLab, which resulted in its approval by CAEP.

Practical Application

The AcousticLab software takes into account the type(s) of aircraft, their flight paths, and the directionality of aircraft noise source for both the calculation of individual and aggregated impact. This led to the qualitative improvement of the Ecoflight Building software suite, especially the modelling and the calculation of sound levels in specified locations in the airport vicinity.

The assessment of the acoustic situation in the vicinity of Vnukovo International Airport shown in **Figure 3** illustrates the capabilities of the software suite. The territory of a residential district comprising 7 high-rise apartment buildings is exposed to aircraft noise L_{Amax} = 73 dBA at facades relative to the noise source and L_{Amax} = 60-62 dBA relative to the yard area of the "investigated area" (i.e. Building #5).

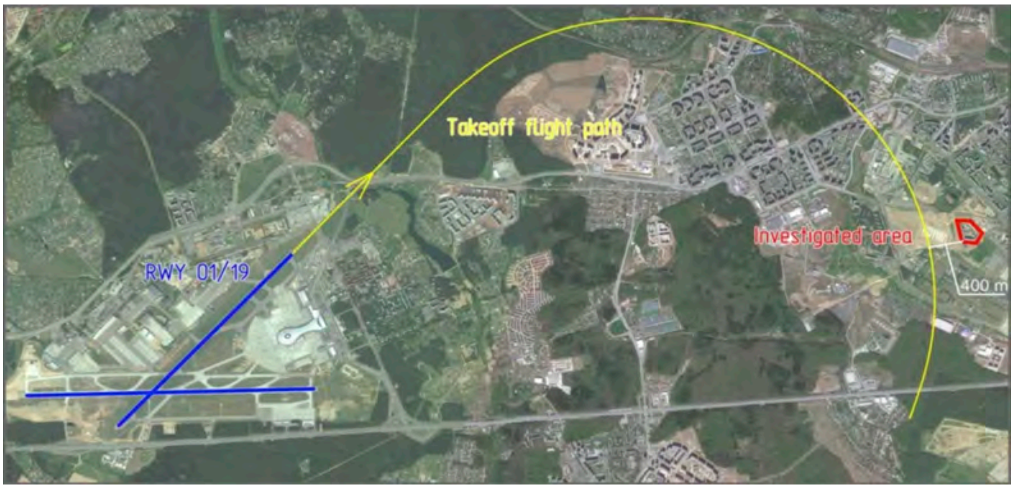

Figure 3. The location of the development site being designed relative to the aircraft take-off flight path.

Figures 4a and 4b graphically illustrate the detailed noise situations at the specific areas being investigated in this example: *the South-west Facades of Building #5(4a) and the North-east Facades of Building #5 and Adjacent Area (4b).*

The predictive calculation based on the design documents shown in **Figure 5** indicate that the construction materials intended for use would not compensate for the external aircraft noise, and all premises were exposed to significantly higher noise exposure than acceptable.

The impact of the most cost-efficient set of corrective measures was assessed. However, as **Figure 6** illustrates, the soundproofing of two end rooms failed to meet the regulated noise levels. To ensure that regulated noise levels are met and mechanical ventilation is performed inside the end rooms, designers had to propose additional corrective measures.

Conclusion

The Ecoflight Building software suite has been successfully used in the vicinity of airports of the Moscow air hub since 2009[4]. Fourteen (14) projects have since been completed, which involved the definition of residential areas based on the noise exposure and recommendations on land-use planning for new buildings, as well as on the required level of soundproofing for individual and collective housing in the investigated region.

As the software has gained popularity, real estate development companies have become increasingly interested in obtaining detailed cost analyses of the materials and soundproofing structures needed for construction, which allows them to meet soundproofing requirements and keep their costs under control. In parallel, predictive information allows airports to share information about expected future noise levels.

This approach meets the objective of identifying the soundproofing and mechanical ventilation levels needed for living areas and schools. This method provides knowledge about noise situation assessment both outside and inside regulated premises for all stakeholders including: aircraft organizations, local governments, and society at large. This information allows stakeholders to base their communications strategies on reliable, robust and transparent data, which is in line with the good practices identified in the newly adopted ICAO Circular on *Community Engagement for Aviation Environmental Management.*

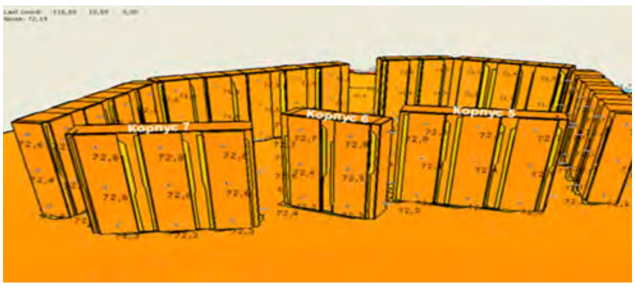

Figure 4a. Cartographic Visualized Assessment of the Noise Situation of Protected Facilities Exposed to Maximum Aircraft Noise Levels at Night. Perspective Projection of the Noise Picture of the South-west Facades of Building #5.

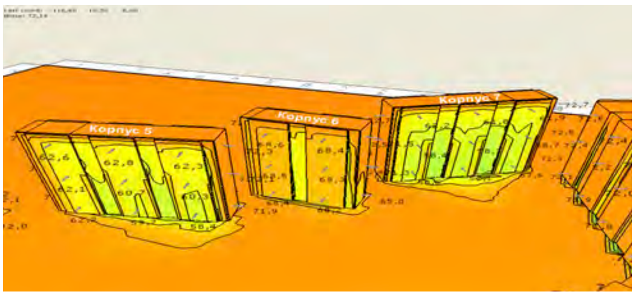

Figure 4b. Cartographic Visualized Assessment of the Noise Situation of Protected Facilities Exposed to Maximum Aircraft Noise Levels at Night. Perspective Projection of the Noise Picture of the North-east Facades of Building #5 and Adjacent Area.

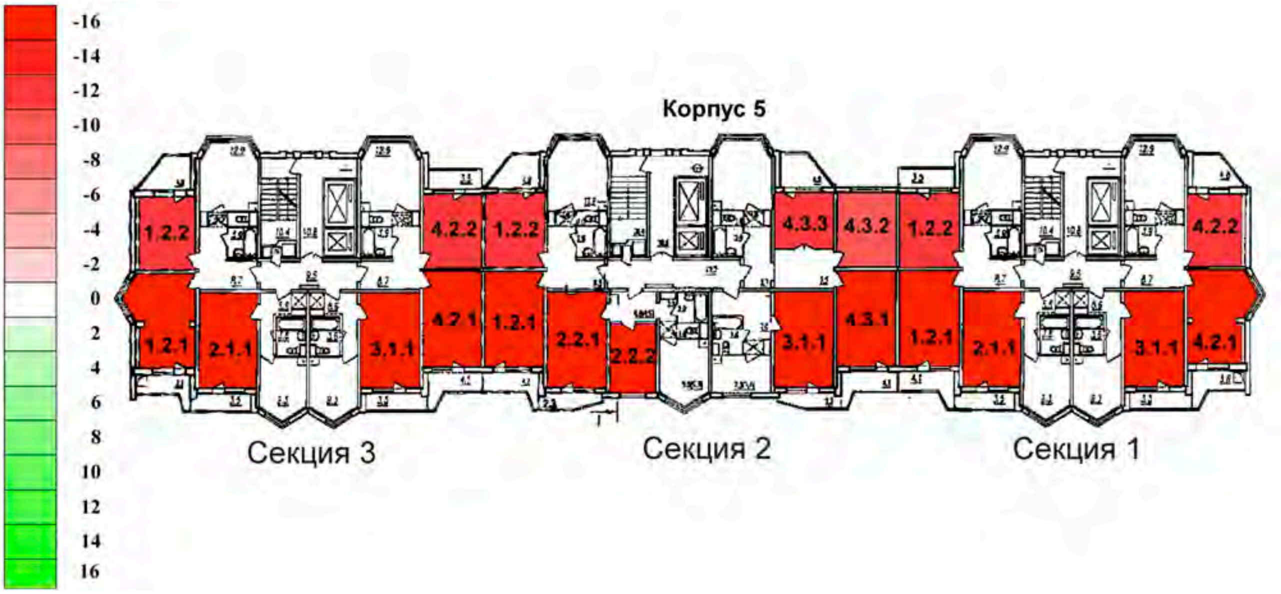

Figure 5. Predicted Excess of Acceptable Noise Levels in Living Areas of Apartments at Night.

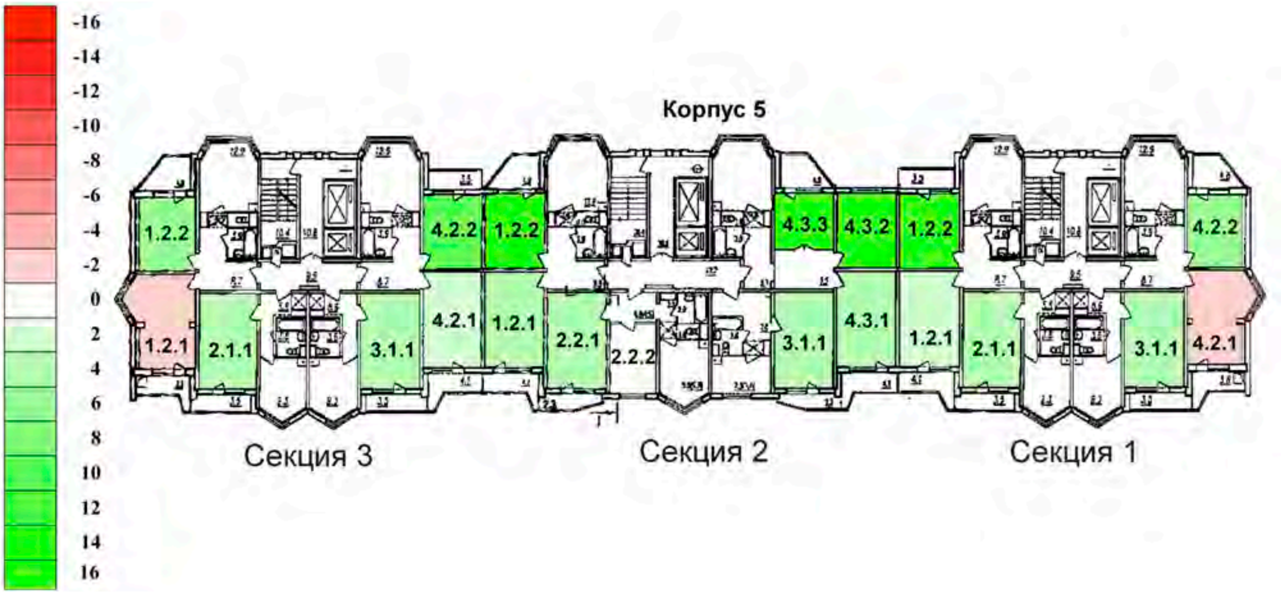

Figure 6. Predicted Excess of Acceptable Noise Levels in Living Areas of Apartments at Night After Implementing the Planned Soundproofing Measures.

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AIRPORT PLANNING MANUAL PART 2 – LAND USE AND ENVIRONMENTAL MANAGEMENT

BY ALEC SIMPSON (TRANSPORT CANADA), SHEILA SANKEY (TRANSPORT CANADA) AND SHANNON GARDINER (TRANSPORT CANADA)

In recent years, there has been increased public concern regarding the protection of the natural environment from the impact of transportation, and consequently, a growing emphasis on the need to employ effective measures to minimize such impacts. Since pollution may be generated within an airport as well as within the area surrounding it, environmental management practices should be applied at the airport and its environs.

The need for land-use planning in the vicinity of an airport was recognized in the early history of civil aviation and focused on use and control of land. The objectives of these measures were to ensure the safety of people in the air and on the ground and to maintain efficient airport operations. In recent years, there has been increased public concern regarding the protection of the natural environment from the impacts of transportation.

To lessen local and global impacts, it is important that the civil aviation industry endeavors to manage environmental impacts. This includes operational impacts

Background

ICAO Doc 9184 Airport Planning Manual is focused on master planning at an airport. The Airport Planning Manual Part 1 (APM Part 1) is primarily focused on operational safety and efficiency. The ICAO Doc 9184 Airport Planning Manual Part 2 – *Land Use and Environmental Management* (APM, Part 2) is focused on land use and environmental management on and around an airport. The purpose of APM, Part 2 is to provide effective practices at an airport to reduce the potential environmental effects caused by the airport and its operations. The scope of APM, Part 2 does include information on impacts from ground sources, but does not focus on reducing the impacts of aircraft in-flight. The recommendations and considerations for airport planning from APM, Part 1 should always be considered in cooperation with the information provided in APM, Part 2 to manage environmental impacts.

The APM Part 2 was released in the early 1980's as a guidance document for new airports. Over time it was recognized as a valuable tool for existing and expanding airports. Since 1996, it has been continually updated by the ICAO Committee on Aviation Environmental Protection (CAEP) Working Group 2 "Airports and Operations", to reflect new and emerging knowledge in the area of environmental management and land-use planning. An update in 2016 expanded the information related to recommended infrastructure decisions to facilitate environmentally-friendly airport design and management.

The following sections outline the essential areas of the APM, Part 2:

- Environmental Impacts Associated with Aviation Activities
- Environmental Management Measures and Considerations
- Infrastructure for Environmental Management
- Land Use
- Land-Use Planning
- Land-Use Administration
- Heritage Considerations
- Climate Change Resilience and Adaptation

General

The compatibility of an airport with its environs can be achieved by proper planning of the airport, management of pollution-generating sources, and land-use planning of the area surrounding the airport. The aim is to provide the best possible conditions for the needs of the airport, the community in the surrounding area, and the ecology of the environment. The location, size and configuration of the airport needs to be coordinated with patterns of residential, industrial, commercial, agricultural and other land uses of the area, taking into account the effects of the airport on people, flora, fauna, the atmosphere, water courses, air quality, soil pollution, rural areas and other facets of the environment.

To the extent that safety and operational considerations permit a choice, decisions on runway alignment and other airport development should take into account their potential effects on the environment in order to prevent or minimize environmental conflicts. In effect, "land-use management" is a term which describes only a portion of the total planning process, and even highly innovative management practices can have little impact unless they are imposed within the context of sound policies and careful planning. "Land-use planning" or "planning for compatible land uses which takes into account the needs of airport development" more adequately describes the process of achieving an optimum relationship between an airport and its environs.

Pollution occurring in and around the airport can have an effect on human health and the ecology of a broad area surrounding an airport. Efforts should be made towards pollution prevention in the first instance and impact management in the second instance. Environmental management thus provides a means of either decreasing pollution at the source or reducing the potential for negative environmental impacts. Environmental management includes items such as air and water quality guidelines, aircraft engine or ground-sourced noise limits, waste management plans, environmental emergency plans, and environmental management plans. By planning for intended growth and development, estimations can be made about the type and extent of potential future environmental impacts to allow for a more integrated approach to environmental management.

Environmental Impacts Associated with Aviation Activites

APM Part 2 identifies most of the major environmental issues that may be directly associated with air transport and civil aviation in particular. The environmental issues described focus on land use, soil erosion, impacts on surface and subsurface water drainage, and the impact on flora and fauna. For each environmental issue presented, a brief description is provided, including a summary of past and present ICAO activities aimed at mitigating the issue, as well as comments on the relevant activities of other organizations, whenever pertinent.

Environmental Management Measures and Considerations

Implementation of environmental management measures at airports and surrounding areas is in the best interest of the airport operators, the community and the natural environment. These measures may include compliance with international standards and national and/or local regulations. They are implemented by airports, often in collaboration with airport stakeholders. When planning infrastructure development an airport operator should consider how environmental management will be integrated to reduce the impacts on operations and the environment.

Some measures limit pollution at its source, while others reduce its effect on communities and ecosystems. An Environmental Management System (EMS) is seen as the best method to incorporate environmental management into all levels of corporate operations and decision-making processes. A well planned EMS at an airport can help to manage environmental impacts.

Airport operators can reduce the environmental impacts of their operations by incorporating environmental management plans and procedures with land-use planning. Several important components of environmental management at an airport are noise mitigation, emissions reduction and pollution prevention. Pollution prevention includes the use of materials, processes and practices that reduce or eliminate the creation of pollutants and wastes at the source. Adequate pollution prevention pre-empts the need for remedial actions later.

Infrastructure for Environmental Management

APM Part 2 provides high-level guidance material on the infrastructure that can be included in an airport design that can enable and facilitate environmental management by the airport operator.

Land-Use

Land use around airports can impact community exposure to the environmental effects of airport operations. As guidance on proper airport and land-use compatibility planning, APM Part 2 presents a variety of possible land uses with a broad appreciation of their relative sensitivity to the operational safety of aircraft and airport operations, local third party risk and aircraft noise exposure, and describes their compatibility with aircraft noise and airport operations.

Land-Use Planning

Land-use planning is an effective means to ensure that the activities nearby airports are compatible with aviation activities. Its main goal is to minimize the population affected by aircraft noise by introducing land-use planning measures, such as land-use zoning around airports. Compatible land-use planning and management based on appropriate "planning" noise contours, rather than "current" noise contours, can prevent encroachment of residential development at airports where future aircraft noise levels are projected to increase. ICAO Doc 9829 *Guidance on the Balanced Approach to Aircraft Noise Management* provides guidance on alleviating the problem of noise in the vicinity of airports. This Balanced Approach recommends consideration of four noise management pillars, one of which is land-use planning. There are substantial benefits to be gained from the correct application of land-use planning techniques in the development of airports. While these benefits should not be overstated, more attention should be given to proper land-use planning as a tool with the main objective being to minimize the population affected by aircraft noise. Land-use planning benefits may take time to be fully realized and should be implemented as soon as noise problems are foreseen.

Land-use Administration

Noise exposure is not the only factor to be taken into account for the purpose of land-use management in the vicinity of airports. It is recognized that economic factors are involved in land-use choices. Ideally, land-use decisions around airports would try to find a compatible balance between the interests in the land and the aeronautical use of the airport. For this reason, the authorities, local or central, have an important part to play in ensuring that aircraft noise exposure is taken into account when planning land-use in the vicinity of airports and that the ensuing plans are implemented.

There are many techniques for regulating development or bringing about conversion or modification of existing land-uses to achieve greater compatibility between the airport and its environs. Some of these may be controls, such as zoning or building and housing codes; other methods influence development through acquisition or taxation. The desired goal is for effective land-use planning based on objective criteria to minimize the amount of noise-sensitive development close to airports, while allowing for other productive uses of the land.

Heritage Considerations

Airports may be located within or close to natural or cultural environments that have aesthetic, historic, scientific, social or national significance which States may wish to protect for future generations. Airports may also include buildings and artefacts on site which are deemed to have heritage values. It is important, therefore, to consider in the planning of airport infrastructure whether any development proposal may impact upon heritage elements at the airport and how such impacts may be mitigated.

Climate Change Resilience and Adaptation

The level of greenhouse gas emissions in the atmosphere is understood to be having an effect on climate and will continue to do so into the future. According to the Intergovernmental Panel on Climate Change, "Climate change is projected to amplify existing climate-related risks and create new risks for natural and human systems"[1]. Going forward, despite States' agreement to limit global warming through the United Nations Framework Convention on Climate Change, the effects of a changing climate on human activities are expected to intensify; this presents risks and challenges for all sectors of society including the transportation sector.

APM Part 2 identifies possible impacts, risks and vulnerabilities and provides examples of effective adaptation and resilience practices to reduce projected climate change impacts on airports. Airports are often classified as critical infrastructure by their States and Regions as they facilitate mobility, economic growth, and provide essential services during disaster and emergency recovery situations. Moreover, any disruption that results in a loss of capacity at one airport can have a ripple effect throughout the wider network. In this context, it is important to develop resiliency against the projected effects of climate change, as they may negatively impact service continuity for aircraft and airport operations. The APM Part 2 provides guidance on how to address potential climate impacts in order to build more climate resilient infrastructure.

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COMMUNITY ENGAGEMENT

BY XAVIER OH (AIRPORTS COUNCIL INTERNATIONAL - UNTIL FEBRUARY 2016)

For airport operators and other aviation stakeholders, community engagement is the link between environmental stewardship and mitigating environmental constraints to aviation operation and growth.

An adverse and confrontational relationship can result in political and social pressure against the operation and development of the airport. Engagement between aviation stakeholders and local and regional communities can foster understanding of aviation operations, the extent of environmental impacts, and their mitigation by aviation stakeholders. The importance of the economic and societal benefits of aviation should also be part of the broader understanding of how aviation can be sustainable. A well informed community that understands and trusts the information provided is more likely to make measured and appropriate response to aviation operations and development proposals.

Case Studies of Community Engagement

In 2013 CAEP recognized the importance of community engagement, and undertook a task of collecting case studies of recent activities and developing a circular highlighting both lessons learned and good practices. The publication of the case studies would assist States and the aviation industry, in particular airports, airlines, and Air Navigation Service Providers (ANSPs), to engage local communities to help address environmental matters.

Over the course of 2015, a questionnaire was distributed to CAEP Member States and other aviation stakeholders, and a total of 48 case studies were submitted to CAEP. Of these, over 60% were submitted by operators of international airports, though in virtually all cases many other aviation stakeholders including airlines, ANSPs, government departments and civil aviation authorities were also involved in the studies. The findings below were identified in the case studies.

The most common form of community engagement consisted of the aviation industry providing information to community groups and individuals on aviation operations and development plans, and communicating the current and future environmental, social and economic benefits and impacts. Community members were often able to provide feedback and express their views by means such as mail, telephone, e-mail, websites and meetings.

Environmental issues usually dominated community feedback and, most often, it was the impact of aircraft noise that was the issue of concern. However, increasingly other environmental issues such as air quality, greenhouse gas emissions, land use, and waste management also needed to be addressed during these interactions.

Public consultation was often required as part of the process to gain consent or approval for infrastructure development including both on-airport projects and airspace changes. However, communities' views were not systematically taken into consideration in the decision-making processes.

The responses also showed that many airport operators and other aviation stakeholders had taken their community engagement efforts beyond communications and consultations on environmental issues. Recognizing that the three pillars of sustainability are commonly considered to be environmental, social and economic, aviation stakeholders were increasingly implementing social programs, often as a part of their corporate social responsibility or similar initiatives.

Two examples from *Corporación Quiport S.A.*, the operator of the new Mariscal Sucre International Airport (MSIA) in Quito, Ecuador are illustrated in Figures 1 and 2. The first is from a public consultation and disclosure program and the second is from a scholarship program for children in "social risk" groups living in the vicinity of the airport. The Consultation and Disclosure Plan involved the parishes and local neighborhoods, educative centers, MSIA's commercial operators, health centers, businesses, Quito Municipality's zonal administration office, social organizations, and other social actors influenced by the airport's operations. Quiport implemented the "David Cachago" Scholarship Program for social risk groups and students from public educative institutions in the MSIA's surrounding areas through the annual scholarship's disbursement. From 2007 to 2015, 547 scholarships were delivered.

Lessons Learned and Good Practices

Some important lessons learned and good practices contained within the case studies submitted for the circular can be summarized as follows.

- Starting early and being proactive using a well-planned strategic approach that includes continuing engagement over the long term, not just during the planning application process.
- Providing an open and transparent exchange of information as the basis for building long-term trust.
- Ensuring the process is as inclusive and collaborative as possible,

informing and seeking input from as many stakeholders as appropriate and practicable, and taking into consideration the scale and scope of the project.

- Using new technologies to provide different ways to present information and interact with community members. Social media is a crucial means for reaching a wider audience and yet traditional print and broadcast media should not be ignored.
- Community engagement cannot guarantee that all parties will be pleased with the outcome, so it is important to manage the expectations of all stakeholders.

While many aviation organizations have conducted successful community engagement efforts, including providing information and consulting on development projects, publicly available information to help aviation organizations effectively engage with communities is limited. Therefore, CAEP developed a circular to share lessons learned and good practices to assist States and the aviation industry to engage communities and to address environmental questions/matters. The ICAO Circular *Community Engagement for Aviation Environmental Management* was delivered at the CAEP/10 meeting.

Photos from Quito International Airport:

Figure 1. Quito International Airport community engagement meeting

Figure 2. Quito International Airport scholarship recipients

10 YEARS MEDIATION CONTRACT – 10 YEARS DIALOGUE FORUM

BY CHRISTIAN RÖHRER (FLUGHAFEN WIEN)

10 years ago, a mediation contract was successfully concluded at Vienna Airport and the Dialogue Forum Airport Vienna was founded. The communication and the balance of interests between citizens, politics and aviation, however, date back to several years before. This article reviews the history of a process, which received attention worldwide.

The mediation process at Vienna Airport originated from the "Master Plan 2015", which was published by Vienna Airport in April 1998. At the core of the master plan, were the construction of an additional runway and an extension of the terminal to further enable the effective handling of the growing air traffic. Soon after publishing the master plan, citizens expressed their concerns and worries about the expansion of the airport and wanted to be equally involved in future plans. The newly appointed airport chairpersons took citizens' concerns seriously and wanted to reconcile the airport's interests with those of the neighbouring communities and the local population. Eventually, a mediation process was initiated. The preparatory work started in the beginning of 2000. After a preparation phase of several weeks, the mediation forum held its first meeting on the 18th January 2001. About 50 contracting parties participated in this meeting – including the mayors of the communities most exposed to aircraft noise, the environmental protection authorities, the representatives from Vienna and Lower Austria, the citizens' association against aircraft noise, and the aviation sector. The mediation agreement, signed on the 1st March 2001, defined the environmental impacts linked to the expansion plans of the airport and the noise pollution of the current 2-runway-system as core issues. It also set the rules for the cooperation. The mediation agreement further highlighted that addressing the airport expansion plans and the current noise pollution for the population and the local communities was equally important. In doing so, a first step towards mutual trust between all parties was taken.

Partial Contract "Current Measures"

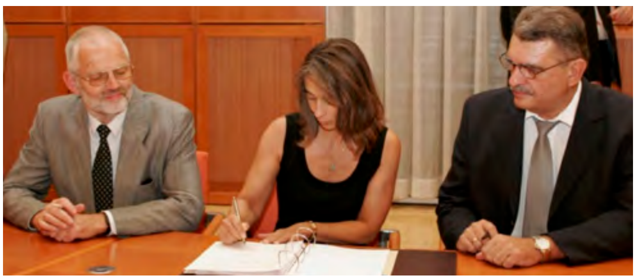
Prior to negotiating the future development of the airport site, measures for the reduction of the existing noise situation had to be stipulated and implemented. Therefore, after numerous meetings of various task forces, the partial contract "Current Measures" was signed on the 27th May 2003. The goal of the agreed measures was to reduce the number of people affected by aircraft noise and to relieve the most affected settlement areas. Above all, measures were implemented to optimally avoid the direct overflight of settlement areas around Vienna Airport. The partial contract regulates the number of take-offs and landings on the individual runway directions within a calendar year, based on target values. Apart from that, also the time frame for the use of the runways was stipulated in the partial contract. Thus, no overflight occurs over individual settlement areas between 9 pm and 7 am, but there are exceptions for ambulance flights as well as any necessary runway closures. Upon the worldwide publication of the new procedures, they became binding for all pilots approaching Vienna Airport. The definite implementation of the measures, taking into account all deadlines, took place at the beginning of the year 2004.

Representatives after signing the partial contract in 2003

From the Partial Contract to the Mediation Contract

The conclusion of the partial contract was the first landmark in the mediation process at Vienna Airport. From that moment on, the negotiations for the conclusion of a mediation contract that would be binding by civil law were given priority. Discussions focussed on the core topics of environmental funds, technical noise control, the position of the 3rd runway and the night flight restrictions. The sustainable development of the entire region was chosen as the benchmark for all suggestions and common decisions. In doing so, every topic was tackled in a way to achieve a balance between economic, environmental and social aspects.

About two years after signing the partial contract, the mediation contract, binding by civil law, was concluded on the 22nd June



Citizens initiatives signing the mediation contract

2005. More than fifty parties signed the summary of the results. The "General Mediation Contract" was concluded between Vienna Airport, Austrian Airlines, the provincial governments of Vienna and Lower Austria, the neighbouring communities as well as citizens' initiatives against aircraft noise. The mediation contract governs, apart from the process agreements, the night flight regulations, the implementation of the technical noise control and the procedure for the project 3rd runway. Therefore, the project had to be submitted to an Environmental Impact Assessment (EIA). A noise zone limit for a future 3-runway-system is also part of the contract.

This mediation process was a great success in demonstrating that it is possible, even in the context of highly controversial infrastructure projects, to carry out a participatory, transparent and fair procedure involving all direct stakeholders.

From the Mediation Process to the Dialogue Forum

The mediation process convinced neighbouring communities and citizens' initiatives to continue the discussion and negotiation process. Already during the mediation process, it became clear that Vienna Airport would have to appoint an institution for permanent regional conflict management, known as "The Dialogue Forum". The "Dialogue Forum" is therefore a direct result of the mediation process. The first meeting of this forum took place on the 27th September 2005. The "Dialogue Forum" attained its full working capacity in the first half year of 2006. The work was taken up by different committees – amongst others by the task force "Environmental Impact Assessment-procedure and mediation contract", which monitors the adherence of the Airport Vienna to the requirements of the mediation contract, while the task force "evaluation and monitoring" is responsible for the monitoring of the compliance with the general requirements. Due to the extremely dynamic air traffic grow that Vienna Airport, additional measures to those included in the mediation contract have been regularly discussed and negotiated in the "Dialogue Forum" in order to mitigate the environmental impacts of air transport. This process continues today.

Citizens` initiatives are equally involved and contribute in every negotiation

Constructive Dialogue

Since the establishment of the "Dialogue Forum" at Vienna Airport, a range of measures have been agreed and implemented. Such measures are developed by the air transport sector – Airport Vienna, Austrian Airlines and the Austrian air traffic control Austro Control – and all citizens' initiatives affected by air traffic, communities and provincial governments, who negotiate on equal footing. Austro Control also decided to engage in the "Dialogue Forum" voluntarily. It regularly contributes to inform possible proposals and to implement agreed measures, after clearing their safety and operational feasibility. The robust decision-making process ensures that the different interests of the parties are brought together in a transparent manner. Dedicated task forces and working groups elaborate solutions for the improvement of quality of living in the region around the airport. These are passed on to the higher levels of approval after unanimous agreement and are eventually evaluated by an extended Board.

10 Years Balance of Interests in the Dialogue Forum

In 2015, the "Dialogue Forum" celebrated its 10th anniversary and its achievements are impressive: about 330 meetings of various committees and 120 regional conferences took place, and a number of measures were successfully implemented. Over the past ten years, the growth of the noise contours has been decoupled from the growth in passenger numbers, despite the use of larger aircraft. Many agreements on air traffic regulations show close to 100% compliance, such as adherence to corridor, turning altitude and single runway operation.

Flughafen Wien Group CEO Mag. Julian Jäger attends meetings of the dialogue forum

The agreed night flight regulations significantly reduce the aircraft noise pollution – many settlement areas are not overflown between 9 pm and 7 am as a rule. During the night time core period, between 11:30 pm and 5:30 am, an absolute limit of 4.700 take-offs and landings within one calendar year has been realised. Within the current 2-runway system, a comprehensive noise protection programme covers areas which are exposed to a continuous sound level of more than 54 decibel during the day and more than 45 decibel at night. This provision goes beyond the existing legal requirements. The number of people exposed to aircraft noise above 54 decibels during daytime has been reduced by nearly 10% since 2005. This can be correlated to the use of quieter aircraft, which results from the introduction of noise charges.

The numerous changes in approach and departure routes to better avoid populated areas as well as the implementation of transition arrivals and rules for visual approaches were negotiated in the "Dialogue Forum" and successfully implemented. The institutionalised participation and the possibility for the population to actively participate in decision-making through the "Dialogue Forum" are clear successes.

Panel discussion due to the 10th anniversary of dialogue forum

In the past ten years, the "Dialogue Forum" contributed to decoupling aircraft noise exposure from the increase of passenger numbers.
An essential outcome from the "Dialogue Forum" is the possibility to relieve some areas from noise exposure. It means that other areas had to accept increased aircraft noise exposure. This was made possible through the "Dialogue Forum", as clear rules, such as the preservation of the quality of life and the environment were underlying the noise distribution process.

A Look into the Future

While the final stages of the approval procedure for the 3rd runway are on-going, the "Dialogue Forum" is already considering its future work programme. A concerted approach is needed to elaborate an evaluation system, which would enable to design flight routes with a minimized impact on the population. Also, the environmental impacts of the flight procedures as a whole should be taken into account, including possible environmental interdependencies between noise exposure and air quality. At the same time, the management of the current measures and the monitoring of the adherence to the agreements related to the 2-runway-system must be continued.

A look into the future shows that the work in the "Dialogue Forum" is crucial for the harmonious development of the region. This cooperation and the ability to overcome challenges with all interested parties is key to balance the economic, social and environmental interests.

Panel discussion due to the 10th anniversary of dialogue forum

MOVING TOWARDS A 4TH GENERATION IN AIRCRAFT NOISE MANAGEMENT

BY RICK NORMAN (HEATHROW AIRPORT)

Heathrow connects Britain to the world. Being responsible of 78 per cent of all UK long-haul flights, Heathrow joins Britain both to our established trading partners and to the world's emerging economic powerhouses.

The airport represents an integral part of the local community in West London and the Thames Valley. A total of 114,000 jobs in the local community are supported by the airport[1], representing more than one in five of all jobs in the area. Thanks to the connectivity that the airport provides, the economic landscape of the surrounding region has been reshaped.

Yet, as well as bringing huge benefits to Britain, an airport of the size and importance of Heathrow has downsides for people living nearby – in particular, the challenge of aircraft noise. At Heathrow we recognise that the problem of aircraft noise is real, serious and needs to be addressed.

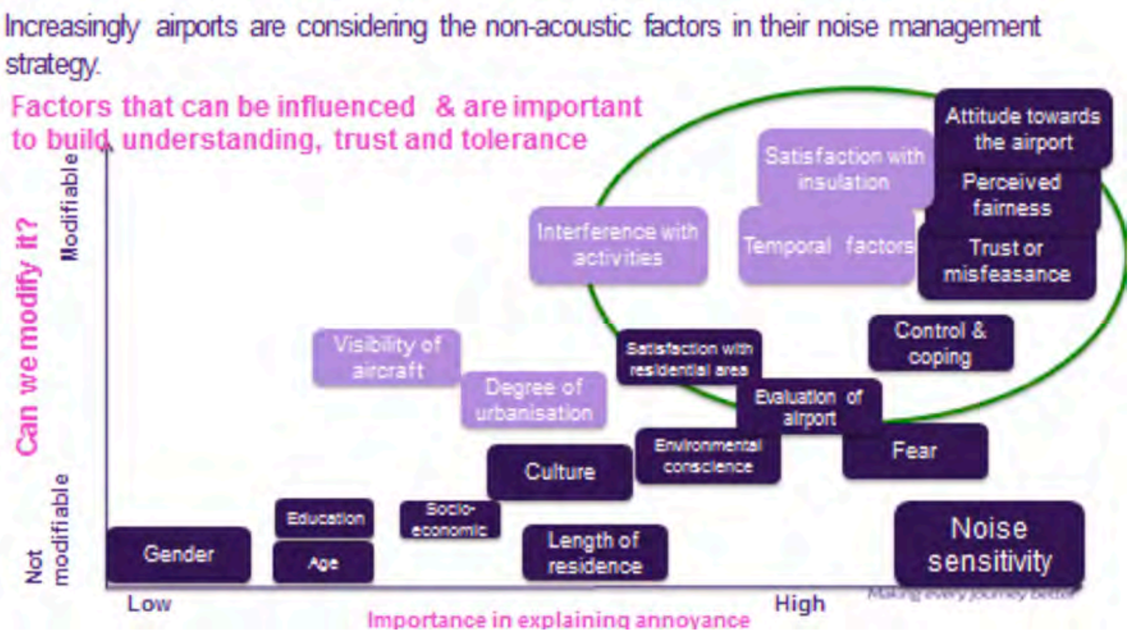
Our Approach to Noise Management

The attitudes of local communities towards an airport are important to its future success. Indeed, their adverse response can result in political and social pressure against the operation and development of the airport. There are numerous examples, particularly in mature economies where growth aspirations have failed or been severely delayed because of fractured relationships.

In seeking to address the concerns of local community stakeholders, we have traditionally closely aligned our activities to the ICAO Balanced Approach. Whilst this remains a key facet of our approach and in general has provided industry, regulatory and policy stakeholders with a clear and a solid bedrock upon which to build noise management plans, it has become increasingly clear to us that something more is needed.

Essentially, the Balanced Approach has focused on abatement i.e. reducing decibels and it is clear that this will remain a critical aspect of noise management – we must always seek to reduce the sound levels where we can. However, more recent research has shown the importance of non-acoustic factors and increasingly airports are recognising this in their assessment of local community reaction to their operations. We have long supported this research through our participation in the Aircraft Noise Non Acoustics (ANNA) group or input into research such as the COSMA study.

Building a strong local relationship across different sectors of local communities could be key in changing the dynamic of the noise issues around airports and intuitively it makes sense – we all react differently to sound levels depending on our relationship



with the source at least as much as the actual level itself. Engaging well with community stakeholders is now seen as a critical part of Heathrow's noise action plan[2].

Indeed, we would now argue that it is another pillar in the Balanced Approach Summarised in the B&K graphic below. An airports noise management strategy evolves over time as it matures. Airports typically move from a position of ignorance, through activities centred on management and abatement towards tolerance – or a 4th generation. Real community engagement and collaboration is critical to this next evolution and whilst the journey will at times be difficult it is a necessary pathway if, as an industry, we are committed to unlocking the impasse that can sometimes exist between community and industry stakeholders.

It is a journey that Heathrow has been on for several years. We are a long way from the end but we believe we have made some good progress and learnt some valuable lessons along the way, which are all consistent with the key principles identified in the new ICAO Circular on "Community Engagement on Aviation Environmental Management" delivered to CAEP/10.

There are three broad areas of activity that summarise how we have enhanced our approach:

- Improving understanding
- Improving collaboration
- Improving communication and transparency

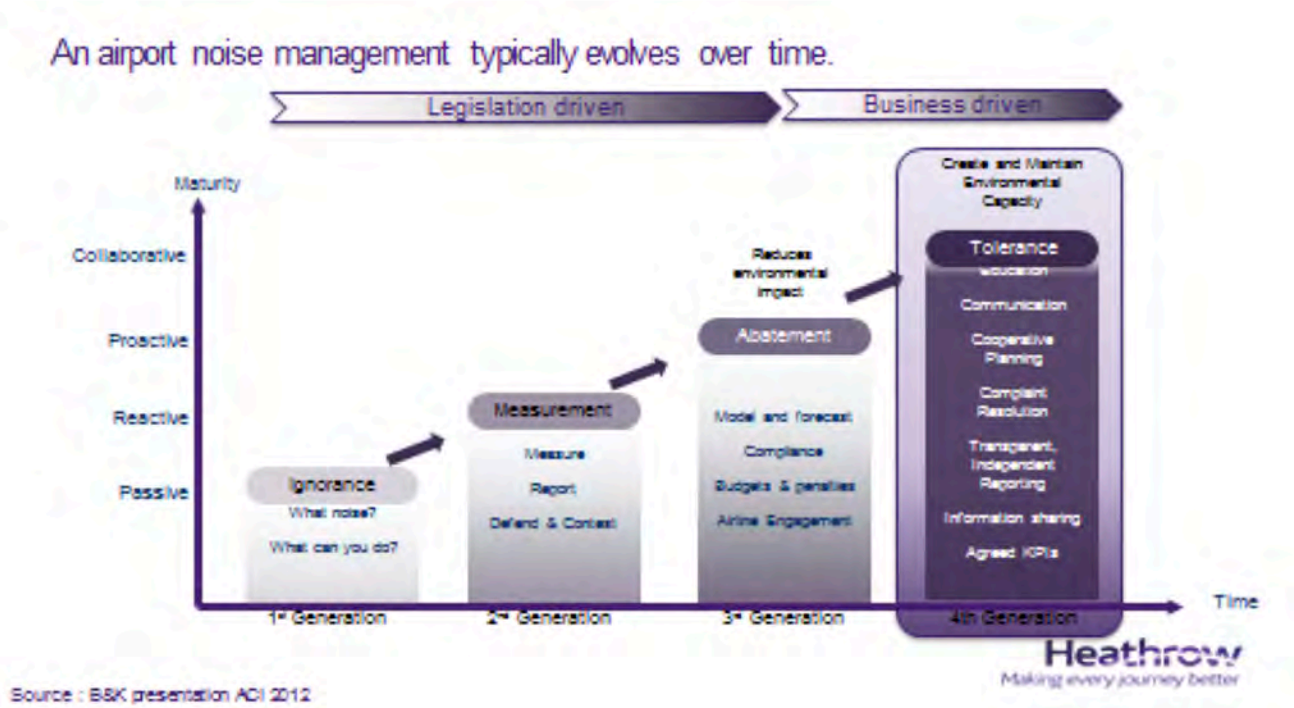
Improving our Understanding

Understanding our local community better has been an important step forward in our approach – we have conducted regular community polling of attitudes towards the airport. Not surprisingly, there are diverse views ranging from those who are strong advocates of the airport to those who feel quite hostile towards it. Historically, dialogue on noise issues has been dominated by these two polar views. However, when invited to elaborate on these views, members of the public tend to express a diversity of opinions.

Conducting and supporting research has become an increasingly important aspect of our approach. We have looked at "independent noise authority" models around the world to help understand current best practice and have actively supported research into the importance of non-acoustic factors in noise management for over a decade. This covers areas such as "defining respite" or trends in property values. However, we firmly believe that broader independent research into a range of issues such as the effectiveness of noise insulation programmes and the relationship between airports and quality of life.

Public consultation is also a key aspect of our approach and one we have used not only in shaping our noise action plan but also our expansion proposals.

Understanding local views to help shape our approach.

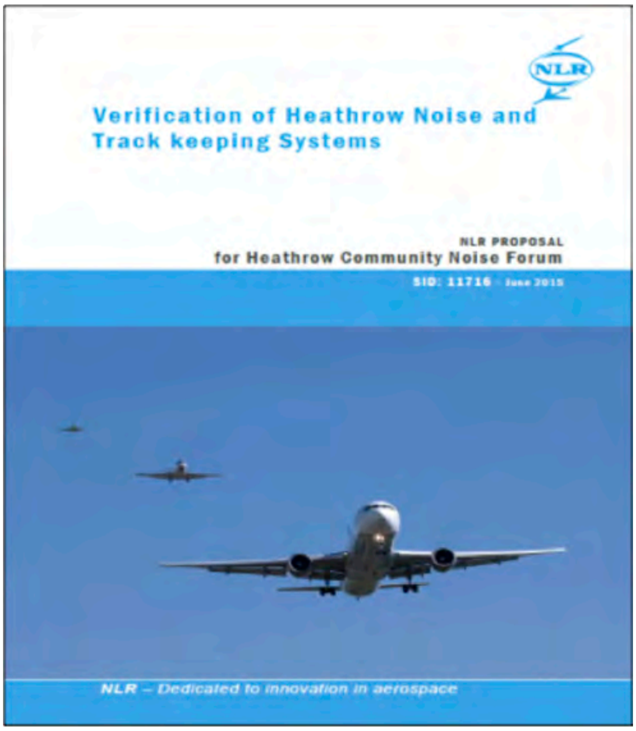


Improving Collaboration

Collaboration has been a fundamental feature of Heathrow's approach to noise management for a number of decades – however that has largely been with industry partners such as NATS, our air traffic services provider, and our major airlines. This has been very successful in reducing sound exposure levels but the historic lack of a community involvement in exploring potential solutions has been a weakness in this approach. the delivered improvement has often met an indifferent or even sceptical response.

The EU Environmental Noise Directive (END or Directive 2002/49) and a political frustration with the traditional polarised debate acted as catalysts for change at Heathrow. The EU Directive ensured that wide public consultation of proposed actions was undertaken. This gathered views from a diverse range of stakeholders and led to a clearer understanding of what was important to focus on. The process required active engagement and at Heathrow, this meant a series of public events and stakeholder group sessions. Community involvement became an integral part of our management approach.

There followed a step-change as the airport operator, industry partners (British Airways and NATS) and the leading community noise group, HACAN decided to come together to find areas of common ground. This resulted in a joint paper submitted to the Department of Transport and highlighted the need to identify supplementary metrics to support traditional contours and investigation of opportunities to offer more predictable respite. As a result, an early morning arrival respite trial[3] was undertaken and a number of additional metrics were included in Heathrow's annual noise assessment reports.



This initial group evolved to form the Heathrow Noise Forum (HNF) which added representation from the regulatory, international airline, local authority and regional perspective. The concept behind this group is that rather than having multiple representation from each stakeholder "cluster" the individual member is charged with gathering and bringing a rounded view from that perspective and in that sense enable a more strategic view of managing the noise issue. But there was also some key learning that the group has taken. In common with the rest of the world, the use of precision based navigation is coming to the UK. The HNF was keen to explore how this could be used positively to provide predictable respite (through multiple routes rather than concentration along one) and supported trials to explore this. As a result, there was a significant increase in complaints and the extent of these complaints was also much wider than seen traditionally. We recognised that the level of communication and engagement prior to the trials had not been sufficient which led to widespread misunderstanding and understandable concerns. Consequently, another engagement group, the Heathrow Community Noise Forum (HCNF)[4] was established which is made up of councillor and resident group representations from local boroughs, including many much further away from Heathrow than we have previously regularly engaged with.

The first key issue to address with the HCNF members was the level of trust in the noise and track keeping systems we use to monitor and measure aircraft operations. There was as strong feeling that these were inaccurate, preventing any further analysis of change, whether temporary due to the trials or over time This is not a problem unique to Heathrow and is frequently an issue raised by other airport operators. To address this, we supported members of the HCNF in drafting a scope of work aimed at verifying the data and invited potential suppliers to respond. The HCNF members selected the preferred supply and then worked directly with them to undertake the verification work. Heathrow involvement was limited to the provision of the data to be verified and payment of the supplier. The final report is due in 2016.

In parallel an independent consultancy was appointed to undertaken some data analysis of longer term trends in flight path patterns. This work has highlighted some incremental changes in some cases which are the subject of further work in 2016. Indeed, the group is currently in the process of agreeing a 2016 action plan through a series of focused working groups.

Improving communication and transparency

Another finding from our regular polling and research has been that awareness of how the airport operates and our efforts to reduce its noise impacts is often low. Equally, feedback on the action planning process has raised local concerns about transparency and access to more detailed data and statistics has been a cause of frustration for some residents and community groups.

To try and address some of these issues, we have been focusing increasingly on our style of communications and identifying opportunities to provide reassurance and transparency of data. There are many examples over recent years but three examples that spring to mind immediately are the Fly Quiet Programme (FQP) our annual noise blueprint and the enhancement of our Webtrak system.

The FQP was the first in Europe to publish a league table of airline performance across a range of noise metrics. These include the composition of their fleet relative to ICAO standards, operational performance and night operations. The league table is published every quarter and has been well supported by many of the airlines5. It has not only provided a level of transparency not previously seen for interested local stakeholders but also offered a chance for airlines to demonstrate sustained good performance or step change improvements and has been broadly welcomed.

Our noise action plan contains over 45 actions and is a detailed and technical document that is, not easily accessible for many stakeholders. So in 2015, we launched our first noise blueprint6. The document is a simple summary of 10 key actions that we have placed particular focus on for the year. As part of the additional emphasis, the CEO of London-Heathrow wrote to his counterpart at 40 airlines to seek their support for the implementation of these 10 key actions.

Like a number of airports globally, Heathrow has had a web-track system in place for a number of years. These typically allow users to investigate and replay individual flights over particular locations. We have been working with our supplier to develop an enhancement to this system that will enable users to conduct their own high level data analysis. As part of our CNF action plan one of the work streams will consider how to potential develop this on-line tool but based on our engagement with community stakeholders to date we have focused on enabling users to answer questions like how high, how many, how often and how these differ between different time periods and years.

By taking the sort of actions outlined above we believe this will build a basis for more constructive dialogue and engagement built on a common understanding of the data and critically trust.

Going Forward

Although moving towards a 4th generation in noise management will not always deliver the clear quantifiable reduction in “noise footprints” that are traditionally sought, it can be expected to deliver changes in perceptions and attitudes from all those involved in seeking to reduce the impacts of aircraft noise. That is not to say that continuing to seek acoustic reductions is not part of the approach, clearly it remains critical, however it recognises that managing aircraft noise is about more than just the decibel.

As the relationship and trust develops on all side, we would hope to see a much more collaborate process in the design and development of our END noise action plan, building on the approach we have taken to date with Forums such as the HCNF and HNF.

Approaching this issue with a philosophy of seeking to build tolerance based on trust and collaboration will be key to achieving a long term solution.

At Heathrow we continue to seek wider community attitudes in order to continually improve our approach.

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CHAPTER 3

LOCAL AIR QUALITY

LOCAL AIR QUALITY - OVERVIEW

BY ICAO SECRETERIAT

Since the late 1970s ICAO has been developing measures to reduce the impact of aircraft emissions on Local Air Quality (LAQ). These measures 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. One of the principal results arising from the work of ICAO 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*") 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 (NOx), 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.

The certification process for aircraft engine emissions is based on the Landing Take Off (LTO) cycle, shown in **Figure 1**, for aircraft engine emissions 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 fuel flow and emissions the data for each of the modes of operation. 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.

Over the past three years work has been conducted by CAEP to continue 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, an industry led combustion technology review, the update to ICAO SARPs to ensure their currency, and an overview of the current state of the science regarding LAQ. The CAEP/10 meeting recommended the first nvPM standard for aircraft engines and this will be considered by the ICAO Council for adoption in the early part of 2017.

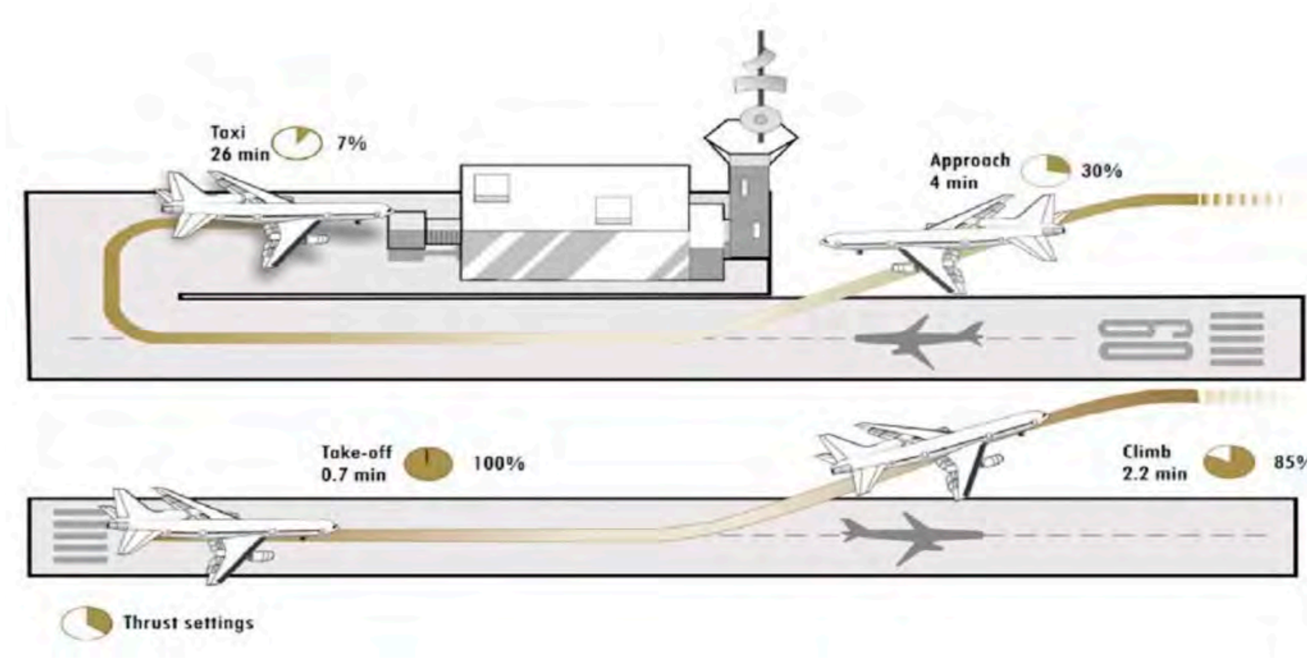

Figure 1. Illustration of ICAO emissions certification procedure in the LTO cycle.

Emissions Standards and 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. The objective of ICAO engine emissions standards is to encourage the use of the latest technology in engine designs. Therefore the setting of standards is closely linked to understanding the research and development of technology. To complement the standard-setting process, CAEP developed, with the assistance of a panel of independent experts, medium- and long-term NOx technology goals (10 and 20 years, respectively). While CAEP did not conduct a NOx technology review in the past three years (the most recent IE review was published in 2010), an industry-led combustion technology review was performed and was presented to CAEP. This industry-led review provided an assessment of advances in engine combustor design technologies for subsonic aircraft and the degree to which these technologies could influence gaseous emissions, and particulate matter, including the potential interdependencies and trade-offs with emissions and noise, and the likely timescales for introduction. The advances in engine combustor design technologies were considered in the context of the existing mid- and long- term CAEP goals. To provide the latest state of technology, currently CAEP is working on an integrated independent expert technology goals assessment and review for engines and aircraft which aims to be delivered to the CAEP/11 meeting in February 2019.

MEDIUM- AND LONG-TERM NOX TECHNOLOGY GOALS

Medium Term (MT) goal for NOx positioned at CAEP/6 NOx Standard minus 45% +/- 2.5% at Operating Pressure Ratio (OPR) of 30 by 2016. The Long Term (LT) NOx goal is CAEP/6 NOx Standard minus 60% +/- 5% by 2026.

Developing a New Standard for Particulate Matter

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. 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). These particles are ultrafine and are invisible to the Human eye.

During the CAEP/10 meeting, CAEP recommended a new standard for nvPM. The nvPM Standard, which will apply to engines manufactured from 1 January 2020, is for aircraft engines with rated thrust greater than 26.7kN and is the first of its kind. It includes a full standardized certification procedure for the measurement of nvPM, with the regulatory limit for the nvPM mass concentration set at the current ICAO smoke visibility limit. The new nvPM Standard is recommended as an amendment to Annex 16, Volume II and is currently being considered for adoption by the ICAO Council. Further details on the work on nvPM can be found in the article on the *Development of a Particulate Matter Standard for Aircraft Gas Turbine Engines*, 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, and to support this ICAO continues to develop international standards, guidance material, and technical documentation as appropriate for the needs of the international community. This includes the maintenance of Annex 16, the environmental technical manuals, and the ICAO engine emissions databank.

Based on the success of recommending the first nvPM requirement, the work of CAEP will now involve the further development of a more stringency nvPM mass and number standard during CAEP/11, which will consider technical feasibility, economic reasonableness, environmental benefit and interdependencies. 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 in the future.

Sustainable Development Goals

WHITE PAPER ON AIR QUALITY AVIATION IMPACTS ON AIR QUALITY: STATE OF THE SCIENCE

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* This White Paper represents the summary of the scientific literature review undertaken by researchers and internationally-recognized experts. It does not represent a consensus view of ICAO.

Summary

Aircraft produce emissions that react in the atmosphere to form pollutants that impact air quality. These emissions have long been regulated through standards for aircraft engines for oxides of nitrogen (NOx), carbon monoxide (CO), unburned hydrocarbons (UHC), and smoke, via a Smoke Number (SN). New standards are being developed for non-volatile particulate matter (nvPM). Much is understood about how these and other emissions affect air quality in airports and in the regions around them. Ongoing research efforts are extending that understanding through better measurements and modelling. Work on PM is directed at developing the new nvPM standard, and increasing the available data on aircraft engine PM emissions. Alternative fuels have the potential to reduce PM emissions significantly. Emissions inventories are developed to calculate the contributions of all emissions to the ambient burden of pollutant concentrations that, in turn, are used to estimate the impacts on air quality and human health. Aircraft emissions at cruise altitude can also propagate back to affect local and regional air quality, and estimates of this contribution and the associated uncertainties have been calculated.

The impact of aircraft emissions on air quality was the concern that gave rise to the first State aircraft emissions regulations that were imposed in the 1960s and 1970s. ICAO adopted stringent standards in 1981 that were applied to all in-production engines in 1986. Air quality issues related to aircraft emissions were reviewed in the 2007 ICAO Environmental Report (ICAO, 2007), covering technology and standards, operational measures, market-based measures, and airport charges guidance. Growing interest in the effects of Particulate Matter (PM) on human health and climate has brought a new focus on measuring aircraft PM emissions. Background and current issues of PM were summarized in the 2013 ICAO Environmental Report in the section titled "Development of a Particulate Matter Standard for Aircraft Gas Turbine Engines" (ICAO, 2013).

Aircraft turbofans (> 26.7 kN thrust) are currently regulated for their emissions, which include oxides of nitrogen (NOx), unburned hydrocarbons (HC), carbon monoxide (CO), and smoke. The smoke regulation also applies to engines with output ratings < 26.7 kN. Smoke emissions are mainly carbonaceous particles emitted as a product of incomplete combustion, and these particles are now the subject of a proposed new standard that will regulate the number and mass of non-volatile particles (nvPM). Airport emissions are also affected by emissions from other sources such as Auxiliary Power Units (APUs), ground service vehicles, and include other sources such as ground transportation and power plants. These various emissions interact with each other, and thus each contribution to the total regional inventory of pollutants must be quantified and evaluated as accurately as possible.

Aircraft engines are successfully meeting increasingly stringent emission requirements. However, more stringent and new requirements are being considered as the understanding of emission impacts on the environment and human health is improved. The need for a new nvPM standard that goes beyond the existing Smoke Number measurement is a prime example of this evolution. Similarly, the ever-increasingly stringent standard for NOx is complemented by a growing concern over the impact of the NO_2 component of NOx (NOx consisting of NO plus NO_2).

This report focuses on the impacts on air quality, as opposed to climate impacts, due to emissions from aircraft combustion engines, including both propulsion engines and APUs. While it is understood that aviation operations include other sources of emissions, they will not be further discussed or analyzed here. As the health and welfare impacts of particulate matter and ozone are well understood and the underlying science has not changed since the last ISG review of aviation's impact on surface air quality, this review focuses on advances in the scientific community's understanding of the emissions that come from the aircraft tailpipe and how these emissions react and disperse in the atmosphere to form ground level PM and ozone (O_3). There is a continuing need to better understand the relative impacts of particle number versus particle mass, fine PM versus ultrafine PM, as well as the relative toxicity of the various ambient and aviation PM components. However, there are no new results on these issues to report at this time.

Measuring and Modelling Emissions

Figure 1 provides a representation of aircraft emissions and how they ultimately contribute to ambient pollutant concentrations that impact public health and welfare. While aircraft emissions can be directly measured at the source and ambient pollutant concentrations can be measured at any location, modelling is required to attribute the contribution of aircraft to ambient pollutant concentrations.

Ambient measurements in the vicinity of airports typically show little to no contribution from airport emissions (Zürich Airport, 2013). However, recent studies have shown elevated PM number levels near airports (Hudda et al., 2014; Keuken, et al. 2015). Measurement protocols and guidance are established for criteria pollutants. However, the ambient measurement of ultrafine particle number concentrations is not yet standardized.

Non-Volatile Particulate Matter (nvPM) Emission Characterization and Quantification

New sampling techniques have been developed and are being finalized for quantifying nvPM mass and number emitted from gas turbine engines (SAE, 2013). Various measurement campaigns have been performed to develop and assess the operability of the sampling methodology (Crayford et al., 2012, Lobo et al., 2015). An instrument manufacturer has developed a commercially available sampling system (AVL, 2015) and OEMs have started to include nvPM measurements in engine certifications. These are challenging measurements since particles are difficult to quantify with high accuracy, and this is compounded by the high temperature, high velocity environment present in the aircraft exhaust.

A particularly difficult challenge in the nvPM measurement arises due to the fact that there is not a straightforward way to calibrate PM instruments and there is not a clear chemical definition of the material that composes the nvPM. For gases, a precise mixture can be prepared that simulates gaseous emissions in the exhaust, which can then be used to calibrate measurements of species like NOx, HC, and CO. Conversely, particle standards are neither easily prepared nor referenced. This problem of the lack of a robust calibration standard, combined with inherent uncertainties in the PM measurements themselves, will need to be considered in how levels and margins are established in setting the new nvPM standard. Furthermore, for the use of nvPM data in emission inventories, an accurate and robust line loss correction methodology is essential. The line loss correction methodology is in the process of being established with open questions regarding the magnitude of its uncertainty and its robustness.

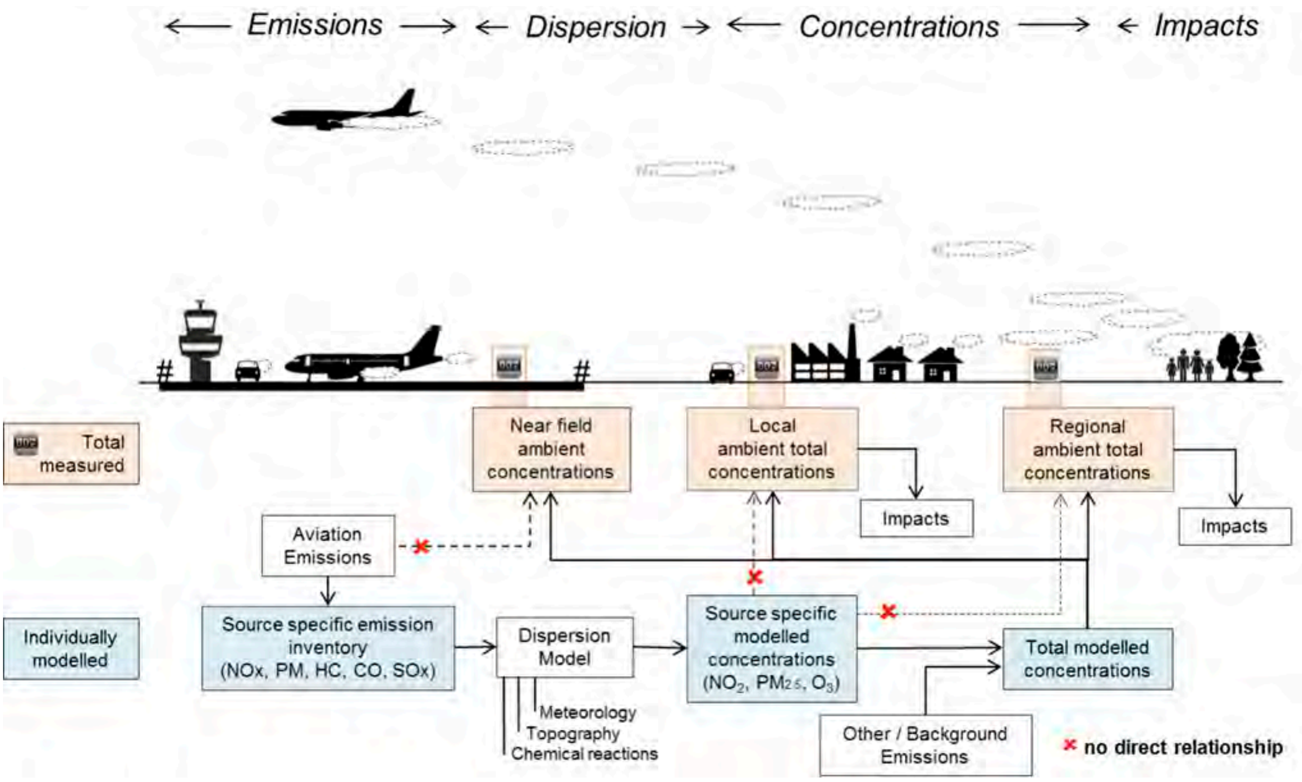

Figure 1. Schematic presentation of emissions, dispension, concentrations and impacts with their interaction at airport level

Exhaust sampling campaigns, which were mainly focused on the nvPM sampling methodology development, also improved the knowledge on particle size distributions, particle effective density, morphology and internal structure of aircraft PM (Durdina, 2014; Johnson, 2015; Liati, 2014; Corbin, 2014). These properties are critical for the understanding of the fate and potential health impacts of these particles. These studies add to the body of data on aircraft engine PM emissions and the volatile contributions to PM from sulfate and organics (Timko et al., 2010, Yu et al, 2010, Timko et al., 2013).

In addition to the main propulsion engines, aircraft can also contribute particles due to PM arising from tyre and brake wear during landing and from operations. Recent work (ACRP, 2013) has quantified these emissions and, while important for inclusion in a comprehensive inventory, their contributions compared to main engine emissions range from negligible for tyres and brakes to modest for APU under routine operations.

PM Emissions from Alternative Fuel Combustion

The need for developing sustainable fuels for aviation has sparked an interest in bio-derived fuels. Despite a range of existing commercial challenges, there are a number of concrete projects to start regular supply of sustainable alternative fuel to airlines at some airports, such as LAX, AMS, OSL and BNE, potentially already in 2015, at a blend ratio in the 1% range.

Such fuels need to meet the requirements of aviation operations, yet may still allow for a range of specific fuel compositions, which lead to variations in emissions compared to conventional jet fuel. Their effects on air quality should be considered at airports that, in the future, will provide alternative fuel blends. In evaluating Alternative Jet Fuel (AJF) candidates, the resulting changes in PM emissions have also been measured. Specifically, the lower fuel aromatic and fuel sulphur levels with the majority of AJFs under consideration have the potential to reduce PM emissions from aircraft and APUs.

Synthetic Paraffinic Kerosene (SPK) fuels are better understood than other AJFs that are being considered by industry; they have reduced PM emissions due to their lower aromatic composition and typically lower sulphur content. **Figure 2** provides a summary of the wide range of PM mass and number emissions measurements that have been taken in recent years (note the figures refer to PM as black carbon). The measurements consistently show that the reduced aromatic content of SPK fuels and blends of conventional jet fuel and SPK fuels results in reduced PM. Similar reductions have also been observed for APUs (Lobo et al. 2015) and models have been developed for accounting for fuel effects in PM mass and number emissions (Speth et al, 2014; Moore et al., 2015; Brem et al., 2015).

It is important to note that AJFs offer a complementary route to reducing PM emissions to that offered by improved combustor technologies that have been lowering PM emissions while using standard jet fuels over the past decades.

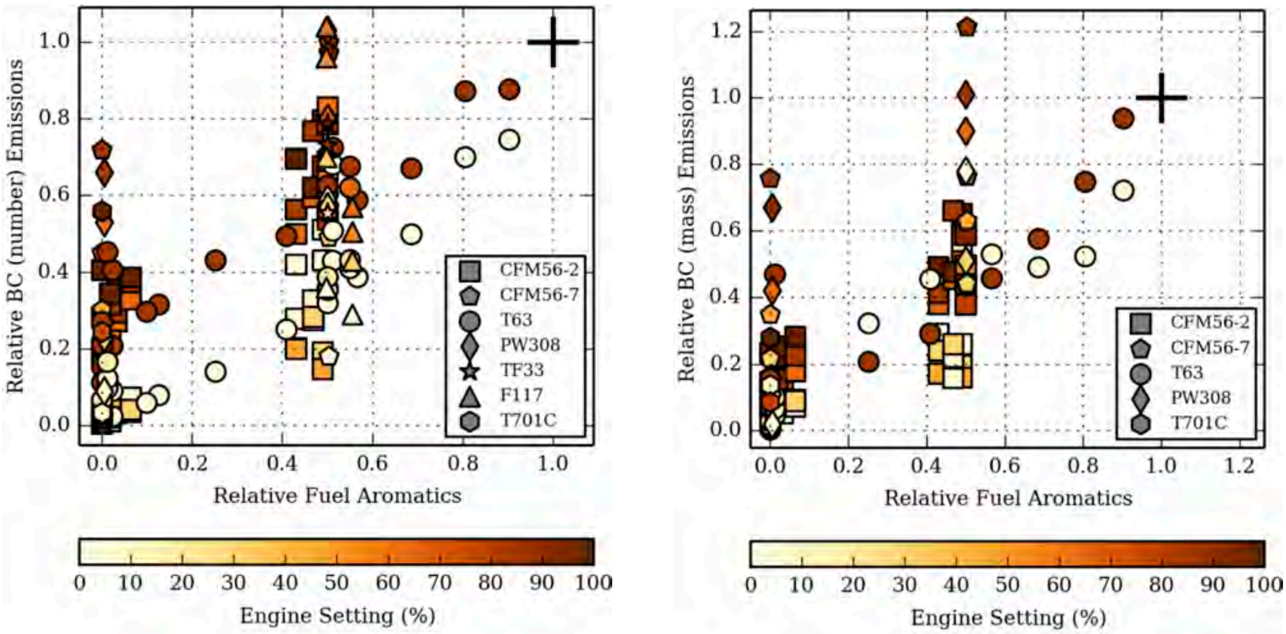

Figure 2. Measured normalized black carbon (BC) number and mass emissions as a function of normalized aromatic content and engine setting (Speth et al., 2014).

Emissions Inventories

Data on emissions provide the primary source values for individual particulate or gaseous substances emitted by combustion, industrial or mechanical processes. The individual emissions are initially determined by measurements under a controlled environment and set activity. For aircraft engines, these emissions are usually measured at the engine exit plane.

Emission inventories from aviation (or similarly from other sources) are produced by modelling the total amount of mass per time period. These are modelled using measured emissions data in combination with known operational data for the use of aircraft in the airport for which the inventory is being developed (emissions = activities x emission factors). Often total airport inventories are developed for a given time period, such as a total annual inventory. If further analysis is required, temporal and spatial resolution is needed (Ref: ICAO, Doc 9889, Airport Air Quality Manual).

In developing detailed airport inventories, the necessary data to describe aircraft operations are not all available with sufficient accuracy or granularity. Typical times-in-mode (especially duration of taxi-in and out and turnaround) strongly depend on the layout of each airport and on operational characteristics such as preferred gate occupation, frequency of departure queues and habits of APU use. Power setting profiles for take-off/climb and approach depend on prescribed flight procedures (mainly for noise abatement reasons) and also vary between airlines or aircraft types. At many airports they are not systematically recorded even as average values. All of these effects result in noticeable uncertainties in modelling aircraft emissions.

Emissions measurements help improve the creation of emissions inventories. For example, estimates of non-volatile PM (nvPM) from aircraft using Smoke Number (SN) are uncertain. Recent

Source	Activity	Emission factor	Calculation
Aircraft engine	Stop & go behaviour, Idle vs taxi, flex take-off	ICAO Engine Emissions Data Bank, but not yet PM	BFFM2, but FOA for PM
Auxiliary Power Unit (APU)	Environmental Control System Duration	Rudimentary in Doc 9889	Simple product
Aircraft frame	Brakes, tires	Assumptions	Simple product
Ground Support Equipment (GSE)	Machinery good, else poor	EU Non Road Mobile Machinery (EUNRMM)	Simple product
Stationary Sources	Usually well known	EMEP-EEA, manufacturer	Simple product
Landside vehicles	Fair, many assumptions	HBEFA, Coppert, etc.	Simple product

Table 1. Level of understanding in airport emission inventory: green (good); yellow (fair); red (poor) (Updated from Forum-AE, 2014)

studies have shown that nvPM emissions estimated using SN value as in First Order Approximation 3 (FOA3) can underestimate actual nvPM quantities by a factor of ~3 (Stettler et al, 2013), and these were corroborated in a recent study at the Los Angeles International - a large U.S. airport (Penn et al, 2015). The use of certified data for evaluating nvPM engine emissions on operational phases will improve these estimates.

Some of the gaps for the production of airport emission inventories are displayed in **Table 1**.

Model Emissions Dispersion and Concentrations

Substances once released into the atmosphere undergo a more or less rapid transformation based on ambient conditions and chemical properties. For instance, aircraft produces mainly NO or NO_2 as a function of the power used on the different operational phases; then, the transition between both forms or toward other nitrogen compounds is a function of ambient chemical compounds that react with them, as well as temperature and available sunlight. Gaseous aircraft emissions can influence the local levels of ozone, and some can also eventually contribute to ambient PM formation. Both the emitted particles and the particle precursor gases contribute to ambient nucleation mode particles, $PM^{2.5}$, and PM^{10}. In addition to chemical transformation, atmospheric processing likewise includes dispersion over time and space, leading to spatially and temporally varying concentrations of the emitted pollutants and their resulting chemical and particle products.

Assessing the concentrations in a regional airshed can be done by either measuring them directly or estimating their concentrations by modelling them based on emissions inventories. The challenge lies in that measuring the ambient concentrations will always include all "contributing" emissions – whether aviation related or not. Modelling the concentrations provides the option to only assess aviation related emissions (source discriminated), but additional effort is needed to numerically model total ambient concentrations that includes all sources and non-aviation background concentrations. In consequence, a careful interpretation and source apportionment of ambient measurements is necessary.

Modelling the Contribution of Aircraft Emissions on Air Quality

On a global scale, emissions from commercial aviation activity (due to LTO and cruise-mode) contribute to less than 3% of total anthropogenic emissions for NOx, and even less (< 1%) for all other primary pollutants such as CO, NMVOC, PM10 and SO2. However, on a local scale near large airports, such as Atlanta Hartsfield, aircraft emissions of NOx during LTO can be as high as 5%. Transportation related sources contribute up to 46% for NOx, and between 4.6 – 32.7% for other pollutants. As a percent of all transportation-related sources, commercial aviation contributes about 6% for NOx, and 0.3 – 2.3% for the other pollutants. (Source: EC 2011)

The topography around each airport, as well as time-varying wind direction and speed, can have a significant effect on the dispersion of emissions. Non-aviation sources, especially the pattern of roads accessing and surrounding airports, but also stationary industries, have a considerable impact on air quality, which is often larger than aircraft operations.

For the simplified characterization of air quality impacts and source attribution, emission inventories from various sources are often used as a surrogate. In the case of aircraft, the landing and take-off Cycle (LTO) is such an assumption. However, only emissions up to approximately 3,000 ft above ground level directly contribute to the surface concentrations near the airport; emissions above are dispersed more widely (Umweltbundesamt, 1992). To this end, emission inventories from aviation would have to be adjusted for that and the difference e.g. for NOx can be 30-40% (EUROCONTROL, 2006).

Current tools and methods allow for more advanced modelling, including not only airport related sources, but often also emissions from other contributors. Such overall modelling will enable the practitioner to actually compare modelled and measured pollutant concentrations at selected receptor points (i.e. measurement stations) and determine the contribution from aviation. However, this requires substantial additional effort. Studies show that airport related contributions quickly drop with increasing distance from the source, as well in absolute values as in relative share of contribution (Zurich Airport, 2013).

Aircraft emissions affect ambient air quality, specifically the concentrations of O_3, NO_2, $PM_{2.5}$ and Hazardous Air Pollutants (HAPs) or air toxics. The chemical reactions of aircraft-emitted species with other background chemicals often occur at downwind distances of up to 200-300 km away from the airport (Arunachalam et al, 2011; Rissman et al, 2013). However, the contribution of aircraft-related air quality impacts for $PM_{2.5}$ to the total ambient air are often in the range of 1-5%, (the higher end of this range applicable for large airports such as Atlanta Hartsfield when modelled at fine resolution) and given the magnitudes of the health-based air quality standards, do not lead to violations of air quality standards on their own. Furthermore, aircraft emissions of NOx and SOx react with ammonia emitted from non-aviation sources to form inorganic $PM_{2.5}$ such as ammonium nitrate and ammonium sulfate. In future years, aircraft-attributable $PM_{2.5}$ levels are likely to be a stronger function of ambient NH_3, and could lead to a disproportionate amount of inorganic $PM_{2.5}$ formed greater than simply the growth in the aviation-emitted primary precursors (Woody et al, 2011). However, moving to a desulfurized jet fuel from the current levels will likely mitigate some of this projected contribution in the future.

Figure 3 shows the contribution of each of 66 U.S. airports to total ambient $PM_{2.5}$ in absolute and relative terms, and as a function of annual LTO operations (Boone et al, 2015). Given the complexity associated with the total $PM_{2.5}$ formed from primary and secondary components, one can see that the airport with the highest LTO operations do not lead to the highest amount of $PM_{2.5}$.

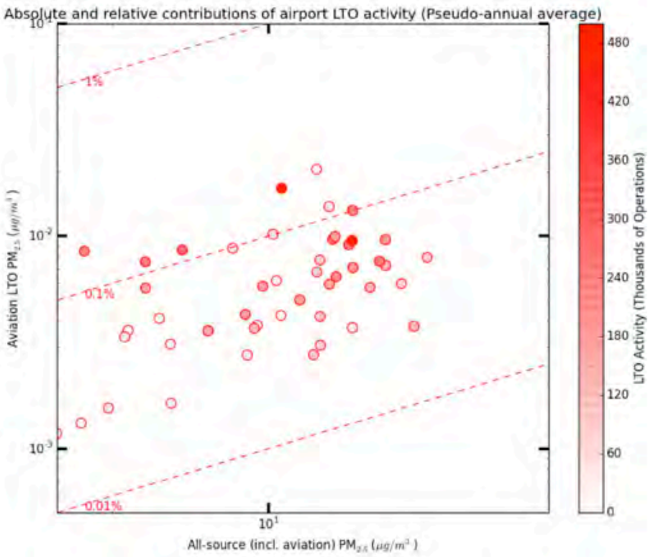

Figure 3. Individual airport-attributable $PM_{2.5}$ contributions compared to all-source contributions as a function of airport operations (each dot represents one of the top 66 U.S. airports, and the dotted line shows the % of airport-attributable $PM_{2.5}$ compared to total $PM_{2.5}$ from all sources)

New classes of semi-volatile and intermediate volatility organic compounds (S/IVOC) precursors that lead to the formation Non-Traditional Secondary Organic Aerosols (NTSOA) have been identified by recent smog-chamber studies (Miracolo et al, 2012). These studies showed that traditional SOA models could under predict traditional SOA formation by up to ~60% at engine loads of 4% and ~40% at 85%. However, when incorporated in comprehensive grid-based models, these precursors led to relatively modest increases in SOA formation, due to the relatively low levels of ambient organic aerosols, but still contributed to about 24% of the total aircraft-attributable $PM_{2.5}$ (Woody et al, 2014).

The main uncertainties in ambient air quality studies lie in understanding the effects of the granularity of models, and the micro-meteorological and chemical reaction effects. The granularity of models includes the information on emissions (emission factors for the relevant sources, actual operations of those sources, e.g. the APU) and the assessment of temporal and spatial resolution. Microscale meteorological and chemical reaction effects include issues like plume-rise and turbulence of exhaust plumes and heterogeneous chemical reactions that are currently not well modelled.

Cruise Emissions Impacts on Air Quality

The FAA has been funding a multi-institute study[3] to compare the impacts of emissions from commercial aircraft activities worldwide on surface ozone (O_3) and fine particulate matter ($PM_{2.5}$; size less than 2.5 micrometers) global chemistry-climate models. The models include climate-response models (CRMs) with interactive meteorology, chemical-transport models (CTMs) with prescribed meteorology, and models that integrate aspects f both. The models all used the same 2006 inventory of global ommercial aviation emissions.

ll of the models in the study find that aircraft increase near-urface ozone (0.4 to 1.9% globally) and the perturbations in the Jorthern Hemisphere are highest in the winter, when ambient zone levels are lower and potentially of not as much concern o human health compared to the higher ozone in the summer nonths. Changes in surface-level $PM_{2.5}$ in the CTMs (0.14 o 0.4%) and CRMs (-1.9 to 1.2%) appear to depend on the ackground aerosol fields and these vary considerably among he models. The inclusion of feedbacks in meteorology also as a strong impact on the results. The CTMs tend to show an ncrease in surface PM2.5 primarily over high-traffic regions in he North American mid-latitudes. The CRMs, on the other hand, lemonstrate the effects of changing meteorological fields and potential feedbacks on aviation emission impacts, and exhibit large perturbations over regions where natural emissions (e.g., soil dust and sea spray) are abundant.

1. At the time this draft white paper was assembled, the report was in review with the FAA. The research team consists of Stanford University, Massachusetts Institute of Technology, National Center for Atmospheric Research, NASA Goddard Space Flight Center, Yale University, and the University of Illinois at Urbana-Champaign.

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NEW AND IMPROVED LAQ MODELS FOR ASSESSMENT OF AIRCRAFT ENGINE EMISSIONS AND AIR POLLUTION IN AND AROUND AIRPORTS

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Many studies emphasize high concentrations of toxic compounds due to airport-related emissions and their significant impact on the environment, and directly on the population living near airports. Today, special attention is being paid to nitrogen oxides (NOx) and particulate matter (PM) emissions from aircraft engines because of their contributions to photochemical smog and the associated hazards to human health[1].

The purpose of local air quality (LAQ) control is to limit or reduce the impact of aviation emissions on local air quality. In practice, this means to limit or reduce the masses of emitted toxic compounds into the environment[2]. Over the years, tremendous efforts have been made and results achieved in reducing aircraft engine emissions at source. Scientists, designers and manufacturers have worked tirelessly to produce cleaner burning aircraft engines and produce an ever cleaner fleet of aircraft. New aircraft engine designs show 50% to 80% less emissions during the landing-take-off cycle (LTO-cycle) of flight, as well as en-route[3].

In order to understand the big picture with respect to the impact of aviation operations, air quality maps are developed. ICAO Doc 9889[4] provides guidance on how to perform robust air quality assessments in and around airports. This requires the conduct of an inventory analysis of all emissions from all sources at the airport. The ICAO guidance also recommends the performance of dispersion calculations and pollution measurements based on the monitoring all air pollution at airports. Ultimately, this allows airport operators to define the mean concentrations of air pollutants and to compare them with the regulatory air quality standard values applicable for humans or/and eco-systems.

Complex Model PolEmiCa

The analysis of emission inventories at major airports, including at Ukrainian airports, shows that aircraft are the dominant source of air pollution[5]. This conclusion was reached by considering a number of elements linked to the dynamic nature of pollutants sources including: emission dispersion parameters, changes to aircraft engine power settings during the LTO cycle between the idle and maximum thrust modes, and the difference between engine emission changes in a wide range of different aircraft engine emission certification data[6]. In addition, a jet engine which travels in parallel to the ground surface may transport pollutants relatively long distances; sometimes more than 1 km[5].

A complex computer model known as PolEmiCa (**Pol**lution and **Emi**ssion **Ca**lculation) was designed to perform an emission inventory and dispersion analysis for the main sources of air pollution at and around airports. It is based on the requirements listed in ICAO Doc 98894 which specifies that the following be covered: aircraft during LTO-cycle, including engine start-up procedures; Auxiliary Power Units and Ground Support Equipment; the main stationary sources; and road vehicles inside the airport area for the pollutants - CO, HC, NOx, SOx, PM. With respect to stationary sources and road vehicles, specific rules exist in Ukraine to define the emission factors, depending on the type of fuel used and the type and technical characteristics of the fuel combustion units. These include corrections for the emission factors due to national and international standard requirements. Comparison of total results (including the contribution of all the character sources listed in ICAO Doc 9889) of inventory analysis for various calculation tools, verified by CAEP MDG for CAEPort[7], shows that PolEmiCa results are within ±10-15% difference from the averaged inventory data from other tools (**LASPORT, EDMS, ALAQS, ADMS, PEGAS**) for all the pollutants, except SOx, because the national standard for content of sulphur in aviation kerosene is equal to 0,5, much higher than other similar national and international norms.

PolEmiCa is built upon a methodology for the calculation of ambient concentrations of harmful substances[8] that is widely used in the former Soviet Union States.

A B

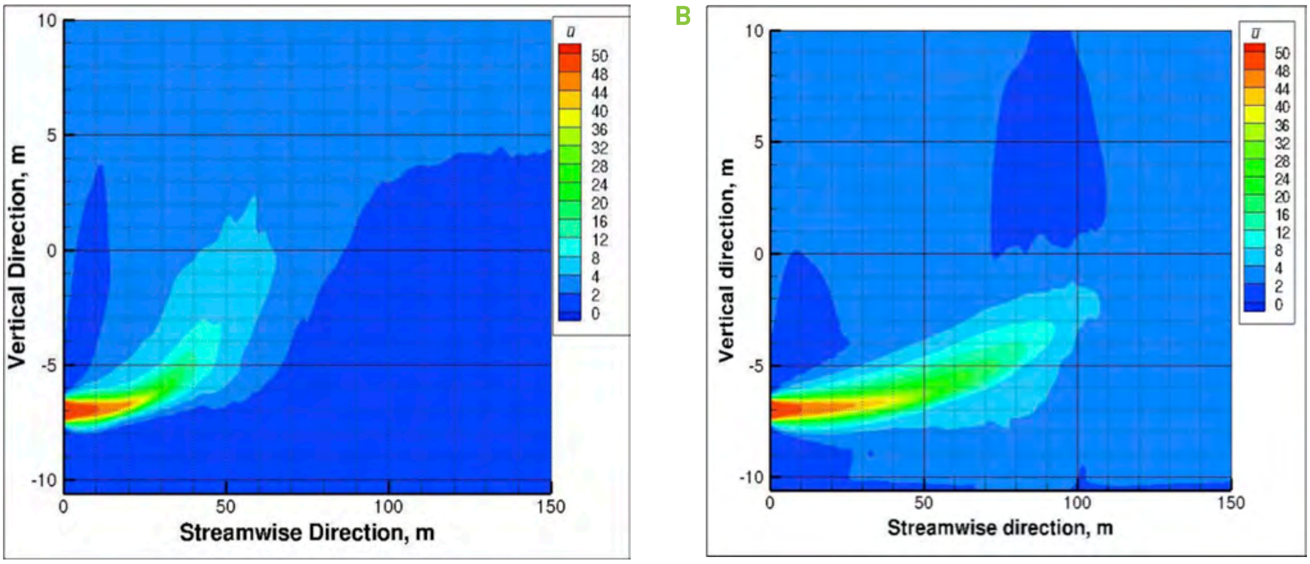

Figure 2. Mean Velocity Contours of the Jets in Streamwise Direction After 10 Seconds: free jet (a) and wall jet (b).

Under normal conditions, during aircraft taxiing (the longest part of the LTO-cycle), the distribution of contaminants by jet engine exhaust occurs within the atmospheric surface layer (i.e. up to 100 m above ground level). PolEmiCa evaluates the basic components of the contaminants emitted and provides basic parameters[9,10] to the dispersion model, including height and longitudinal coordinate of buoyancy effect of the engine exhaust jets. Current jet model (Computer Fluid Dynamics (CFD) modeling results for conditions of ground surface influence are used) in PolEmiCa (**Figure 2, b**) shows engine jet rise approximately[3] times lower and its longitudinal coordinate is approximately 30% longer on ~ in comparison with previous semi-empirical jet (for free jet conditions – without influence of the ground surfaces) transport model (**Figure 2, a**), reducing air contaminants dilution by jet and increasing their concentrations near to ground surface accordingly.

The verification of the PolEmiCa model with measurement data was done during trials conducted at Athens Airport (Greece, 2007) and Boryspol Airport (Ukraine, 2012). Comparison between calculated and measured NOx concentrations in aircraft engine plumes under real operating conditions (e.g. aircraft accelerating on the runway during take-off at Athens Airport) is shown in **Figure 3**. The improvements brought by the use of a CFD codes for assessing the dispersion of the jet are evident.

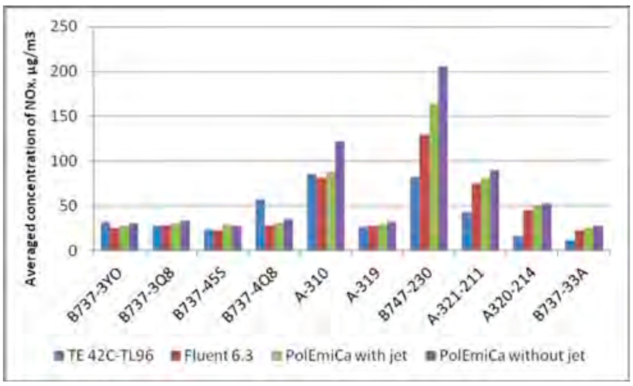

Figure 3. Comparison of Measured and Modeled NOx Concentrations (averaged for 1 min) Under Take-off Conditions (maximum thrust operation mode of aircraft engine).

Experimental studies at Boryspol Airport[11] focused on measurements of NOx concentrations in aircraft engine jets using the chemi-luminescence technique, and by estimating NOx emission indices under real operating conditions (i.e. aircraft taxiing and accelerating on the runway for take-off).

Figure 4 shows the emission indices from the study when compared with ICAO values for idle and maximum engine modes[6]. The variations between measured and ICAO certificated data were clearly evident in this trial.

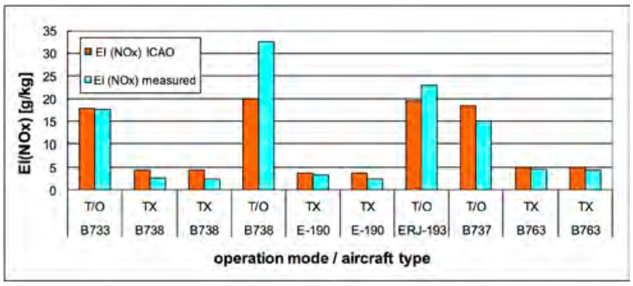

Figure 4. Comparison of Measured EINOX, Under Real World Operating Conditions (take-off (T/O) and Taxing (TX)) with the ICAO Database.

Those measured emission indices served as input for the validation and enhancement of the PolEmiCa model. NOx concentration calculations were improved by taking into account the interactions between the jet engine exhaust and the wing trailing vortices during aircraft take-off, **Figure 5**.

The analysis of the air pollution model developed from aircraft engine emissions allowed the definition of the main operational parameters that may influence air quality in the vicinity of an airport. A key finding shown in **Figure 6** is that, close to the aircraft the maximum concentrations may be derived at weak to moderate atmospheric turbulence intensity, but for very weak intensity – at greater distances. The higher the wind speed, the higher the concentration.

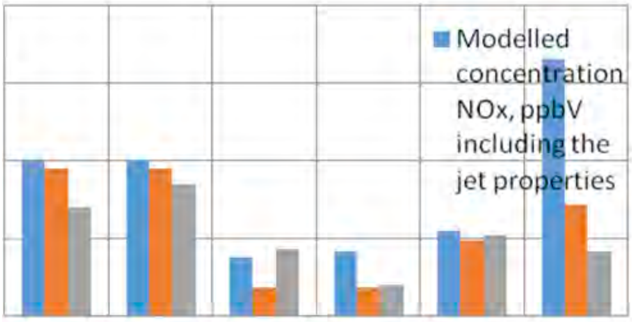

Figure 5. Comparison of the PolEmiCaResults (previous and improved by wing trailing vortices versions) with the Measured NOx Concentration from Aircraft Engines Exhausts under Maximum Operation Mode: blue columns – modeled concentrations for engine jet transportation model; orange columns – modeled concentrations for model of interactions between the jet engine exhaust and the wing trailing vortices; grey columns – measured concentrations.

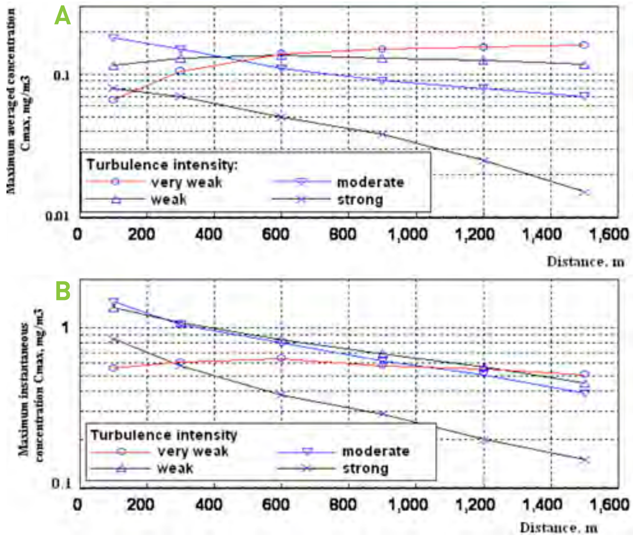

Figure 6. Influence of Atmospheric Turbulence Intensity on the Levels of Air Pollution Produced by Aircraft Engine Emissions: a) maximum average concentration (per 20 minutes); b) maximum instantaneous concentration (per 1s).

Conclusions

PolEmiCa is still under development, and future enhancements to this model will have two important objectives: to improve the jet/wake transportation modelling by CFD codes, and to verify the modelling results against measurement data collected at various airports.

Further improvements to dispersion calculations are expected, based on the use of more accurate engine emission data which is expected to come from the use of aircraft engines operating under real airport conditions, as power thrust and other operating conditions, such as weather have an impact on the emission parameters. For example, the NOx emissions factor shows variations of up to 25% when compared with the value for Standard Atmosphere (air temperature 15ºC) for temperatures as low as -20ºC, or as high as 30 ºC.

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NEW PARTICULATE MATTER STANDARD FOR AIRCRAFT GAS TURBINE ENGINES

BY THEO RINDLISBACHER (FEDERAL OFFICE FOR CIVIL AVIATION, SWITZERLAND) AND S. DANIEL JACOB (US FEDERAL AVIATION ADMINISTRATION)

Particulate matter (PM) emissions from aircraft gas turbine engines are known to adversely impact both health and climate. The proposed new particulate matter standard for aircraft gas turbine engines is an important development that will lead to an overall reduction of the PM emissions and associated impacts. This new standard is a critical milestone that contributes to ICAO's strategic objective to minimize the adverse environmental effects of civil aviation activities.

At the engine exhaust source of an aircraft, particulate emissions mainly consist of ultrafine soot or black carbon emissions. Such particles are called "non-volatile" (nvPM). They are present at high temperatures in engine exhaust and they do not change in mass or number as they mix and dilute in the exhaust plume behind an aircraft. The geometric mean diameter of these particles is extremely small and ranges roughly from 15nm to 60nm (0.06 Microns).

Additionally, gaseous emissions from engines 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 the so-called secondary particulate matter. Volatile particulate matter is dependent on precursor emissions, which are controlled by gaseous emission certification and the fuel composition (e.g. sulfur content).

The new ICAO standard is an attempt to control the ultrafine non-volatile particulate matter emissions.

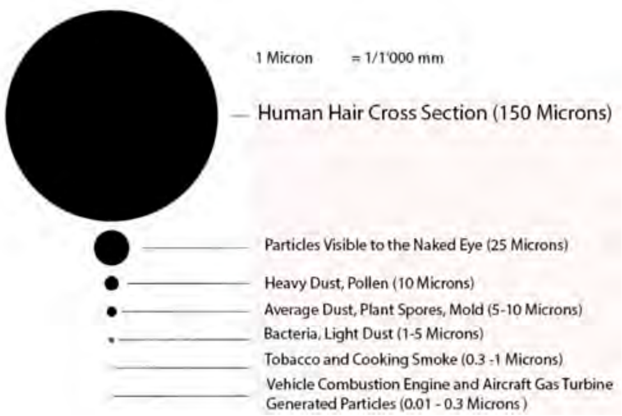


Figure1. Comparison of Particle Sizes from Different Sources.

Historical Background

Adverse health and climate impacts of particles emitted by various combustion sources have been studied for a long time. For aircraft engines, detailed scientific studies were initiated nearly 15 years ago in the United States and Europe to better understand and quantify the characteristics of their particle emissions. In 2008, first proposals for the introduction of an ICAO particulate standard for aircraft engines were made, and subsequently a plan was developed and agreed at the 8th meeting of ICAO Committee on Aviation Environmental Protection (CAEP/8). That plan was implemented during CAEP/9 and the newly formed Working Group (WG3) Particulate Matter Task Group (PMTG) was tasked with the development of a nvPM standard, first for turbofan engines of rated thrust > 26.7 kN. WG3 also asked the SAE International E-31 Committee to develop a standardized measurement methodology. ICAO Member States, the European Union and the industry provided both the human resources and funding needed for this development.

By late 2010, the SAE E-31 Committee had agreed to a conceptual system for nvPM measurements. The key element for testing of such a system was the availability of an engine test cell and frequent engine runs. In order to keep costs low, the CAEP was searching for an engine maintenance facility to make use of test runs performed after engine maintenance. SR Technics, a private company in Zurich, Switzerland agreed to make their test cell available for this purpose and the Swiss Federal Office for Civil Aviation (FOCA) built and installed the first complete system prototype, including a retractable sampling probe, in their engine test cell. Led by the Swiss Federal Laboratories for Materials Science and Technology (Empa), the prototype system then became the permanently installed reference system used for the development of the nvPM sampling and measurement system (see **Figure 3**). In parallel to the Swiss effort, the SAE E31 Committee tested a prototype of the system and instrumentation in March 2011 during the National Aeronautics and Space Administration (NASA) led Aviation Alternative Fuels Experiment-II (AAFEX-II).

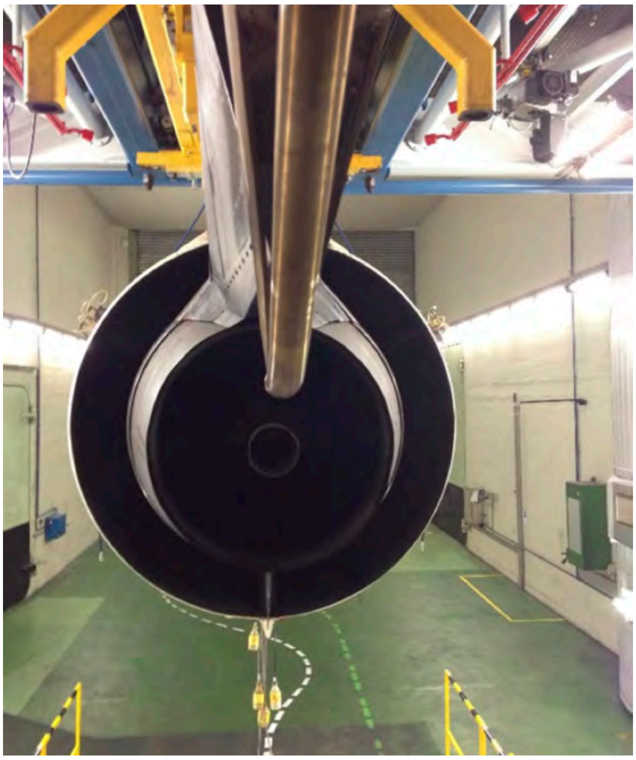


Figure 2. Turbofan Engine Seen From Behind With Tube of a Sampling Probe.

After these initial system tests, many campaigns followed, as detailed in an article in Chapter 3 of this report titled: "From smoke to nanoparticles: international campaigns for the establishment of a new nvPM regulation". Results of those tests led to the publication of the SAE Aerospace Information Report (AIR 6241) in 2013. The AIR6241 report documented the specifications of the standardized nvPM sampling and measurement system. Subsequent tests in Switzerland, USA and UK, all validated the AIR6241 specifications and led to further refinements of the calibration procedure of some of the instrumentation used. The knowledge gained from these campaigns forms the backbone of the CAEP/10 nvPM certification

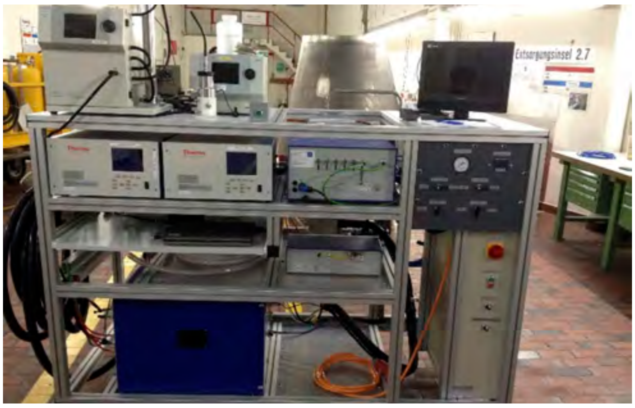


Figure 3. Sections of the Swiss nvPM Sampling and Measurement System With Added Particle Sizing Instrumentation. (Sections 4 and 5 in **Figure 4**).

requirement and standard, as specified in the new proposed Appendix 7 in the ICAO Annex 16 Vol. II (**Figure 4**).

The New CAEP/10 nvPM Standard

The CAEP/10 nvPM standard uses a mass concentration limit that is equivalent to the smoke number regulatory level in the following sense: if an engine passes the current smoke number standard, by design of the regulatory level, it will pass the first nvPM standard. Therefore, a new stringency is not introduced through the CAEP/10 nvPM standard. However, it sets the stage for health and climate relevant nvPM standards.

The new CAEP/10 nvPM standard mandates the reporting of:

- The fuel flow at each thrust setting of the certification landing and take-off cycle (LTO).
- The nvPM mass and number emission indices (EIs) for the four LTO points.
- Maximum nvPM EI mass.
- Maximum nvPM EI number.
- Maximum nvPM mass concentration.

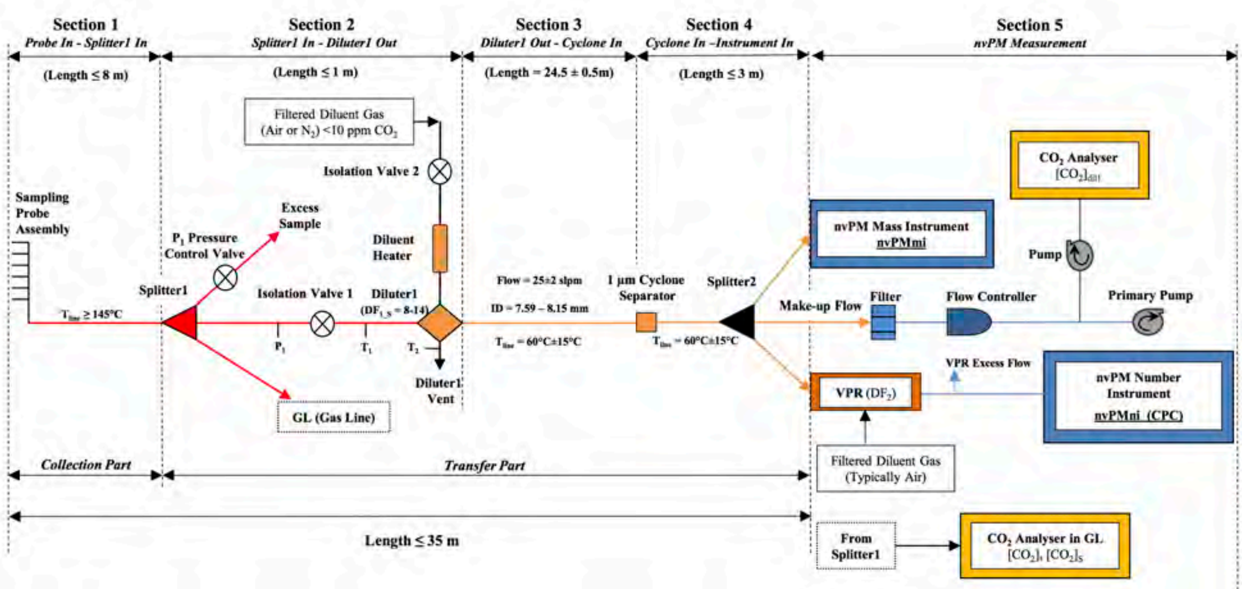


Figure 4. nvPM Sampling and Measurement System (ICAO Annex 16, Vol, II, Appendix 7).

The new standard applies to all in-production engine types of rated thrust greater than 26.7 kN, on or after 1 January 2020. The reported certified parameters will allow comparisons of engine technology and engine type comparisons for health and climate relevant nvPM emissions. Furthermore, the maximum nvPM mass concentration obtained from the nvPM certification measurement is used to maintain regulation of the non-visibility criteria of the exhaust and provides a pathway for the potential removal of the old smoke number standard for engines of rated thrust > 26.7 kN as early as 2020.

The regulatory level for the CAEP/10 maximum nvPM mass concentration was developed based on a statistical relationship between nvPM mass concentration and the smoke number. A graphical representation of the CAEP/10 nvPM regulatory limit for maximum nvPM mass concentration is shown in **Figure 5**.

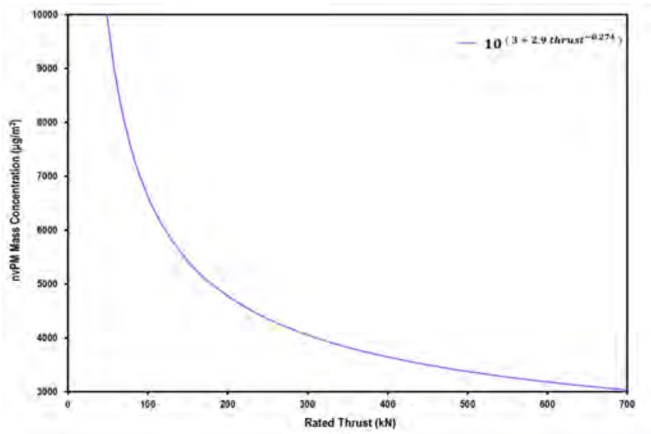


Figure 5. CAEP/10 nvPM Standard Regulatory Level.

Correction For nvPM Losses in the Standardized Sampling and Measurement System

A sampling system for gas turbine nvPM will lose a portion of the particles when they travel through the sampling lines because of the very small size of these particles. Therefore, the nvPM emissions measured at the instruments will be lower than the values at the engine exit plane.

The purpose of emission certification is to compare engine technologies and to ensure that the engines produced comply with the prescribed regulatory limits. The ICAO nvPM sampling and measurement system requirements standardise the particle losses in the system such that engine measurements performed by different engine manufacturers and test facilities can be compared directly.

However, for emission inventories and impact assessments, nvPM emissions at the engine exit should include the particle size dependent losses in the sampling and measurement system. A standardized methodology to estimate such system losses is described in the new proposed Appendix 8 to the ICAO Annex 16 Vol II nvPM update so that all engine manufacturers can report loss correction factors using the same procedure. The CAEP/10 update to the ICAO Annex 16 Vol.II includes a recommendation that engine manufacturers report the system loss correction factors together with the nvPM emissions data as soon as engine data are certified.

CAEP/11 Outlook

The CAEP/10 nvPM standard is a first step in the development of a mass and number nvPM standard for aircraft engines. The CAEP/10 standard requires the reporting of health and climate relevant nvPM mass and number while maintaining equivalency to the smoke number based visibility standard. A nvPM mass and number standard requires data from around 25 in production and project engines that will represent the current and future aircraft fleet. Work has already been undertaken during CAEP/10 to acquire nvPM emissions data from these engines.

Data from the representative aircraft engines will be available to CAEP by February 2017 and will be used in the development of LTO-based nvPM mass and number metric systems, stringency options, technology response, and cost effectiveness analysis. In addition, plans are in place to develop corrections to measured nvPM emissions for ambient conditions and fuel sensitivity. Similar to gaseous and smoke emissions, factors to determine characteristic nvPM mass and number emissions will also need to be developed. These efforts will inform the development of a health-based mass and number nvPM standard during CAEP/11.

The maximum nvPM mass concentration and smoke number emissions data from the representative engines will also be used to update the mass concentration-smoke number relationship. Based on this update, efforts will be undertaken to potentially replace the smoke number with the maximum nvPM mass concentration.

Figure 6 shows a roadmap of CAEP/11 activities of CAEP WG3 Particulate Matter Task Group (PMTG).

New nvPM Standard in Context of Evolving Gas Turbine Combustor Technology

Gas turbine engine combustor technologies continue to evolve, leading to significant reductions in exhaust emissions. To accomplish medium and long term NOx reduction goals, engine manufacturers are developing advanced rich burn and lean burn combustor technologies. In particular, significant reduction in nvPM mass and number is seen with the lean burn staged combustors. So far, this technology has been implemented by one engine manufacturer in medium to large commercially available turbofan engines.

Implementation of such technologies across the industry will lead to significant reduction in nvPM emissions in the future. The potential impact of the future technology implementation is shown in **Figure 7**.

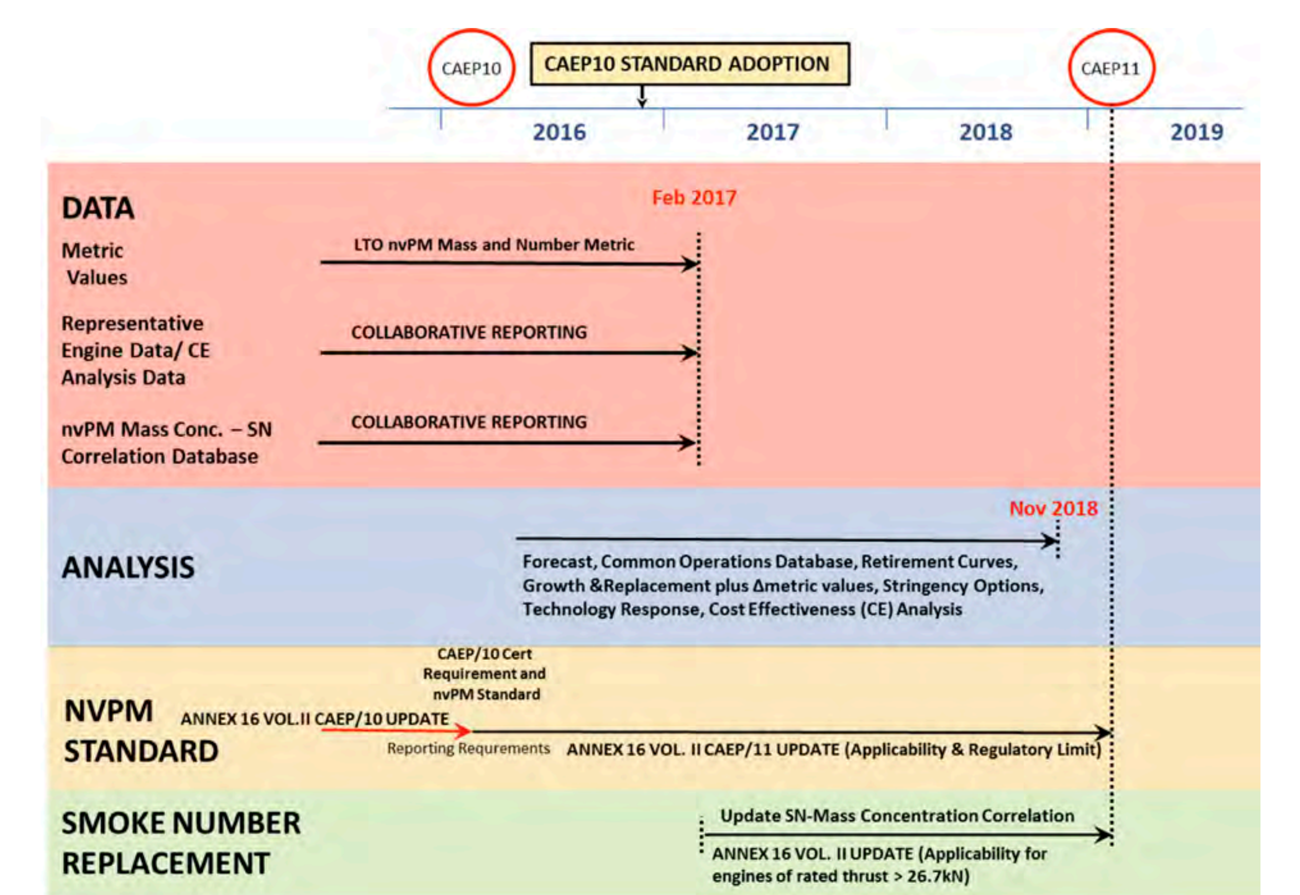
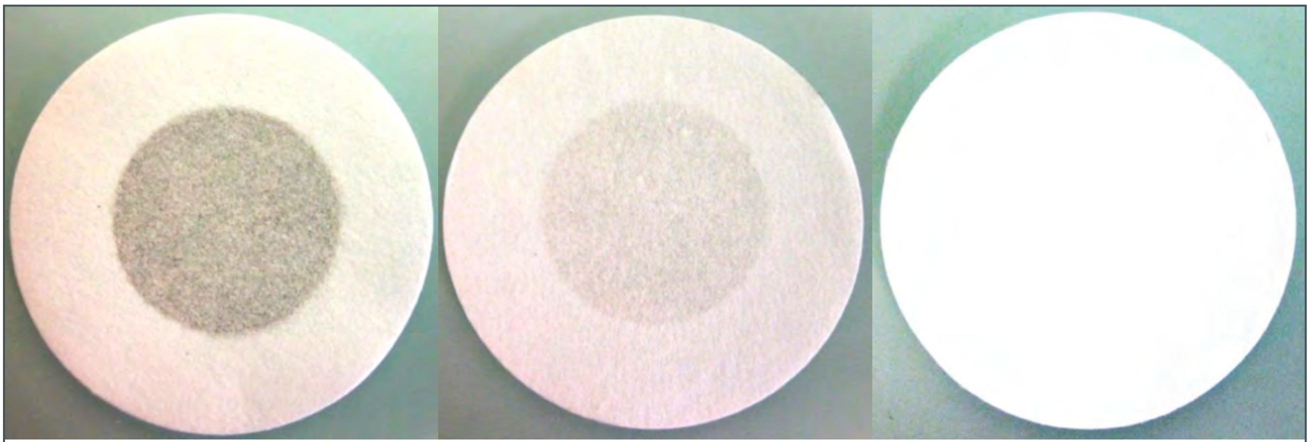


Figure 6. Roadmap of CAEP/11 Activities Toward the Development of a Health-Based Mass and Number nvPM Standard.



1990
Visible fine smoke trail at take-off (actual smoke number filter measurement for illustration).

2014
Almost invisible smoke trail at take-off (actual smoke number filter measurement for illustration).

Beyond 2020
Barely detectable nvPM at take-off, technology currently used by one engine manufacturer in medium to large engines.

Figure 7. From smoke number standard to the new nvPM standard.

FROM SMOKE TO NANOPARTICLES: INTERNATIONAL MEASUREMENT CAMPAIGNS FOR THE ESTABLISHMENT OF A NEW nvPM REGULATION

BY RICK MIAKE-LYE (CENTER FOR AERO THERMODYNAMICS AT AERODYNE RESEARCH, INC) AND BENJAMIN BREM (SWISS FEDERAL LABORATORIES FOR MATERIALS SCIENCE AND TECHNOLOGY)

Particle emissions of civil aviation aero engines have been the focus of much scientific research prior to the establishment of the new non-volatile particulate matter (nvPM) standard. Examples of such research efforts include the NASA campaigns APEX and AAFEX[1] and the DLR PartEmis[2] studies. The latter resulted in the EASA supported Studying, sAmpling and Measuring of aircraft ParticuLate Emissions (SAMPLE) studies[3], which drew the attention of regulatory agencies to sampling and measurement issues associated with a new standard (**Figure 1**). Developing a standard requires the collaboration of scientists, engineers, regulatory agencies, and instrument and engine manufacturers in an international and multi-institutional effort. The Society of Automotive Engineering (SAE) International E-31 Aircraft Exhaust Emissions Measurement Committee played an essential role by elaborating the measurement and calibration procedures in the aerospace information report "Procedure for the Continuous Sampling and Measurement of Non-Volatile Particle Emissions from Aircraft Turbine Engines" (AIR 6241)[4]. The applicability of the developed procedures was tested in numerous field campaigns, which are the main focus of this article.

A particularly difficult challenge in nvPM measurements is due to the absence of a direct way to calibrate PM instruments and the lack of a clear chemical definition of the material that composes the nvPM. For gases, a precise mixture can be prepared that simulates gaseous emissions in the exhaust, which can then be used to calibrate measurements of species like NOx, HC, and CO. Conversely, particle standards are neither easily prepared nor referenced. The lack of a robust calibration standard is compounded by other challenges such as particle losses within the sampling system and instruments, which had to be considered in the establishment of the method and required field testing and evaluation. Furthermore, all of these challenges are compounded by the need to make the measurements in the high temperature, high velocity, and high vibrational environment of an aircraft exhaust.

Figure 1. nvPM Methodology Standard Campaigns and Milestones (Courtesy of Cardiff University Gas Turbine Research Centre).

Aviation Particle Regulatory Instrumentation Demonstration Experiments (APRIDE)

Access to in-production aircraft engines for emissions measurements is rather difficult. A unique measurement opportunity was established in 2011 in collaboration between the Swiss Federal Office of Civil Aviation (FOCA) and SR Technics in the engine test cell of SR Technics at Zurich Airport. This facility performs maintenance service on in-production engines, A permanently installed retractable single orifice probe (**Figure 2**) was developed that allows the sampling of PM-laden exhaust for various engine models and variants.

Figure 2. Single Orifice Probe nvPM Measurements in the Test Cell of SR Technics, Zurich Flughafen (Courtesy of SR Technics).

The initial APRIDE campaigns focused on studying and identifying suitable measurement equipment. For example, various models of particle counters and volatile particle removers were tested and evaluated. After these initial efforts led by FOCA with the participation of DLR Stuttgart, the unique measurement platform and the FOCA support funded by the Swiss domestic fuel tax saw the contribution of various Swiss institutions and partners from the SAE E31 Committee, including the FOCA supported Swiss Federal Laboratories for Materials Science and Technology (Empa), the EASA funded SAMPLE consortium, the FAA supported Missouri University of Science and Technology and Aerodyne, Transport Canada supported National Research Council of Canada and U.S. EPA.

Systematic investigations were performed on particle counters and system operability parameters which determined instrument and system specifications (APRIDE 3/SAMPLE III.2)[5]. System to system variability was the main focus in APRIDE 4[6]. This effort continued in APRIDE 5/ SAMPLE III.3[7] with a three way system inter-comparison [**Figure 3**]. APRIDE 5/SAMPLE III.3 further investigated the effect of various dilution factors on the particle number measurements and measured relevant nvPM characteristics for particle losses within the sampling system, such as particle effective density and particle size distributions. In addition, the particle chemical composition and internal structure were examined with online and offline measurement methods.

Figure 3. The APRIDE 3/ SAMPLE III.2 Campaign Team (Courtesy of SR Technics).

The APRIDE 5/SAMPLE III.3 campaign was the greatest effort at SR Technics to date, with more than 35 participants, 95 hours of dedicated engine operation, and more than 130 tons of jet fuel burned [**Figure 4**]. An important highlight of this major effort was the "certification-like" engine test, which was a dedicated "mock" engine nvPM certification test that followed the draft standard specifications as would be performed in the facility of an engine manufacturer. The first commercial nvPM measurement system prototype was evaluated in a cooperative effort with the manufacturers in APRIDE 6. Empa, SNECMA, GE Aviation and FOCA further investigated the effect of total fuel aromatic content on nvPM emissions[8]. This campaign also collected SN data in parallel, allowing SN nvPM mass correlations, and investigated the spatial variability of nvPM and gaseous pollutants at the engine exit plane.

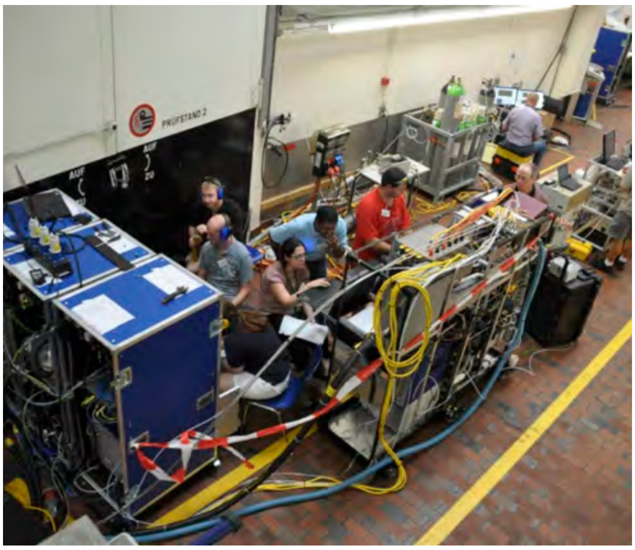


Figure 4. nvPM Measurements of the SAMPLE Consortium and Missouri University of Science and Technology In Action During the APRIDE 5/SAMPLE III.3 Campaign (Courtesy of SR Technics).

VARIAnT and MANTRA

APRIDE provided much needed data and experience with these nvPM measurement systems, but these studies also raised some specific questions. Most notably, the issue of system-to-system variability is critical for regulatory measurement systems used across the industry. In order to better understand and quantify this system-to-system variability in general, the VAriable Response in Aircraft nvPM Testing (VARIAnT) program conducted campaigns in the summers of 2014 and 2015 at the US Air Force Arnold Engineering and Development Complex (AEDC) in Tennessee, USA [**Figure 5**].

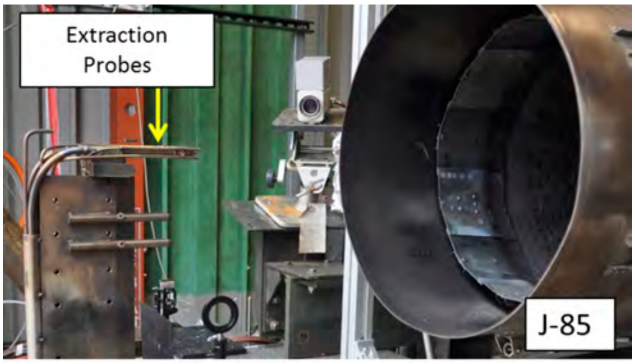


Figure 5. The VARIAnT Probe System (Courtesy of AEDC).

The 2014 VARIAnT1 campaign, as well as APRIDE and the engine manufacturer testing described below, highlighted measurement variability in the nvPM mass measurement instruments in particular, and a campaign that focused specifically on this variability, called Mass Assessment of nvPM Technology Readiness for Aviation (MANTRA), was carried out in early 2015 at Rolls-Royce in Derby, UK [**Figure 6**].

Figure 6. The MANTRA Experimental Set-up (Courtesy of Cardiff University Gas Turbine Research Centre).

The objectives of the VARIAnT1 study were to perform a systematic evaluation of the sources of variability in the measurement of nvPM mass and number and, where possible, determine the largest sources of variability and methods to potentially reduce these to the lowest degree possible. The second campaign, VARIAnT2, continued to assess the variability between two independently assembled, compliant nvPM measurement systems, but had an additional goal of conducting more detailed investigations of particle losses in those compliant sampling systems.

The VARIAnt1 test campaign showed little effect on measurements within the range of conditions for a wide variety of operating parameters of the sampling system defined by the draft ARP. This confirmed that the sampling system was robust. Multiple sampling systems with multiple instruments gave confidence in the resulting comparisons performed. However, the reliability of one of the mass instrument types was brought into question, which resulted in a lack of confidence in a single instrument suite, as would be used in routine testing in the future. VARIAnT2 data analysis and interpretation is ongoing. However, differences in repeated pre-test mass calibrations have already been identified. This was unexpected and is being further investigated. Both mass instrument types responded differently to the laboratory calibration soot aerosol as compared with the engine, and the same instrument that raised questions in VARIAnT1 showed greater variation. Thus, the issues raised by VARIAnT1 require ongoing study, and cast doubt on the nvPM mass measurement in particular.

The differences in the response of mass instruments over ranges of nvPM size, elemental to organic carbon ratio, and mass concentration, were the focus of the MANTRA study. Laboratory diffusion flame sources and a turboshaft engine were used in the study. Soot optical and structural properties, as well as chemical composition, were investigated in parallel to the mass instruments as a function of fuel air equivalence ratio or engine power setting. The data analysis of this campaign is still ongoing but a better understanding of calibration and gas turbine nvPM properties is expected, which will lead the way to an improved calibration procedure for the mass instruments.

Engine Manufacturer Testing and Comparison

As details are being worked out in APRIDE, VARIAnT, and MANTRA, a parallel effort has begun to ensure that these systems can be used by engine manufacturers in their facilities during certification test scenarios. In coordination with an ad hoc group on measurements (MEASURE) of CAEP Working Group 3, and with the International Coordinating Council of Aerospace Industries Associations (ICCAIA), a series of "demonstration" tests and "comparison" tests are being pursued.

The goal of these tests is to deploy one of the reference systems that was characterized in APRIDE such that every engine manufacturer can gain experience and obtain data using these reference systems on their engines. In a "demonstration" test, either the North American Reference System or the European Reference System is transported to the engine company's test facility and used to collect data in a certification-like test environment. If all of the certification requirements are met, there is agreement with the regulatory authorities that the data will subsequently be acceptable as nvPM certification test data once an nvPM emissions standard has been put in place. In this way, the engine manufacturer can learn how the system is used and can obtain important and costly nvPM certification data at the same time.

In a "comparison" test, one of the nvPM reference systems is used in parallel with the engine manufacturer's own nvPM measurement system. For a "comparison" test, all of the same experience and data are obtained as in a "demonstration" test, but in addition, the results of the engine manufacturer's system can be compared with either the European or North American Reference systems. This comparison will provide more system-to-system consistency data and will show how the individual systems operated by engine manufacturers compare with these extensively deployed reference systems. A "comparison" test is required for each manufacturer. While a "demonstration" test is available as a convenience, and for obtaining nvPM data sooner, a "demonstration" test is not required once a "comparison" test is done.

A number of tests with engine manufacturers have already been conducted and additional tests are planned. Together, this will build an nvPM base of a few dozen engines in the coming years, including several repeats of some engine model types. All of the major engine manufacturers have now gained some experience in operating these new nvPM measurement systems, and nvPM data from representative engines are currently being accumulated.

Additional Studies and Future Work

Much progress has been made in advancing the research measurement technology to a standardized system that can be used in regulatory certification for nvPM emissions. The focused field campaigns described here have taken the recommendations of the SAE E-31 Committee, and tested and refined those procedures such that Appendix 7 to Annex 16 can be the basis of the new nvPM standard.

Nevertheless, additional work is still needed and ongoing. The variability in mass measurement, in particular, needs to be understood and reduced. The ability to accurately account for nvPM losses in the probe and sampling system needs to be finalized and fully documented. The current Appendix 7 standard is based on a maximum PM concentration metric, yet there is interest in going further and developing a more detailed PM standard based on a Landing Take-Off (LTO) cycle as is done for gaseous emissions. To do that, the effects of ambient conditions and fuel effects on PM levels need to be more fully understood. However, the extensive efforts already performed in these many field campaigns have provided ICAO with the strong technical support needed for the new nvPM standard of Appendix 7 of Annex 16.

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MEASURES TO REDUCE PARTICULATE MATTERS AT AN AIRPORT: THE CASE OF COPENHAGEN AIRPORT

BY INGER SEEBERG STURM (COPENHAGEN AIRPORT)

Copenhagen Airport is the main airport in Denmark and the largest airport in Scandinavia, with 26.6 million passengers, 254,838 flights and 372,748 tons of freight handled in 2015. Copenhagen Airport is operated by Copenhagen Airports A/S (CPH). CPH owns and operates Copenhagen Airport and Roskilde Airport.

Copenhagen Airport has a very central location, with only 15 minutes by metro to Copenhagen City Centre. The airport is located by the sea, and with the main part of all flights taking place over water this location is beneficial in terms of environmental impacts on the surroundings.

CPH plans to develop Copenhagen Airport to be able to handle at least 40 million passengers yearly. The main principles for the development are to maintain a compact, efficient one roof airport and to implement new technology in order to support the most seamless travel possible.

Local Air Quality – the health and safety perspective

Like many other airports, CPH has been working with air quality management for a number of years. Focusing on the airport's possible impact on the neighboring communities, CPH has monitored the air quality at the fence since 2000. The monitoring program has been focusing on particles (PM2.5), NO and NO2. Results have always been well below regulatory limit values.

Based on the air quality monitoring program, CPH was convinced that we were doing quite well in terms of air quality. However, following measurements of polycyclic aromatic hydrocarbons (PAH) at the apron at the Leonardo Da Vinci Airport in Rome (Cavallo et al., 2006), the air quality in terms of working environment at the apron area gained more focus among staff as well as management in both CPH and among our partners at the airport. With the aim of taking a fact-based approach to this challenge, a thorough survey of air pollution related to the working environment of Copenhagen Airport was conducted from 2009 to 2011 by Danish Centre for Environment and Energy, Aarhus University (DCE) for CPH. The findings are published as a scientific report: Assessment of the air quality on the apron of Copenhagen Airport Kastrup in relation to working environment (Ellermann et al. 2011).

The aim of the survey was to map the air pollution at the apron and to determine the sources of air pollution. Giving the focus on working environment, the emphasis was on determination of air pollution in those areas of the apron where staff are working. **Figure 1** shows the locations of the airport's air quality monitoring stations.

Figure 1. Overview of Copenhagen Airport. The red stars illustrate the locations of the airport's air quality monitoring stations: Station West (NO, NO_2, $PM_{2.5}$ and UFP), Station East (NO, NO_2, $PM_{2.5}$) and the apron station, Station B4 (NO, NO_2 and UFP).

The study led to the main conclusion that for the majority of the investigated air pollutants (nitrogen oxides, $PM_{2.5}$, PAH, VOC, particulate organic and elemental carbon) the concentrations at the apron are below the comparable levels measured at H.C. Andersens Boulevard (HCAB), one of the busiest streets in Copenhagen (approximately 60,000 vehicles per day). Also, all measured pollutants were below air quality limits for the pollutants, where such exist.

However, the number of particles (as shown in **Figure 2**) did not match this picture. The levels measured at the apron showed that the particle number (6 – 700 nm) was about two to three times higher at the apron than at HCAB and 85-90% of the particle number consisted of particles with a diameter between 6 and 40 nm. This particle fraction accounted for the difference between the particle number at the apron and HCAB. The ultrafine particles (particles with a diameter less than 100 nm) originated from the combustion of jet fuel and diesel at the apron. At the outskirts of the airport, the particle number was about 20 – 40 % lower than at HCAB. It is important to note that there is no air quality limit value in Denmark for particle number.

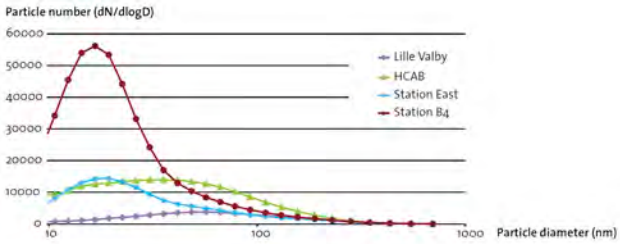

Figure 2. Particle number measurement results at Copenhagen Airport. Measurements for an urban busy street (HCAB) and rural background (Lille Valby) are shown for comparison.

The Copenhagen Airport Air Quality Program

The DCE study made it clear that the most prevalent air pollutant at the apron area was ultrafine particles On this basis, CPH established the Copenhagen Air Quality Program in its current form. The program is organized across the airport companies with personnel on the apron, with the common goal of minimizing the exposure of ultrafine particles to employees.

The Copenhagen Airport Air Quality Program is managed by CPH, but the strength of the program is the cross organizational set-up and the fact that representatives in the program include both employees, management at various levels, union representatives from handling companies, main carriers, ANSPs and authority representatives. The work is voluntary and based on collaboration and an open dialogue between the partners and the success of the program is highly dependent on this partnership.

The program is organized in four work streams:

- Behavior
- Ground support equipment
- Stand technology and operations
- Research and analysis

In each work stream a number of various projects and initiatives have been and are being conducted. The scale of these projects varies from time limited awareness campaigns to scientific studies.

CPH has, on a voluntarily basis, established continuous monitoring stations for ultrafine particles at two locations: At the central apron (B4) and at the western boundary close to residential areas. Measurements started in August 2010 and are done 24/7. This means that CPH has been measuring continuously for 6 years and will continue measurements in order to collect data for documentation of effects from the various remediation initiatives. The stationary measurements are supplemented by ad hoc measurements with handheld devices (the measurement of ultrafine particles with a handheld device is shown in **Figure 6**).

Environmental and Operational Results Go Hand In Hand

Looking at the global perspective, operations at airports only account for a small part of the environmental impact of air travel. However, seen in a local perspective, this fraction is very important for the local communities in and around airports, and in the case of ultrafine particles in Copenhagen Airport, especially for the working environment for staff. And of course the global and local aspects of environmental impact are connected. CPH is welcoming the focus ICAO has set on particle emissions from aircraft engines, and expect the new nvPM standard to have a positive effect on the local as well as the global air quality – even if it is in the long term perspective. Also, our work within the Air Quality Program goes hand in hand with our Airport Carbon Accreditation at level 3, optimization: A reduction in emission of ultrafine particles involves a reduction of CO_2-emissions.

Locally, the projects conducted within the frames of the Copenhagen Airport Air Quality Program have resulted in a reduction in ½-year mean levels at the central apron area of about 50% (see **Figure 3**).

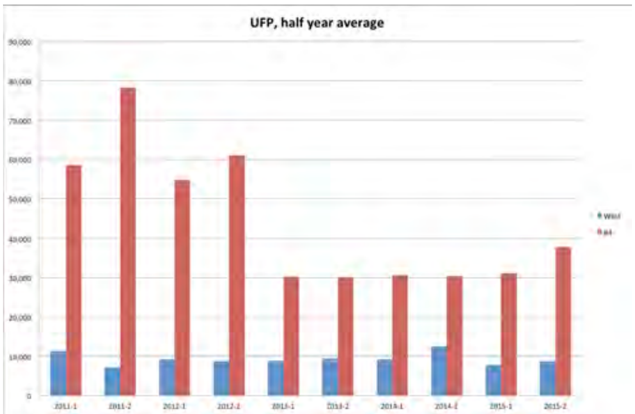

Figure 3. ½ year mean levels of UFP measured at the central apron and the western boundary. Since 2011, the level at the central apron has been reduced with about 50%.

All the conducted projects and initiatives play their part in the reduction. However, the one that really made a difference was a project within the "Stand technology and operations" work stream. With this project, the standard push-back procedure was changed and an environmental push-back procedure was implemented, on basis of a test period.

The former standard procedure, involving start-up of aircraft main engines in an area between two piers and with a large apron area is now replaced by the environmental push-back

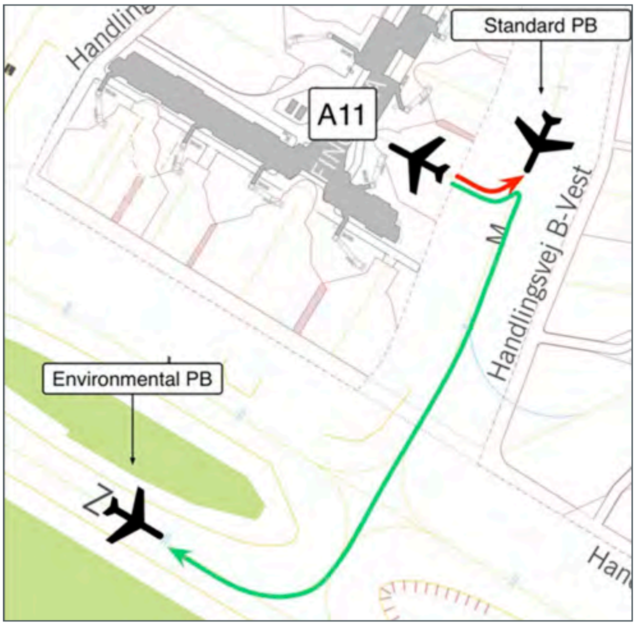

Figure 4. Illustration of the environmental push-back procedure.

procedure involving towing the aircraft to the closest taxiway before start-up of the main engines (see **Figure 4**).

Both the safety aspects and the expected operational consequences of the change of procedure were thoroughly examined and found to be sound before implementation.

As it turned out, the operational effects have been moderate in general and even positive in some traffic situations, especially for arriving aircraft, since the environmental push-back procedure makes more room on taxiway M for arriving traffic.

These results are characteristic for CPH's work towards better air quality at the aprons: the aim is to minimize the amounts of ultrafine particles emitted without compromising the operational efficiency.

What's next?

Figure 5. Employee driving one of CPH's electrical stairs.

Even though the Copenhagen Airport Air Quality Program has been in place for a number of years, there is still work to be done. There are still active and new initiatives in each of the four work streams:

The "behaviour" work is a continuous process, which among others focuses on behavior and awareness at the apron area, such as single-engine taxiing, stop of main engines at gate, limiting use of APUs, limiting time of idling with vehicles etc.

In terms of ground support equipment, CPH has set a standard for "green equipment" with yearly targets for the percentage of green equipment in Copenhagen Airport. Again, the focus is on minimizing the particle emissions from the equipment, meaning that for example electrified equipment and diesel equipment with functional particle filters currently both comply with the standard. **Figure 5** shows one of CPH's electrical stairs.

When it comes to stand technology and operations, the work stream participants are currently analyzing the possibilities to change more push-back procedures.

The research and analysis work stream will be focusing on the results from a scientific cohort study, which are expected in 2016 and the start-up of a new scientific project with the aim of researching the toxicity of ultrafine particles in airports. The results of this project are expected reported in 2019.

If you would like to read more about Copenhagen Airport Air Quality Program: http://dit.cph.dk/wp-content/uploads/2015/07/EN-6-Air-Quality-Air-Quality-Programme.pdf

Figure 6. Senior Project Manager Jesper A. Jacobsen measuring ultrafine particles with a handheld P-trak. Mr. Jacobsen manages Copenhagen Airport Air Quality Program on a daily basis. Photo by Ernst Tobisch.

CHAPTER 4

GLOBAL EMISSIONS

INTRODUCTION TO THE ICAO BASKET OF MEASURES

BY ICAO SECRETERIAT

Introduction to Global Emissions

The main greenhouse gases (GHGs) emitted by aviation are CO_2 and water vapour (H_2O), and aviation is responsible for two percent of anthropogenic CO_2 emissions [IPCC Fourth Assessment Report, 2004], and approximately 65% of this two percent are from international aviation (i.e. approximately 1.3% of anthropogenic CO_2 emissions). Aviation also emits nitrogen oxides (NOx) that impact the concentrations of other GHGs, mainly ozone (O_3) and methane (CH_4). Black carbon (soot) is a directly emitted aerosol, and sulphur oxides (SOx), NOx, and hydrocarbons (HC) lead to aerosol production after emission. Water vapour emissions in combination with emitted or background aerosol lead to contrail formation, and persistent contrails increase cloudiness. Additionally, aviation aerosols may modify natural clouds or trigger cloud formation. There is substantial scientific understanding of the components of aviation impacts on the climate and it is estimated that aviation contributes to surface warming. While CO_2 is particularly understood, there are important uncertainties regarding some of the non-CO_2 impacts and the underlying physical processes which require further investigation. Further information on Aviation Impacts on Climate: State of the Science can be found on page 99.

One of the most valuable references on the effects of aviation on the global climate is the Intergovernmental Panel on Climate Change (IPCC) Special Report on Aviation and the Global Atmosphere, published in 1999 [IPCC, 1999]. This was prepared at the request of ICAO in collaboration with the Scientific Assessment Panel to the Montreal Protocol on Substances that Deplete the Ozone Layer, and was the first IPCC Special Report to consider an individual industrial sector. The report, which is based on data and studies dating back to 1992, highlights the state of understanding of the relevant science of the atmosphere, aviation technology, and socio-economic issues associated with aviation and its climate impact. As the twentieth anniversary of the report approaches, the tenth meeting of the Committee on Aviation Environmental Protection (CAEP/10) considered a number of options to update some of the information contained in the 1999 IPCC Special Report. The meeting agreed that it is premature to ask the IPCC to update the Special Report of 1999, and acknowledged that other means exist to provide independent scientific information to CAEP that is peer reviewed. Led by the ICAO Secretariat, options are currently being explored to update some of the scientific information leading up to the CAEP/11 meeting in February 2019.

ICAO Basket of Measures to Reduce International Aviation CO_2 Emissions

Resolution A38-18, adopted by the 38th ICAO Assembly in 2013, sets forth an overarching policy for the Organization to address the impacts of international aviation on the global climate. It affirmed the global aspirational goals for the international aviation sector of improving annual fuel efficiency by 2%, and stabilizing the sectors' global CO_2 emissions at 2020 levels (carbon neutral growth from 2020).

With a view to achieving the global goals and ultimately the sustainable future for international aviation, ICAO has made important progress, focusing on the development and implementation of a "basket of mitigation measures" to reduce CO_2 emissions from international aviation. The "basket" includes advancements in aircraft technology, operational improvements, sustainable alternative fuels, and market-based measures.

Addressing CO_2 emissions from international aviation through the basket of measures is the ICAO's long-standing comprehensive approach, and provides flexibility for States to mix and match such elements in light of their circumstances.

Aircraft Technology and Standards

Technology can play a major role in reducing emissions; aircrafts produced today are about 80 percent more fuel efficient per passenger kilometre than in the 1960s. A major area of activity of the Organization in the field of aviation and climate change is the development of Standards and Recommended Practices (SARPs), with a view to ensure that the latest technology is incorporated to aircrafts. In particular, the development of a CO_2 emissions certification Standard for aeroplanes has been one of the most challenging tasks being undertaken by the Organization under its Committee on Aviation Environmental Protection (CAEP), which achieved a major milestone at CAEP/10 meeting in February 2016. This new Standard, as the first global Standard for CO_2 emissions of any sector, will apply to new aeroplane type designs from 2020 and to aeroplane type designs that are already in-production in 2023 (see article page 112).

Operational improvements

Operational measures are also among the elements in the basket of measures available to States to reduce aviation CO_2 emissions. Improved operational measures defined in the ICAO Global Air Navigation Plan (GANP) reduce fuel consumption, and in turn,

CO_2 emissions. For every tonne of fuel reduced, an equivalent amount of 3.16 tonnes of CO_2 are saved.

For example, CAEP, in partnership with the operational community, has been assessing the environmental benefits of the Aviation System Block Updates (ASBUs), which is a major initiative to improve global air navigation efficiency (see article page 120).

Sustainable Alternative Fuels

Impressive progress in the development and deployment of sustainable alternative fuels for aviation has been achieved, including commercial flights using sustainable drop-in fuels from a variety of feedstocks and a number of aviation alternative fuel initiatives are currently underway worldwide.

ICAO continues to be at the forefront in facilitating the timely availability of such fuels in sufficient quantities for use in aviation in a sustainable manner, supporting States and stakeholders in their efforts (see article page 153).

Global Market-Based Measure (MBM) Scheme

Since the decision by the 38th ICAO Assembly in 2013, governments and other stakeholders have been working together to develop a proposal for a global market-based measure (MBM) scheme for international aviation, which will play a complementary role as part of the basket of measures to fill the emissions gap and achieve the carbon neutral from 2020.

Significant efforts have been put in place, in particular to find practical means to accommodate special circumstances and respective capabilities of countries that would best fit for the international aviation sector, for decision by the 39th ICAO Assembly in October 2016 (see article page 141).

Sustainable Development Goals

WHITE PAPER ON CLIMATE CHANGE AVIATION IMPACTS ON CLIMATE: STATE OF THE SCIENCE

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*This White Paper represents the summary of the scientific literature review undertaken by researchers and internationally-recognized experts. It does not represent a consensus view of ICAO.

Summary

Aircraft emit gases and aerosol that change the composition of the atmosphere, cause increases in cloudiness through contrail formation and spreading, and modify natural clouds. At present, these changes together are estimated to cause a net positive forcing of Earth's climate system, which contributes to surface warming and other responses. There is substantial understanding of the components of aviation climate forcing, particularly CO_2. Important uncertainties remain in quantifying some of the aviation non-CO_2 climate terms and in the underlying physical processes. This paper presents a summary of recent progress in the state of the science since the 2012 ICAO/CAEP/ISG paper, especially related to contrails and induced cloudiness, contrail avoidance, and aerosol and NOx effects. The number and diversity of newly available studies has created a need to re-evaluate best estimates of aviation climate forcings. Our understanding and confidence in aviation climate forcings would be enhanced by a new international scientific assessment.

Aviation represents an important component of the global economy by transporting people and goods between essentially all nations. The aviation sector is expected to grow in the coming decades as demand grows, especially in the developing world. Aviation operations at altitude and on the ground rely heavily on fossil fuels, which emit combustion by-products that contribute to regional and global air quality, and climate change. In addition, aircraft emissions lead to contrail formation and increased cloudiness. The Intergovernmental Panel on Climate Change laid out the basic concepts of aviation's role in climate change and quantified its contribution in a Special Report in 1999 (IPCC, 1999). Since then, progress has been made to fill gaps in our understanding and refine quantitative estimates of climate forcing. The present paper represents an updated summary of the state of the science following on from the 2012 ICAO/CAEP/ISG paper on this topic (Fahey *et al.*, 2012), (see ICAO Environmental Report, 2013, p 48-53).

The connections between aviation emissions and radiative forcing, climate change, and its impacts and potential damages are shown in **Figure 1.** Direct emissions undergo various chemical transformations and accumulate in the atmosphere leading to radiative forcing. Radiative forcing (RF) is a measure of the imbalance in the Earth's radiation budget caused by changes in the concentrations of gases and aerosols or cloudiness. The principal greenhouse gases (GHGs) emitted are carbon dioxide (CO_2) and water vapor (H_2O). Emissions of nitrogen oxides (NO_x) impact the concentrations of other GHGs, mainly ozone (O_3) and methane (CH_4). Black carbon (soot) is a directly emitted aerosol, and sulfur oxides (SO_x), NO_x, and hydrocarbons (HC) lead to aerosol production after emission. Water vapor emissions in combination with emitted or background aerosol lead to contrail formation. Persistent contrails, which form at high ambient humidity and low temperatures, increase cloudiness. Additionally, aviation aerosol may modify natural clouds or trigger cloud formation. There is high confidence that these are the primary pathways by which aviation operations affect climate.

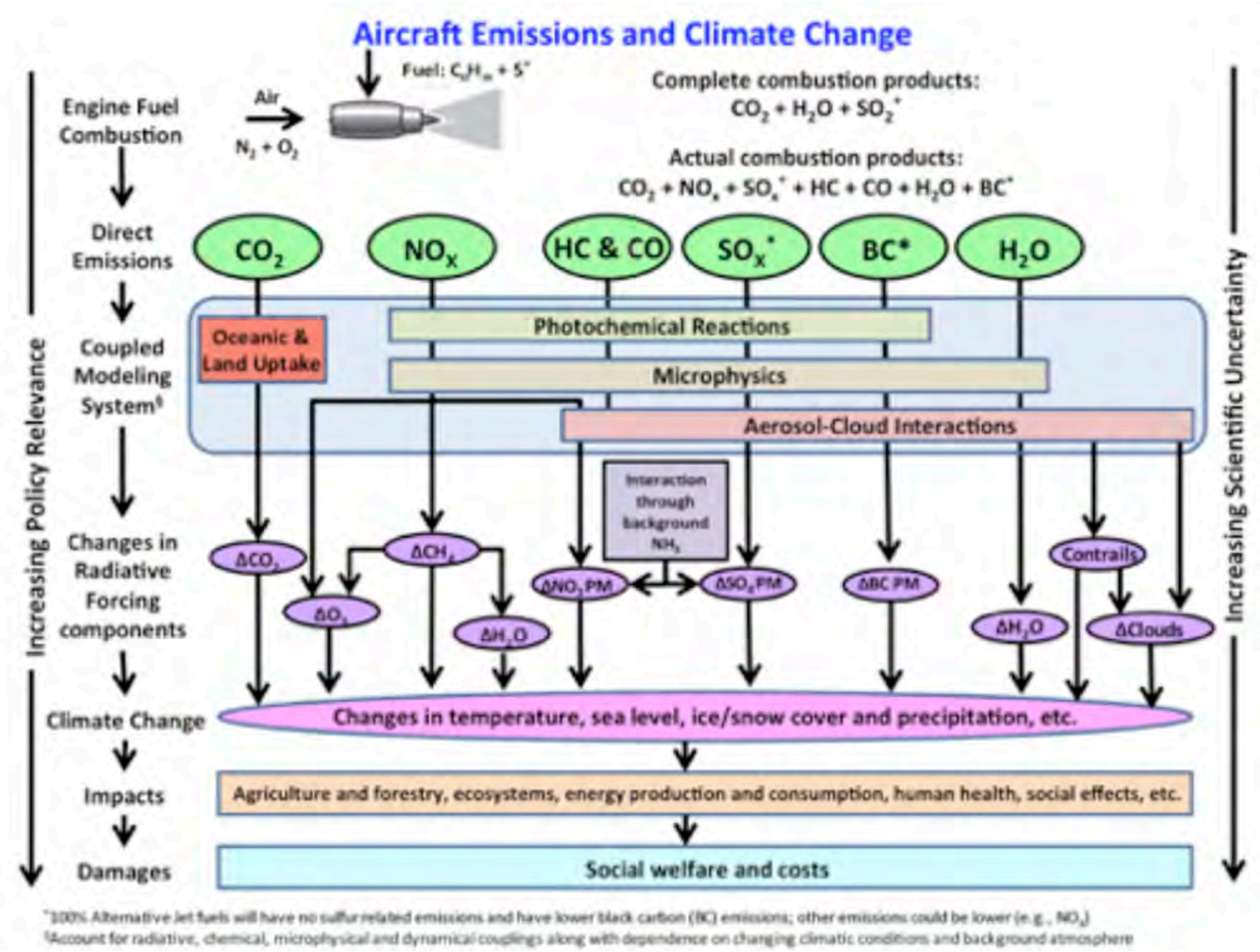

Figure 1. Updated schematic of the principal emissions from aviation operations and the relationship of emissions to climate change and impacts. The terminology, ΔX, indicates a change in component X. The term, Δclouds, represents contrail-induced cloudiness and aerosol-cloud interactions. (From Brasseur et al., 2015).

Aviation Fuel Use and CO_2 Emissions

All aircraft emit CO_2 as a fuel combustion product. Fuel use by the global aircraft fleet has increased approximately linearly over four decades (up to 2013) based on International Energy Agency estimates. Fuel use per revenue passenger kilometer (RPK) has decreased since the 1970s as aircraft structures, aircraft engines and aircraft operations have become more fuel efficient (Lee *et al.*, 2009). Aviation fuel use and CO_2 emissions are projected to continue increasing in the coming decades as aviation demand increases, even as CO_2 per RPK decreases due to technological and operational improvements.

Radiative Forcing of Current-Day Aviation from CO_2 and Non-CO_2 Agents

The RF of current-day aviation from CO_2 and non-CO_2 agents is established by a quantitative evaluation of each of the pathways shown in **Figure 1**. The evaluation requires knowledge of many physical and chemical processes in the atmosphere and requires summing over the global aircraft fleet operating under diverse meteorological conditions in the upper troposphere and lower stratosphere where most emissions occur. The Lee *et al.* (2009) study is the most recent assessment in the literature of the best estimates of aviation RF terms. The study updated estimates presented in the IPCC Special Report (IPCC, 1999) and Sausen *et al.* (2005). More recently, the Aviation Climate Change Research Initiative (ACCRI) program conducted by the Federal Aviation Administration in the USA provided important new results for aviation RF terms (Brasseur *et al.*, 2015).

With the passage of time, the scientific results underlying the best estimates of RF terms in Lee *et al.* (2009) are becoming superseded by more recent studies using updated methods and data. The exception is the CO_2 RF, which can be confidently and quantitatively calculated from fuel use and emission data over time (Lee *et al.*, 2009). For non-CO_2 terms, defining best estimates and their uncertainties, as outlined in the IPCC assessment process, requires a comprehensive synthesis of the available results in the scientific literature. Without such a synthesis, the newly available results generally form an incomplete and sometimes inconsistent picture, thereby leaving policymakers without a coherent basis for evaluation or other decisions. The recent ACCRI report drew similar conclusions in noting that recommendations for best estimates were precluded in their study due in part to the varied modeling approaches that did not all account for climate system couplings and feedback processes (Brasseur *et al.*, 2015). Continued progress in understanding and quantifying aviation climate forcings and responses requires continued focused research activities and would be enhanced by a new international scientific assessment that would assess new published results available, for example, for contrails, contrail cirrus and indirect cloud effects. An updated science assessment would also identify important remaining gaps in understanding and, hence, guide future research directions.

Another consequence of the lack of best estimates for aviation climate forcing terms is that the total RF from aviation cannot be computed with confidence. The total value and uncertainty rely on the addition of best estimates of various interdependent terms (and processes) and the propagation of underlying uncertainties. Comparison of RF terms with different lifetimes, such as those from CO_2 and contrails, in general require careful consideration as outlined in Section 8. Without a total RF, aviation's present contribution as a sector to climate change cannot be usefully compared to that from another sector. The exception is CO_2 for which emissions and RF comparisons over a defined time period are valid.

NOx Effects

Aircraft NOx acts as a catalyst to produce O_3 in the oxidation of CO, CH_4, and a variety of hydrocarbon compounds. While NOx is not a greenhouse gas, it alters the abundance of two principal GHGs, O_3 and CH_4, through complex photochemical processes. Increased O_3 at cruise altitudes leads to a positive RF (warming). NOx also increases the abundance of the hydroxyl radical (OH), which reacts with CH_4, thereby reducing its abundance and causing a negative RF (cooling). This long-term CH_4 reduction also leads to a relatively small long-term reduced production of O_3 and an associated small negative forcing. Recent studies, such as ACCRI and REACT4C, have included this term (Brasseur *et al.*, 2015; Søvde *et al.*, 2014). In addition, reductions of CH_4 result in small reductions of water vapor in the stratosphere, yielding another small negative forcing.

A principal difficulty in quantitatively evaluating the climate response to aviation NOx is that the atmospheric lifetimes associated with O_3 and CH_4 responses lead to non-uniform hemispheric-to-global scale perturbations in these forcing agents. Furthermore, the magnitudes of the O_3 and CH_4 responses depend on the geographic location of the NOx emissions and the NOx background amounts from other anthropogenic and natural sources. This difficulty is reflected in differences between model simulations of O_3 and NOx increases from 2006 aviation emissions as shown in **Figure 2** (Olsen *et al.*, 2013). The chemistry and climate models used were part of an ACCRI program effort to evaluate the agreement and consistency of NOx effects across global models. General tendencies are seen in the results, such as an increase in O_3 and a reduction in OH, with large differences in magnitude in some cases. Model analyses by Holmes *et al.* (2011), Myhre *et al.* (2011), Søvde *et al.* (2014) show a spread of at least a factor of two in net NOx RF values. These differences indicate that further evaluation of these results is required before a refined best estimate for RF from NOx emissions can be derived from these community results (Olsen *et al.*, 2013).

Aviation Cloudiness

Increased cloudiness from aircraft operating at cruise altitudes is a key aspect of aviation impacts and one that is often visible to the human eye. The increases are typically divided into contributions from persistent (linear) contrails and contrail

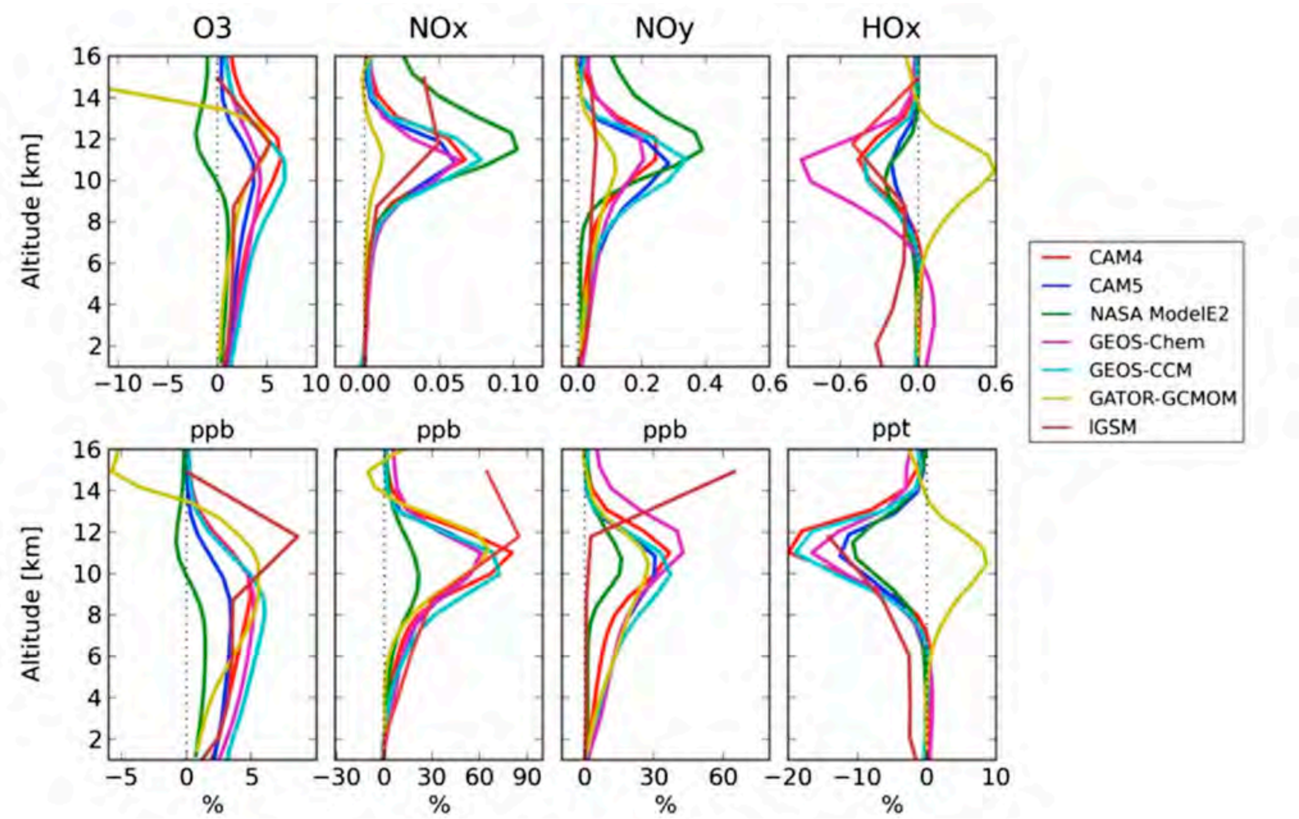

Figure 2. Effect of aviation emissions on O_3, NOx, NOy, and HOx amounts. Profiles are zonal means averaged over 30°N to 60°N from individual models (chemical transport models, chemistry-climate models, and 2D model). Absolute perturbation (top row) and percent perturbation (bottom row) at each altitude level are relative to the non-aviation background amounts. The study uses Aviation Environmental Design Tool (AEDT) 2006 aviation emissions. (From Olsen *et al.*, 2013)

cirrus. Aviation cloudiness causes an RF in a manner similar to natural cirrus clouds that cause a net warming (positive RF). Aviation cloudiness forcing estimates require integration over the lifecycle of contrail cloudiness from the diverse global aviation fleet operating in varying meteorological conditions. In the IPCC Special Report (IPCC, 1999) and many subsequent studies, only linear persistent contrails were evaluated, leaving contrail cirrus formed from spreading contrails unquantified. The updated evaluation in the most recent IPCC report (IPCC, 2013) now quantifies both these terms as discussed below.

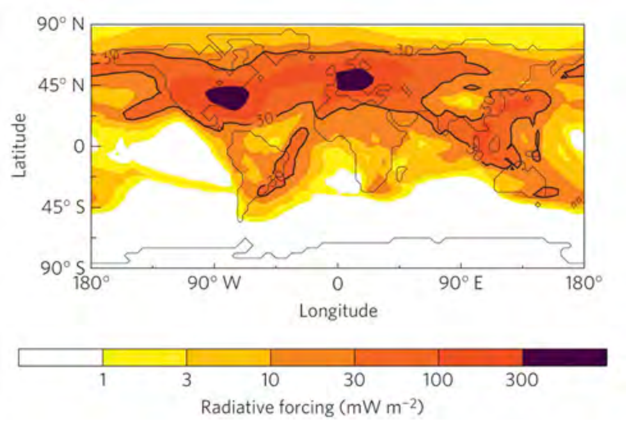

Figure 3. Global distribution of contrail cirrus radiative forcing for the aviation fleet in year 2002 from a global climate model with full contrail parameterization. (From Burkhardt and Kärcher, 2011)

A comprehensive treatment of the radiative forcing from contrails and contrail cirrus has been conducted in a global climate model for 2002 emissions (Burkhardt and Kärcher, 2011). Global contrails and their interactions with background (natural) cirrus are simulated by parameterizing the processes by which young persistent contrails are formed and age into spreading cirrus cover. This modeling effort represents a major advance in quantifying the aviation contribution to climate change. The resulting direct RF from contrails and induced cirrus cloudiness, including the reduction in background cirrus, is estimated to be 31 mW m^{-2} with the geographic distribution shown in **Figure 3**. A more recent evaluation with an improved climate model has yielded nearly identical results for the 2002 emission and yields a preliminary value of about 45 mW m^{-2} for 2006 emissions (Bock, 2014). For comparison, the estimate of CO_2 RF for 2005 is 28 mW m^{-2} (Lee et al., 2009). Another study derived a global annual contrail and contrail cirrus RF of 13 mW m^{-2} using a model that accounts for interactions of aircraft emissions with ambient clouds (Chen and Gettelman, 2013). The Burkhardt and Kärcher (2011) and Bock (2014) studies reveal the importance of accounting for contrail interactions with natural clouds by showing how contrails reduce natural cloudiness and how natural cloudiness shields a large fraction of contrails, thereby reducing the net radiative effect of contrails. These studies imply an increasing trend in cirrus coverage and properties from aviation operations that has not yet been confirmed by analyses of long-term observations of cirrus cloudiness from space.

Another major study has examined cloudiness the North Atlantic (NA) air traffic corridor using several years of satellite data for cirrus cover and outgoing longwave radiation (OLR) (Schumann and Graf, 2013). The diurnal cycle observed in OLR and cirrus cover is interpreted as a regional *aviation fingerprint*. A similar NA fingerprint is found with the Contrail Cirrus Prediction (CoCiP) model that simulates the lifecycle of contrail from reported air traffic data (Schumann *et al.*, 2012). The NA fingerprint features combined with certain assumptions, such as the natural cloud cover in the absence of aircraft, the absence of any other aviation cloud effects, the ratio of longwave to shortwave radiation effects, and the regional to global contrail cover, yields an RF estimate for total aviation cirrus of 50 (40–80) mW m^{-2} (2006 air traffic). The value of 50 mW m^{-2} is on the high end of the 13 - 49 mW m-2 range estimated from climate models. Based on a direct analysis of contrail spreading over land in otherwise clear skies using satellite data, Minnis *et al.* (2013) estimated for 2006 air traffic that the combined linear contrail and contrail-induced cirrus would also be ~50 mW m^{-2} globally in the absence of cloud shielding and with the assumption that all observed contrails have similar spreading rates. The actual global number is expected to be lower since the conditions in the study are optimal for maximizing the cirrus effect.

The most recent IPCC report (IPCC, 2013) provides an RF estimate for persistent contrails of 10 (5–30) mW m^{-2} for 2011, based primarily on the Burkhardt and Kärcher (2011) and Schumann and Graf (2013) results. This value and the recent 6 mW m^{-2} result from the first hemispherical analysis using 2006 satellite data (Spangenberg *et al.*, 2013) are both reasonably consistent with the 2005 best estimate from Lee et al. (2009) (12 mW m-2). Further, the IPCC estimates the combined contrail and contrail-cirrus effective RF from aviation to be 50 (20–150) mW m-2 with low confidence while noting important uncertainties of spreading rate, optical depth, ice particle shape, and radiative transfer processes.

Soot and Sulfur Emissions

Aviation engines emit aerosol (small particles) directly and aerosol precursor gases that subsequently form aerosol 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. Soot and sulfate aerosol have direct radiative forcings of opposite signs: soot causes a positive RF, leading to warming, and sulfate causes a negative RF, leading to cooling. Direct effects result from aerosol interactions with solar radiation. Indirect effects

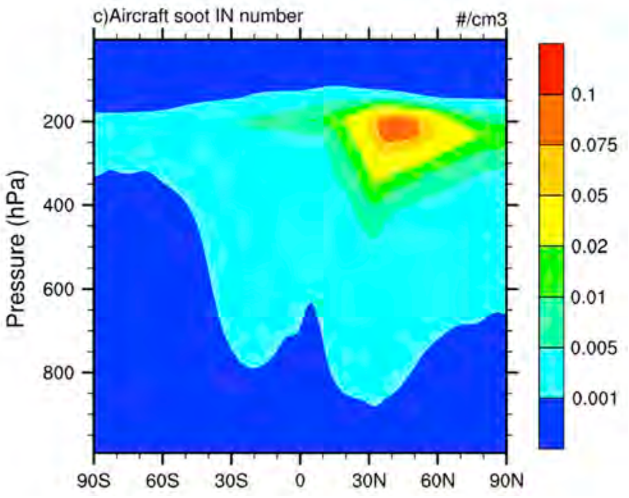

Figure 4. Annual and zonally averaged aircraft soot ice-nuclei number concentrations. All results are from the low sulfur and low dust case. (From Zhou and Penner, 2014)

result from aerosol induced changes in background cloudiness. Indirect effects are less well studied with few published RF estimates reflecting the difficulty in understanding and modeling the necessary nucleation processes. For example, IPCC provides no estimates of indirect effects of aviation aerosol (IPCC, 2013).

Recent results from general circulation model studies highlight the large uncertainties associated with aerosol indirect effects. Zhou and Penner (2014) calculate a range of –350 to +90 mW m^{-2} depending on the assumptions of the amount of sulfate and dust aerosol in the background atmosphere and the fraction (0.6%) of aviation soot that is active as ice nuclei to form clouds. **Figure 4** illustrates where soot emissions form ice nuclei for 2006 aviation emissions. In contrast, other studies find no significant effect (less than 10 mW m^{-2}) in part because of assuming a much less active soot fraction (0.1%) (Gettelman and Chen, 2013; Pitari *et al.*, 2015). The community currently lacks a sound basis to derive a best estimate from these most recent studies because of the poor process understanding and the absence of suitable measurements of the nature, abundance, and distribution of aviation aerosol in the background atmosphere. With the existing uncertainties, it is not possible to extrapolate soot impacts to future engines or conditions with confidence.

An important aspect of soot emissions is their influence on contrail formation. For typical fuel sulfur concentrations, the number of ice particles formed in the near-field plume of a contrail is nearly equal to the number of soot particles emitted (Kärcher *et al.*, 1998; 2015). Recently, Lewellen (2014) has evaluated parametrically how the integrated radiative forcing of an individual contrail over its lifetime varies with different atmospheric conditions for a single airplane type. A key conclusion of the study is that the forcing depends on the number of initial ice particles. Although this modeling result has not been experimentally validated, it suggests that engine combustor technology may also play a key role in reducing contrail effects. Efforts to reduce aviation soot mass and number emissions to protect air quality may have a dual benefit because of the consequential reductions in contrail RF.

Sulfate aerosol formed after emission has a small to negligible direct effect. Its indirect effect results from changes in liquid clouds in the background atmosphere well below flight altitudes. Few indirect cloud forcings have been estimated for sulfate and are typically absent from earlier assessments; one recent study estimates –46 mW m^{-2} (Gettelman and Chen, 2013). Righi *et al.* (2013) simulated the combined direct and indirect aerosol effects from aviation emissions via soot, sulfate and nitrate aerosols. The resulting cloud changes cause an RF of –15 mW m^{-2} (cooling) for the year 2000, with a range from –70 to +2 mW m^{-2} due to parameter uncertainty.

Metrics and Timescales

With the large number and diversity of anthropogenic climate forcing mechanisms associated with aviation, there is often interest in aggregating the effects by converting the non-CO_2 terms to so-called CO_2-*equivalent* terms, as is done under the Kyoto Protocol, or to use other scales or metrics. The application of an emission metric provides policymakers a basis to consider trading or other approaches to mitigation and affords scientists a framework to examine climate effects. The use of metrics is hampered by significant challenges related both to scientific

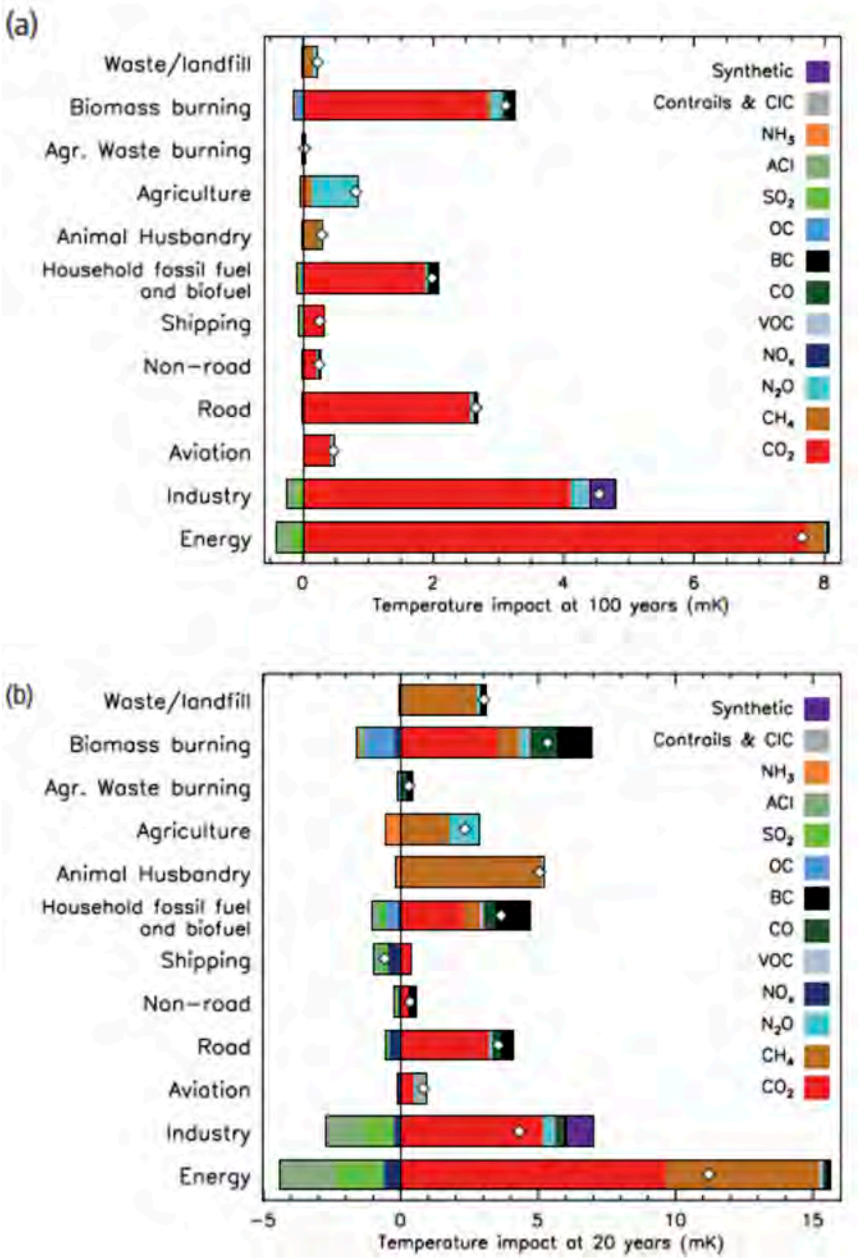

Figure 5. Net global mean temperature change by source sector after (a) 100 and (b) 20 years (for 1-year pulse emissions). Emission data for 2008 are taken from the Emission Database for Global Atmospheric Research (EDGAR) database. There are large uncertainties in the calculated temperature responses. (From IPCC, 2013)

issues and policy choices. For assessments of aviation effects and associated mitigation strategies, metrics such as the Global Warming Potential (GWP) or Global Temperature change Potential (GTP) (using integrated RF over a chosen time horizon and temperature change for a selected year, respectively) have been used in scientific studies. Metrics that capture regional patterns in response have also been explored for aviation (Lund *et al.,* 2012; Brasseur *et al.*, 2015), and some of these are based on experience from application of such metrics to surface sources (Collins et al., 2013; Lund *et al.*, 2014). Various approaches that adopt concepts and approaches from economics have also been evaluated (e.g., Azar and Johansson, 2011; Deuber *et al.*, 2014).

The emissions and RF mechanisms associated with aviation cause effects that operate on a broad range of time scales. The differences in lifetimes of climate forcing agents also lead to different spatial patterns of radiative forcing. Assessment of trade-offs between the climate impact of CO_2 and non-CO_2 effects involves weighing effects over time and therefore also value judgments. In particular, the comparison of climate forcing of contrails to that of CO_2 is challenging. While the RF and the temperature response from CO_2 emissions occur on a millennial time scale (IPCC, 2013), the lifetime and forcing of contrails is of the order of hours with a temperature response that may last for a few decades.

The importance of time scales in comparing aviation with other climate forcing agents is illustrated in **Figure 5**. The relative contributions of aviation induced cloudiness and CO_2 emissions to global temperature changes on 20- and 100-year time scales are compared with other emission sources for a 1-yr pulse of emissions. As the time scale increases, the warming from long-lived effects (e.g., CO_2) dominates those from short-lived effects (e.g., NOx and cloudiness). Overall, the global mean temperature changes after 20 and 100 years in response to one year of current emissions from aviation are small relative to other sectors.

Evaluation of the climate effects of aviation may also include estimates of the impacts and damages to natural systems and society, which are sometimes quantified in monetary units. Various damage-based metrics have been formulated. The Social Cost of Carbon (SCC) is an often-used metric based on a damage function that discounts future damages to the present and uses a baseline trajectory of emissions and the resulting temperature change (Kolstad *et al.*, 2014). There is an ongoing scientific debate on the estimate for SCC (e.g., Moore and Diaz, 2015; Marten and Newbold, 2012; IPCC, 2014). It is particularly difficult to estimate the social cost of climate change from aviation non-CO_2 agents due to methodological challenges and limitations in the knowledge about climate responses and damages.

In addition to challenges related to comparing effects over time, there are also issues related to the variability in the spatial patterns of aviation climate effects. The global distribution of enhanced CO_2 concentrations from aviation or other sources is essentially uniform because of its long lifetime. As a consequence there is no fingerprint of aviation CO_2 in the global-scale pattern of anthropogenic present-day RF or associated temperature changes. In contrast, O_3 increases from aviation, for example, vary on regional to hemispheric scales, while RF from contrails is much more confined to the areas of traffic. This is further complicated by the fact that the spatial distribution of temperature response to any RF mechanism is determined by both the RF pattern and the dynamics and feedbacks of the climate system. Thus, comparing non-CO_2 aviation effects with other forcing agents only in terms of a global-mean metric such as global mean RF GWP or GTP overlooks the potentially important role of regional variability in forcing responses (Lund *et al.*, 2012).

Emissions from Alternative Aviation Fuels

Recent studies have characterized the emissions from alternative fuels, using commercial engines in ground-based tests. Since 2011, three alternative fuels have been approved for blending with petroleum derived Jet-A/A1. They are Fischer-Tropsch (FT) hydroprocessed synthesized paraffinic kerosene (SPK), synthesized paraffinic kerosene from hydroprocessed esters and fatty acids (HEFA), and synthesized iso-paraffins (SIP) from hydroprocessed fermented sugars (see ASTM D7566-14c for details). Research is underway to produce and evaluate other bio-derived fuels that offer substantial net reductions in CO_2 emissions based on a lifecycle or well-to-wake evaluation.

The reduced sulfur and aromatic contents in synthetic, paraffinic biofuel, 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.* (2015) and Miake-Lye *et al.* (2012)). In a recent NASA project, emissions from HEFA biofuel blends measured on the ground produced similar results. The results are summarized in an evaluation of fuel properties on non-volatile particulate matter by Moore *et al.* (2015) and are described in more depth in the accompanying Miake-Lye *et al.* (2015) ISG air quality paper (see article page 75).

NOx and CO emissions are similar or reduced for FT fuels and JP8 fuel blends compared to JP8 while VOCs show a mixed response (Timko *et al.*, 2011). Preliminary ACCRI results indicate that deployment of alternative fuels leads to a decrease in modeled climate impacts from aviation sulfate and black carbon aerosols (Brasseur *et al.*, 2015). 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. A complication in the use of low aromatic fuels to reduce particulate matter is that current sealing materials in fuel systems require some aromatic content to swell in order to avoid fuel leakage in legacy aircraft.

Contrail Avoidance for Climate Change Mitigation

There is considerable interest in the potential of contrail avoidance to reduce aviation RF while accounting for potential tradeoffs such as increased fuel burn. This potential rests in part on the flexibility in aviation operations to change routing to avoid ice-supersaturated regions. Ice supersaturated conditions are required for persistent contrail formation and induced cirrus cloudiness. The first potential avoidance option is temporary altitude changes. It is particularly effective in prospect because ice-supersaturated layers are typically found in narrow vertical layers. The sensitivity of contrail forcing to altitude changes has been modeled in a parametric study as a function of zonal latitude regions for four vertical displacements of the global fleet routing (**Figure 6**) (Frömming *et al.*, 2012). The response is strongest in the northern hemisphere, consistent with air traffic density. The global mean changes in contrail RF are +7% and –49% for +2 kft and –6 kft, respectively. It is also important to note that CO_2 emissions increase for operations below optimum flight altitudes due to greater fuel burn rate. The second potential option is heading changes en route at constant altitude in order to avoid ice supersaturation regions. In practice, route changes generally increase both the flight length and associated CO_2 emissions, which offset any contrail RF reductions (Irvine *et al.*, 2014).

The effectiveness of both contrail avoidance methods depends, in part, on obtaining accurate, near real-time forecasts of the vertical and geographical extent of ice-supersaturated regions along a planned flight track. For example, a leading global meteorological forecast model was shown to have difficulty in reproducing ice-supersaturated regions where contrails form (Dyroff *et al.*, 2015).

Evaluating the tradeoff between contrail RF, which is short lived

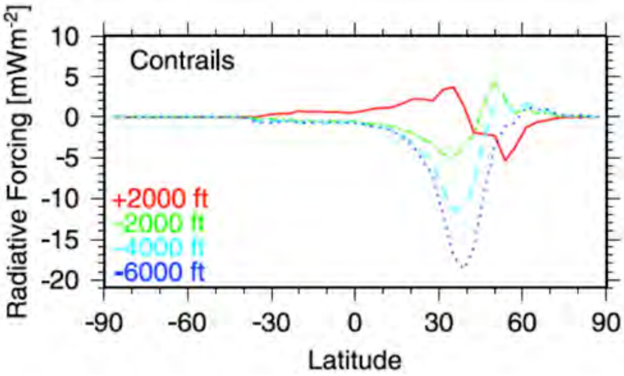

Figure 6. Changes of the zonal annual mean net radiative forcing (mW m^{-2}) of contrails in response to flight altitude changes by 2000 ft up, 2000 ft down, 4000 ft down, and 6000 ft down. Aircraft movements are from the TRADEOFF 2000 base case (25.4 x 10^9 km/yr flown distance, 152 Tg/yr fuel consumption, 0.6 Tg(N)/yr NOx emission). (From Frömming et al., 2012)

and has large uncertainty, and the more certain long-term CO_2 RF requires a choice of metric, such as the GWP or GTP, as well as a time horizon. Other short-lived climate terms are also likely to change if these avoidance methods are implemented. For example, the amount of O_3 formed from NOx emissions changes in response to altitude changes (Frömming *et al.*, 2012).

For contrail avoidance to be implemented in global aviation operations, a comprehensive approach would be needed that combines policy choices with scientific, operational and cost considerations (Irvine *et al.*, 2014; Deuber *et al.*, 2013; Grewe *et al.*, 2014). In practice, individual flight trajectories could be determined by minimizing a total climate cost function that combines contrails and induced cloudiness effects with CO_2 and all other non-CO_2 aviation effects. Within the European REACT4C project, Grewe et al. (2014) successfully applied such a procedure for selected weather situations.

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ICAO CARGO AND PASSENGER CALCULATOR

BY ICAO SECRETARIAT

ICAO Passenger Carbon Emissions Calculator

Today a large number of independently produced aviation carbon calculators is available to the public. These are developed by either NGOs, offsetting companies, international institutions, industry associations, academia, or a combination of all these. However all these carbon calculators provide very diverse results for the same flight that can differ by a factor up to four or more. The reasons for these variances rely in the availability and use of reliable and representative sets of data (such as aircraft configuration, load factors, freight load, engines and fuel burn), simplifications in the methodologies and scientific uncertainty.

Recognizing the need for a fully transparent and internationally approved calculator, ICAO began work on a methodology through its Committee on Aviation Environmental Protection (CAEP). In June 2008, ICAO launched an impartial, peer-reviewed and approved Carbon Emissions Calculator that estimates CO2 emissions from passengers' air travel. The methodology used by the ICAO calculator[1] applies the best publicly available industry data to account for various factors such as aircraft types, route specific data, passenger load factors and cargo carried. ICAO fuel formula is used to estimate fuel consumption based on distance flown. Although the only inputs from the user are origin/ destination airports and the class of service, the ICAO calculator uses a series of databases (Multilateral Schedules Database, Cargo/ Passengers Ratio and Load Factors) for its calculations (see **Figure 1**).

The ICAO methodology is regularly improved and the databases used are periodically updated by a dedicated group of technical experts from CAEP (see related article page 10).

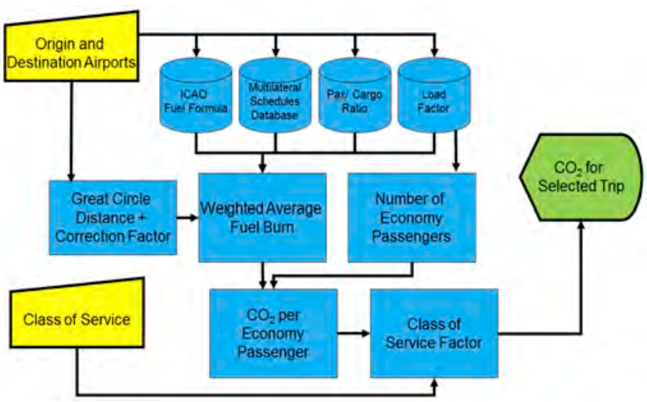


Figure 1. ICAO Carbon Emissions Calculator methodology

The online version of the ICAO Carbon Emissions Calculator is publicly available on the ICAO website:http://www.icao.int/environmental-protection/CarbonOffset/Pages/default.aspx.

In addition this tool is available in the Apple App Store as an iPhone and iPad application and in Google Play for Android devices. The ICAO Calculator webpage is the most visited of the ICAO website with more than 3,000 daily hits. In addition, it is the official tool for Global Travel Distribution Systems (GDS) such as Amadeus.

Cargo Methodology

Following the growing interest from the UN, general public and freight forwarders to receive CO2 information on cargo shipped by air, the capabilities of the ICAO carbon calculator have been further extended to estimate carbon emissions associated with these activities.

The first step was the development by CAEP of a methodology to estimate emissions associated with a future shipment that would complement a procedure that can be implemented by operators to compute the CO2 emissions for shipments that have already occurred.

This ICAO methodology is articulated in three parts so that precise data on the aircraft type and routing can be used when known, and estimated otherwise. ICAO only adopted the use of Part 1 and Part 2 in the carbon calculator as Part 3 is not a predictive tool but a post-flight calculation. The three parts, shown in **figure 3**, can be described as follows:

- Part 1 – Predictive Methodology (Dedicated Cargo Aircraft) – is aimed at the typical consumer who wishes to ship a package by air. Users will likely not have access to any information beyond the origin and destination of their shipment and the weight of the item.
- Part 2 – Predictive Methodology (Belly Cargo) – assumes that a package is being shipped on board a passenger aircraft and that the user knows the origin and destination airport for the item as well as any intermediate airports that the item may transit.
- Part 3 – Post-flight Methodology (Dedicated Cargo Aircraft and Belly Cargo). To be implemented at the operator level.

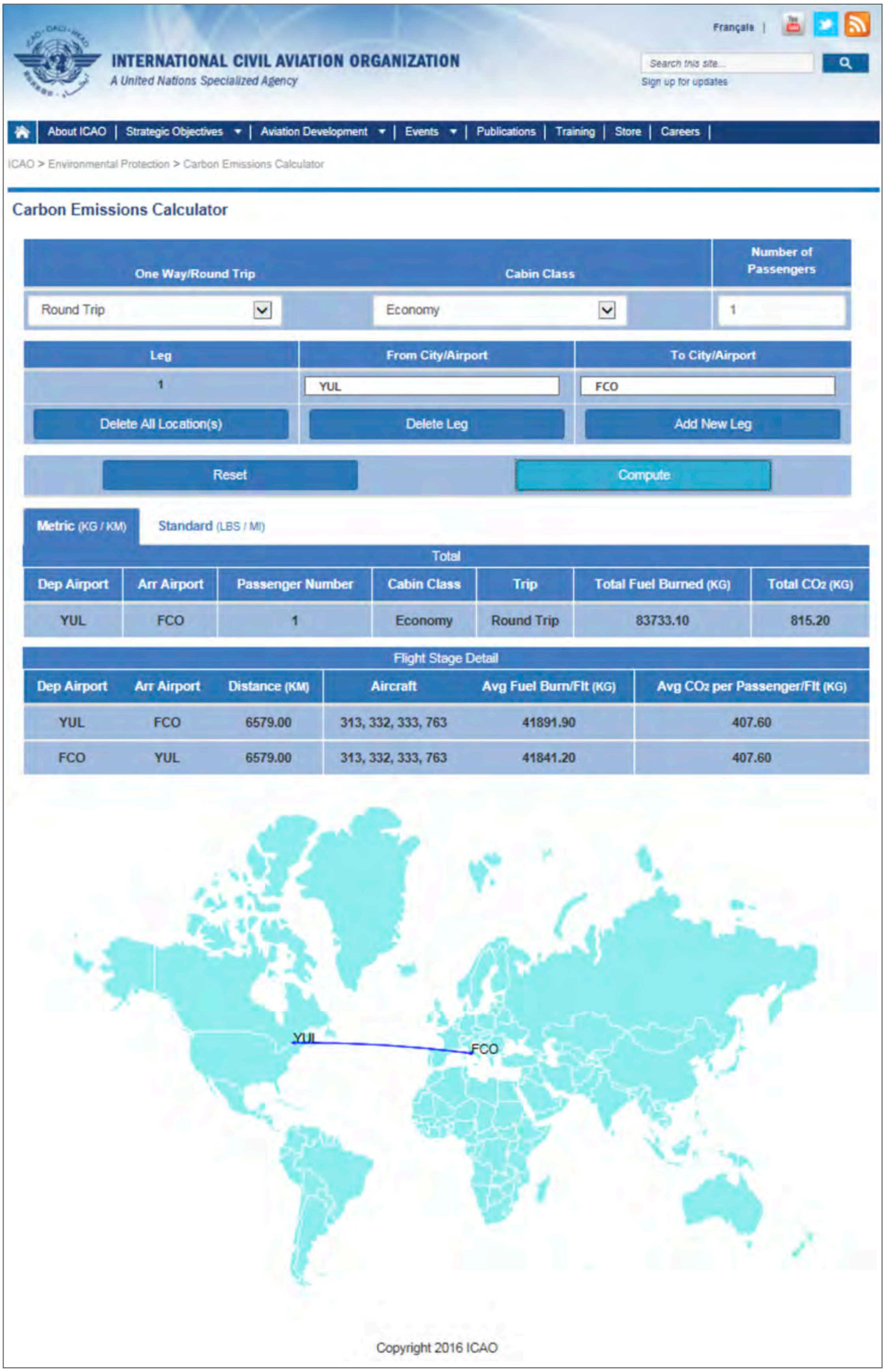


Figure 2. Screenshot of the online version of the ICAO Carbon Emissions Calculator

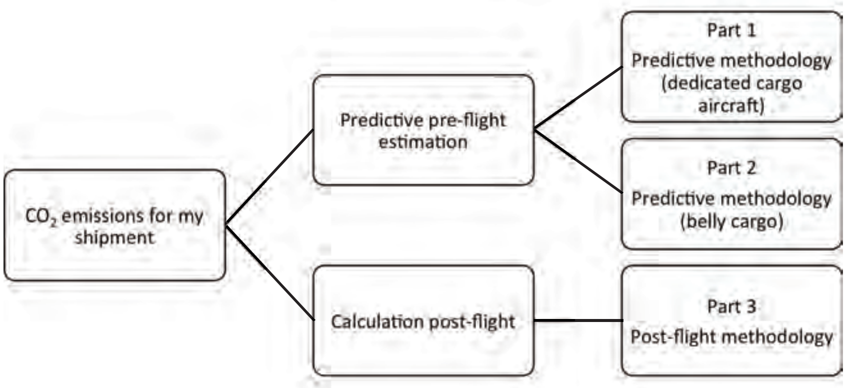


Figure 3. ICAO Cargo emissions methodology

Similar to the passenger methodology, Part 1 approach applies the ICAO fuel formula to estimate fuel consumption based on distance flown. The user enters the origin and destination city along with the weight of the package that is being shipped by air. Unlike the passenger methodology, the exact routing flown is not required, since air cargo often transits through a centralized facility for sorting while in transit. Depending on the region, there may be more than one hub due to market competition. Based on an analysis of dedicated air cargo traffic it is possible to identify the primary hubs within each region. As illustrated in **Figure 3**, data on the types of aircraft operating from the origin to the hub(s) and from the hub(s) to the destination are retrieved and used. Cargo load factor data are then used to apportion the emissions associated with each possible flight to the weight carried. Similar to the passenger methodology, a weighted average of the emissions is computed based on the observed traffic.

Due to a lack of information on the exact routing flown, the package is assumed to travel from an airport near the origin city to the hub within the region to an airport in the destination city. If the item is being shipped between regions, then it is assumed to travel from the origin city to a hub in the origin region then to a hub in the destination region, and then finally to the destination city, as illustrated in Figure 3. A weighted average is used when more than one airport serves dedicated cargo traffic in either the origin or destination city. Similarly, a weighted average is computed based on possible routings if there is more than one hub in the region.

Part 2 approach is directly derived from the passenger methodology, which already includes as passenger to cargo ratio for passenger aircraft.

Part 3 is intended to be implemented, once the delivery has concluded, by an operator with perfect knowledge of the routing flown, load factor, and the aircraft types used for a given shipment. This method provides the highest accuracy of result, but also requires the most data and cannot be used to estimate the emissions in advance of a shipment.

Parts 1 and 2 have been added to the ICAO carbon calculator for use by the public, the UN system, and other users. Although this predictive methodology is limited to the air travel related portion of the shipment - and not to the entire shipment which might also include other modes of transport - it complements the ICAO carbon calculator for passenger and enhances ICAO's contribution to the UN-system-wide Climate Neutral UN initiative and other offset programmes.

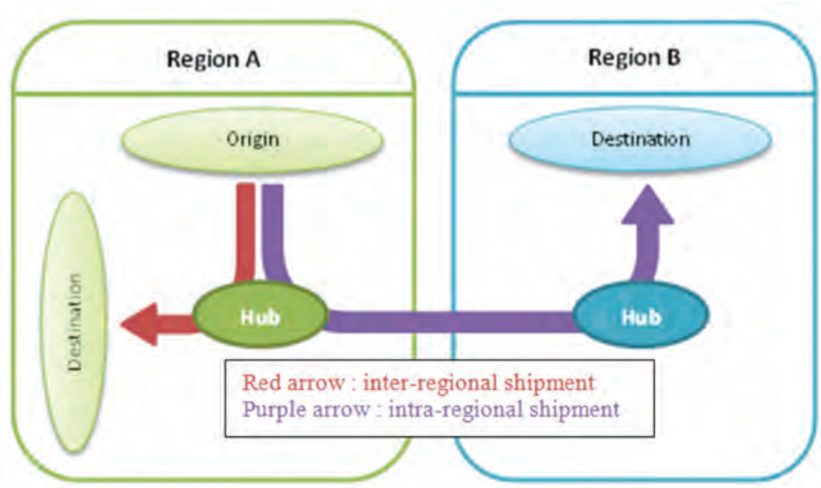


Figure 4. Use of hubs for inter and intra-regional air cargo shipment

UN-system-wide use of the ICAO Calculator

In April 2009 the UN Environmental Management Group (EMG) adopted the ICAO Carbon Emissions Calculator as the official tool for all United Nations entities to quantify their air travel CO_2 footprint, in support of the United Nations Climate Neutral initiative. Since then, interfaces to the calculator have been made available to United Nations environmental sustainability focal points, travel offices and enterprise resource planning (ERP) systems, as well as through a special agreement with GRS companies such as Amadeus. Some UN travel offices have integrated the ICAO Calculator directly into their travel reservation and approval systems, providing real-time information to assist travel planning decisions.

Almost all United Nations organizations reporting their GHG inventories to the UN EMG through the UNEP Sustainable UN (SUN) are using the ICAO air travel carbon emissions calculator. Indeed the use of a common UN methodology and interface across the UN-system facilitates the aggregation of air travel emissions data and guarantees integrity and consistency of reported inventories. The ICAO calculator was recently used to estimate the carbon emissions generated by UN meetings such as the UNFCCC COPs, the UN Climate Summit and the UN Environmental Assembly. This ICAO tool was also used to estimate the carbon footprint of official travels of the UN Secretary General Ban Ki-moon and his Climate Change Support Team.


United Nations
Climate Change Secretariat

Certificate

presented to

the Executive Office of the Secretary-General
at the United Nations Secretariat

to confirm the voluntary cancellation of

5,736 Adaptation Fund Certified Emission Reductions

from the Clean Development Mechanism

for the purpose of

compensating the greenhouse gas emissions

from the travel activities of the Secretary-General, his Executive Office
and his Climate Change Support Team in the years from 2011 through 2015

Christiana Figueres
Executive Secretary

Climate Neutral Now

Figure 5. Transaction statement confirming the cancellation of 5,736 CERs representing the equivalent of the unavoidable remaining GHG emissions from the travel activities of the Secretary-General, his Executive Office and his Climate Change Support Team.

Sustainable Development Goals

References:

1. http://www.icao.int/environmental-protection/CarbonOffset/Pages/default.aspx

THE CAEP/10 RECOMMENDATION ON A NEW ICAO AEROPLANE CO_2 EMISSIONS STANDARD

BY STEPHEN ARROWSMITH (EUROPEAN AVIATION SAFETY AGENCY) AND LASZLO WINDHOFFER (US FEDERAL AVIATION ADMINISTRATION)

Following six years of development, ICAO's Committee on Aviation Environmental Protection (CAEP) at its tenth meeting (CAEP/10) recommended an Aeroplane Carbon Dioxide (CO_2) Emissions Certification Standard. This new standard is part of the ICAO "basket of measures" to reduce greenhouse gas emissions from the air transport system, and it is the first global technology Standard for CO_2 emissions for any sector with the aim of encouraging more fuel efficient technologies into aeroplane designs.

This technology-based approach is similar to the current ICAO Annex 16 Standards on engine emissions for local air quality (Volume II) and aircraft noise (Volume I). The recommended CO_2 Standard has been developed at the aeroplane level, and therefore has considered all technologies associated with the aeroplane design (e.g. propulsion, aerodynamics and structures). Once adopted by the ICAO Council, the Aeroplane CO_2 Emissions Certification Standard will be published as a new Annex 16, Volume III.

The framework for the CO_2 Standard consists of a certification requirement and regulatory limit, as shown in Figure 1, and the work to develop the CO_2 Standard was divided into two phases. Phase 1, which was completed 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, the CO_2 Metric System and the development of a CO_2 Standard certification requirement. Phase 2 involved the development of the regulatory limit lines and the applicability requirements such as scope and date.

In the ICAO Environmental Report 2013, a summary was provided of the work that had been completed during Phase 1. This new article provides an overview of both phases over the past six years, the lead up to the CAEP/10 meeting and the recommendation from the CAEP/10 meeting on the first ICAO Aeroplane CO_2 Emissions Certification Standard.

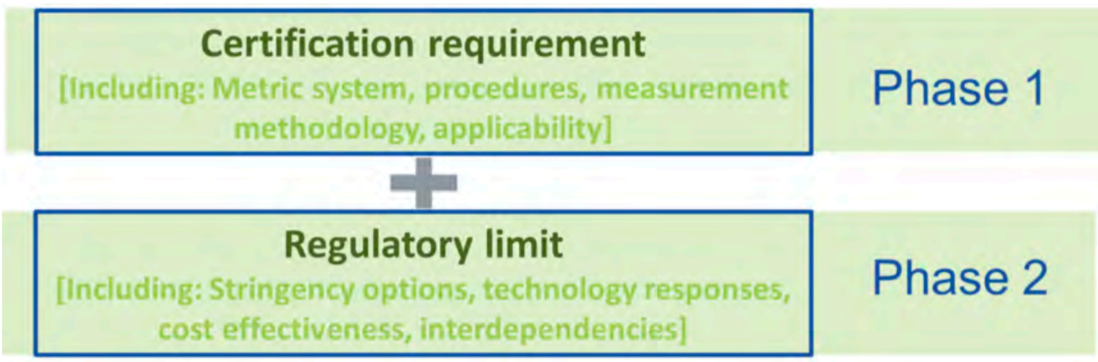


Figure 1. The framework and development phases of the CO_2 Standard.

Phase 1 work- The Development of Certification Requirement

An important Phase 1 milestone in the development of the CO_2 Standard was the agreement on a CO_2 metric system to measure the aeroplane fuel burn, and therefore CO_2 emissions, performance. The intent of this CO_2 metric system is to equitably reward advances in aeroplane technologies (e.g. propulsion, aerodynamics and structures) that contribute to reductions in aeroplane CO_2 emissions, and differentiate between aeroplanes with different generations of these technologies. As well as accommodating the full range of technologies and designs which manufacturers can employ to reduce CO_2 emissions, the CO_2 metric system has been designed to be common across different aeroplane categories, regardless of aeroplane purpose or capability. An overview of the CO_2 Metric System can be found in **Figure 2**.

GENERAL CO_2 STANDARD APPLICABILITY SCOPE FOR AEROPLANE CATEGORIES

- Subsonic Jet Aeroplanes Over 5700 kg
- Propeller-Driven Aeroplanes Over 8618 kg

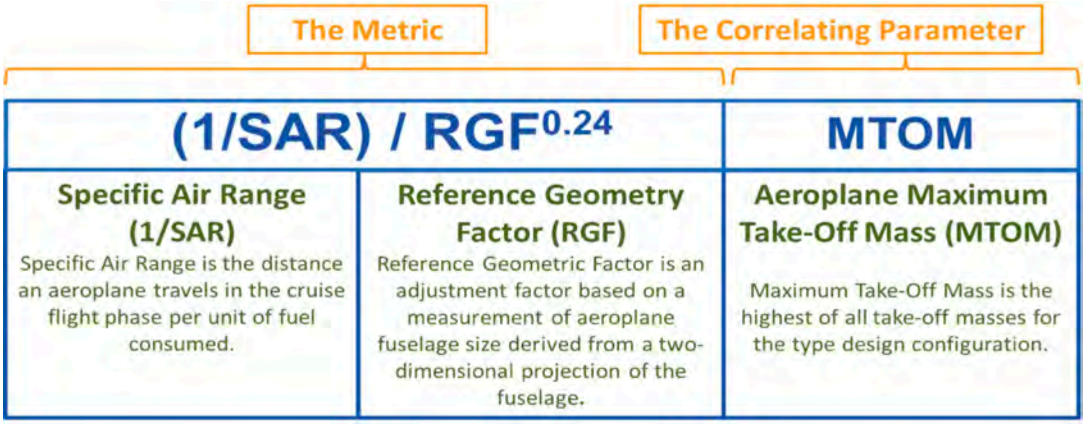


Figure 2. An overview of the CO_2 Metric System

To establish the fuel efficiency of the aeroplane, the CO_2 metric system uses multiple test points to represent the fuel burn performance of an aeroplane type during the cruise phase of flight. Specifically, there are three averaged (i.e. equally weighted) points representing aeroplane high, middle and low gross masses, which are calculated as a function of Maximum Take-Off Mass (MTOM). Each of these represents an aeroplane cruise gross mass seen regularly in service. The objective of using three gross mass cruise points is to make the evaluation of fuel burn performance more relevant to day-to-day aeroplane operations.

The metric system is based on the inverse of Specific Air Range (i.e. 1/SAR), where SAR represents the distance an aeroplane travels in the cruise flight phase per unit of fuel consumed. In some aeroplane designs, there are instances where changes in aeroplane size may not reflect changes in aeroplane weight, for example when an aeroplane is a stretched version of an existing aeroplane design. To better account for such instances, 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), and it is a measure of aeroplane cabin size based on a two-dimensional projection of the cabin. This improved the performance of the CO_2 metric system, making it fairer and better able to account for different aeroplane type designs.

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

Based on the CO_2 metric system, 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. CAEP utilised manufacturers' existing practices in measuring aeroplane fuel burn in order to understand how current practices could be used and built upon for the new Standard. Based on this information, the ICAO Annex 16 Volume III CO_2 Standard certification requirement was developed; and, pending some future work, this was initially approved by the CAEP/9 meeting in February 2013. This was a crucial component in the CO_2 Standard development and allowed CAEP to move onto Phase 2 of the work.

Phase 2 Work – Setting the Regulatory Limit

ICAO environmental Standards are designed to be environmentally effective, technically feasible, economically reasonable, while considering environmental interdependencies. These four tenets of CAEP guided Phase 2 work, which involved carrying out a comprehensive assessment of the costs and benefits of all the options which could be selected to form the CO_2 Standard. This involved defining an analytical space within which CAEP would work to investigate the options available. This included the development of options for the regulatory limit line, applicability options and dates, and all the associated assumptions which allowed the CAEP working groups to perform the cost-effectiveness analysis required to make an informed decision on the Standard at the CAEP/10 meeting. The foundation of the CAEP/10 recommendation on the CO_2 emissions Standard was supported by this significant data informed process, involving input from ICAO member states and stakeholders. The modelling exercise involved several analytical tools, including fleet evolution modelling, environmental benefits, recurring costs, non-recurring costs, costs per metric tonne of CO_2 avoided, certification costs, applicability scenarios and various sensitivity studies to inform the decision-making process. This work allowed CAEP to conduct an analysis, with the aim of providing a reasonable assessment of the economic costs and environmental benefits for a potential CO_2 standard in comparison with a "no action" baseline.

CHOICES CONSIDERED DURING THE CO_2 STANDARD WORK

- Ten Regulatory Limit Lines;
- Treatment of aeroplanes above and below 60 tonnes;
- New Type and In-Production applicability;
- Production cut-off; and
- Applicability dates of 2020, 2023, 2025 and 2028.

A WIDE COVERAGE OF AEROPLANES
The standard is most stringent for larger aeroplanes with an MTOM of greater than 60 tonnes. This accounts for more than 90% of international aviation emissions.

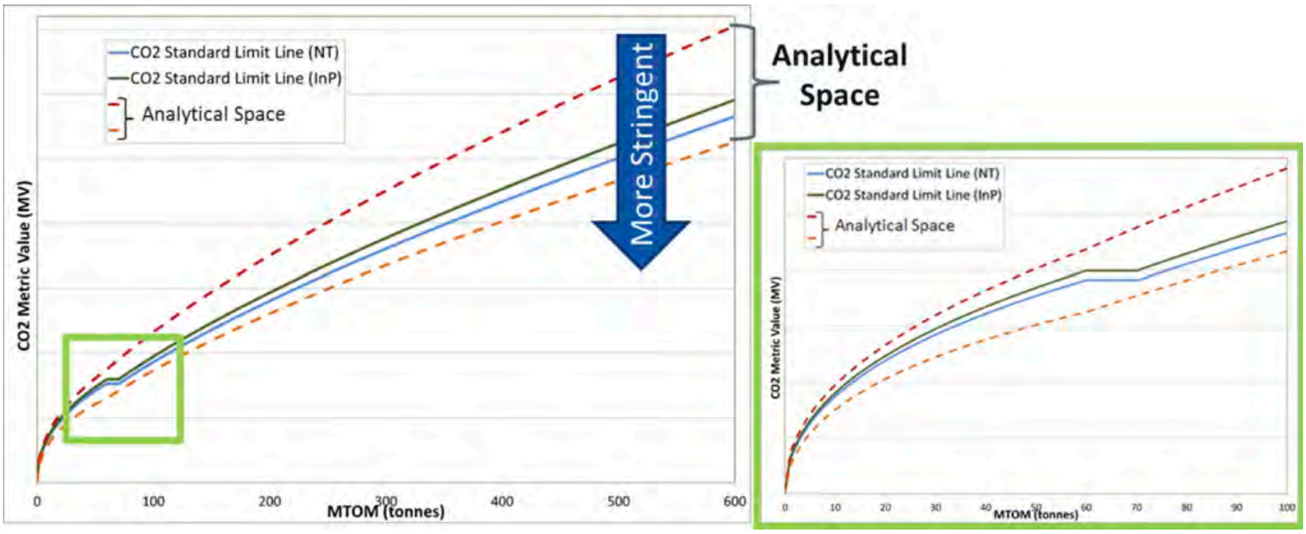


Figure 3. The CO_2 Standard regulatory limits

A full overview of the work and input into the CAEP/10 meeting can be found in the *Report of CAEP/10*, ICAO Doc 10069.

The CAEP/10 Recommendation

Taking into account all the analysis and data, the CAEP/10 meeting was able to make a recommendation on the first ICAO aeroplane CO_2 Standard.

The Standard will apply to subsonic jet and turboprop aeroplanes that are new type (NT) designs from 2020. It will also apply to in-production (InP) aeroplanes from 2023 that are modified and meet a specific change criteria. This is subsequently followed up by a production cut-off in 2028 which means that InP aeroplanes that do not meet the standard can no longer be produced beyond 2028 unless the designs are modified to comply with the Standard. Figure 3 shows an overview of the CO_2 Standard regulatory limit lines for both NT and InP CO_2 Standards.

The CO_2 Standard covers a broad range of aeroplane masses and types and is especially stringent where it will have the greatest impact: for larger aeroplane types with an MTOM of greater than 60 tonnes. CAEP considers technical feasibility very carefully during the development of environmental standards, and as such, the decision at CAEP10 recognised the fact that the larger aeroplane designs have access to the broadest range of CO_2 emissions reduction technologies. This is less so for aeroplanes below 60 tonnes where the standard provides additional margin for a sector. This is particularly recognised for aeroplanes of MTOMs less than 60 tonnes and with fewer than 19 seats maximum passenger seating capacity, where for new aeroplane type designs the applicability date of the standard is 2023.

The Contribution of the CO_2 Standard to Reducing CO_2 Emissions from International Aviation

It is complex to fully understand the impact of the CO_2 Standard due to potential unknown market driven responses to the regulation, and the fact that the CO_2 Standard cost-effectiveness analysis was a comparative investigation of regulatory limit lines. However, it is clear that the new standard will have direct effects by increasing the importance of fuel efficiency in the design process such that an aeroplane type not just meets the regulatory limit but also has good relative product positioning in terms of a margin to the limit.

The Next Steps and Consideration by the ICAO Council

The CAEP/10 recommended CO_2 Standard is currently going through the adoption process within ICAO. This involves a review for the Air Navigation Commission (ANC), a consultation process with all the 191 ICAO Member States, before being considered by the Council for adoption during early 2017. Following this the First Edition of Annex 16, Volume III should become applicable during the latter part of 2017.

References

ICAO Circular 337 - CAEP/9 agreed certification requirement for the aeroplane CO2 emissions standard
ICAO Doc 10069 - *Report of CAEP/10*
ICAO Environment Report, Destination Green, 2013

PUSHING THE AIRCRAFT AND ENGINE TECHNOLOGY ENVELOPE TO REDUCE CO_2 EMISSIONS

BY THE INTERNATIONAL COORDINATING COUNCIL OF AEROSPACE INDUSTRIES ASSOCIATIONS (ICCAIA)

It is widely known that improvements in aerodynamic, propulsion, and light-weight materials technologies have a direct link to aircraft emissions reduction. However, it is less well known that improvements in design and manufacturing technology are also key to achieving future CO_2 reduction goals for existing and new aircraft.

In the past five years, entirely new advanced long-range airplanes (such as the Boeing 787-8 and 787-9, the Airbus A350-900) have entered into operational service with significant improvements in each of these technology areas. Completely new shorter-range aircraft (such as the Bombardier C Series) and several derivative aircraft with major propulsion and airframe technology upgrades (such as the Airbus A320neo, the Boeing 737MAX, and the Embraer E2 family), have entered, or will enter into service soon; resulting in further substantial reductions in fuel burn per aircraft. Also, new and derivative business-jet and regional aircraft have been introduced with important reductions in CO_2 emissions.

Large national and international research programs have been started in the past decade with cooperation involving industry, government and academia. These alliances are considered key enablers to advance and mature the state of the art in breakthrough technologies that can lead to further reduction in aviation's environmental footprint. Flight demonstrations offer important technical and integration data to advance progress on potential game changers such as laminar flow, adaptive materials, and electrically powered aircraft. Integration and certification challenges are significant, and the time frame necessary to deploy improvements into production is probably 10-20 years. Nevertheless, the continued development and enhancement of these technologies represents equally huge opportunities for the aeronautical sector's environmental footprint.

Aerodynamics

Profile (skin-friction) drag and lift-dependent drag, are by far the largest contributors to aerodynamic drag on commercial aircraft. Advances in materials, structures, and aerodynamics are enabling significant reduced lift-dependent drag by increasing the effective wing span. Wing-tip devices can increase the effective aerodynamic span. Eventually, to further increase wing span in flight, airplanes may include a folding wing-tip mechanism for use on the ground to alleviate span constraints. Wing-span increase without significant concomitant weight increase is facilitated by suitably reliable systems for load alleviation, will allow reduced aerodynamic design loads while maneuvering and in gusty conditions.

Skin-friction drag remains an area with potentially significant opportunities to increase aerodynamic efficiency. Progress is being made in developing and testing of practical aerodynamic and manufacturing technologies to reduce *laminar* and/or *turbulent* boundary-layer flow skin friction on portions of wings, nacelles, empennages, and fuselages.

Significant *turbulent* skin-friction reduction with very small riblet geometries applied to the surface has been shown in previous research tests to allow significant net benefit. Development and demonstration efforts to practically apply and maintain riblet shapes (**Figure 1**) to painted aircraft surfaces are continuing to progress the improvement of operational riblets.

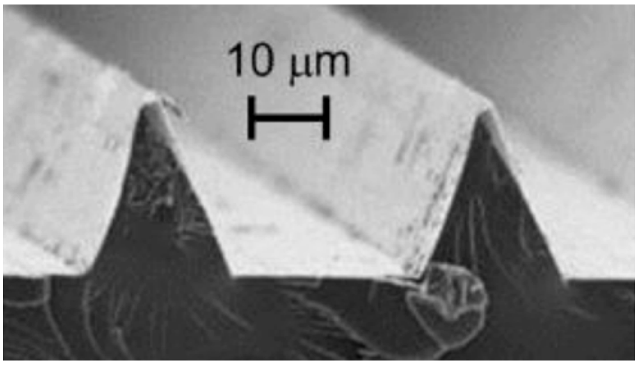


Figure 1. Microscopic Image of Surface With Riblet Shape[1].

Significant reduction in viscous drag is possible by maintaining laminar flow on forward sections of nacelles and wing surfaces. Surfaces intended for *Natural Laminar Flow* (NLF) are present on in-production commercial and business-jet aircraft (i.e., on nacelle-inlet lips and wing tips of some large aircraft, and on wings of some business jets).

Achievement of laminar flow requires validated aerodynamic, structural, and practical manufacturing methods that meet required surface tolerances. Progress has been made towards flight test demonstrations to assess potential integration challenges for *NLF* applied to wing surfaces of large passenger aircraft. Under the European *Clean Sky 2* program[2], flight test design is underway for testing *NLF* integration on modified outboard wings of a large demonstrator aircraft (**Figure 2**). In the USA, under the *NASA Environmentally Responsible Aviation* (ERA) public-private partnership research program[3], flight tests were conducted on a modified B757 flight test aircraft (**Figure 3**) to assess the impact of advanced surface coatings to minimize contamination impact on laminar flow.

Figure 2. Integrated NLF Design Concepts Installed on A340 Wing Tips of Clean Sky 2 Flight Demonstrator[2].

On wings of very large aircraft and on geometries with significant sweep (such as a vertical fin), laminar flow can be realized using boundary-layer suction control (*Hybrid Laminar Flow Control, HLFC*). Recent incorporation of an *HLFC* system on an in-production airplane indicates progress in laminar-flow manufacturing and suction-surface technologies.

Active flow control (AFC), using modest localized blowing from small embedded actuators can be used on highly deflected surfaces (such as a rudder) to keep the flow streamlined near the surface This application may allow reduction in size (weight and drag) of vertical fin and rudder. A recent B757 research test as part of the *NASA ERA* program was conducted to verify *AFC* rudder effectiveness (**Figure 3**). Potential applications of *AFC* to wings and flaps at low-speed flight conditions are also being studied, e.g., as part of the European AFloNExt research effort[4].

Figure 3. B757 EcoDemonstrator With AFC on Vertical Fin[3])

Previous estimates[5] suggest skin-friction drag reduction opportunities on order of 1% to 2% for riblets and on order of 5+% for laminar-flow. The magnitude of potential benefit is greatly dependent on the area of the airplane surface with laminar flow or with riblets.

Propulsion

There are three fundamental technology paths to reduce the fuel consumption of propulsion systems: increase thermal efficiency (by increasing the compressor Overall Pressure Ratio); increase propulsive efficiency (by increasing the engine ByPass Ratio - BPR); and decrease installed engine weight and drag. Over the last decade, newly introduced aircraft and major derivatives with new engines have followed these paths as diameters of engines have increased relative to wing chord length.

In the near-term, through 2020, new technology engines will enter service on new aircraft equipped with newly designed engines aircraft of various sizes. New technology engines at BPR = 9 to 12 for regional jets and single-aisle aircraft such as the MRJ, E2 jets, C Series, A320neo, 737MAX, MC-21 and C919 will provide a dramatic 15% reduction in fuel burn relative to earlier technology BPR~5 engines. Next generation engines for new production wide-body aircraft including A330neo and 777-9 will deliver 10% fuel burn reduction relative to current technology.

Next generation engines for new production wide-body aircraft including A330neo and 777-9 will deliver 10% fuel burn reduction relative to current technology.

Below is a summary of several major programs aimed at demonstrating and advancing promising propulsion technologies along these three paths:

The US national research program CLEEN (Continuous Lower Energy, Emissions, and Noise) Phase II[6] is an FAA-led public-private partnership effort to accelerate development and deployment of promising certifiable aircraft technologies towards reducing aircraft fuel burn by as much as 40%. So far, *CLEEN* Phase I benefits (**Figure 4**) have demonstrated the potential for a 1% fuel-burn reduction with: a Ceramic Matrix Composite engine exhaust nozzle (demonstrated on a B787); 5% with improved impeller/turbine materials and seals; and, either 20% with Ultra-High Bypass ratio engine (including Geared Turbofan technology), or 26% with an Open-Rotor engine configuration. Within the USA, *NASA's ERA* program[7] also contributed towards development and demonstration of propulsion technologies.

The Canadian *Green Aviation Research and Development Network (GARDN)* is a non-profit organization funded by the Business-Led Network of the Canadian Government and the Canadian aerospace industry[8]. Running from 2014 to 2019, one

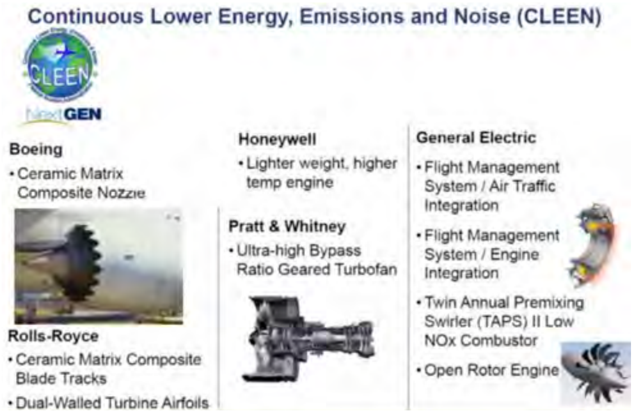


Figure 4. Propulsion Research Topics Studied Under FAA CLEEN Program[6].

project deals with energy-efficient aircraft configurations and operations, including studies on advanced propulsion systems to enable cleaner Unmanned Aerial Vehicles operations.

Europe's *Clean Sky 2* Joint Technology Initiative aims to develop and demonstrate breakthrough technologies for the civil aircraft market that could reduce CO_2 emissions by 20% (2025) to 30% (2035) compared with current state of the art aircraft [9]. *Clean Sky 2* intends to shorten the time to market for new and cleaner solutions tested on full-scale demonstrators, thus contributing significantly to reducing the environmental footprint of aviation. *Clean Sky 2* will build on the success of the previous *Sustainable and Green Engines (SAGE)* program to validate more radical engine architectures, including:

- Flight Test of a second Geared Open Rotor demonstrator **(Figure 5)**
- Ultra High Propulsive Efficiency demonstrator addressing Short/Medium-Range aircraft market, 2014-2021: design, development and ground test of a propulsion system demonstrator to validate selected low-pressure modules and nacelle technology topics.
- A short-range regional turboprop demonstrator, in the 1,800-2,000 shp class and small aero-engine demonstration projects for fixed-wing piston/diesel engines to small turboprop engines.
- Full-scale ground and flight test demonstration of advanced geared and very high bypass ratio large turbofan engine configurations for large aircraft and Middle of Market demonstrator.

Figure 5. Open Rotor Configuration Studied in Clean Sky Program[9].

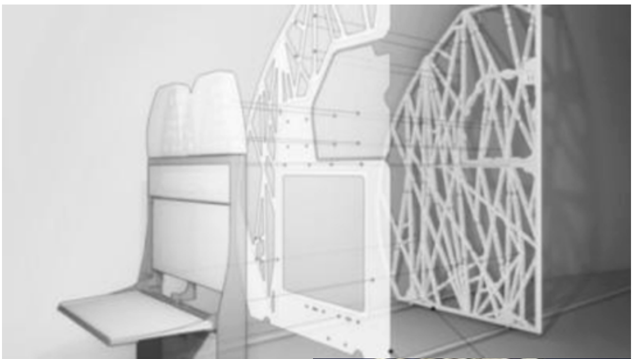
Beyond these demonstration program examples, research of future more radical system architectures, such as hybrid-electric, and distributed propulsion opportunities are being pursued by government, industry, and academia.

Structural Design and Materials

A key factor to be addressed when looking for ways to reduce fuel burn, and thus CO_2 emissions, is the aircraft empty weight. Significant use of advanced composite materials for the structure has become the baseline for new aircraft such as: Airbus A350XWB, Boeing 787, and 777-9 aircraft, as well as the Bombardier C Series. However, the aircraft manufacturers recognize the individual advantages of using both composites and advanced metallic alloys, aiming for an optimum balance of both materials.

Research on light alloys is expected to grow in the coming years, including the use of *Additive Layer Manufacturing (ALM)* technologies, or 3D printing, whereby instead of manufacturing a part by machining material away from a solid block of metal, the part is built layer-by-layer, from the inside out. Such parts can provide more efficient structural geometries and be much lighter than conventional parts.

For instance, Airbus (and its subsidiary APworks) came up with a new design shape, inspired by nature, for a partition wall for cabin interiors (**Figure 6**). The component was created with custom algorithms that generated a design that mimics human cellular structure and bone growth in nature. This "bionic" inspired design was then produced using 3D printing techniques. This breakthrough in design, supported by new alloys, developed specifically for ALM solutions, has been made possible by the increased capacity of computational technology. This ALM-based "bionic" partition is structurally very strong while weighing about 45% less than current designs. Flight tests are in progress.



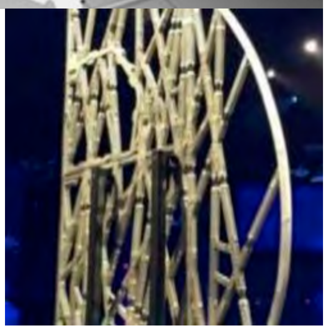


Figure 6. Additive Layer Manufacturing (ALM) "Bionic" Partition Demonstrator (Airbus)[10].

The next step forward involves dynamic programmable materials, like adaptable carbon fiber (**Figure 7**), or *Metallic Shape Memory* materials that are able to change shape when exposed to external conditions (e.g. pressure, loading, or temperature). For example, today's environmental-control and ventilation air inlets are generally static, so the air flowing through them varies greatly according to the speed of the aircraft. Programmable material embedded in the structure would allow the air inlet to adjust the air flow automatically to an optimized value, allowing reduced drag, and avoiding installation of mechanical actuation. The industry is exploring the feasibility, benefits and technical risks of these technologies for possible future realization.

Figure 7. Programmable Adaptable Carbon Fiber (laboratory test coupon).

In the nearer term, aircraft systems architecture changes could provide significant improvements to aircraft weight. Wireless technologies, recently authorized by the International Telecommunication Union in 2015 are good examples. Aircraft systems engineers believe that up to 30% of the electrical wiring harness may be substituted by wireless systems, thus reducing aircraft weight, and hence fuel consumption.

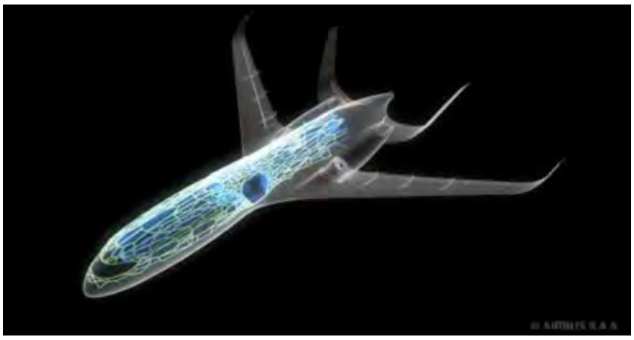


Figure 8. Conceptual Sketch of Aircraft Configuration Using "Bionic" Inspired Structural Design.

These potential materials and technologies can trigger major transformations in the way engineers of tomorrow will design and build airframes. They may enable significant CO_2 reductions while providing safe and certified aircraft structures and systems with novel design, manufacturing processes, and novel materials; all aided by innovative computational methods. Moreover, transformative structural and adaptable-material design and integration methods can facilitate new aircraft configurations with synergistic aerodynamic, propulsion, control systems and structural integration to further improve fuel efficiency. **Figure 8** provides a conceptual example using "bionic" inspired fuselage concepts.

Summary

New fuel-burn efficient aircraft, as well as derivative airplanes with very significant improvements in fuel-burn-reduction technologies, are entering into the global aviation system today and are expected to continue to do so at an accelerated pace in the coming years.

Airframe and engine manufacturers are working with governmental, regulatory, and academic research agencies to continue the progressive development of promising fuel-burn-reduction technologies in the areas of propulsion, aerodynamics, and structural design. These new technologies must be safe, economical, and easy to integrate into existing and new highly optimized aircraft. Continued support and cooperation from these bodies is needed to progress technology concepts from laboratory-scale testing and computational research, to full-scale demonstration and validation, towards operational and certification readiness. Opportunities in propulsive technology, aerodynamic drag reduction methods, manufacturing and structural design, and aircraft configuration design, can be expected to result in further continued reductions in aircraft emissions.

In general, in addition to technology readiness, practical operational and economic considerations need to be assessed, when evaluating fuel-burn-reduction aircraft and engine technologies. Due to integration complexity, some of the above-mentioned technologies may require incorporation into a new airplane design (versus retro-fitting a part of the geometry of an existing aircraft).

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SPEEDING DEVELOPMENT OF TECHNOLOGIES TO MAKE AIRCRAFT CLEANER, QUIETER AND MORE FUEL EFFICIENT

BY BOEING

In March 2015, the Boeing ecoDemonstrator 757 took to the skies to evaluate more than 15 new technologies to improve commercial aviation's efficiency and reduce noise and carbon emissions.

Boeing collaborated with European customer TUI Group and NASA on flight tests for the 757, the third ecoDemonstrator airplane. On the 757's left wing, Boeing tested technologies to increase aerodynamic efficiency by reducing environmental effects on natural laminar flow, including a Krueger shield to protect the leading edge from insects.

Two technologies tested were under contract with NASA's Environmentally Responsible Aviation (ERA) project. On the vertical tail, NASA and Boeing tested active flow control to improve airflow over the rudder and maximize aerodynamic efficiency. Based on NASA wind-tunnel testing, active flow control could improve the rudder's efficiency by about 17 percent and may allow for a smaller vertical tail design in the future.

On the 757's right wing, NASA and Boeing tested "bug phobic" coatings that can reduce aerodynamic drag from insect residue, enabling more laminar flow by smoothing the airflow on the surface of the wing. Except for Boeing proprietary technology, NASA knowledge gained in collaboration with Boeing from ecoDemonstrator research will be publicly available to benefit the industry.

The ecoDemonstrator Program plays a key role in the company's environmental strategy by using testing to accelerate technologies that can reduce fuel use, carbon dioxide emissions and noise. In this effort, Boeing partners with selected suppliers, airlines and government agencies toward the shared goal of testing, refining and completing technologies that will make aircraft cleaner, quieter and more fuel efficient.

To date, the program has tested more than 50 technologies, using a Next-Generation 737-800 (2012), 787 (2014) and 757 (2015) as flying testbeds. In 2016, Boeing and Brazilian airplane manufacturer Embraer will test ecoDemonstrator technologies on an Embraer airplane.

ENVIRONMENTAL BENEFITS ASSESSMENT OF AVIATION SYSTEM BLOCK UPGRADES

BY DAVID BRAIN (EUROCONTROL) AND DON J. SCATA (US FEDERAL AVIATION ADMINISTRATION)

Forecasted air traffic growth, if not properly supported by the necessary Air Traffic Management (ATM) infrastructure, can lead to significant capacity challenges, increased safety risk, and adverse environmental impacts. In order to address these challenges, ICAO collaborated with States, industry, and international organizations to develop the Aviation System Block Upgrades (ASBU) strategy, which was adopted at the Twelfth Air Navigation Conference in 2012. The ASBU framework was developed to reflect and build consensus around the series of technologies, procedures, and operational concepts needed to meet future capacity and ATM challenges. This strategy, as laid out in the GANP (Global Air Navigation Plan), aims to harmonize regional air traffic management improvement programs by laying out a roadmap for the implementation of a series of essential ATM operational concepts which ensure that safety is maintained while future capacity, efficiency and environmental benefits are maximized.

During the Committee on Aviation Environmental Protection's 9th Meeting (CAEP/9) in February 2013, CAEP agreed to undertake an environmental benefits assessment of the ASBU Block 0 modules. Block 0 is the first of four blocks scheduled to be implemented between 2013 and 2031 (see **figure 1**). Many of the ASBU modules have potential to reduce the adverse environmental impacts of aviation, and quantifying these benefits can further support the facilitation and adoption of ASBU globally.

CAEP developed an approach to conduct the ASBU analysis that was in line with the environmental assessment approach outlined in the recently published ICAO Doc 10031, *Guidance on Environmental Assessment of Proposed Air Traffic Management Operational Changes*. Doc 10031 was developed by CAEP to provide "States, airport operators, Air Navigation Service Providers (ANSPs) and other stakeholders with environmental assessment guidance to support sound and informed decision making when analysing proposed ATM operational changes". **Figure 2** presents the ASBU analysis approach.

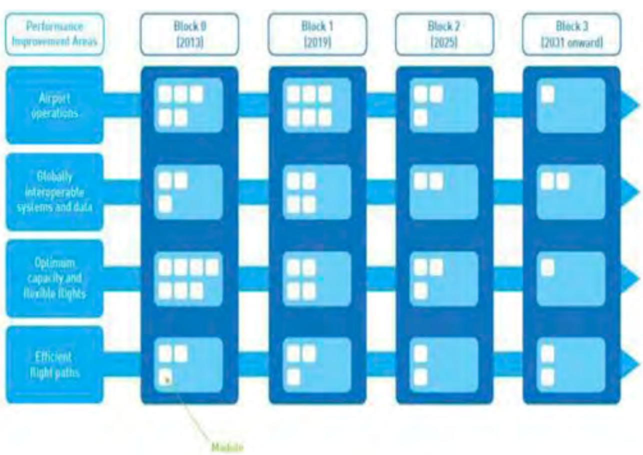

Figure 1. ASBU Timescale

The first step involved the screening of each ASBU module within Block 0 for potential environmental benefits. For Block 0, CAEP identified that the operational improvements in 15 of the 18 Block 0 modules had the potential to provide quantifiable environmental benefits. For the Block 0 analysis, CAEP created 23 Rules of Thumb for 13 of the Block 0 modules (see **table 1**).

To create a Rule of Thumb, the operational improvements identified in the Block 0 modules were analysed to identify how the associated data and information from pre- and post- implementation analyses would best capture the

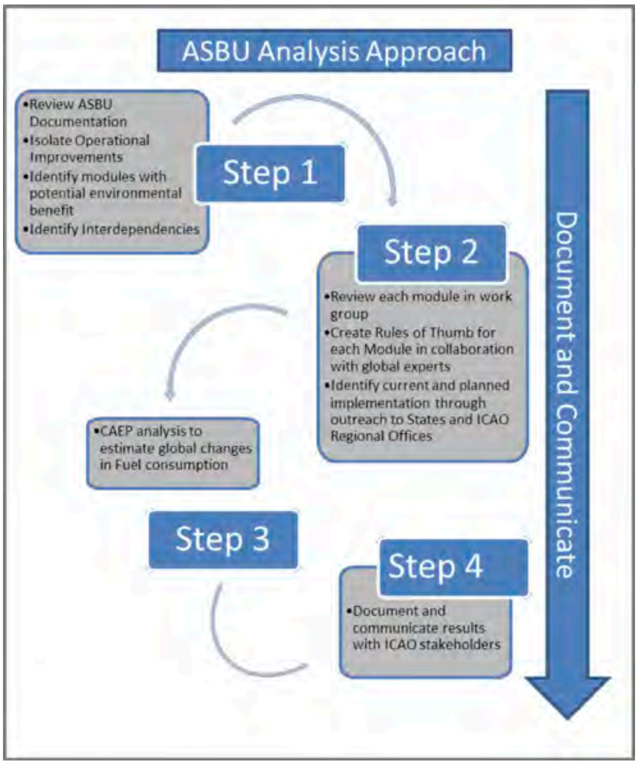

Figure 2. ASBU Analysis Approach

B0 Module	Environmental benefits in OI (Y/N)	RoT defined
APTA	Y	■■
ACDM	Y	■■
AMET	Y	■
ASUR	Y	■
CCO	Y	■■
CDO	Y	■■
FRTO	Y	■■
NOPS	Y	■■■
OPFL	Y	■
RSEQ	Y	■
SURF	Y	■■■
TBO	Y	■
WAKE	Y	■■
DATM	Y	-
FICE	Y	-
ACAS	N	-
ASEP	N	-
SNET	N	-
	Total rules of thumb:	23

Table 1. Block 0 modules, potential environmental benefits and rules of thumb

APTA-Approach procedures including vertical guidance; WAKE-Wake vortex; RSEQ-AMAN / DMAN; SURF-A-SMGCS, ASDE-X; ACDM-Airport CDM; FICE-Increased efficiency through ground - ground integration; DAIM-Digital AIM; AMET- Meteorological information supporting enhanced operational efficiency; FRTO-En route Flexible Use of Airspace and Flexible routes; NOPS-Air Traffic Flow Management; ASUR-ADS-B satellite based and ground based surveillance; ASEP-Air Traffic Situational awareness; OPFL-In-Trail procedures (ADS-B); ACAS-ACAS improvements; SNET-Ground based safety nets; CDO-Continuous Descent Operations, PBN STARs; TBO-Data link en-route; CCO-Continuous Climb Operations

potential environmental benefits, taking into account any interdependencies between the different modules with the objective to follow a conservative approach to avoid any double counting of benefits. Information was received from many States, regional implementation projects, e.g. SESAR, and a host of stakeholder groups and organisations in order to develop as realistic a rule of thumb as possible. Each rule of thumb consisted of a high-level formula or procedure for calculating a range of the fuel savings for a particular operational improvement, along with assumptions and applicability. Some Block 0 modules had more than one Rule of Thumb in order to capture multiple operational improvements brought about by the module and/or impacts to different phases of flight. One example is detailed below:

Current and planned Block 0 implementation levels were identified through responses from States to ICAO State Letter 56 distributed on 10 September 2014. Responses were received from more than 60 States in addition to aggregated regional implementation data from EUROCONTROL and ICAO regional offices. In total, responses covered States representing more than 92% of global traffic (see **figure 3**). To identify the total fuel and CO_2 savings following the implementation of Block 0, the rule of thumb fuel savings (based upon current (2013) and future planned (2018) implementation levels), were applied to 2013 and 2018 traffic levels[2]. This allowed an estimation of the potential environmental benefits that would be achieved from B0 module implementation during the Block 0 timeframe and of the total Block 0 concept.

Based upon States' planned implementation of the ASBU Block 0 modules between 2013 and 2018, fuel burn savings are estimated to range between 49-102kg per flight globally. This corresponds to 2.2-4.6Mt in global annual fuel savings in 2018 resulting from planned ASBU Block 0 implementations since 2013. In addition, traffic growth will also contribute by increasing the pool of potential recipients of the environmental benefits from modules implemented before the end of 2013. Overall, an increase in total fuel savings of 0.62-1.31% in 2018 relative to the 2013 fuel savings is estimated to be attributed to Block 0 implementation.

Module	Operational improvement	Phase of flight	Rule of thumb	Notes	Implementation 2013	Implementation 2018
B0-WAKE	Optimised Wake Turbulence-RECAT	Ground	21-32 seconds reduced taxi time (range)	Benefit to be available during Peak hours Peak hours concern 17% departure movements (based upon SESAR / NextGen assumptions)	See response to ICAO SL/56	See response to ICAO SL/56

Table 2. Rule of thumb example

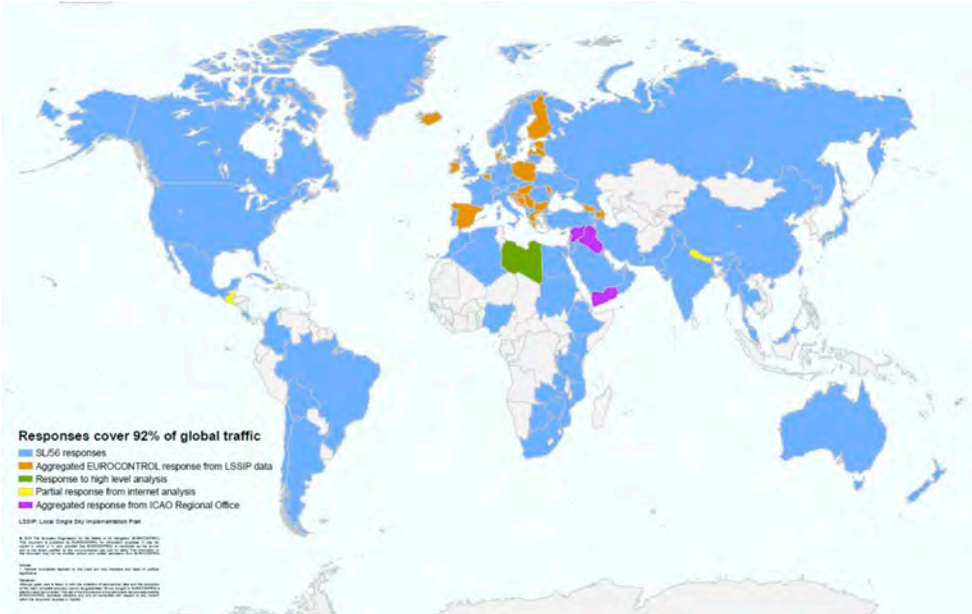

Figure 3. Coverage of responses to ICAO SL/56

The implementation of some of the ASBU Block 0 modules will lead to better predictability within the global air traffic system as well as overall efficiency improvements. Therefore, the amount of fuel loaded onto aircraft can be reduced by the amount of the estimated benefit, which, as explained in ICAO Doc 10013 - *Operational Opportunities to Minimize Fuel Use and Reduce Emissions*, can result in an additional 2.5-4.5% savings relative to the reduction described above due to the reduced weight of the aircraft. In this analysis, the reduction in fuel load was estimated to provide up to an additional 5.4kg of fuel burn savings per flight, resulting in a total average fuel savings of 55-107kg per flight globally. Overall, therefore, a total annual fuel saving of 2.5-4.9Mt in 2018 can be attributed to ASBU Block 0 implementation since 2013, with a corresponding increase in total fuel savings of 0.69-1.38% in 2018 relative to the 2013 fuel savings. This corresponds to a global CO_2 saving of between 7.8-15.4Mt. In fuel costs, these figures correspond to yearly fuel savings of up to €2.1 billion or $2.3 billion. **Figure 4** places these results in the context of the annual CO_2 emissions of several States.

A total annual fuel saving of 2.5-4.9Mt in 2018 can be attributed to ASBU Block 0 implementation since 2013, with a corresponding increase in total fuel savings of 0.69-1.38% in 2018 relative to the 2013 fuel savings. This corresponds to a global CO_2 saving of between 7.8-15.4Mt.

It should also be noted that although the ASBU framework was first developed in 2012, many of the operational improvements contained within the ASBU Block 0 modules are existing concepts that already have provided substantial environmental benefits prior to 2013. The fuel saving benefits from Block 0 operational improvement implementations prior to 2013 are estimated to range between 95-152kg per flight. This is equivalent to between 3.6-5.7Mt fuel savings (11-18Mt CO_2) in 2013.

Therefore, in total, the fuel saving benefits that could be attributed to the operational improvements defined in the Block 0 modules that will be implemented by the end of 2018 are equivalent to between 150-259kg of fuel per global aircraft movement in 2018. Additional savings can also be obtained from traffic growth between 2013 and 2018, which increased the pool of potential recipients of the environmental benefits from modules implemented before the end of 2013. The total savings are therefore equivalent to 6.8-11.8Mt fuel savings (21-37Mt CO_2 savings) or 2.1-3.6% of total global fuel burn in 2018, taking into account the benefits from both module implementation and the increased traffic between 2013 and 2018. These results are summarised in **Figure 5**.

ICAO Region	Total estimated fuel burn savings (Mt)	Total estimated fuel burn savings (% of total fuel burn 2018)
Asia / Pacific	0.46 to 1.10	0.36 to 0.93
North America	**0.71 to 1.32**	0.80 to 1.56
Europe	0.61 to 1.23	0.68 to 1.45
Africa	0.15 to 0.24	0.95 to 1.60
Middle East	0.26 to 0.44	1.15 to 2.04
Latin America/ Caribbean	0.37 to 0.61	**1.45 to 2.47**

Table 3. Total fuel savings per ICAO region and relative % fuel savings compared to 2018 fuel burn per ICAO region

Table 3 displays the range of estimated Block 0 fuel savings (from 2013-2018 implementation) per ICAO region, and the percentage estimated fuel savings per ICAO region relative to 2018 regional fuel burn (also detailed in **Figure 6**).

In conclusion, it can be seen that the estimated total fuel savings are higher in those regions with higher traffic movements as

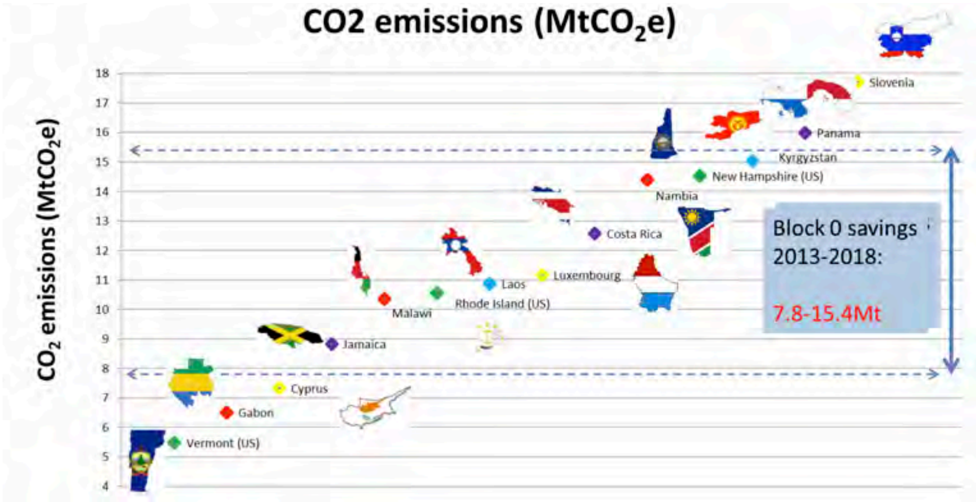

Figure 4. CO_2 savings from B0 implementation compared to Country and US State emissions[3]

such regions usually have an enhanced need to mitigate ATM inefficiencies and, due to the higher traffic levels, have more potential to benefit from such efficiency enhancing measures, e.g. Europe and North America. However when comparing the regional percentage fuel burn savings relative to 2018 regional fuel burn, it can be seen that the relative savings are much similar between regions, in fact, it appears that regions with lower total fuel burn may be reaping the benefits of the operational improvements detailed in the ASBU framework, e.g. Latin America, Middle East and Africa. This may be a clear demonstration of how the ASBU framework is supporting the ICAO 'No Country Left Behind' initiative, where the main goal is to ensure globally harmonized implementation so that all States have access to the significant socio-economic benefits of safe and reliable air transport.

In addition to the overall assessment, CAEP analyzed the module-level benefits across all ICAO regions. Of the studied Block 0 modules, four modules (six operational improvements) are estimated to provide up to 85% of the expected fuel savings due to planned worldwide implementation between 2013 and 2018. These modules are: B0-ASUR B0-CCO B0-CDO and B0-ACDM. The operational improvements within modules B0-APTA, B0-AMET, B0-RSEQ, B0-TBO and B0-SURF are estimated to provide the next 13% of the total fuel saving benefits.

Due to the usefulness of the results of this analysis, it is expected that a similar analysis of ASBU Block 1 modules will be completed during the CAEP/11 cycle.

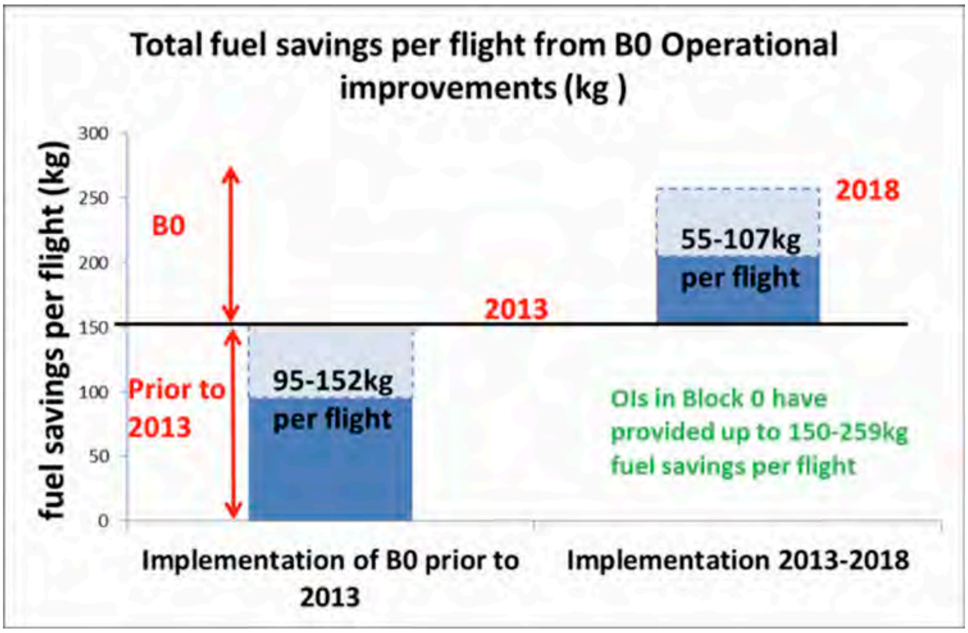

Figure 5. Range of ASBU Block 0 per-flight Fuel Savings

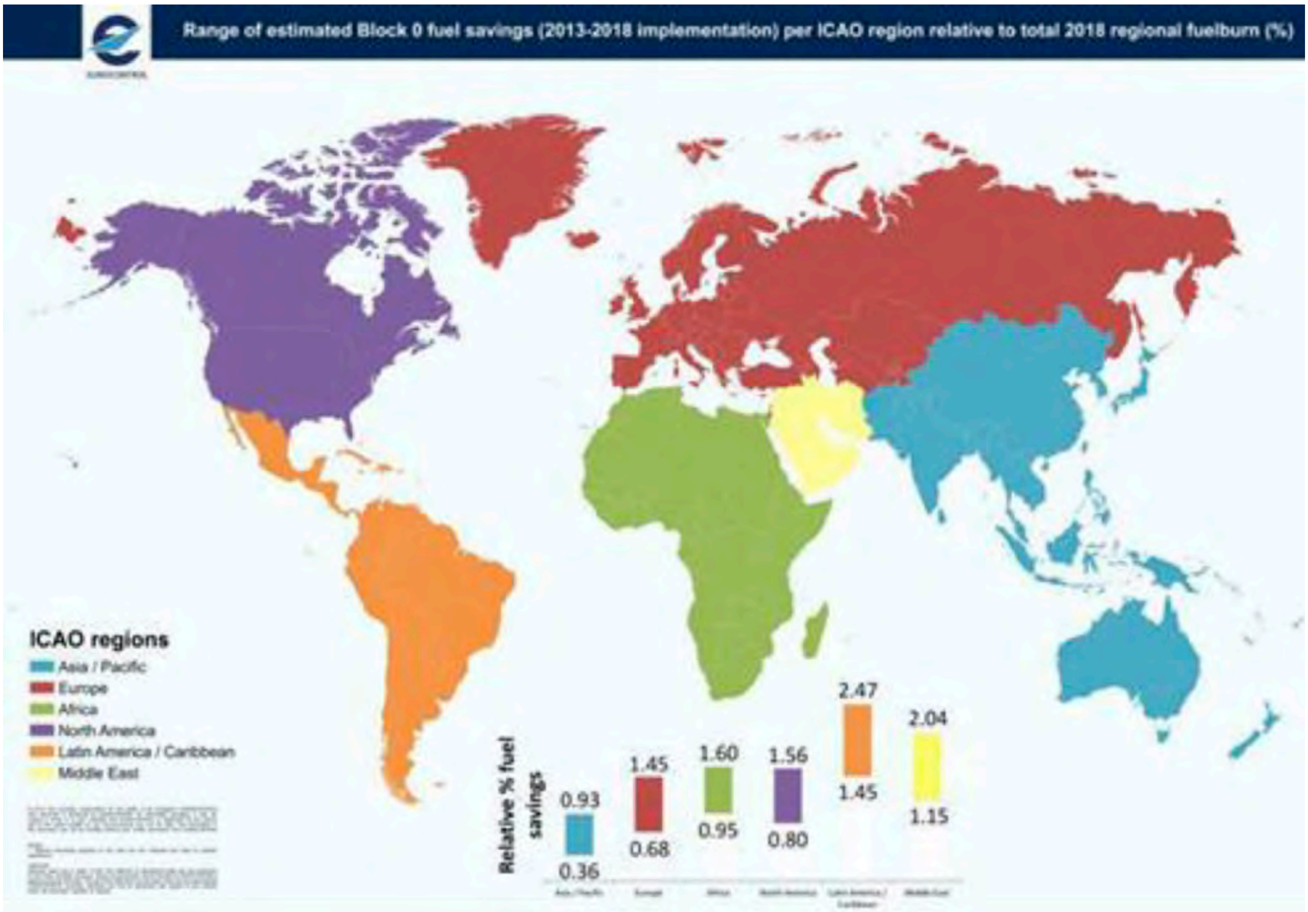

Figure 6. Block 0 fuel savings (Mt) per ICAO region relative to 2018 regional fuel burn

References

1. The ASBU environmental analysis estimated benefits to be attributed to implementations between the B0 timeframe (2013 and 2018) as detailed in the GANP 2013. It is expected that the GANP 2016 will propose an extended definition of B0 to 2019.
2. World Resources Institute (2014) for countries (Total Country GHG emissions excluding emissions from land-use change and forestry 2012 (MtCO2e)) and US Environmental Protection Agency (2013) for US States (CO2 Emissions from Fossil Fuel Combustion - Million Metric Tons CO2 (MMTCO2)).

SHARING EXPERIENCE AND LEARNING TO IMPROVE ENVIRONMENTAL ASSESSMENTS OF PROPOSED AIR TRAFFIC MANAGEMENT OPERATIONAL CHANGES

BY ROBIN DERANSY (EUROCONTROL)

Although aviation is only responsible for 2 to 3 percent of anthropogenic CO_2 emissions in the world, all facets of the industry are heavily engaged in managing and reducing its environmental impacts, including climate change, and impacts on local air quality and noise around airports. It is well known that most of the impact reductions are expected to come from more efficient airframe and aircraft engine technologies, as well as sustainable bio-fuels. Nevertheless, air traffic management (ATM) improvements can also make a significant contribution to the CO_2 emission reduction efforts.

One of the key benefits of introducing a change in the ATM system is that it can be applied to all aircraft in a specific airspace or region, in a relatively short timeframe. With ATM, a change can be applied literally overnight, and apply immediately to all aircraft. An excellent example of this was the introduction of Reduced Vertical Separation Minima (RVSM) in Europe on 24 January 2002. This introduced six (6) new flight levels, cutting fuel burn and greenhouse gas emissions by 5% above FL290, in a single stroke. Such a major project required years of preparation and assessment, but once it was implemented, it clearly demonstrated that ATM can deliver step-change improvements in efficiency and capacity enhancement across the fleet in a particular airspace.

Environmental Assessments

One of the critical activities for the successful development and deployment of an operational improvement is the performance of any required environmental assessments. Environmental assessments can help ensure that the benefits of an improvement are adequately captured, communicated, and potentially maximized. It can also support the overall acceptability of a change among aviation stakeholders, including potentially affected communities.

There is no one unique way of performing environmental impact assessments for ATM. In fact, many countries around the globe have already developed their own robust and detailed environmental assessment methodologies that must be followed before an air traffic management change can be implemented. However, some countries that either have no formal requirements, or do not have the capability to perform these assessments, might benefit from general guidance on how to perform environmental assessments. That is why CAEP has developed a guidance document in response to a growing need for ICAO Member States to measure the environmental impacts associated with operational ATM changes in a globally harmonized and compatible way.

This *Guidance on Environmental Assessment of Proposed Air Traffic Management Operational Changes* was published in May 2014 as ICAO Doc 10031. It provides States, airport operators, air navigation service providers (ANSPs) and other stakeholders, with environmental assessment guidance to support sound and informed decision-making when analysing proposed ATM changes such as those related to operational procedures, airspace re-design, etc. This environmental assessment guidance was developed without specific geographic restrictions, in order to make it applicable worldwide.

In particular Doc 10031 provides a "multi-steps review" process, as shown in **Figure 1**. That approach will ensure that the following fundamental questions are addressed:

- When should a formal environmental assessment be carried out?
- What needs to be prepared before conducting an assessment?
- How should the proposed change, its purpose, and its alternatives, be described?
- How should the scope and extent of the assessment required be determined?
- What types of environmental impact should be taken into account, and when?
- How should the assessment be conducted?
- Which documents should be produced and communicated?

Through examples, Doc 10031 also provides insight into the interdependencies and trade-offs between environmental impacts (e.g. fuel, emissions and noise), and environmental impacts and non-environmental performance aspects (e.g. safety, capacity, flexibility).

Learning From Case Studies

In addition to Doc 10031 guidance, lessons can be learned from the actual case studies of existing environmental assessments and methodologies. Sharing experience and learning from each other will help improve and harmonize environmental assessments processes worldwide. While Doc 10031 already included an

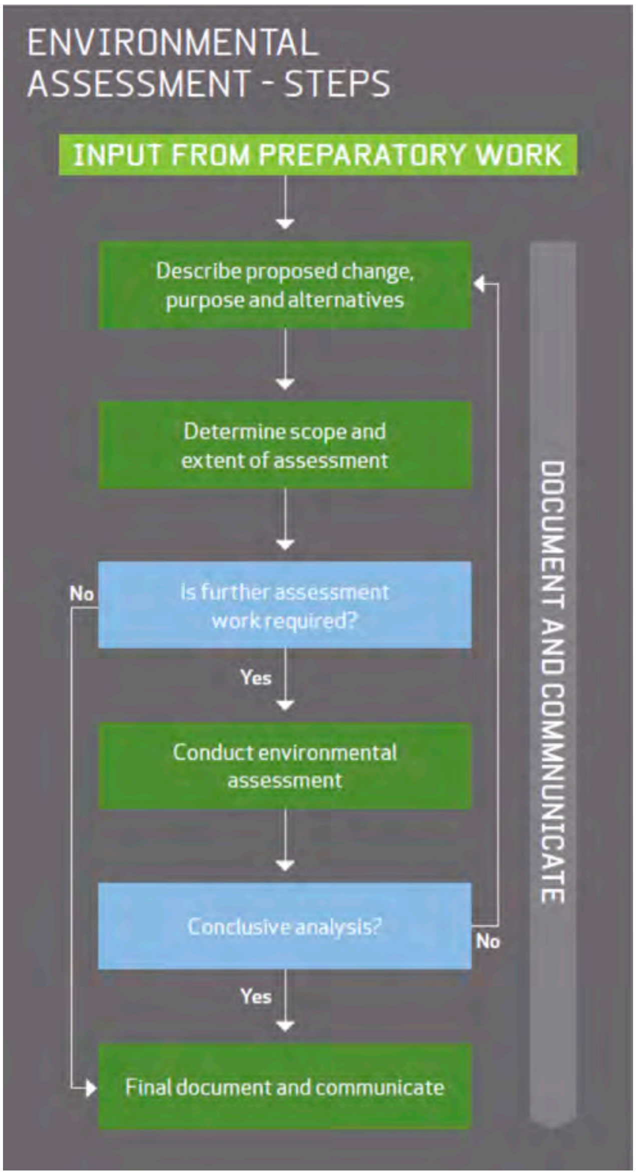

Figure 1. Environmental Assessment Steps.

appendix of assessment examples at local, non-local, and intercontinental levels, it was determined that a greater variety of examples from which everyone could learn would be beneficial. This is why ICAO/CAEP started to collect other examples of case studies, using the template that is provided in Appendix E of Doc 10031.

Ten case studies have been collected to-date. These have all been reviewed by CAEP and are now available on an ICAO web page specifically designed to inform readers about Doc 10031 and to provide examples of environmental impact assessments. (http://www.icao.int/environmental-protection/Pages/EnvironmentalAssessment.aspx)

These case studies are listed below, followed by their reference:

- CAEP Working Group 2, Aviation System Block Upgrade (ASBU) analysis, 2015 (WG2 – ASBU, ID: ASBU).
- Changes to the Required Navigation Performance (RNP) approach and departure procedures for Canberra Airport, 2013 (Australia – ID: AU).
- FRAMaK (Free Route Airspace Maastricht and Karlsruhe), a joint project of DFS Deutsche Flugsicherung GmbH, Deutsche Lufthansa AG and EUROCONTROL Maastricht UAC, funded by the SESAR Joint Undertaking, 2014 (ID: DE).
- ILS interception altitude increase in the Paris area, 2008-2011 (France – ID: FR1).
- New Global Navigation Satellite System (GNSS) procedure QFU 30 at Nevers airport, 2012 (France – ID: FR2).
- “Italian Airspace Reorganization”, 2012-2014 (Italy – ID: IT).
- Validation and implementation of next generation airspace at Göteborg Landvetter Airport (VINGA), from the approach, landing, and surface phase until parking at the gate, 2011 (Sweden – ID: SE).
- Point Merge concept in the London Terminal Control Area (TMA), 2012 (United Kingdom – ID: UK1).
- LAMP Phase 1A is the first phase of the London Airspace Management Project which will implement Performance Based Navigation (PBN) and modernise the airspace structures supporting airports in South East England (ID: UK2).
- Greener Skies over Seattle: Proposed Arrival Procedures to Seattle-Tacoma International Airport submitted by US Federal Aviation Administration (FAA), 2012 (ID: US).

As can be seen in **Table 1**, the ten case studies collected so far illustrate different types of environmental assessment. They range from simple cases looking only at noise, or fuel burn and CO_2 emissions, to more complex examples that also had to consider interdependencies with other performance factors such as capacity, predictability, and air traffic controller workload. Different kinds of operational change such as: airport approach, local and regional airspace reorganization, and gate-to-gate improvement, were assessed. The process advocated by Doc 10031 has even been found to be applicable to analyses being undertaken within CAEP, such as the high-level analysis of the fuel saving benefits of ASBU[1] Block 0.

The ten environmental assessment case studies also highlight the importance of some of the guiding principles discussed within Doc 10031. Below are some examples of instances where a case study reinforces a key recommendation of Doc 10031:

- **Choosing appropriate indicator or metric to best communicate results of an environmental assessment (Doc. 10031, section 2.4):** The FR1 case study describes a “lesson learned” in this area. A metric initially used in the environmental assessment appeared not to be appropriate (i.e. was not easily understood by the public) when presenting results to the public. For this reason this metric was not included in further assessments and other metrics, more easily understood by the public (density and NA65dB/25 events), took its place.

- **Choosing appropriate environmental assessment methodology (Doc. 10031, section 3.3):** The UK1 case study notes

Study ID	Assessment aspects	Operational change	ASBU Blocks[2]	Operational Maturity	Base Methodology followed
ASBU	Fuel burn/CO_2	Gate-to-Gate	All	Deployment	Doc 10031
AU	Fuel burn/CO_2	Airport approach	CDO; APTA	Deployment	Air services Environment Management System (EMS)
DE	Fuel burn/CO_2	Regional En-route	FRTO	Demonstration	SESAR
FR1	Noise	Airport approach	APTA	Deployment	DSNA internal process
FR2	Noise	Airport approach	APTA	Deployment	DSNA internal process
IT	Fuel burn/CO_2	Regional airspace	Partially NOPS, FRTO	Deployment	ENAV S.p.A. internal process
SE	Fuel burn/CO_2 and Noise	Gate-to-Gate	APTA; CDO; CCO	Deployment	Own VINGA methodology
UK1	Noise, Fuel burn/CO_2, capacity, predictability & ATCO workload	Airport approach	RSEQ	Demonstration	SESAR methodology + UK CAP725
UK2	Fuel burn/CO2	Airport approach, enroute, SIDs, Holds / point merge	CDO, CCO improvement	Deployment	Process followed UK CAP724/725 and DfT Air Navigation Guidance
US	Noise, Fuel burn/CO_2 and emissions and other aspects	Airport approach	All	Deployment	FAA Order 1050.1E, FAA Order 7400.2K (Chapter 32); Council of Environmental Quality (CEQ's), Regulations for Implementing the National Environmental Policy Act (NEPA)

Table 1. Attributes of Case Studies Collected So Far.

that there may be a need to satisfy requirements at both the State level (i.e. the UK Civil Aviation Authority) and the regional level (i.e. the European Civil Aviation Conference) when carrying out environmental assessments of SESAR concepts.

- **Integrating environment into the decision-making process (Doc. 10031, section 1.3):** The AU case study highlights Airservices Australia's efforts to embed environment into the procedure-design process, thereby supporting Airservices' mission to provide safe and environmentally responsible air traffic services.

- **Communicating results of the environmental assessment (Doc. 10031, section 3.5):** The AU case study also describes various mechanisms used to communicate the results of the environmental assessment, including: a technical assessment document; an "assessment on a page" technical summary document to support advance preparation of communication strategies for internal stakeholders; a community consultation package, including text and a PowerPoint presentation – communicated through a Community Aviation Consultation Group (CACG) meeting; and a summary assessment document – produced for government and industry briefing and published on the Airservices Australia website.

- **Engaging with stakeholders (Doc. 10031, section 2.5):** The US case study describes the importance of early engagement with all stakeholders, including local communities, as the FAA continues to implement Performance Based Navigation. The project in the case study was deemed successful due to the collaborative approach taken and a commitment to effective communication and engagement.

The ten case study examples mentioned, illustrate how we can all learn from the experience of others when conducting environmental assessments. They could also provide potentially useful data points for quantifying the environmental benefits of certain operational changes. The Swedish VINGA case study, for example, showed that the implementation of RNP STARs and RNP AR approaches has a potential for saving around 22-90kg of fuel per flight, compared with the traditional P-RNAV STAR structure followed by an ILS approach. This type of data can be used as a high-level reference point in other environmental assessments of aviation system block upgrades.

Conclusion

CAEP will continue to solicit examples of environmental assessments of ATM operational changes and post them on the ICAO CAEP Environmental Assessment web page. Learning from stakeholder feedback on the application or applicability of the guidance provided in Doc 10031 will help CAEP refine Doc 10031 in the future and ensure that it still provides the most current thinking in an area that is critical to the sustainability and growth of aviation.

Case studies may be submitted via the dedicated "Environmental assessment" web page below (which also includes a link to download Doc 10031): http://www.icao.int/environmental-protection/Pages/EnvironmentalAssessment.aspx.

References

1. The Aviation System Block Upgrade (ASBU) initiative is a programmatic framework that develops a set of ATM solutions or upgrades, taking advantage of current equipage in order to enable global interoperability. It consists of a number of operational improvements or modules (e.g. CDO) defined by time periods or Blocks (e.g. Block 0: 2013 to 2018), which may be deployed in a coherent transition from basic to advanced capability as time progresses. Such modules are grouped together in Performance Improvement Areas (e.g. Greener airports) to provide operational and performance objectives.
2. see article " Environmental Benefits Assessment of Aviation System Block Upgrades"

STUDY ON THE VARIATION IN THE FUEL CONSUMED AND EMISSIONS PRODUCED BY AIRCRAFT IN THE AIRSPACE MANAGED BY ASECNA

BY HALIDOU MOUSSA (ASECNA)

In the framework of the cooperation between ICAO and the Agency for the Safety of Air Navigation in Africa and Madagascar (ASECNA) towards the achievement of ICAO's global goal of reducing the impact of aviation on the environment through a reduction in aircraft CO_2 emissions, an initial joint study was conducted in 2012 to estimate the variation in the fuel consumed and emissions produced by aircraft in the airspace managed by ASECNA between the 2005 and 2011.

The results of this study found a substantial reduction in unit fuel burn and CO_2 emissions by flight in 2011 compared to 2005 leading to the conclusion that operational improvements implemented during that period resulted in fuel savings and emissions reductions.

As part of its "Plan, Do, Check, Act" approach, and in order to assess its contribution to the achievement of ICAO's global environmental goals, ASECNA initiated a second study in 2015 covering the period 2011-2014 in order to estimate the difference in fuel burn and CO_2 emissions by aircraft during the cruise phase in the airspace managed by ASECNA.

The aim of this second study is to determine whether the technological and operational improvement measures implemented through the Services and Facilities Plan (SFP) 2011-2014 have continued to produce environmental and economic benefits for airspace users. These results may also be used by ASECNA Member States in the preparation of action plans to reduce CO_2 emission from international aviation.

How the Project Contributes to Reducing the Environmental Footprint of the Sector

The study was conducted using real traffic data during the cruise phase, registered in the airspace managed by ASECNA in 2011 and 2014. This airspace covers about 16.1 million km^2 and is composed of 6 Flight Information Regions (FIRs) extending from the Atlantic Ocean to the Indian Ocean, and crossing both West and Central Africa (Dakar continental, Dakar oceanic, Niamey, N'Djamena, Brazzaville and Antananarivo).

The data used in the study was composed of about a million records/rows containing raw data of the traffic managed by the 13 ASECNA ATS Centres responsible for providing en-route air traffic services. The raw data was subject to a preliminary filtering leading to data that is pertinent to the study and that are in the format required for use in ICAO's ATFEET/IFSET tool. As a consequence, the study does not take into consideration the following: flights of piston aircraft, helicopters, military and VFR flights. The range of flight levels taken into consideration spans from FL100 to FL410, inclusive, most commonly used by commercial flights. An aggregation phase of the various flight segments registered by ATS centres has allowed the reconstitution of each flight within the airspace managed by ASECNA.

Using the ICAO ATFEET/IFSET tool, the unit fuel burn (in kg per second) was estimated for each flight taking into account the aircraft category, the flight level, the distance flown and the flight time. The total fuel burn for each flight was obtained by multiplying the unit fuel burn by the flight time in the airspace managed by ASECNA.

The variation in total fuel burn from 2011 to 2014 may be explained by four possible factors: traffic growth (increase in the number of flights crossing the airspace managed by ASECNA) and/or a change in airline networks (change in the origin-destination pairs) and/or a change in aircraft category and/or a change in air navigation operational conditions (optimum flight levels, direct and/or shortened routes, etc.).

Thus, a two-step approach was adopted. In the first step, an overall analysis was performed to assess the variation in fuel burn due to all four factors above. In the second step, a more focused analysis was performed in order to isolate the impact of ATM improvements only.

Associated Quantitative/Qualitative Benefits

Results of the overall analysis covering all flights for 2011 and 2014

The overall analysis covered all the flights, in both years, on which the following estimations were made:

- The total fuel burn for each year: which is the sum of the fuel burn of all individual flights in the airspace managed by ASECNA in the given year.
- The average fuel burn per flight for each year: which is the ratio of the total fuel burn by the total number of flights in the given year.
- The gap in the average fuel burn per flight between 2014 and 2011: which represents the average fuel savings per flight and is estimated at 351 Kg
- The total fuel savings achieved for all flights in 2014: which is obtained by multiplying the average fuel savings per flight by the total number of flights in 2014.

The number of flights crossing the airspace managed by ASECNA increased by 14.2% in 2014 compared to 2011, while the total annual fuel burn increased by 7.6%: the rate of increase in fuel burn is **twice lower** than the rate of increase in traffic. Similarly, the average fuel burn per flight has declined by **5.8%** in 2014 as compared to 2011, representing an average fuel savings of about 351 kg per flight.

The total fuel savings of about 108 million kg represent an environmental benefit equivalent to about 341 million kg of CO_2 emissions avoided (1 kg fuel generating 3.157 kg of CO_2). In terms of operating expenses, this is equivalent to about USD 48.6 million savings in aircraft operators' fuel costs (considering an average fuel price of USD 0.45 per kg in 2014).

These fuel savings cover all flights registered during both years 2011 and 2014 including in particular, the new flights introduced after 2011 and those existing in 2011, but for which the operated aircraft category has changed, as well as the 2011 flights that ceased to exist in 2014.

Between 2011 and 2014, the equivalent of about 341 million kg of CO_2 emissions was avoided

The observed fuel savings result from the combined effects of the three following factors: the changes in aircraft operated on certain routes, the changes in operators' networks (due to the opening of new routes and the closing of existing ones), and the changes in air navigation operational conditions linked to ATM (due to the introduction of new Communication, Navigation, Surveillance - CNS-ATM equipment, services and procedures). The first two factors are controlled by the air carrier, whereas the third one is under the control of the Air Navigation Service Provider.

In order to evaluate the environmental impact of ASECNA's initiatives, a more detailed analysis was performed in order to focus only on the ATM factor.

Results of the detailed analysis covering the common flights for 2011 and 2014

The detailed analysis covered a total of 247,281 flights operated from the same origin to the same destination with an aircraft in the same ATFEET/IFSET category in the years 2011 and 2014. Focusing only on those flights eliminates the impact of changes in aircraft in operation and in operators' networks.

- Using the total fuel burn data per flight, an average fuel burn (AFB) per flight per combination "Origin - Destination - ATFEET/IFSET aircraft category" is estimated for both years: 2011 and 2014.
- The 2014 total fuel burn for the 247,281 common flights may be obtained either by summing up the fuel burn of individual flights

	Total number of flights	Total Fuel Burn (Kg)	Average Fuel Burn per Flight (Kg)	Total Distance Travelled (Km)	Average Distance per Flight (Km)	Total Flight Time (hours)	Average Time per Flight (hours)	Average FL
2011	269 373	1 629 699 365	6050	143 489 845	533	365 919	1.36	300
2014	307 712	1 753 797 731	5 699	158 487 092	515	402 686	1.31	300
Gap: 2014-2011	38 339	124 098 366	351	14 997 247	-18	36 767	-0.05	
Growth rate	14.2%	7.6%	-5.8%	10.5%	-3.4%	10%	-3.7%	

The fuel savings for all flights in 2014, on the basis of average fuel savings per flight, amounted to: 108,006,912 Kg.

Table 1. Results of the overall analysis covering all flights for 2011 and 2014.

or by using the corresponding 2014 AFB per flight instead.

- The 2014 total fuel burn for the 247,281 common flights assuming that operational conditions were identical to those in 2011, may be estimated by replacing the fuel burn of individual flights with the corresponding 2011 AFB per flight before calculating the sum.

The 247,281 common flights operated in 2014 had a total fuel burn lower by 0.5%, compared to the total quantity of fuel consumed had the air navigation operational conditions remained the same as in 2011. This corresponds to fuel savings of about 7 million kg of fuel.

Furthermore, it is worth noting that the distance travelled and time spent in the airspace managed by ASECNA were also reduced by 2.7% and 4.5%, respectively. These results indicate greater efficiency of flights in 2014 due to ATM improvements. These fuel savings lead to an environmental benefit equivalent to about 22,464 tons of CO_2 emissions avoided. In addition, this represents savings of about USD 3.2 million in fuel costs for aircraft operators.

The detailed analysis highlights the contribution of air navigation operational conditions (ATM improvements) in the reduction in fuel burn in 2014. This contribution results from the improvements introduced by ASECNA in the provision of air navigation services (CNS and ATM) in this airspace between 2011 and 2014, in particular the extension since September 2012 of the Atlantic Ocean Random Routing Area (AORRA) to Latitude 4° North; the implementation of several additional 10 Require Navigation Performance routes on a permanent basis in the continental and oceanic airspace in the FIRs of Dakar, Niamey, N'Djamena et Brazzaville, from April 2011 to October 2012; the introduction of flexible routes (iFLEX) in the Brazzaville FIR since March 2012 in order to facilitate and improve the transit to and from the AORRA airspace; the implementation of new surveillance Radar and Automatic Dependent Surveillance/Contract systems, as well as Controller Pilot Data Link Communications in the FIRs of N'Djamena and Brazzaville since April 2012 after the Dakar et Niamey FIRs in 2010. All these improvements have allowed aircraft operators to use more direct routes and have offered them an increased flexibility in the selection of more efficient flight levels.

Project Evolution and Outlook: 3 Years and Beyond

In general, tools developed by ICAO, including IFSET, and made available to States and Air Navigation Service Providers are suitable to pursue such studies to measure the environmental benefits, as well as economic gains associated with air navigation operational improvements.

For ASECNA, it is planned in the short term to prepare a similar study on the 2005-2015 period to take into account the implementation of its SFP over the same period. In the medium term, it is envisaged to also prepare a third study covering the period 2015-2017, following the completion of the ongoing project aiming to extend the current surveillance capabilities which includes the equipment of 11 additional ATS Centres of ASECNA with surveillance facilities (RADAR Secondary Surveillance Radar and ADS-C) and implementation of CPDLC communications. A fourth study will be conducted at the end of the planned coverage of all airspace managed by ASECNA by ADS-Broadcast. Similarly, at the end of the implementation of the modules of Block 0 ASBU, including PBN procedures and CCO and CDO at all airports, a fifth study will be prepared regarding the traffic in terminal phase of flights (arrivals and departures).

These studies will provide ASECNA with indicators enabling it to measure the environmental and economic performance, and relevance of its investment efforts in CNS-ATM.

End Notes:

ATFEET/IFSET: Air Traffic Fuel Efficiency Estimation Tool/ ICAO Fuel Savings Estimation Tool.

	Total Fuel Burn (Kg)	Total Distance (Nm)	Total Flight Time (hour)
2011	1 295 621 342	124 595 714	328 285
2014	1 288 505 858	121 246 075	312 894
Gap: 2014-2011	-7 115 484	-3 349 639	-15 391
Growth rate	-0, 5%	-2.7%	-4.7%

The savings of fuel achieved in 2014 based on the flights that are common to both 2011 and 2014 amount to: 7 115 484 Kg

Table 2. Results of the detailed analysis covering the common flights for 2011 and 2014

SESAR - ACHIEVING ENVIRONMENTAL BENEFITS THROUGH OPERATIONAL EFFICIENCY

BY CÉLIA ALVES RODRIGUES, (SESAR JOINT UNDERTAKING)

Background on SESAR

The performance of Europe's air traffic management (ATM) system is critically important for the sustainability of aviation and air transport, two sectors which drive European competitiveness, mobility and employment.

SESAR is the technological pillar of the Single European Sky (SES), an EU-wide policy designed to enable ATM to handle a three-fold increase in capacity, improve safety by a factor of 10, enable a 10% reduction in CO_2 emissions per flight and reduce the unit cost of ATM services to the airspace users by 50%. As European traffic is expected to increase from 9.5 million flights in 2012 to nearly 14.4 million in 2035, the challenge for Europe is to meet this expected growth in demand while minimising its environmental impact. SESAR's research and development (R&D) phase is managed by the SESAR Joint Undertaking (SJU) a public-private partnership.

The ATM Master Plan is the strategic plan for ATM improvements in Europe with an outlook period of 20 years, fully aligned with the Global ATM Operational Concept (GATMOC) and the ICAO Global Air Navigation Plan (GANP). Guided by and supporting the European ATM Master Plan, the SESAR Joint Undertaking (SESAR JU) is responsible for concentrating all ATM R&D efforts, and for defining, developing and validating SESAR Solutions in preparation for their deployment. These solutions address all parts of the ATM value chain, from airspace users, airports, air traffic services to the network, as well as the underlying systems architectures, technical systems and infrastructural enablers, validated in real day-to-day operations systems. The early implementation of several of these solutions is already underway, demonstrating SESAR's role in transforming Europe's ATM network into a modern, cohesive and performance-based operational system.

Further proof of the readiness of SESAR R&D is the decision by the European Commission to package a first set of SESAR solutions into a Pilot Common Project (PCP)[1], which are considered mature enough and ready for synchronised deployments across Europe (2015-2020). The SESAR Deployment Programme, which is managed by the SESAR Deployment Manager, aims to ensure that solutions delivered by the SESAR JU are delivered into everyday operations across Europe, delivering significant benefits to airspace users and the environment. Preparations are underway to deploy the solutions contained in the PCP between 2018 and 2025.

In line with the performance-based approach for ICAO's Aviation System Block Upgrades (ASBUs) methodology implementation, the whole SESAR framework stems from a performance-based approach, with the setting up of SESAR performance ambitions, aligned the policy targets of the Single European Sky requiring the design of the European ATM system to be able to handle a three-fold increase in capacity, improve safety by a factor of 10, enable a 10% reduction in CO_2 emissions per flight and reduce the unit cost of ATM services to the airspace users by 50%. Those SESAR performance ambitions have been expressed in terms of Key Performance Indicators (KPIs) in the areas of capacity, cost efficiency (ANS productivity), operational efficiency, environment, safety and security. Those KPI's include e.g. departure delays, fuel burn per flight, CO_2 emission, gate-to-gate ANS cost, as illustrated in the figure below.

SESAR ambitions to enable a 10% reduction in CO_2 emiissions per flight

Figure 1. SESAR's Performance targets

This article presents a summary of the SESAR R&D developments from an environmental perspective (by end-2015). Details of the entire SESAR R&D work programme can be found on the SJU website (www.sesarju.eu).

Delivering 'High-Performing Aviation for Europe'

The specific SESAR contribution to the SES high-level goals are continuously reviewed and kept up to date in the European ATM Master Plan, the main planning tool for defining ATM modernisation priorities and ensuring that the SESAR Target Concept becomes a reality. Built in collaboration with all aviation stakeholders, the Plan provides a high-level view of what is needed in order to deliver a high-performing aviation system for Europe. It also sets the framework for the related development and deployment activities, thereby ensuring that all phases of the SESAR lifecycle remain connected.

Published in December 2015, the latest edition provides a comprehensive vision of the future ATM system, which is built around the notion of 'trajectory-based operations' and the provision of air navigation services (ANS) in support of the execution of the civil business or military mission trajectory — meaning that aircraft can fly their preferred trajectories without being constrained by airspace configurations. This vision is enabled by a progressive increase of the level of automation support, the implementation of virtualisation technologies, as well as the use of standardised and interoperable systems. The system infrastructure will gradually evolve with digitalisation technology, allowing air navigation service providers (ANSPs), irrespective of national borders, to plug in their operations where needed, supported by a range of information services. Airports will be fully integrated into the ATM network level, which will facilitate and optimise airspace user operations.

Deployment synchronisation of critical changes is also reflected in the Plan, ensuring convergence of timelines across stakeholders. Through this collaborative and holistic approach to planning and reporting, European stakeholders continue to demonstrate their commitment to lead the way in the global ATM and aviation market. In this global arena, the plan is instrumental for aligning priorities and planning across world regions to ensure harmonisation and interoperability.

The performance targets for environment in the 2015 Master Plan are to reduce fuel burn by between 250 and 500 kg per flight by 2035. The programme first phase (SESAR 1) from 2007 to 2016 aimed to contribute a 2.8% reduction to the SES objective, which amounts to approximately 134kg of fuel per flight.

The programme first phase (SESAR 1) from 2007 to 2016 aimed to contribute a 2.8% reduction to the SES objective, which amounts to approximately 134kg of fuel per flight

Delivering Concrete Solutions Targeting Fuel Efficiency

SESAR defines, develops, validates and delivers to aviation stakeholders innovative technological and operational solutions for managing air traffic in a more efficient manner in the form of yearly Releases. A SESAR Release is a sub-set of the SESAR Programme that focuses on groups of validation projects delivering, in a specific timeframe, R&D results that will support a decision to move related activities to the industrialisation phase. It is expected that the SESAR R&D work programme will result in over 50 solutions by the end of 2016, delivered in five Releases. In order to assess the environmental benefits SESAR has developed a set of tools, *IMPACT*, to measure the environmental impact of each of its solutions for fuel, noise and local air quality impacts.

Each solution consists of a series of simulations and/or live trials with associated validation targets and goals that are assessed in a harmonised and consistent manner. Some examples are provided below of the Solutions that have significant environmental benefits that were assessed using IMPACT.

Integrating Airports and Optimising Operations on the Ground

Taxiing can represent almost one third of total fuel burn for a short haul flight if waiting in queue adds to the time on the ground. SESAR developed solutions which allow aircraft to move more smoothly and efficiently from the terminal to the runway, without unnecessary queuing or stops. The SESAR solution **departure manager (DMAN) baseline to be used for the integration of AMAN and DMAN** validated at Paris Charles de Gaulle airport showed benefits in terms of environment sustainability and cost-effectiveness, with a significant reduction in fuel burn and CO_2 emissions (average reduction of 14.6 kg per flight, corresponding to 46.6 kg drop in CO_2 emissions) due to reduced waiting and taxi times.

Another solution improving ground operations is **pre-departure sequencing supported by route planning** to deliver an optimal traffic flow to the runway. The main objective of this solution is to optimise the traffic flow delivered to the runway supported by a DMAN and the routing and planning function of advanced surface movement guidance and control systems (A-SMGCS). The combination of these two systems allows a reduction in the waiting time at the runway holding point, increased taxi-out accuracy and hence greater take-off time predictability, as well as provides for a more stable pre-departure sequence (target start-up approval time or TSAT).

SESAR is also working on de-icing procedures at airports, which in addition to improving operational efficiency can also allow for better management of wastewater, for example. Validation exercises aiming to integrate de-icing operations into the airport operations plan (AOP) have been carried out in Oslo. The ultimate goal is to see a de-icing management tool (DIMT) shared among all airport stakeholders in the A-CDM so that everybody can plan adequately.

En-route: Flying the Optimum Route

SESAR makes it possible for aircraft to freely plan and fly the most efficient route between departure and destination, both within Europe and on trans-continental flights. The concept of **free routing** provides important fuel savings by reducing flown distance and flight time in all en-route airspace categories and allowing carrying less fuel. Flight-trials in the Maastricht Upper Airspace Control Centre have shown that the free route solution could reduce flight distances by 5% and flight times by 2 minutes, leading to a 12% reduction in fuel burn and emissions.

Extended flight plan is another example of achieving efficiency and reducing fuel in the en-route phase. It makes use of the flight management system and communication capabilities of the aircraft and ground systems in order to share and integrate data, and optimise the aircraft trajectory in all four dimensions. This enables a more efficient and predictable handling of flights.

The SESAR solution enhanced terminal operations with LPV procedures consists of an innovative required navigation performance (RNP) approach procedure to localizer performance with vertical guidance (LPV) minima focusing on the initial and intermediate approach segments. LPV procedures do not require any new equipment at the airport. This new approach design may be useful either to shorten the flightpath for certain traffic flows or simply to overlay the existing ILS and be used as a fall-back procedure in case of airborne or ground ILS-equipment malfunction.

Departures and Arrivals: Creating Fewer Delays, Optimising Descent Paths and Reducing Aircraft Noise

Today, aircraft making their final approach to land are obliged to maintain minimum distances between one another. In strong headwinds, longer gaps inevitably develop between airplanes. The SESAR solution of **time-based separation** replaces current distance separations with time intervals. Exercises at London Heathrow Airport showed that this solution allows up to five more aircraft to land per hour in strong wind conditions, thereby reducing holding times by up to 10 minutes, and fuel consumption by 10% per flight.

Continuous descent operations (CDO) from top of descent to runway in medium to high density/complexity TMAs will bring the largest environment benefits by reducing level-offs in the descent phase. CDO enabled by Point Merge in high density and complex environments have also been proven to be beneficial.

Approach procedures with vertical guidance (APVs) have been shown to provide fuel efficiency benefits in low density areas.

Another example is **extended arrival management** (E-AMAN). Today, arriving airport traffic is managed and sequenced in the airspace close to the airport. Faced with increasing traffic, airports are looking for ways to overcome congestion and reduce the need for holding. E-AMAN allows for the sequencing of arrival traffic much earlier than is currently the case, by extending the AMAN horizon from the airspace around the airport to further upstream. Controllers in the upstream and cross border sectors, including those in neighbouring FABs, can instruct pilots to adjust aircraft speed before beginning descent, thereby reducing the need for holding. The results from SESAR flight trials show that this solution offers valuable reductions in fuel consumption and CO_2 emissions.

SESAR solutions also aim to improve the measurement and management of noise. At Brussels airport, a SESAR-enabled **optimised descent operations** allowed aircraft to reduce its noise impact on the ground of up to 6dB, at between 7.5 to 30 nautical miles from the airport runway.

Already implemented!
The solutions below are currently being used in live operations by airspace users:

- Time-based separation at Heathrow Airport;
- Cross-border arrival management (XMAN) for London Heathrow, managed by NATS, is the world's first implementation of the SESAR Extended Arrival Management solution with multi-ANSP partners;
- Point Merge procedures implemented in Paris Charles de Gaulle and Oslo.

Seeing is Believing

In addition to its R&D activities, the SJU co-finances demonstration projects run by consortia, including an even wider range of different types of stakeholders, and mandatorily an airline. Since 2009, 33 Atlantic Interoperability Initiative to Reduce Emissions (AIRE) projects were co-financed, demonstrating SESAR solutions in real operational conditions with commercial flights. A total of 15,483 flight trials were conducted involving 17 ANSPs, 26 airlines, and 9 airports. These projects demonstrated savings ranging from 60 to 3,100 kg of CO_2 per flight. The solutions demonstrated often resulted in improved day-to-day operations. Furthermore, important findings on ATM capabilities and data assessment needed were highlighted during these demonstrations.

Since 2009, a total of 15,483 flight trials were conducted as part of the AIRE projects, demonstrating savings ranging from 60 to 3,100 kg of CO_2 per flight

These trials have almost entirely used technology which is already in place, but until the relevant AIRE project came along, air traffic controllers and other users had not necessarily thought deeply about how to make the best use operationally of that technology. The following improvement areas/solutions have now been implemented to a large extent thanks to these trials:

- **Lateral [separation] optimisation** for any flight that requests it in Santa Maria and New York oceanic airspace;
- **Continuous descent operations** procedures published for Madrid, Gothenburg, Prague, Toulouse, and Riga airports;
- Development of **required navigation performance authorisation required (RNP AR) procedures** in Sweden and Latvia;
- Development of required **navigation performance standard terminal arrival route (RNP STAR)** and **authorisation required approach (RNP AR)** procedures in Lanzarote and La Palma airports.

AIRE has been a pioneer programme and helped other regions to follow the same path. For example, the ENGAGE project led by NAV CANADA capitalising on trials carried out in Santa Maria and New York oceanic airspace has successfully demonstrated the viability and safety of aircraft varying speeds (Mach) and altitudes while transiting the unsurveilled airspace also over the North Atlantic, and the TOPFLIGHT project demonstrated multiple elements of the SESAR concept in the gate-to-gate optimisation of transatlantic flights between North America and Europe. TOPFLIGHT demonstrated the feasibility and benefits of the SESAR concept and reinforced commitment regarding the early transition of some of those elements into sustainable operations in complex TMA, high-density en-route and oceanic environments.

Future Activities

In 2014, the European Union adopted legislation extending the legal mandate of the SJU until December 2024. In addition, the amending regulation entrusted the SJU with executing and delivering the SESAR Research & Innovation 2020 Programme (SESAR 2020) to contribute towards achieving the Single European Sky and more specifically, the European ATM Master Plan.

SESAR 2020 activities have already started with the launching of exploratory research activities, and will continue in 2016 with new R&D projects to deliver solutions in response to the evolving needs of Europe's aviation and air transport industries captured in the European ATM Master Plan. More solutions bringing environmental benefits will be developed and will aim to contribute to achieving high performance aviation in Europe.

Conclusions

Consistent with the ASBUs methodology, Europe's approach to the GANP implementation is based on the SES institutional/ regulatory framework and the SESAR programme. The ATM Master Plan is Europe's strategic plan in fully alignment with the GATMOC and the GANP.

With 25 delivered solutions to date and over 30 more to be delivered during its first phase, the SESAR R&D programme is undeniably meeting its environmental objectives and providing concrete options and ways to help reduce the environmental impact of aviation.

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ENGAGING AIRLINES AND AIRPORTS ON CONTINUOUS DESCENT OPERATIONS

BY IAN JOPSON (NATS, SUSTAINABLE AVIATION UK)

In 2014, the United Kingdom (UK) Sustainable Aviation (SA) coalition launched a campaign to improve continuous descent operations across the UK. The goal was to increase this by 5% and to deliver 30,000 individual quieter flights, as well as save around 10,000 tonnes of CO_2 emissions and achieve fuel savings of GBP2 million, as part of a wider sustainability programme to reduce noise and CO_2 emissions.

Continuous Descent Operations (CDOs) is a descent technique that reduces noise, fuel burn and CO_2 emissions. A number of London airports have traditionally been successful in managing CDOs, supported in 2002 by an Arrivals Code of Practice and subsequent close monitoring and reporting of performance. To date, continuous descent performance has been promoted only at UK airports where a significant noise issue already exists. Building on the success at these airports, the UK aviation industry is seeking to drive further improvements by expanding the number of airports actively managing CDOs and monitoring performance from higher altitude.

In the UK, the increase of CDOs by 5 per cent would save around 10,000 tonnes of CO_2 emissions

Historically in the UK, CDOs have focused on reducing noise when aircraft are descending below 6,000 ft. Continuous descents are achieved when aircraft remain in a smooth continuous descent profile, instead of descending in a series of steps. This means an aircraft is higher for longer above the ground and is quieter. It is also more fuel and environmentally efficient than a stepped descent. Sustainable Aviation is delivering improvements to aircraft descent profiles from cruise to ground.

Planning for the CDO campaign began over a year before launch. Two Sustainable Aviation sub-groups worked closely with NATS to establish initial points of contact in the airlines and airports and gain their formal agreement to participate. The communication materials to support the campaign, including a video, booklets and posters, were then developed over the subsequent months. These targeted air traffic approach controllers, pilots and airport environmental performance managers. The video[1] was watched by thousands of aviation professionals, while 50 pilot crew rooms displayed campaign posters, and 10,000 booklets were distributed to pilots and controllers, in addition to face-to-face briefings with more than 500 NATS controllers and 7,000 pilots. The Continuous Descent Campaign encouraged best practice across 15 Air Traffic Control Units, 23 airports and eight airlines (including airports where NATS does not provide a tower service). The unique aspect of this campaign was the large-scale simultaneous effort across air traffic control units, airlines and airports to jointly deliver a step change in performance.

SA members worked closely to prepare for monitoring CDO performance from the traditional 6,000ft level, as well as from 10,000ft and 20,000ft. The latter will be possible once future planned airspace improvements are deployed. In the meantime, the campaign was focused on realising short-term improvements from wider adoption of best operational practice. Many airports and airlines had only limited experience with CDOs and so NATS worked with them to develop their systems and policies. Being able to measure is of course the first step to improving – and that has been a key outcome of the campaign.

In the UK, Continuous Descent Operations is more commonly known as Continuous Descent Approaches, which typically starts from an altitude of 6,000 feet, whereas CDO applies from the cruise.

CDOs are enabled by airspace and procedure design, as well as tactical air traffic control and pilot procedures in which an arriving aircraft continuously descends from cruise to landing. Achieving a smooth continuous descent requires extra effort from pilots and air traffic controllers as they need to liaise with each other more closely to manage the aircraft's speed, thrust and landing settings against external factors, e.g. wind and air traffic routing requirements.

One example of the collaborative approach in the campaign was when a British Airways pilot reported difficulty achieving

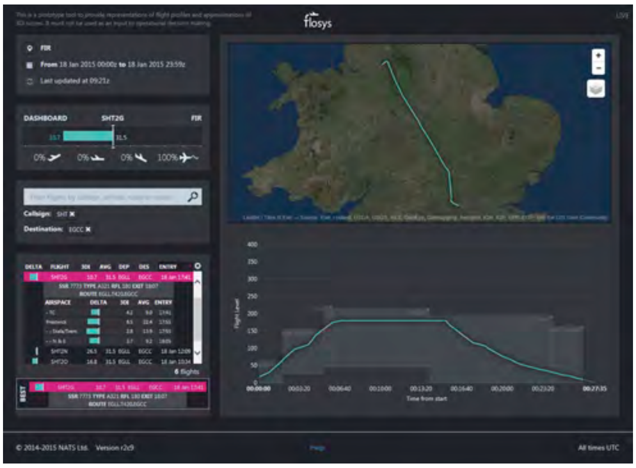

Figure 1. BA flight achieving CDO at Manchester Airport

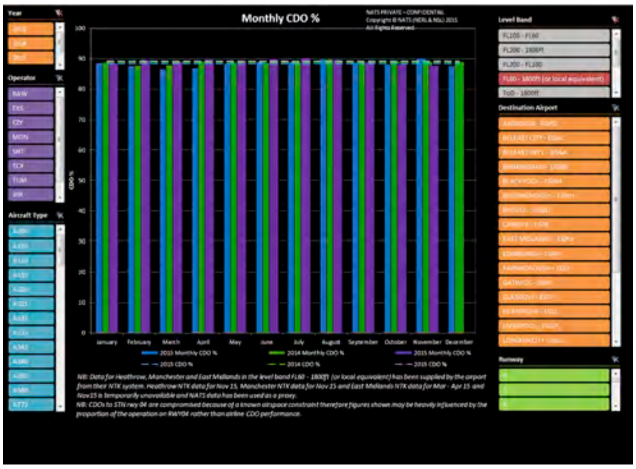

Figure 2. Flight Profile Monitor

continuous descent into Manchester Airport, a NATS controller accompanied the pilot in the cockpit during a subsequent flight and identified an inconsistency in the approach procedure. As a result, BA changed their standard operating procedure and NATS made a procedural change which better enabled CDOs on that route.

A world-first launched in 2005, Sustainable Aviation (SA) is a unique alliance of UK airports, airlines, engine and airframe manufacturers, and air traffic management. SA is a long-term strategy set up to tackle the challenge of ensuring a sustainable future for our industry.

A number of tools and reporting dashboards were created for the benefit of all the SA members working on the CDO campaign. For example NATS developed a new controller tool called FLOSYS (**Figure 1**), which allows controllers to review individual flights and their descent profile. This provides immediate feedback on a controller's interaction with pilots and the resulting flight profile. It is highly engaging for controllers and brings the whole programme to life in a live operational environment.

A "Flight Profile Monitor" reporting tool was developed to support airline CDO operations and help monitor CDO performance at airports. This data is regularly shared with all the participants to identify problems and by working collaboratively, solutions are found and implemented.

The return on the investment for the CDO campaign helps airlines reduce fuel consumption, cut costs and make their businesses more efficient and sustainable. It also helps reduce aircraft noise for communities around airports. This supports both SA's noise and CO_2 roadmaps.

At a national level, CDOs have increased from an average of 56% of arrivals in 2006 to 77% in 2015, which is an exceptional achievement. This has been a long-standing area of focus with SA organisations since the launch of an Arrivals Code of Practice. The campaign outcomes included:

- Being able to measure CDO performance at a national scale is a world first;
- Change in absolute number of CDOs across all airlines at 22 participating airports is 68,321 additional CDOs since 2013;
- These increases are in the context of traffic growth of around 10%;

The campaign will continue to operate and in 2015 was recognised by Business in the Community annual awards, with NATS receiving the "Engaging customers on sustainability" award.

In 2016 the Sustainable Aviation CDO campaign was reaccredited for the "Engaging customers on sustainability" award.

We look forward to building on the outstanding success of the campaign and thanks all those in the Sustainable Aviation coalition who made it possible.

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HOW NATS MANAGES AIRSPACE EFFICIENCY

BY JARLATH MOLLOY (NATS)

NATS was the first Air Navigation Services Provider to adopt a target to reduce air traffic management (ATM) related CO_2 emissions, committing to reduce it by 10% by 2020, using a 2006 baseline. In 2012, NATS and the UK Civil Aviation Authority (CAA) agreed on a methodology for measuring airspace efficiency. This became known as the 3 dimensional inefficiency, or 3Di, metric. 3Di is a proxy for airline fuel burn and is used as a key performance indicator to help measure progress against the CO_2 emissions target.

For historical reasons, aircraft fly from origin to destination airports along invisible tracks, via fixed individual way points. These tracks can be complex close to airports as they weave to and from runways, around airport communities and up to high-level airspace. If the performance of this system is to be improved and ATM-related CO_2 emissions reduced, a means to be able to measure the airspace performance is needed, which itself is a difficult task.

The 3Di metric came about after discussions with NATS' airline customers on how they would like to see airspace efficiency measured. The CAA and airline customers are interested in NATS' performance and have sought improvements by setting targets. NATS can a earn a bonus or incur a penalty depending on 3Di performance, equivalent to 1% of revenue per year, which is equal to the level of incentives on NATS' delay performance.

The 3Di metric is calculated using a bottom-up approach, whereby every commercial flight, every day of the year (with only 'return to base' flights excluded) will have an individual 3Di score calculated, and these are averaged for the full year. Scores run from 0 (zero inefficiency which is good), to 100+ (lots of inefficiency which is bad). Each year, all the scores are combined to produce a single annual average score for UK airspace and compared to the target.

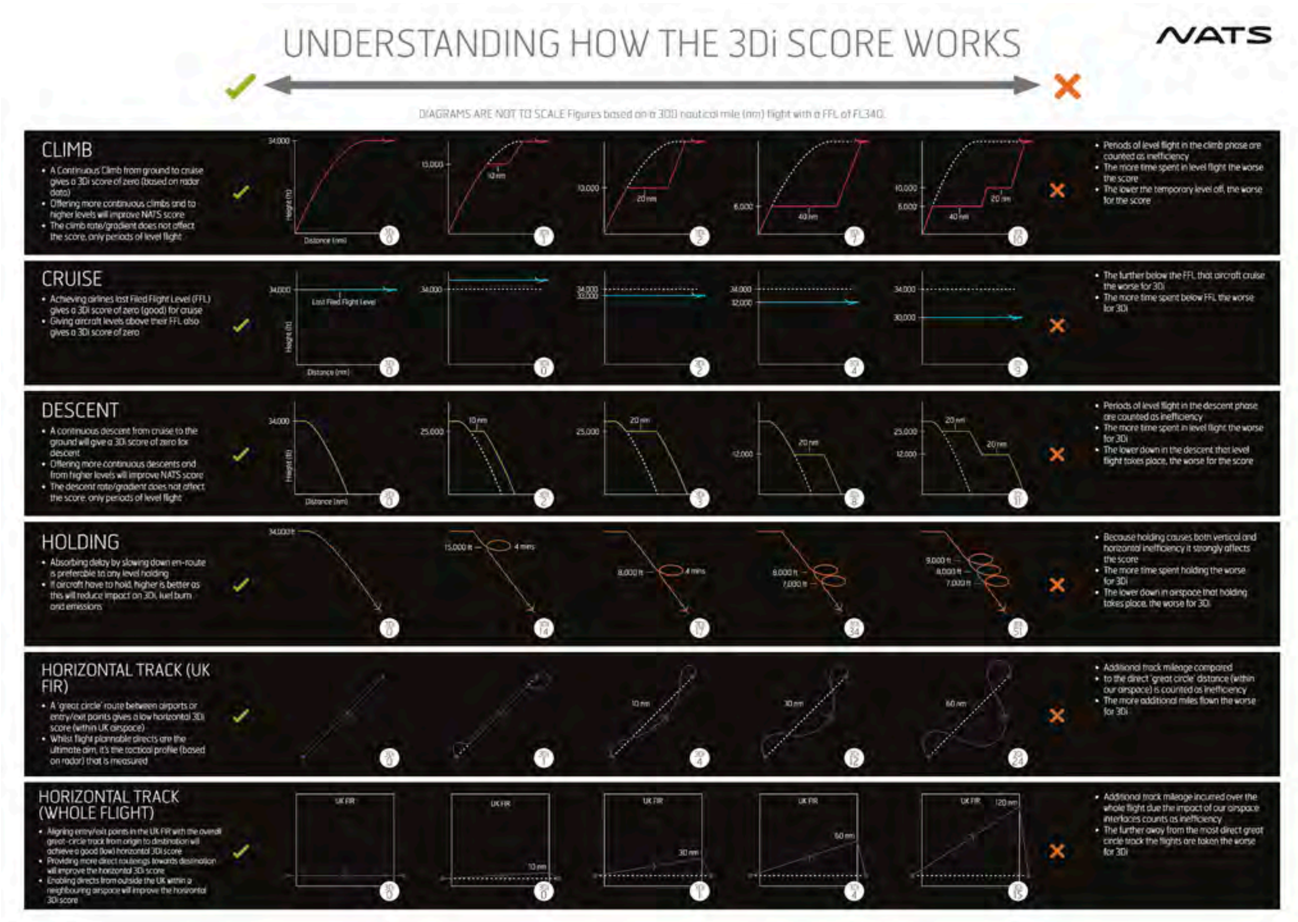
The 3Di metric compares the actual trajectory that aircraft take, based on real radar data, with a theoretical "great circle" or shortest route, together with the airline's requested flight level. The radar data shows how efficient the actual flight was, compared to the minimum fuel burn trajectory and the flight level the airline had originally requested. This comparison is a compromise made to allow the metric to work, but it does help in other ways. For example, opportunities can be identified both inside and outside NATS' airspace where changes can be made or supported elsewhere that improve the overall performance of the network.

Each flight is scored according to six categories; level flight in i) climb, ii) cruise and iii) descent, iv) holding, v) horizontal track (UK) and vi) horizontal track (whole flight). Depending on the category and the extent of the sub-optimal profile, each flight will accrue 3Di points. This helps identify hotspots where airspace is not performing as well as it could. NATS then reviews why this is the case, e.g. there could be very good reasons for a restriction or procedure to be in place for safety or capacity reasons. In other cases, NATS might discover something that a Standing Agreement no longer required and will remove it. ATM related CO_2 emissions are reduced and the 3Di score improved by delivering more aircraft closer to the airlines' preferred flight trajectories, which includes:

- More continuous climb and descent operations to/from higher levels
- More direct routes across UK airspace
- Reduced airborne holding at destination airports
- Working with neighbouring air navigation service providers, military and general aviation airspace users to deliver more direct routes across the whole flight profile
- Achieving airlines' preferred cruise levels
- Working to improve the score from the previous year by looking at all aspects of inefficiency, whether caused by NATS or others and working collaboratively to reduce it.

Together with British Airways, Heathrow and Edinburgh Airports in 2010, NATS tested a "Perfect Flight" concept. Every factor within the journey from push back off the stand and taxiing, to optimised flight profile and continuous descent approach was calibrated to achieve minimal CO_2 emissions. The 3Di score for the perfect flight was 1.4 points; there was no vertical inefficiency and the score was directly attributed to the noise preferential routes on departure from Heathrow and manoeuvring on to final approach at Edinburgh. No flight will ever have a zero score and there will always have to be some inefficiency in the system due to runway direction and weather conditions, and of course, the need to maintain separation of traffic to ensure safety is uncompromised.

Only by gathering and analysing huge amounts of radar data from across the network over time is NATS able to obtain a real understanding of how it is performing in the delivery of services to its customers. Ultimately the 3Di metric allows NATS to track its performance and identify opportunities to reduce air traffic management related CO_2 emissions, while at the same time reducing airline customer fuel costs.



The 3Di methodology has evolved since inception to take account of improvements to data and analysis of performance. As a result, the CAA and NATS have agreed on revisions to the methodology and baseline. NATS' performance and progress to 2019 will be measured against whatever happened in the updated 2014 baseline (e.g. ATM strike days, bad weather days, runway closures, repositioning, diverts, holding issues), to be able to measure performance consistently.

The CAA has set annual targets for NATS which are broken down across control centres and airport units, based on traffic levels and the 3Di baseline. NATS includes all UK airports even if an ATM service is not provided there, and non-NATS controlled airspace (i.e. uncontrolled and delegated airspace). In turn, NATS is able to split the score and target across individual airspace sectors and review progress across controller shift patterns, which is helpful to identify and share best practices.

NATS' air traffic controllers are able to analyse the environmental efficiency of flights in near real-time, thanks to a Flight Optimisation System, or 'FLOSYS', which takes real radar data, updated every three minutes, and combines it with NATS' 3Di airspace efficiency metric to produce a graphical representation of every flight in UK airspace. Controllers can then analyse the efficiency of an individual aircraft through every phase of flight and airspace sector, as well as compare it against other flights along the same route, up to 12 months ago, including the average and best performing. By having access to this granularity of data, controllers and airspace managers are able to better identify the opportunities for operational improvements that will save our airline customers fuel and reduce air traffic management related CO_2 emissions.

The 3Di metric isn't perfect; it's not an academic research project designed in a lab – it's a metric developed using near-time operational data which must be responsive and dynamic. There are a number of simplifications and assumptions built in to the metric to make it work, given the volume of data from the 2.2 million flights handled annually. NATS seeks to be honest about what it can and cannot do, and have highlighted what it was designed to do from the outset. Indeed, some of the recent improvements have been based on constructive feedback received from controllers, and some of it is based on lessons learned. 3Di has been exceptionally useful in helping to identify, challenge and resolve inefficiencies in airspace. The monthly 3Di scores are reviewed by NATS senior management, and NATS continues to work with its controllers, customers and other stakeholders to identify opportunities and solutions to improve the score. NATS also regularly reports to its customers, regulator and with the public on progress against the 3Di targets.

The alternative EUROCONTROL KEA (average horizontal en route flight efficiency) metric is useful to benchmark performance across NATS' European peers; however, as with any metric, it also has its weaknesses. For example, KEA is limited to the portion of the flight trajectory beyond a 40 nautical mile circle around departure / arrival airports and does not capture airspace inefficiency close to airports, e.g. in the London Terminal Manoeuvring Area. KEA also does not cover vertical profile inefficiency. The 3Di metric shows that in 2015, 80% of the inefficiency in UK airspace fell within the 40 nm zone near airports, while 26% of the inefficiency in UK airspace was vertical.

NATS' 3Di metric and the alternative EUROCONTROL KEA metric both support measurement of operational performance. This enables air navigation service providers to identify areas for impermanent and to benchmark their relative performance. The metrics additionally are useful to help measure the environmental benefits of implementing various Aviation System Block Upgrade (ASBU) modules, as part of the ICAO Global Air Navigation Plan.

The improvements made to airspace efficiency, even if quite small, cumulatively add up to significant savings for NATS' airline customers in terms of delay, CO_2 emissions and fuel. It is a complicated relationship, which is why airspace performance is managed separately with its own targets. NATS' initiative has been recognised across the industry and received the "Sustainable product and service award" from BITC in 2014 and was re-validated in 2015 after demonstrating further improvement.

NATS is grateful to all those who have contributed to the success of 3Di, including its airline customers and regulator. NATS has demonstrated the potential of 3Di and FLOSYS with a number of other Air Navigation Service Providers and is happy to continue sharing its experiences with other stakeholders across the industry to improve the network's efficiency and reduce ATM related CO_2 emissions.

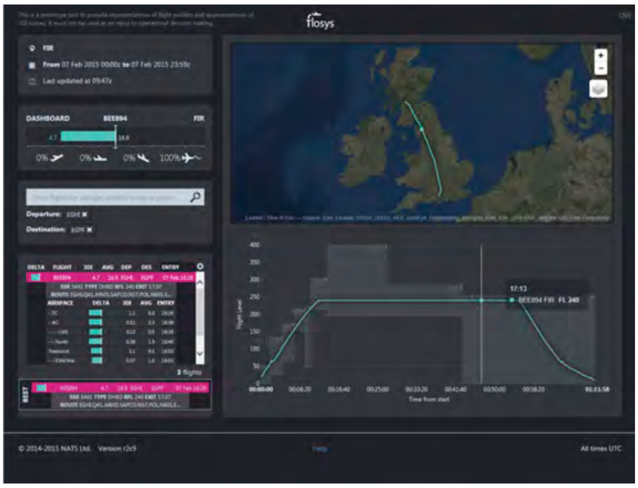


Figure 1. UK domestic flight profile

Figure 2. UK overflight profile

ICAO'S WORK ON THE DEVELOPMENT OF A GLOBAL MBM SCHEME FOR INTERNATIONAL AVIATION

BY ICAO SECRETARIAT

Market-based measures (MBMs) have been on ICAO's agenda for a number of years as one of the elements of the basket of measures to mitigate the climate change impacts of international aviation. In 2013, the 38th ICAO Assembly resolved that ICAO and its Member States with relevant organizations would work together to strive to achieve a collective medium term global aspirational goal of keeping the global net CO_2 emissions from international aviation from 2020 at the same level (so called Carbon Neutral Growth 2020). Aiming to ensure the fulfillment of this aspirational goal, the Assembly unanimously decided to develop a global MBM scheme for international aviation. Assembly also requested the ICAO Council to finalize all preparatory work, organize seminars and workshops, identify major issues and problems, and make a recommendation for a global MBM scheme that addresses them. Assembly requested the Council to report the results of the above work for decision at the 39th Assembly in 2016.

Why MBMs for International Aviation?

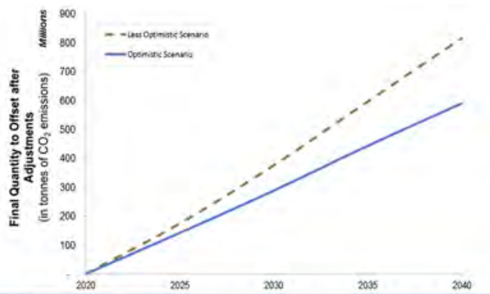
According to the Intergovernmental Panel on Climate Change (IPCC 4th Assessment Report, 2007), aviation (both international and domestic operations) is estimated to be responsible for approximately 2% of global CO_2 emissions. International operations account for approximately 65% of total aviation emissions, thus representing 1.3% of the global CO_2 emissions. The assessment undertaken by ICAO's Committee on Aviation Environmental Protection (CAEP) concluded that annual CO_2 emissions from international operations were 448 Mt in 2010. Significant improvement in efficiency of air transport operations and technological progress has been made in the aviation sector, with aircraft produced today being much more fuel efficient per passenger kilometre than in the 1960s. Total aviation emissions, however, are forecasted to grow in the coming decades, and the aggregate environmental benefit achieved by these measures will be insufficient for the sector to reach its aspirational goal of carbon-neutral growth from 2020.

In addition to improving operational efficiency and achieving technological progress, aviation community is putting significant efforts in promoting the use of sustainable alternative fuels that have a reduced carbon foot print compared to conventional jet fuel (see article page 153). However, hurdles (mainly economic) still exist to prevent a large scale production.

A complementary global MBM scheme would act as a policy tool that would allow for an immediate response to the need for stabilising the emissions in a cost-effective manner for international aviation to meet its aspirational goal.

Assessment of the Impacts of the Global MBM

As requested by the ICAO Council, CAEP and its Global MBM Technical Task Force (GMTF) provided the analyses on the impacts of a global MBM. Firstly, CAEP analysed the total quantities of CO_2 emissions from international aviation, and estimated the total expected quantities to offset. Based on the analysis (see summary of the results in **Figure 1**), the estimated quantity to be offset by the whole international aviation sector would be of the order of 142 to 174 million tons of CO_2 in 2025; and 443 to 596 million tons of CO_2 in 2035.



Final Quantity to Offset after adjustments (in Million tonnes of CO_2 emissions)	2020	2025	2030	2035	2040
Less Optimistic Scenario	-	174	376	596	816
Optimistic Scenario	-	142	288	443	590

Figure 1. Final Quantities to Offset. Source: CAEP analysis presented at EAG/15

CAEP also analysed possible costs of the proposed global MBM scheme by multiplying the estimated quantities of offsets with the assumed prices of an emissions unit (or carbon price). It should be noted that the carbon prices drive significant uncertainty in total cost impacts of offsetting CO_2 emissions from international aviation, and total cost estimates vary, depending on the assumptions.

In 2025, total offsetting costs vary from 1.5 to 6.2 billion US$, and in 2035, total costs vary from 5.3 to 23.9 billion US$ in 2035, depending on the assumed carbon prices (see summary of the results in **Figure 2**).

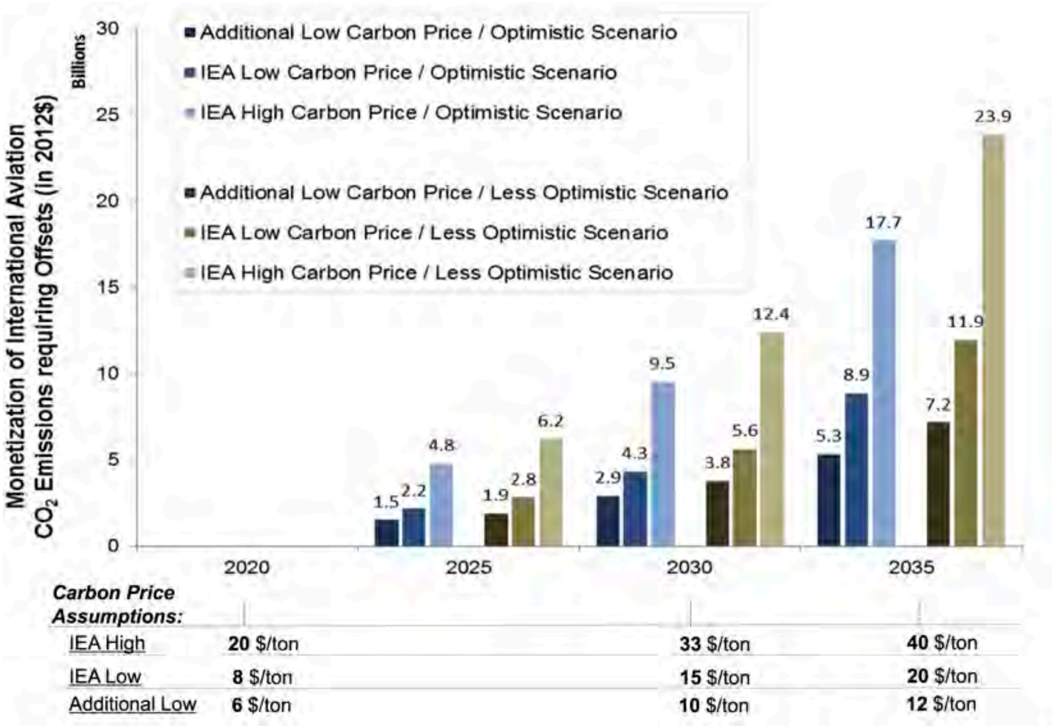


Figure 2. Cost of Offsetting with different Price Scenarios. Source: CAEP analysis presented at EAG/15

Putting in perspective with the reality of the business, the analysis also shows that the cost of carbon offsetting for operators would range from 0.2 to 0.6 % of total revenues from international aviation in 2025; and 0.5 to 1.4 % of total revenues from international aviation in 2035.

The cost of carbon offsetting for operators would range from 0.2 to 0.6 % of total revenues from international aviation in 2025; and 0.5 to 1.4 % of total revenues from international aviation in 2035.

According to a related cost analysis conducted by IATA, the offsetting costs related to the implementation of a global MBM scheme are expected to have a much lesser impact on international aviation than that caused by fuel price volatility. The estimated offsetting cost in 2030 is equivalent to that of a 2.6 US$ rise in jet fuel price (per barrel); an extra 10 US$ per barrel on the price of jet fuel would cost the industry about four times the estimated cost of offsets in 2030. To give a reference on magnitude, over the past decade the standard deviation of the jet fuel price annually has been almost 40 US$ per barrel, meaning that airlines have managed to cope with oil price volatility (mostly upwards) of more than 15 times the size of the estimated offsetting cost in 2030.

Technical analysis also included estimating the cost impacts of various options for distribution of offsetting requirements to individual aircraft operators under the global MBM, e.g., using different combinations for individual operator's growth rate and the international aviation sector's growth rate, as well as the route-based approach, accumulative approach, and comparison of these approaches[2].

Progress at ICAO

Since the 38th Assembly, ICAO Member States and relevant international organizations have actively been engaged to fulfill the request for the development of a global MBM scheme. In March 2014, the ICAO Council established the Environment Advisory Group (EAG), composed of 17 Council Representatives, to oversee all the work related to the development of a global MBM scheme and make recommendations to the Council. The EAG met a total of 15 times, and at its final meeting in January 2016, summarized deliberations and analyses conducted over the two years on options for a global MBM scheme.

Progress was pursued by the EAG, starting with a basic proposal for a global MBM scheme with a view to generating discussion and analyses on advantages and disadvantages of design elements, thus allowing for improvements. The EAG also discussed the work by CAEP to develop technical elements of a global MBM scheme, i.e., monitoring, reporting and verification (MRV), emissions unit criteria (EUC) and registries. The tenth meeting of the CAEP (1 to 12 February 2016) reviewed a vast amount of technical work related to the global MBM scheme and made recommendation to the ICAO Council. Pending to further decisions on a global MBM scheme by the Council and the 39th Assembly, GMTF's work programme for years 2016 – 2019 aims to produce additional technical recommendations that are needed to implement the global MBM.

In addition, as a means to ensure the full engagement of all States and other stakeholders and widest possible range of inputs, and to respond to the Assembly's request to organize seminars and workshops on a global MBM, ICAO organized two rounds of Global Aviation Dialogues (GLADs). The first round of five GLADs was organized throughout April 2015 across the ICAO regions in Peru, Kenya, Egypt, Singapore and Spain, with 362 participants in total from 79 States and 22 international organizations[3]. The second round of GLADs was organized in March/April 2016 in Egypt, Senegal, Indonesia, the Netherlands and Mexico, with 390 participants in total from 60 States and 20 International Organizations[4]. The GLADs was a forum for information sharing and exchange of ideas, rather than a forum for decision-making. The main objective of the GLADs was to reach out to those States that are not directly engaged in the Council or CAEP. The GLADs allowed for well-informed deliberations on a global MBM scheme in the ICAO process toward the 39th session of the ICAO Assembly.

362 participants in total from 79 States and 22 international organizations attended the first round of GLADS in 2015 and 390 participants in total from 60 States and 20 International Organization attended the second round of GLADS in 2016


2016 GLAD in Cairo, Egypt


2016 GLAD in Dakar, Senegal


2015 GLAD in Madrid, Spain


2015 GLAD in Nairobi, Kenya

2016 GLAD in Bali, Indonesia


2016 GLAD in Mexico City, Mexico

In January 2016, the Council established a High-level Group on a Global Market-Based Measure Scheme to facilitate the convergence of views on a proposal for a global MBM scheme. The Group was comprised of high-level aviation and/or transport representatives of 18 States on the Council, taking into account equitable geographical representation. The group met in February and April 2016, and made progress on improving the proposal text.

Further in the process to develop a global MBM scheme for international aviation, a High-level Meeting on a global MBM scheme was held in May 2016 in Montreal with the purpose of facilitating a high-level discussion of a proposal on a global MBM[5]. The Meeting successfully clarified and improved a number of provisions in the proposal. The Meeting also recognized issues where further improvements were necessary, as well as possible alternative approaches and ideas to address the issues. The outcome of the Meeting was considered by the ICAO Council in June, after which the Council invited States to hold bilateral and multilateral consultations related to the draft Assembly Resolution text on a global MBM scheme. A "Friends of the President" informal group meeting was held in Montréal, Canada, from 22 to 23 August 2016, to evaluate the results of these consultations and develop compromise text for consideration by the Council, and its subsequent submission to the 39th Session of the ICAO Assembly. Timeline towards the 39th ICAO Assembly and beyond is presented in **Figure 3**.

GLADs –
Unique Format to Reach out ICAO Member States
To facilitate the engagement of participants, the GLADs used a unique small-group format to organize thematic dialogue sessions on design elements and implementation aspects of a global MBM scheme. The GLADs also featured an interactive panel discussion with representatives from States, industry, environmental NGOs and financial institutions.

In terms of the outcomes of the GLADs, 2015 GLADs identified major considerations for the design of a global MBM scheme, such as: administrative simplicity, environmental integrity, cost effectiveness, differentiation/non-discrimination, and avoiding excessive cost or administrative burdens. 2016 GLADs highlighted the links between these major considerations identified by 2015 GLADs with the proposed global MBM scheme.

The structure and format of the GLADs successfully familiarized participants with the proposed global MBM scheme; provided opportunities to receive feedback from Member States and relevant organizations; and served as preparation towards the 39th Assembly.

ICAO's Proposal for a Global MBM Scheme for International Aviation

In early 2016, the ICAO Council started to discuss a proposal (in a form of draft Assembly Resolution text) for the global MBM scheme. The proposal would create an offsetting scheme for international aviation, aiming to its achieve carbon neutral growth from 2020 (or a 3-year average around 2020) onwards. A baseline

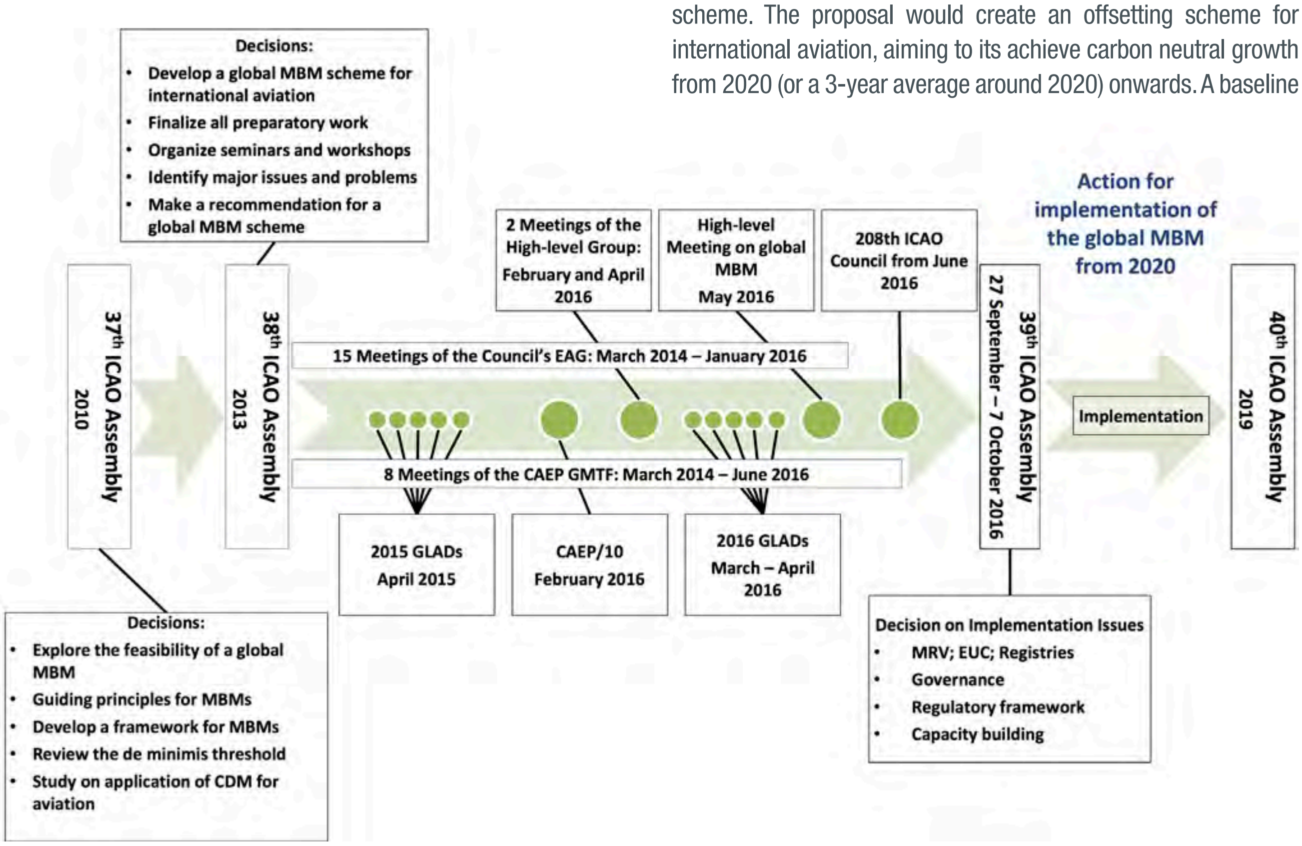


Figure 3. Timeline towards the 39th ICAO Assembly and beyond

Main Features of the Proposed Global MBM Scheme*

Phased implementation

- To accommodate special circumstances and respective capabilities of the States, the proposed global MBM scheme introduces a phased-in implementation, which classifies States in groups with different implementation timelines.
- To further acknowledge States' different capabilities, Least Developed Countries (LDCs), Small Island Developing States (SIDS) and Landlocked Developing States (SIDS) and Landlocked Developing Countries (LLDCs) would be exempted from the scheme
- Nevertheless, States not included in the scheme are encouraged to voluntarily participate in the scheme.

Route exemptions

- The global MBM would apply to all aircraft operators on the routes between States, both of which are included in the scheme. Provision ensures equal treatment of all operators on the same routes, thus avoiding market distortion between operators.

Distribution of offsetting requirements

- CO_2 emissions required to be offset by an aircraft operator would be defined by combining operator's emissions growth with a sector-wide growth factor.

Technical exemptions

- In order to simplify the global MBM scheme and avoid unnecessary administrative burdens, the proposal provides exemptions for small operators, new entrants and special operations, such as firefighting and search and rescue flights.

Implementation of the proposed global MBM scheme

- The proposal requests ICAO Member States to implement a MRV system, which includes procedures on how to monitor the fuel use, collect data and calculate CO_2 emissions; report emissions data; and verify emissions data to ensure accuracy and avoid mistakes.
- EUC ensures that operators purchase appropriate emissions units from eligible mechanisms, programmes or projects. Reduction of one tonne of CO_2 equals one emissions unit. One example of emissions reduction programmes is the UNFCCC Clean Development Mechanism (see article page 146)
- Registries are a means to check that the operators are in compliance with the global MBM.
- To ensure uniform application of the scheme, the proposal calls for ICAO and Member States to take all necessary actions in providing the capacity building and assistance and to build partnerships to ensure successful implementation of the global MBM scheme.

for international aviation emissions in 2020 would represent the basis against which emissions in future years are compared. The difference between the emissions in any year after 2020 and the baseline would represent the sector's offsetting requirements for that year.

The proposal builds on the progress and feedback from the process since the 2013 ICAO Assembly and considers the need for a global MBM scheme to be simple, cost-effective, ensure environmental integrity, avoid excessive administrative burden as well as accommodate differentiation of States without discrimination.

Once agreed, implementation of the global MBM can begin. The proposal outlines an ambitious timeline for preparing the implementation towards year 2020, and requests ICAO Council to ensure that necessary capacity building and assistance will be in place. ICAO is already identifying partnerships amongst Member states and stakeholders to facilitate provision of technical and financial assistance for ensuring universal implementation of the MRV system and Registries, building upon existing assistance projects in this area.

Conclusion

ICAO has made tremendous progress in developing a global MBM scheme for international aviation. Subject to the final decision on the design elements by the 2016 ICAO Assembly, the CORSIA (Carbon Offsetting and Reduction Scheme) would be the first global MBM scheme for a whole sector, and a major step to complement the efforts made by States in the context of the Paris Agreement. Action for the implementation of the global MBM scheme for international aviation from 2020 will start right after the Assembly.

Sustainable Development Goals

*Reflects the main features of the proposal as of May 2016. Further updates were expected prior to the 39th Assembly. For final result from the Assembly, please refer to the Green pages in this report's post-Assembly edition.

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3. For all material considered by the 2015 GLADs and full results, please visit the webpage: http://www.icao.int/meetings/GLADs-2015/Pages/default.aspx
4. For all material considered by the 2016 GLADs and full results, please visit the webpage http://www.icao.int/meetings/GLADs-2016/Pages/default.aspx
5. For all material considered by the High-level Meeting, please visit the webpage: http://www.icao.int/Meetings/HLM-MBM/Pages/default.aspx

AVIATION, OFFSETS AND THE PARIS AGREEMENT

BY NICLAS SVENNINGSEN (UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE - UNFCCC)

After many years of intense negotiations, the 195 parties to the United Nations Framework Convention on Climate Change (UNFCCC) adopted on 12 December 2015 in Paris a new global agreement on how all countries collectively will tackle climate change. The Paris Agreement is widely recognized as the most significant environmental treaty ever adopted, with strong positive implications on development, international cooperation and, of course, for the climate. The ambition is to hold the increase in the global average temperature to well below 2ºC above pre-industrial levels and pursue efforts to limit the temperature increase to 1.5ºC.

One of the fundamental aspects of the Paris Agreement is that it is entirely inclusive. For the case of aviation, however, there is a long standing understanding that the effort to address greenhouse gas emissions from international air traffic, which does not fall under any national jurisdiction, is under the authority of the International Civil Aviation Organization (ICAO). ICAO also regularly updates the UNFCCC's Subsidiary Body for Scientific and Technological Advice on its climate change related work, thereby ensuring consistency between the two processes. It is therefore very timely that ICAO's 39th General Assembly will convene already in September 2016, and at that time will be in a position to decide on the aviation sector's contribution to the global response to climate change. The Paris Agreement clearly sets a baseline for the ambition for such considerations.

ICAO has actively addressed climate change in aviation since several years. In 2013, the 38th ICAO Assembly decided that ICAO would develop a global market-based measure (MBM) scheme for international aviation, with a final decision expected to be taken at the 39th ICAO Assembly, to allow the scheme to be fully operational from 2020 onwards. MBM is one of the measures in the "Basket of Measures" to reduce emissions from civil aviation that ICAO is working to develop, with MBM allowing the aviation sector to use offsets as one of several ways to address its climate footprint.

The fundamental idea with offsets is that while it is clearly the responsibility of all parts of society to reduce their emissions as much as possible, the technology and economics of today do not always allow them to achieve more significant emission reductions immediately. In that situation offsets represent a way for the emitters to invest in emissions reductions elsewhere, and to count the achieved emission reductions, represented as offset certificates, as part of their contribution to global emission reductions. From the perspective of the atmosphere, it does not matter where emission reductions are achieved as long as they happen in addition to in-house emission reductions, not instead of in-house emission reductions. By cancelling (tearing up) the offset certificates, they cannot be transferred onwards, and thereby the corresponding emission reductions are permanently counted to the stakeholder who invested in, and cancelled, the offsets.

Offsets are not a new approach, but were introduced at a global level already in 1997 with the adoption of the UNFCCC Kyoto Protocol. Among other tools conceived by the Kyoto Protocol was the Clean Development Mechanism (CDM), which became fully operational in 2004. CDM generates offsets by enabling investments in emission reduction projects in developing countries, partly being financed through the sale of CDM offsets (Certified Emission Reductions - CER). Each CER represents one ton of reduced greenhouse gas emissions, which are rigorously verified and validated by both UNFCCC and independent third-party verifiers before they are issued by UNFCCC. From an initially shaky start, CDM has evolved, improved and strengthened its functions and environmental integrity to become the mechanism it is today. With close to 8000 registered projects in 103 countries and almost 300 "programme of Activities" (large scale CDM project clusters), and with a current potential offset generation capability of close to 5 billion CERs up to 2020, it represents the largest mechanism of its kind in the world.

CDM encompasses 8000 registered projects in 103 countries with a current potential offset generation capability of close to 5 billion CERs up to 2020

Originally, the CDM offsets were intended to be used by developed countries to meet their Kyoto Protocol emission reduction targets that they may not be able to achieve only through domestic measures. Over time, however, the quality and environmental integrity of CERs have also made them popular for voluntary use in the corporate sector or by countries outside the Kyoto Protocol. This use is labeled "voluntary" since their use is not counted under any Kyoto protocol obligation.

The Paris Agreement, through Article 6, confirmed that the use of market mechanisms will continue to play an important role in the global effort to address climate change. Cooperative Approaches, generating as well as a new mechanism contributing to mitigation and sustainable development, were introduced by Article 6, as was the concept of non-market approaches. Both the Cooperative Approaches and the new mechanism represent ways in which offsets or other forms of emission reductions units may be recognized in the new climate architecture created by the Paris Agreement. The accompanying COP decision further clarifies a number of principles for how the new mechanism should be designed, including that it should be based on lessons learned from mechanisms previously created under UNFCCC, such as CDM. It is noteworthy that Article 6 is inclusive, not exclusive, in the sense that it indicates that Cooperative Approaches under the UNFCCC process need to be consistent with guidance to be adopted by the parties, but do not prescribe any unique mechanism for generating the ITMOs.

When CDM several years ago took the step to also allow the use of CERs outside the Kyoto Protocol it became evident that a system originally created for country-to-country level cooperation was not always easily accessible for users in corporate and voluntary sectors. UNFCCC therefore launched in September 2015 an on-line platform (www.offset.climateneutralnow.org) that allows anybody with an internet connection to simply select, pay, and cancel the CERs they wish to use.

The online platform provides direct access to CERs so that the user can identify the CDM project that the CERs come from, the host country, the type of emission reduction technology, or the associated sustainable development benefits. The cost for a CER is set by each CDM project and is today typically in the range of half a USD to five USD per CER. The user can thus select the type and number of CER they wish to purchase by putting them in the "shopping basket". At the online check out, they pay with a credit card or PayPal. Immediately when this is done, the ownership of the CERs are transferred to the buyer and they are automatically cancelled in UNFCCC's CDM Registry, which holds all CERs available at the on-line platform. The user receives confirmation on-screen and via e-mail that the transaction is complete, and normally within two working days the user also receives an official certificate from UNFCCC confirming the cancellation of the CERs. The certificate states the number of CERs cancelled, the name of the canceller as well as the purpose for which the CERs have been cancelled, as indicated by the user.

The experience from purchasing/cancelling CERs at the online platform is thus similar to many other online transactions, e.g. booking of hotels, reservation of flight tickets or purchasing of merchandise online.

Following the successful launch of the online platform in late 2015 it will be further developed and strengthened. Significant new features planned include:

- additional means of payment, such as through bank transfer;
- improved access to information about sustainable development benefits associated with the CERs on offer;
- business-to-business capabilities to allow companies to integrate the online platform into their business systems, thereby enabling automatic cancelling of CERs, e.g. every time a ticket is issued.
- increased supply of CERs to encompass the wider supply from all registered CDM projects.
- an express option that allows users to only indicate the number of CERs to be cancelled, without having to select from what projects they come from.

In September 2015, the UNFCC launched its first on-line offsetting platform.

The advantage for stakeholders in the aviation sector, or really any other sector wishing to offset their climate footprint, is that the cancellation is easy, quick and comes with virtually no costs apart from those paid for the CERs[1]. The system also allows for selecting the country, technology, or the sustainable development benefits that are associated with the CERs, so that the CERs selected may have some link with e.g. the country of the user. In addition the environmental integrity of the offsets is guaranteed by UNFCCC.

So what challenges and opportunities lie ahead for CDM and the online platform? A fundamental uncertainty, which was resolved through the Paris Agreement, was whether offsets would be recognized at all in the new climate regime. Article 6 confirms that offsets will continue to be recognized well beyond 2020. The nuts and bolts of what criteria these offsets or ITMOs need to meet, and how they will be counted for so as to ensure that there is no double counting of emission reductions is now in the hands of parties to develop. CDM will continue at least until the end of the second commitment period of the Kyoto protocol (2023) but it seems that it will gradually be replaced by the Paris Agreement as it comes into force.

Since CDM effectively already today operates outside the compliance markets defined by the Kyoto Protocol, and since the mechanism is financially self-sufficient, CDM is well equipped to continue to operate also in the new climate architecture. This, of course, requires that CDM will evolve as needed to respond to the criteria to be established for ITMOs. This is the same requirement that will be put on any other mechanism generating ITMOs. That CDM will evolve as needed is not a farfetched assumption considering the tremendous investments and efforts that has gone into CDM over the past decade and the flexibility it has shown in responding to lessons learned and new requirements.

A clear difference between CDM in the Kyoto protocol and the CDM in the post-2015 world is that it will no longer be "the only game in town". The new mechanism defined by Article 6 in the Paris Agreement, and any other mechanism (or "cooperative approaches" in the Paris Agreement language) that may aspire to generate ITMO's will in reality offer alternatives to CDM. However, in this universe CDM has comparative advantages that put the mechanism in a good position to continue to evolve and support mitigation action globally. This includes its rigorous UNFCCC approved standards, its extensive infrastructure, and its readily available supply of CDM offsets.

From the perspective of international aviation, it is clear that the Paris Agreement has provided significant clarification about the context within which a MBM would operate. The expectations on ICAO from stakeholders and parties alike are clearly conveyed through the overarching well-below-2^{o}C target with the aim of 1.5^{o}C of the Agreement. The conditions for building a MBM that is aligned with the international climate architecture under UNFCCC have never been so favorable. With high quality, easily accessible offsets immediately available under UNFCCC, and with a clear direction for the future development of offsets under the Paris Agreement, there should be nothing stopping ICAO from taking an ambitious, yet realistic and practical, decision on how aviation will be part of the solution to climate change.

References:

1. The operation of the Online platform is funded by CDM itself (see reference[2]). This, however, does not include the nominal fees that PayPal or credit cards charge for any transaction.
2. CDM's operations are funded through a small fee (share of proceeds) that is charged for every CER that is issued.

CARBON MARKETS, THE SIMPLE REALITY

BY KATIE SULLIVAN (INTERNATIONAL EMISSIONS TRADING ASSOCIATION-IETA)

Carbon markets around the world received a boost from the new Paris Climate Change Agreement, adopted by Parties to the United Nations Framework on Climate Change (UNFCCC) in December 2015. Article 6 of the historic Agreement allows for the cross-border trade of greenhouse gas (GHG) reduction units, as well as establishing a new international crediting mechanism to encourage sustainable development. Accompanying decisions will see experiences and lessons from existing market mechanisms used in developing the rules for this new global system – including the Kyoto Protocol's Clean Development Mechanism (CDM), the regulatory body that has been gearing-up to potentially serve the aviation sector[1].

The Paris Agreement's inclusion of market provisions was made possible by a groundswell of carbon market support and action around the world. Whereas at the last major UNFCCC climate talks, in 2009 in Copenhagen, the EU Emissions Trading System (ETS) was the only major game in town, the intervening six years have seen other carbon markets sprout across the globe.

According to the World Bank's Carbon Pricing Watch 2016[2], approximately 40 countries now put a price on carbon, with over half using some form of ETS. At the sub-national level, over 20 states and provinces have implemented, or are planning to implement, trading and offset crediting programs. When China's seven existing pilot cap-and-trade programmes transition to a national ETS from 2017, the world's annual value of implemented carbon pricing initiatives will potentially double to USD 100 billion from today's USD 50 billion year. These figures and trends tell the story, and the message is clear: markets are here to stay.

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With the spread of emissions trading more broadly, time is running out for sectors to remain exempt from compulsory actions to cut their emissions.

The 1997 Kyoto Protocol tasked both the International Civil Aviation Organization (ICAO) and the International Maritime Organization (IMO) with tackling their respective sectoral emissions, given the global nature of aviation and shipping. However, after minimal progress by 2009, the EU took matters into its own hands and passed legislation extending its ETS to aviation, applicable to all planes taking off or landing in an EU nation from 2012, regardless of its destination or point of origin – or where it is flagged. Cue uproar, legal challenges and a diplomatic row.

But it was not until the airlines had received their allocations, priced in compliance costs to fares and were well into the first year of compliance that a détente was reached. At the end of 2012, the EU agreed to temporarily suspend the aviation provisions for one year (i.e., for 2012), to allow the ICAO Assembly to reach a deal on a plan at its 2013 triennial General Assembly. The provisions were later amended in 2013 to only apply to flights between airports in the European Economic Area region until 2016. The rationale behind idea was the understanding that, by the end of 2016, ICAO would have a decision to implement a global Market-Based Mechanism (MBM) to ensure carbon neutral growth from 2020.

Meanwhile, at ICAO's 2013 Assembly, governments endorsed a proposal to decide on a global MBM for aviation at the next triennial Assembly meeting in 2016, to take effect from 2020. Given the temporary derogation in the EU ETS, along with the momentum for climate action globally, this year's 39th Session of the ICAO Assembly is crucial.

To ensure the programme is of high environmental integrity, this last criteria – emission reductions that are beyond business-as-usual (i.e., they would not have occurred without the programme) is crucial. This concept, known as *additionality*, is integral to existing offset programmes, such as the CDM, Gold Standard, and Verified Carbon Standard (VCS), and other similar voluntary and compliance systems. Independent verification of claimed reductions is also important, which would measure the reductions against an accepted baseline.

Bringing a market to the aviation sector makes sense. Since 1999, IETA has championed the use of well-designed market-based mechanisms – trading and offsets – to curb greenhouse gas emissions, ensure certainty in environmental outcomes, and achieve these goals at least cost to business, consumers and society at large.

Markets and the use of offsets are also a good way to bridge borders and encourage wider participation in a global response to the global environmental challenge – an especially important

Figure 1. IETA carbon pricing map, June 2016

feature for an international sector like aviation. Offsets are also proven and powerful cost-containment tools. The opportunities for low-cost 'internal' reductions for aviation are limited, and are already being pursued as part of the carbon neutral growth strategy. Thus, access to a broad and robust pool of low-cost offsets can help the sector go further, faster, and cheaper en-route to reaching its climate goals.

With several offset programmes already in operation, there is a wealth of experiences and tools that an ICAO MBM can draw upon. Rather than start anew, there is nothing to stop ICAO's programme from deciding to use one or more of these existing systems. This would ensure that a 2020 start date could be met – particularly then as the amount of institutional and technical architecture needed, not to mention MBM design features, would be greatly reduced.

Tapping existing offset markets and programmes, with all the accompanying methodologies, rules and procedures, would also allow for more energy to be spent on the political question of obligations: who will do how much, and by when. These questions are pivotal to the successful design and implementation of market-based mechanisms in general, and gain more attention in the context of international aviation. Indeed, international aviation is the first-ever sector to consider the adoption of a global MBM, thus crystallizing expectations. Being a pioneer means that new pathways have to be created but international aviation has demonstrated on numerous occasions that it can respond to this type of challenge.

Since the 2013 Assembly, ICAO has actively engaged with its Member States and relevant international organizations in the development of a global MBM scheme. To this end, the ICAO Council established the Environment Advisory Group (EAG), composed of 17 Council Representatives, in March 2014. The EAG, under the direction of the Council, was to oversee all the work related to the development of a global MBM scheme and based on the results of its deliberations, to make recommendations to the Council. The Council was supported in its technical and analytical work by the Global MBM Technical Task Force (GMTF) of the ICAO Committee on Aviation Environmental Protection (CAEP). The current proposal would create a global offsetting system for the aviation sector, whereby operators can acquire or trade emissions units from approved programmes, projects or emissions trading scheme which reduce emissions beyond business-as-usual.

References:

1. In November 2015, the CDM Executive Board approved the first methodology to credit GHG reductions from aviation, for the installation of electric motors to the landing gear of aircraft to reduce emissions from taxiing.
2. World Bank Group, Ecofys "Carbon Pricing Watch 2016" (May 2016)

CDM METHODOLOGIES

BY ICAO SECRETARIAT

The Clean Development Mechanism (CDM) of the United Nations Framework Convention on Climate Change (UNFCCC) was established as part of the 1997 Kyoto Protocol. It incentivizes the implementation of emission-reductions projects in developing countries, which earn saleable certified emission reduction (CER) credits for each tonne of CO_2 that the project reduces. During the first commitment period of the Kyoto Protocol (2008 to 2012), more than 1,650 projects were initiated under the CDM, producing CERs amounting to more than 2.9 billion tonnes of CO_2[1].

Baseline and monitoring methodologies are agreed by the UNFCCC Executive Board in order to provide a consistent means for determining the emissions reductions associated with the project. They are required to establish a project's emissions baseline, or expected emissions without the project, and to monitor the actual ongoing emissions once a project is implemented. The difference between the baseline and actual emissions determines what a project is eligible to earn in the form of CERs, as shown in Figure 1.

Methodologies exist for nearly every conceivable type of project, but prior to 2015 there were none in the aviation sector. Following the successful collaboration of the ICAO and UNFCCC Secretariats, today two aviation-related methodologies are recognized within the CDM programme: AM0116, "Electric taxiing systems for airplanes" and AMS-I.M., "Solar power for domestic aircraft at-gate operations." These methodologies are available for use on projects related to domestic aviation, as international aviation emissions are outside of the scope of the CDM programme.

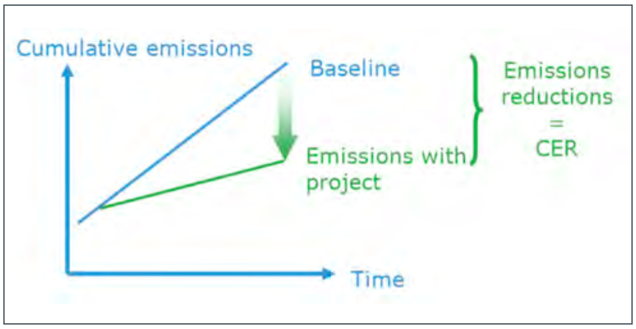


Figure 1. How a CDM project generates a CER.

Electric Taxiing Systems for Airplanes (E-Taxi)

Electric taxiing, or E-taxi, systems allow aircraft to move on the surface without requiring any power from the main engines. Instead, electric motors that are powered by the on-board Auxiliary Power Unit (APU), which consumes significantly less fuel, are used, as shown in **Figure 2**. One of the aims of the CDM programme is to accelerate the implementation of new measures. Since this technology is not yet widely deployed, it was identified as a candidate.

The methodology requires the definition of a baseline scenario, which will be the basis against which the benefits are measured. This baseline is defined based on the standard operating procedures for the project aircraft and may include any combination of multi multi-engine taxi, single-engine with APU taxi, and even the use of towing operations. The CO_2 emissions savings delivered from the project are the difference between the fuel consumed by the APU powering the E-taxi system and the baseline. An aircraft with an E-taxi system installed will burn slightly more fuel while airborne, due to the approximately 300 kg mass of the system. An adjustment factor is included in the methodology to account for this.

33 kg of CO_2 per minute saved

The use of electric taxi systems can save 33 kg of CO_2 per minute on a typical narrow body aircraft while the aircraft is taxiing. For flights of 9 hours or less, the benefits are positive, even when considering the fuel burn penalty from the weight of the system.

Figure 2. An aircraft with an e-taxi system installed taxiing using only the power from the APU.
Source: http://articles.sae.org/12662/

Figure 3. Solar panels at an airport and an aircraft receiving pre-conditioned air and power while parked at a gate.
Source: http://www.passengerterminaltoday.com/viewnews.php?NewsID=36516

Solar Power for Domestic Aircraft At-Gate Operations

Whenever aircraft are being serviced, loaded, and unloaded, they require power to operate their electrical systems as well as the internal heating, ventilation, and air conditioning systems. Most passenger aircraft are able to generate their own power using the APU, or receive power and pre-conditioned air, either from a ground power unit or directly from the gate. The solar power for domestic aircraft at-gate operations methodology aims to replace CO_2 intensive sources of energy for parked aircraft with renewable solar energy as illustrated in **Figure 3**.

The infrastructure in place at airports can vary widely, from a fully equipped gate that includes power and pre-conditioned air, to a stand with no service, thereby requiring the aircraft to run its APU. As a result this methodology provides guidance for defining baseline emissions based on the systems serving parked aircraft. Each minute that an aircraft does not need to run its APU while parked saves an average of 5.6 kg CO_2.

5.6 kg of CO_2 saved per minute

Sustainable Development Goals

Looking to the Future

The successful development of these two CDM methodologies have paved the way for projects related to domestic aviation to generate CERs. The ICAO and UNFCCC Secretariats are continuing to investigate other potential projects within the sector for which methodologies could be developed.

References

1. Source: http://unfccc.int/kyoto_protocol/mechanisms/clean_development_mechanism/items/2718.php

PROGRESS IN CLEAN RENEWABLE ENERGY SOURCES FOR AVIATION

BY ICAO SECRETARIAT

Sustainable Alternative Fuels

The use of sustainable alternative fuels is an important element of the basket of measures for reducing aviation's impact on the global climate and also on air quality. Recognizing the need for information exchange in this important area, ICAO held its first Conference on Aviation and Alternative Fuels in 2009 and launched the ICAO Global Framework on Aviation Alternative Fuels (GFAAF). This online platform (http://www.icao.int/altfuels) provides a continuously updated database of activities and developments in the field of alternative aviation fuels, as well as useful documentation and links, to support information sharing and dissemination for the benefit of the aviation fuels community.

In the nearly seven years that have passed since the ICAO Conference, the progress achieved in this area has been impressive. At that time, ASTM D7566, *Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons,* which provided the framework for approving alternative jet fuel pathways had just been published. Today, there are five pathways that have been approved under ASTM D7566 for producing alternative jet fuel and two airports are providing significant quantities of biofuel to their customers, demonstrating beyond any doubt the technical feasibility of producing alternative fuels for aviation that do not require changes to aircraft or fuel delivery infrastructure.

GFAAF

Global Framework for Aviation Alternative Fuels

While the technological feasibility for alternative jet fuels is proven, barriers to large-scale deployment of such fuels remain. The most significant challenge affecting the demand for alternative fuels is the tremendous price gap between conventional fuels and biofuels for aviation. Suppressed demand for alternative aviation fuels then, in turn, limits the investment in biorefineries that is needed in order scale-up production. Incentives and policies are possible means to facilitate sustainable, commercial-scale deployment (see articles page 155, page 159 and page 166).

2009	2010	2011	2012	2013	2014	2015	2016
• ASTM D7566 Approved • ICAO GFAAF Launched	• First single-engine propeller transatlantic flight from Canada to Germany powered on biofuel	• First commercial flights operated using biofuel	• Flightpath to a Sustainable Future, an ICAO special Rio+20 global initiative, the first-ever series of connecting flights powered by sustainable alternative fuels, on which the ICAO Secretary General, travelled from Montréal to Rio de Janeiro	• First regular flight operations using alternative fuel began between New York, United States and Amsterdam, Netherlands	• 21 airlines used alternative fuel on commercial flights	• Oslo Airport in Norway became the world's first "bioport" by offering 2.5 million litres of aviation biofuel annually to its users	• Fifth pathway for alternative jet fuel approved on 14 April 2016 and Los Angeles international airport in the United States, will have more than 56.8 million litres of aviation biofuel available over a 3-year period

Other Sources of Clean, Renewable Energy

Sustainable alternative fuels is an important form of clean energy being embraced by the aviation sector, but it is not the only one. As reported by the International Renewable Energy Agency, IRENA, the cost to install renewable electricity facilities, in particular wind and solar power, has fallen sharply in recent years and are expected to continue declining over the near term. This trend is enabling the transition to renewable, clean sources of energy for aviation. Based on the Action Plans on Emissions Reduction submitted by States, 59 States representing 79 per cent of global international air traffic indicated that they will pursue investments in sustainable alternative fuels for aviation and 37 States representing nearly 35 per cent of global international air traffic intend to engage in clean and renewable energy use at airports. ICAO is currently implementing a pilot project in Jamaica for the use of solar power at airport gates for providing electricity and pre-conditioned air to parked aircraft. In addition, as described in later in this chapter, a methodology under the UNFCCC Clean Development Mechanism (CDM) for the quantification of emissions reductions from the use of solar-at-gate was approved in 2016 (see article page 151).

Figure 1. Solar at airport

Emerging Technologies

Although not ready for wide-scale application today, the use of solar energy offers promise for aircraft propulsion over the long term. As announced in 2014, ICAO is an Institutional an Aeronautical Partner for the Solar Impulse around-the-world flight that is demonstrating the potential of using clean, renewable, solar energy for powering an aircraft in flight. In addition, a number of experimental electrically-powered aircraft demonstrations have been conducted, showing a future where aircraft may no longer be dependent on liquid fuels (see article page 174).

Figure 2. Solar impulse (courtesy of Solar Impulse)

Next Steps

Promotion, further information sharing and exchanges between States on clean, renewable sources of energy continue to be pursued through ICAO. Recognizing the substantial progress achieved in recent years, an ICAO seminar on the topic is planned for February 2017 to serve as an information session for a Conference on sustainable alternative fuels and clean energy for aviation that will be held in November that year to ensure the right steps are taken to foster the development and deployment of clean energy sources to power aviation activities.

Sustainable Development Goals

HOW SkyNRG IS TAKING SUSTAINABLE JET FUEL TO THE NEXT LEVEL

BY MEREL LAROY (SkyNRG)

SkyNRG was founded in 2010 and officially launched after supplying the first commercial biofuel flight, operated by KLM in 2011. SkyNRG was set up to create a market for sustainable jet fuel and has built up a track record in recent years, supplying most of the biofuel flights to date.

The need for aviation to become part of the bio-based economy was evident. Especially as there has been a strong focus in recent decades from governments and industry on the development of a bio-based economy. This trend has emerged for three reasons: the need for carbon emissions reductions, energy security and resource resilience, and economic development and industry innovation.

However, the global nature of the aviation industry makes it difficult to regulate biofuels and carbon emissions as in some other industries. The aviation industry has recognized the need for sustainable biojet fuel as there is no other known practical alternative to liquid energy carriers. Biofuels are the only option to bridge a transition to any (yet unknown) new propulsion technology, which may emerge in the next 30 years.

In the last five years, aviation has emerged as one of the front runners in voluntarily embracing the development of sustainable fuels. After SkyNRG supplied the world's first commercial biofuel flight in 2011, the company received biofuel requests from all over the world and over the following two years the company supplied biofuel to more than 20 customers, including: Finnair, Alaska Airlines, Etihad, Qantas Australia, LAN Chile, and Air Canada. The biofuel flights by those companies demonstrated the feasibility of the product and that biofuel, when produced according to strict standards, is a safe and sustainable aviation fuel. Since then, there has been growing interest from the aviation industry in sustainable jet fuel and a large collective effort is underway to scale production capacity.

However, high price premiums have been the biggest challenge that limited the uptake of sustainable jet fuel to-date. This has partly been caused by an uneven playing field with the mandated road transport biofuels sector (in the EU and USA). The road transport suppliers are under these mandated systems obligated to blend biofuels into the existing fuel system. As the aviation industry is not obligated, existing production capacity allocates its resources towards road transport biofuels, consequently driving up the prices of biojet fuel. Since airlines do not have enough capital to pay the premium for sustainable jet fuel, SkyNRG installed several "smart" co-funding mechanisms to bridge the price gap with fossil fuels. For example, in 2013 SkyNRG started to actively involve other stakeholders such as governments, airports and even an airline' corporate customers; all parties which can also benefit from developing a market for aviation biofuels. By co-funding the premium, these parties help to aggregate demand and enable production capacity in the short term.

SkyNRG & Sustainability
From the start, SkyNRG set the bar high when it comes to the sustainability of biojet fuel. SkyNRG has its operations RSB certified and is advised by an independent Sustainability Board in which the World Wide Fund for Nature (WWF-NL), Solidaridad, and The Energy Academy hold a seat. SkyNRG's sustainable jet fuel has the potential to reduce CO_2 emissions by up to 80%, compared with fossil jet fuel.

A successful example is the **KLM Corporate BioFuel Programme** that was launched in 2012. This programme offers KLM's corporate customers such as ABN AMRO, Nike and Accenture an opportunity to reduce their corporate carbon footprint from business travel by flying (partly) on sustainable biofuel. The programme enabled SkyNRG and KLM to launch the first weekly series of biofuel flights between New York and Amsterdam, demonstrating that biofuel can provide a real sustainable solution for the aviation industry in the long term.

Figure 1. KLM Corporate BioFuel Programme: Biofuel Flights From Amsterdam to Aruba and Bonaire. (Photo credit: KLM)

The KLM Corporate BioFuel Programme

The KLM Corporate BioFuel Programme (CBP) was launched in 2012 with a series of biofuel flights to the RIO+20 United Nations Conference on Sustainable Development. The corporate partners in the programme pay a surcharge that covers the price difference between sustainable jet fuel and fossil jet fuel. With this biofuel, these companies reduce their CO_2 footprint from business travel and at the same time contribute to the further development of this market. So far, the programme has enabled biofuel flights to Rio de Janeiro from Amsterdam Paris, from New York to Amsterdam, from Amsterdam to Aruba and Bonaire, and from Oslo to Amsterdam. Current partners in the programme are ABN AMRO, Accenture, CBRE Global Investors, FMO, FrieslandCampina, City of Amsterdam, Heineken, Loyens & Loeff, Nike, Perfetti van Melle and the Schiphol Group.

The Fly Green Fund

The Fund, a first of its kind in the world, enables organisations and individuals to reduce their carbon footprint, by flying on sustainable jet fuel. Its main focus is to secure the necessary funding to increase the demand for sustainable jet fuel in the Nordics. The Fly Green Fund is different from carbon offsetting schemes run by airlines around the world. Instead of compensating for CO_2 emissions, the Fly Green Fund helps to make the aviation industry itself more sustainable. This industry can only be build when all key stakeholders work together. That's why the Fly Green fund is not just restricted to one airport or airline but welcomes all partners that are committed to make sustainable jet fuel a reality in Sweden.

In 2015 SkyNRG launched a similar corporate program in The Nordics, called the **Fly Green Fund**. The fund was co-founded by NISA and Karlstad Airport, with Partners from the aviation industry such as Swedavia, SAS, KLM, Braathens, and European Flights Services. The fact that the Nordic countries are booming in the field of sustainable jet fuel was also proven by the recent **Launch at Oslo Gardermoen Airport**. In January 2016, this airport was the first in the world to make sustainable jet fuel available for all airlines refuelling from the airport's main fuel farm, via the existing hydrant system. This was partly made possible by Avinor, the Norwegian airport operator that has taken a very proactive role in phasing in jet biofuel for aviation, making Oslo Airport available for the project and covering a significant share of the premium cost of the sustainable jet fuel.

Figure 2. Fueling With Biofuel at Oslo Gardermoen Airport. (Courtesy Avinor).

Another initiative is a business model that engages airports as key stakeholders in growing the market for sustainable jet fuel. For this initiative, SkyNRG is partnering with Carbon War Room, a non-profit entity that accelerates the adoption of business solutions that reduce carbon emissions and advance the low-carbon economy (see article page 159). Currently, SkyNRG is also working on an end-customer proposition, offering individual travellers the opportunity to buy their personal 'biofuel-ticket' and contribute to sustainable flying.

In parallel with these co-funding programmes, SkyNRG is setting up regional supply chain "BioPorts" for sustainable jet fuel. The company is teaming up with airlines and airports around the world to create the structure and the market pull that will enable regional sustainable jet fuel supply chains to get financed and built. The BioPort model is based on a regional approach which means that the benefits can go well beyond carbon reduction. SkyNRG sees energy security, reduced price volatility, (potential) development of local communities and rural areas, adding value to (marginal) lands and economic growth, as main drivers to engage a broader group of stakeholders (e.g. governments, farmers, investors, NGOs). For a Bioport, SkyNRG uses the feedstock that makes most sense for the subject region and engages the right conversion technology.

SkyNRG already launched several BioPorts including: BioPort Karlstad, BioPort Brisbane, and BioPort Holland. Apart from SkyNRG being a Dutch company, an important reason why a BioPort is being developed in the Netherlands, is the incentive structure, offered by the government. Since 2013 the Dutch government has allowed biojet fuel to voluntarily opt-in under the European Renewable Energy Directive (RED) mandate for road transport fuel. This opt-in allows biojet fuel suppliers to generate biofuel certificate, which can be sold to the obligated party in the road transport sector. Therewith, biojet fuel counts towards the member states' 10% Renewable Energy Share target and at the same time this mechanism helps to bridge the price gap between fossil and bio jet fuel. SkyNRG is currently actively encouraging other EU Member States to follow this example as the company considers this a very important tool to accelerate the development of sustainable aviation biofuels in Europe.

BioPort Holland

BioPort Holland is an initiative focused on creating a local supply for sustainable bio jet fuel in the Netherlands. The stakeholders aim to create a structural bio jet fuel supply and demand hub for Western Europe. Current partners are: KLM, Schiphol Airport, SkyNRG, Port of Rotterdam, Neste, the Ministry of Economic Affairs (EZ), and the Ministry of Infrastructure and Environment (I&M).

In the short term (2014-2018), the partners focus on getting a bio jet fuel supply chain up and running tosupply significant quantities of sustainable bio jet fuel to Schiphol Airport. Key efforts for 2016 are: setting up the physical supply chain, ensuring sufficient volumes of truly sustainable feedstock, developing financial mechanisms to overcome the initial premium price, and assisting with project development financing.

With its BioPort model, SkyNRG is bringing together technology players, governments, airlines, airports and NGOs all over the world to further develop the market for sustainable jet fuel. In Europe, these activities are brought together under the RenJet project; a collaboration involving industry, entrepreneurs, and knowledge institutes that jointly aim to lay the basis for regional bio jet fuel supply chains in Europe. RenJet is facilitated, driven, and sponsored by Climate KIC and is regarded as one of the highest impact projects on sustainable jet fuel in the European Union.

Project Solaris (Photo Credit:Sunchem)

Biofuel at Oslo Gardermoen Airport

From January 2016, all airlines refueling at Oslo Airport can have sustainable jet fuel delivered from the airport's main fuel farm, via the existing hydrant system. The fuel was made available by SkyNRG, Air BP and Avinor, the Norwegian airport operator. Avinor played a key role in the commercial offtake agreements by the early commitment to the project and by paying a significant share of the premium cost of the sustainable jet fuel for all flights at Oslo Airport that are powered sustainable jet fuel. The sustainable jet fuel is produced by Neste in the framework of the demonstration project ITAKA, funded by the European Union's Seventh Framework Programme. ITAKA (Initiative Towards sustaAinable Kerosene for Aviation) is the first project worldwide that demonstrates the entire value chain for biojet production and the first supported by the EU of this scope. This project has received funding from the European Union's Seventh Framework Programme for research technological development and demonstration under grant agreement No 308807. In addition to using biofuel from the hydrant system, some of the biofuel for KLM will be delivered by refueling trucks. In cooperation with Embraer, biofuel efficiency will be assessed in comparison with fossil kerosene.

Project Solaris

Sunchem SA and SkyNRG have teamed up to scale the energy rich tobacco crop "Solaris" in South Africa, supported by South African Airways and Boeing. Solaris is a nicotine-free and GMO-free crop variety that yields significant amounts of sustainable oil (as feedstock for bio jet fuel) and high quality animal feed. As of September 2015 the cultivation of Solaris has been certified by the Roundtable on Sustainable Biomaterials (RSB) ensuring compliance with rigorous environmental and social standards. Starting in Limpopo province, the partners are laying the basis for a new regional bio jet fuel supply chain. Through this project they will bring economic and rural development to the region in a sustainable way.

Currently the company is involved in a number of feedstock projects. One of these collaborations is project **Project Solaris**, an effort to develop sustainable jet fuel in South Africa from the nicotine-free tobacco plant variety, called Solaris. The project involves SkyNRG and Sunchem, and is supported by Boeing, South African Airways, and RSB. In Canada, SkyNRG is involved in a project with Boeing, Air Canada, WestJet, Bombardier and the University of British Columbia to turn forestry-industry waste into sustainable jet fuel.

In the coming years, SkyNRG expects that an important change in supply dynamics will come from the certification of renewable diesel as a blend-stock with fossil jet fuel. The certification of this product as a jet fuel component is expected in the second half of 2016 and will increase the capacity to 3 million tons globally. At the same time, there are a growing number of initiatives that focus on optimizing the supply process of biofuel by moving from delivery by truck to an integrated supply chain, whereby the fuel will be distributed via the hydrant system of the airport. Oslo Airport is a great example of this. These are very important steps to truly integrate sustainable jet fuel into the existing infrastructure, making this fuel just like any other fuel, but with the extra advantage that it is much more sustainable.

The RenJet Project – by Climate KIC
The RENJET project accelerates the development of sustainable Bio Fuel supply chains that may account for up to 20% of jet fuel demand in the European Union in 2025. The project develops knowledge, practices, procedures and tools, tests and pilots them, towards the overall goal of a self-sustaining network of regional renewable jet fuel supply chains throughout Europe and beyond.
The activities range from: selecting and expanding the supply of available feedstock(s), managing stakeholders and conversion steps, support of ASTM certification up to signing offtake agreements for certified Bio Fuel, and defining business models that take all stakeholders into account.

SUSTAINABLE ALTERNATIVE FUELS: AN OPPORTUNITY FOR AIRPORT LEADERSHIP

BY ADAM KLAUBER (CARBON WAR ROOM), ANNIE BENN (CARBON WAR ROOM) AND PETRA KOSELKA (CARBON WAR ROOM – UNTIL 2016)

Low-carbon alternative fuels are critical for reducing aviation greenhouse gas emissions. Production and uptake of Sustainable Alternative Fuels (SAF) have progressed steadily since the first-ever biofuel flight in a commercial aircraft in 2008, and more than 1,500 commercial flights have used SAF since 2011[1]. Airlines, OEMs, and governments have played key roles in spurring this advancement, but true commercial scale remains elusive under the current paradigm.

Commercializing SAF is a new frontier, which requires a bold and creative new approach. We at the Carbon War Room are proposing a paradigm shift for the industry, engaging airports to act as key players in catalyzing commercial-scale uptake. The airport-led business model we have developed will establish SAF demand centers, providing a strong market signal to producers and supporting robust supply chains. While we recognize that most airports today are not directly involved in aviation fuels, this innovative, airport-led model, with buy-in from airlines and other airport stakeholders, can overcome the last barriers to commercial-scale SAF use.

Carbon War Room, a business unit of the independent non-profit organization Rocky Mountain Institute, is tackling this challenge directly by working with airports to implement the SAF program described here.

Introduction

The aviation sector has adopted ambitious goals to address its contribution to climate change, with alternative low-carbon fuels as a key element to achieve these goals. Recognizing the importance of alternative fuels in the future of aviation, governments, multi-stakeholder initiatives, and individual airlines have set SAF adoption targets: the European Commission set a target for the European Union of 3% to 4% SAF penetration by 2020, and 40% by 2050, and for the United States, the FAA's goal is 5% SAF market share by 2018[2].

We have a long way to go to reach these targets. Far from being an integrated part of the global aviation fuel mix, SAF today is primarily distributed via boutique supply chains with high associated transaction costs and logistical burdens. The volume of SAF in the market is increasing, but market penetration is still close to zero. Substantial industry shift is required in order to realize a mature SAF industry that is fully integrated into global aviation fuel markets and that can meet stated penetration targets.

Carbon War Room envisions this shift occurring at the individual airport level, with the airport itself playing a key role. Integrating SAF directly into the on-airport fueling infrastructure, at an airport-wide blend ratio, will transition SAF from an alternative product used by some airlines on a project basis, to a standard product that is used for business-as-usual. This standardization would send a strong and consistent demand signal to the SAF industry, which boosts investor confidence and catalyzes industry growth. Individual breakthroughs driven by airlines, such as United's leadership at Los Angeles International with AltAir Fuels, are difficult to replicate given the associated administrative burden and costs for the carrier. We believe that airports are thus key to unlocking this new paradigm.

Why Airports?

Airports can leverage their unique position at the intersection of airlines, fuel suppliers, fuel operators, governments, and communities to support SAF's transition from isolated procurement transactions to use in regular operations. Because

FIGURE 1. ADVANTAGES OF AIRPORT- BASED APPROACH

an airport can aggregate fuel demand across all airlines, and also plays an integral role in the regional economy where it is located, an airport-led approach will benefit airlines, communities, and the airport itself. **Figure 1** illustrates key advantages to each of these stakeholders.

These advantages include:

- **Economies of scale.** Aggregating demand across all airlines at the airport increases total volume while reducing transaction costs, logistical complexity, and administrative burden.
- **Reduced risk.** Fuel requirements at an airport level are generally stable, providing a bankable commitment for SAF producers. Additionally, the increased diversification of the fuel pool adds robustness to the fuel supply, decreasing fuel supply risk.
- **Equality.** Refueling all airlines at the same blend ratio enables smaller airlines without the resources to implement a SAF off-take agreement to participate. It also avoids the competitive distortion resulting from a single airline shouldering the SAF procurement burden.
- **Regional economic development.** A proven airport demand center can encourage investment in regional feedstock production and alternative-fuel refinery capacity, and can stimulate increased downstream activities in the region.
- **Reduced CO_2 emissions.** Using SAF can be up to 80% less carbon intensive on a lifecycle basis than conventional jet fuel[3]. As airports increasingly address their carbon footprint (138 airports around the world participate in Airports Council International's successful Carbon Accreditation program),[4] leading airports could consider implementing an SAF program as an innovative carbon reduction initiative.
- **Improved local air quality.** SAF use reduces SOx and particulate matter emissions during takeoff and landing, improving local air quality.
- **License to grow.** The environmental benefits of SAF use can mitigate environmental impact concerns related to proposed future airport activities and/or infrastructure.
- **Unique value proposition.** SAF availability enhances airport attractiveness for air service development opportunities by providing a unique service to interested airlines.
- **World leadership.** The airport-led approach is an opportunity to demonstrate world leadership in a bold, new, green initiative. Early adopter airports will earn public recognition and enjoy a PR advantage.

The specific business model proposed by Carbon War Room can support this innovative new role for airports by enabling these benefits while minimizing changes to existing procedures and processes.

The Carbon War Room Approach

Carbon War Room has developed a unique business model to deliver an airport SAF program. Carbon War Room (CWR) is a business unit of the Rocky Mountain Institute, an independent non-profit that delivers market-based solutions to a decarbonized economy. We further refined the model in cooperation with our partner SkyNRG, a global market leader in the blending, distribution, and sales of sustainable jet fuel. SkyNRG has the capability to orchestrate the logistics of this business model. As a partnership, we bring expertise in both alternative fuels and innovative low-carbon business solutions.

Using sustainable alternative fuels can be up to 80% less carbon intensive on a lifecycle basis than conventional jet fuel.

Our business model centers on the airport as an aggregator of fuel demand and of funds, and as an orchestrator of the procurement and delivery of SAF. SAF would be provided to all jet aircraft refueling at the airport at an airport-wide blend ratio. We envision an initial low blend ratio of 1% to 3%; a ratio which minimizes total costs while laying the groundwork for future volume increases.

The current refueling process would remain unchanged for most stakeholders. Airlines would continue to procure fuel from their current suppliers, at current prices, and refuel at the airport as usual. They would receive fuel that fully meets ASTM and other relevant standards. Additional administrative and logistical requirements for airlines would be minimal. Fuel supply security would be unaffected or improved. Fuel suppliers already operating at the airport would have minimal changes to their operations, if any.

The airport authority would designate an individual or team to manage the aggregation of funds to purchase the SAF (see the Funding and Cost section, below). The funds would be designated for the SAF project, and we recommend a transparent bookkeeping approach that allows all stakeholders to monitor the disbursements of designated funds. The funds cover the price premium of SAF, its blending, and its delivery to the airport fuel farm.

The project also requires an "orchestrator." The airport could assign internal personnel to this role, or contract an expert team. The roles of the orchestrator include: managing the procurement of the pre-blended, or neat, SAF (described as "biocomponent" in Figure 2B), overseeing the blending of the fuel, verifying fuel certification, and ensuring delivery of the final blended fuel. The fueling would be delivered directly to the existing airport fueling infrastructure (i.e., tank farm, hydrant system, etc.), to allow all jet aircraft refueling at the airport to use the blend. It is important to note that once the neat SAF has been blended into the conventional fuel, the resulting blended fuel is fully certified as Jet A or Jet A-1 and can be blended into the rest of the fuel pool, using existing airport infrastructure and standard procedures. **Figures 2A** and **2B** illustrate the current and proposed supply chains in one of our candidate airports.

FIGURE 2A. CURRENT AIRPORT FUEL SUPPLY CHAIN (ILLUSTRATIVE)

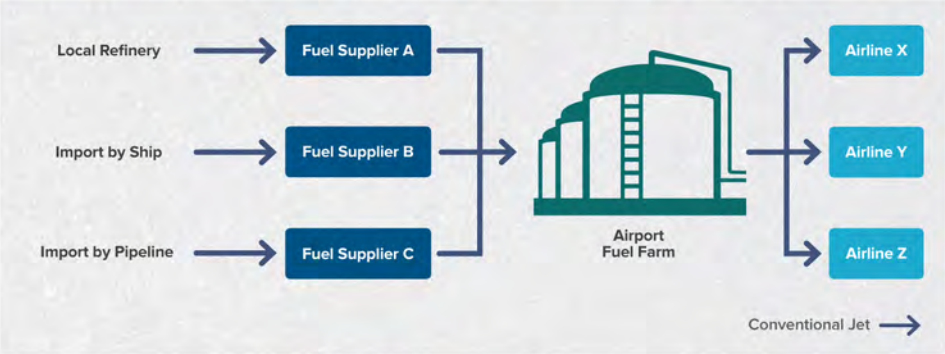
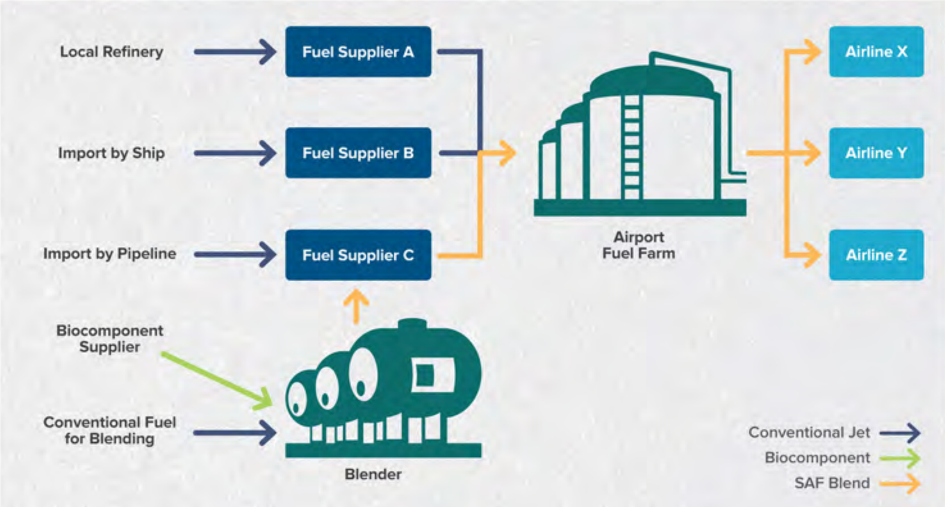


FIGURE 2B. PROPOSED "HYBRID BLENDING" (ILLUSTRATIVE)



The fuel supply chain schematic illustrated above is based on the situation at a specific candidate airport. Supply chain modifications will vary on an airport-by-airport basis. Note that the blender can be a new or existing fuel supplier.

The orchestrator would also ensure the sustainability and traceability of the fuel, manage reporting to airport stakeholders, (e.g. airlines, fuel suppliers, etc.), and coordinate the communication of progress and achievements in the media. As the environmental and social sustainability of feedstocks are key concerns for many aviation stakeholders, including passengers, we recommend the airport procure fuel that adheres to the standards put forth by the Roundtable on Sustainable Biomaterials (RSB). Financial responsibilities of the orchestrator would include budgeting, accounting for any relevant credits or subsidies, insurance and risk management, financial reporting, and any obligations under an offsetting scheme. The orchestrator would procure as much SAF as possible with the available funds (this may vary from year to year).

Assigning these responsibilities to a centralized orchestrator minimizes stakeholder burden while accelerating impact.

Funding and Cost

As indicated above, the airport authority would manage covering the SAF cost premium. The cost of SAF relative to conventional jet fuel has decreased substantially over time, but a price differential remains. The airlines would cover the base jet fuel price as usual, so the airport would only need to cover the difference. Total cost would depend on the fuel volume at the airport, the blend ratio, and the type of SAF procured. **Figure 3**[1] illustrates sample per-passenger cost calculations. Note that the costs in the United States are lower than the costs in Europe due to the incentives provided by the US Renewable Fuel Standard.

The airport, working with its airline partners, would identify the best mechanism for covering the cost premium. This decision should be made on a case-by-case basis, taking into account the financial profile and preferences of the airport. Several potential funding sources to cover these costs are presented below. This list is not meant to be exhaustive, but rather illustrative of the variety of options available to airports interested in pursuing this business model.

Possible sources of revenues to cover the SAF cost premium include:

[1]Costs will vary by airport due to logistics, average fuel usage, and regional incentives. Airport identification has been removed for confidentiality. Per passenger rates are based on total passengers, and all values expressed in USD.

FIGURE 3. SAMPLE ESTIMATED COSTS

	EUROPEAN AIRPORTS		US AIRPORTS	
	Airport 1	Airport 2	Airport 3	Airport 4
Total Passengers	25 million	55 million	34 million	45 million
Per Passenger Cost (2.5% blend)	$0.70	$1.02	$0.33	$0.45

Non-aeronautical airport revenues, for example from activities such as vehicle parking.

Operational cost savings from sustainable energy infrastructure, cost reductions through capital investments, efficiency subsidies, and renewable energy incentives can be tracked and redirected towards the biofuels program.

Government subsidies, policies and grants could decrease the price differential. For example, in the US, under the Renewable Fuel Standard, blending of alternative fuels generates saleable credits (called RINs), and RIN revenue decreases the price gap. A similar "bioticket" system exists in the Netherlands. If the EU's Renewable Energy Directive could be applied in this way to aviation, it could reduce the premium by almost one-third. Additional possibilities in this category include municipal tax breaks and subsidies for job creation.

Contributions from locally based corporate sponsors/customers (similar to SkyNRG's Fly Green Fund model) would decrease the amount of airport funding required and provide a PR opportunity for the sponsors.

Impact

The primary environmental impact from increased SAF uptake is reduced CO_2 emissions. SAF can be up to 80% less carbon intensive, on a lifecycle basis, than conventional jet fuel[5]. The actual emissions reduction achieved depends on many factors, including the fuel volumes at the airport, the blending ratio, the type of feedstock, and refinery process, among other factors. For illustrative purposes, an airport using 25,000 tons of SAF (for example, as a 2.5% blend over 1 million tons of fuel airport-wide) would reduce emissions by 39,000–62,400 tons.

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FIGURE 4. IMPACT ON LOCAL AIR QUALITY*

POLLUTANT	REDUCTION (2.5% BLEND)
CO_2 (Life cycle basis)	-1.9%
LTO SO_x	-2.5%
LTO Fine Particles	-2.3%

*Extrapolated from NASA APEX, AAFEX and ACCESS missions. NOx and CO are excluded, as the impact of biofuels use on these emissions is inconsistent across fuel types. Table shows impact on aggregate emissions from total fuel burn.

Because many biofuels are more energy dense than conventional jet fuel,[6] carbon benefits are enhanced by factoring in the energy requirements associated with the liquid weight of the aircraft fuel. On longer routes, significant aircraft energy is required to transport the weight of the fuel itself. So if the fuel is more energy dense, then less fuel is required to travel a given distance, resulting in a beneficial feedback loop that further decreases emissions reductions.

An additional benefit of SAF use is the improvement of local air quality and associated human health benefits. SOx and fine particles are both proven to have negative impacts on human health7. They contribute to air pollution around the airport when emitted during takeoff and landing. Both SOx and fine particles can be reduced with SAF. **Figure 4** provides estimates of these improvements.[7, 8]

Looking Ahead

The airport-led approach described above represents a paradigm shift with the long-term impact of catalyzing rapid increases of SAF usage. As the international aviation sector pursues carbon-neutral growth from 2020, a mature SAF industry will provide valuable emissions reductions. This business model can jumpstart the transition of SAF from intermittent use to become the new business-as-usual.

[7]CO_2 calculations in Figure 4 assume a 75% lifecycle carbon reduction over conventional fossil jet fuel. Actual carbon reductions depend on the type of fuel, and in general range between 50-80%.

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LOOKING BEYOND CO_2

BY ROLF HOGAN (RSB)

The aviation industry contributes an estimated 13% of global transport CO_2 emissions[1], but simply looking at the climate impacts does not offer a full picture of aviation's impact. Even when biofuels are used for jet fuel in place of fossil fuels, they are not necessarily sustainable just because they are bio-based or made of renewable materials. The sustainability of biofuels goes beyond its environmental life-cycle. In line with the three pillars of sustainability, economic and social aspects can also be considered along with CO_2 emissions. This can cover: human and labor rights, rural and social development, local food security, conservation and biodiversity, soil impact, water and waste management, air quality, impact on small farmers, land use rights, and more. The good news is that there is movement towards achieving improvements in aviation's global impact.

Relevant stakeholders within the aviation sector are utilizing the standards and certification system developed by the Roundtable on Sustainable Biomaterials (RSB) as a way to improve its entire environmental and social impact, not just CO_2 emissions. RSB certification is helping key aviation players track and prove the sustainability of their biofuels. They use RSB's 12 principles and criteria to look at the aforementioned areas of concern, such as human rights, water management, local food security, etc. By looking at the entire biofuel impact and earning RSB certification, aviation companies can ensure that their biofuels are truly sustainable.

Importance of Strong Sustainability Standards

There are many benefits for aviation leaders to implement more rigorous and credible standards like the RSB standard to demonstrate sustainable biofuel, as follows:

- Implementing RSB's standard, can guarantee that an operation, or supply chain, is sustainable and addresses key global challenges, not just CO_2 emissions: food security, biodiversity, water, and poverty.
- It incorporates the sustainability issues that matter to leading global NGOs like WWF and UN agencies such as UNEP and FAO.
- It is recognized world-wide and provides access to global voluntary sustainable markets (as well as regulated markets).
- Associating with RSB can strengthen an airline's brand as a front-runner in aviation sustainability.

Once proven to meet RSB's standards, certified aviation operations are able to:

- Gain support from local communities, NGOs and governments by applying the RSB's stakeholder approach.
- Apply one system for all feedstocks and any bio-products.
- Have flexibility for local conditions as well as novel feedstocks and new technology.
- Identify and mitigate risks using the RSB's risk-based management approach.
- Ensure easy access for smallholders into supply chains with RSB's simplified approach for smallholders.
- Apply one system to the full supply chain and choose from different traceability options including mass balance.

For these reasons, the Sustainable Aviation Fuel Users Group (SAFUG), composed of leading airlines and airframe manufacturers, supports the development of global sustainability standards and has endorsed RSB's comprehensive sustainability principles through its pledge[2].

RSB also counts several airlines and airplane manufacturers among its members including Airbus, Boeing, JetBlue, South African Airways and Swiss International Airlines.

RSB ensures a comprehensive approach to sustainability by providing a framework to identify and mitigate key sustainability risks. It includes the following key components:

- Screening system to identify sustainability issues that need to be addressed.
- A range of guidance to assess and effectively manage issues identified by the screening, including soil, water, food security.
  - If operating in a region of food insecurity, RSB has an approach which helps operators to assess and develop plans to ensure food production is increased in the local area.
  - For operations in a region of poverty, RSB offers a framework to support development in line with the expectations of civil society groups.
- Stakeholder consultation helps achieve consensus /acceptance by local communities and substantially reduces the risk of conflict with producers and communities. The certification process also includes third party consultation during the audit which can help build trust with local communities.
- RSB's Environmental and Social Management Plan shows how to integrate all mitigation measures into a single comprehensive management system.

> "Membership of the RSB not only serves as recognition of SAA's African biofuels programme, but provides us with a further networking platform to engage with NGOs and leaders in the biomaterials field." **- Nico Bezuidenhout SAA's Acting CEO**

The Role of Sustainable Biofuels In Achieving ICAO's Climate Goals

Sustainable biofuels have an important role to play in addressing the climate change impacts of flying – but how do they interact with the other tools in ICAO's "basket of measures"? The most high-profile climate change measure in aviation right now is ICAO's market-based measure, for decision at this year's Assembly, to initially stabilise net CO_2 emissions at 2020 levels. It is expected that aircraft operators will have to offset growth in emissions above 2020 levels, but how do emissions reductions from sustainable biofuels fit in among the ICAO measures? It is currently an open – and important – question.

One option would be to "zero-rate" emissions from all biofuels. This option would be straightforward to implement and would probably incentivise the use of biofuels in the short term. However, "zero-rating" would ignore the real lifecycle emissions as well as social and wider environmental impacts of the biofuels. Another option would be to account for lifecycle and land use emissions, and introduce criteria to ensure that positive and negative sustainable development impacts are taken into account.

The RSB has developed several tools to simplify these tasks – including a sophisticated and user-friendly online Greenhouse Gas Calculator, and most recently, a module to help producers demonstrate that their biofuels pose a low risk of indirect land use change (ILUC). ILUC can cause damage to natural environments, undermine food security, and can even cancel out the emissions benefits of biofuels. It has heavily damaged the reputation of the road biofuels sector, but the aviation industry has a unique opportunity to learn from the past mistakes of other sectors and position itself as a leader on sustainability. RSB stands ready to work with ICAO and the aviation industry to facilitate the development of robust GHG methodologies and sustainability criteria.

Making An Impact

The aviation sector supports and endorses RSB as the most credible global standard for ensuring the sustainable production of biofuels and biomaterials. Etihad Airways, Virgin Atlantic, Boeing, United Airlines, NRDC (Natural Resources Defense Council), and WWF (World Wide Fund for Nature) have noted RSB's positive impact for sustainable aviation.

Certifications in the aviation sector include Sunchem Holdings, SkyNRG, and biojet fuel made with RSB certified camelina oil from Camelina Company España (CCE), which is now available for all airlines at Oslo airport. CCE has over 150 farmers in Spain demonstrating that large groups of farmers can be certified successfully and efficiently according to the RSB Standard.

RSB's impact, however, goes beyond certifications. RSB has been involved in several initiatives recently such as smallholder projects, addressing indirect land use change (iLUC) issues, and involvement with UN Sustainable Energy for All Initiative (SE4All), summarized below.

Smallholder Impact

As smallholder farmers in vulnerable communities and developing countries, which lack adequate environmental and social safeguards, seek to increase and intensify biomass production so as to participate in the global bioeconomy, they are at risk of inadvertently causing land and water degradation, loss of biodiversity, and food insecurity. If aviation projects are developed in areas currently dominated by smallholder farming communities, then care must be taken to ensure economically equitable treatment of smallholder farmers.

In general, smallholder producers are challenged with low institutional capacity, limited access to technology for higher yields, limited market access, and insufficient external support. These constraints make it more difficult for them to both achieve access to new markets, and to reach compliance with the RSB Standard and receive certification.

With the support of the Boeing Corporate Citizenship Program and the Swiss government, RSB's Smallholder Program seeks to improve the livelihoods of smallholder farmers by linking them to markets and promoting sustainable practices based on the RSB Smallholder Standard[3].

An example of the aviation industry coming together to support smallholders is 'Project Solaris'4. RSB's first smallholder project in South Africa was certified for the Solaris seed tobacco produced for biojet fuel. This collaboration with SkyNRG, South African Airways (SAA) and Sunchem is helping improve market access for local communities in the Limpopo region of South Africa while providing the aviation industry with a sustainable biojet fuel supply chain.

Indirect Land Use Issues

In 2015, RSB became the first sustainability certification standard to create "Low iLUC Risk Biomass Criteria and Compliance

Figure 1. Project Solaris Field, Photo Credit: RSB.

Indicators"[5] also known as the "iLUC Standard". This Standard helps producers demonstrate that biomass was produced with low indirect land use change (iLUC) and therefore minimal impact on food production or biodiversity. This is especially important for aviation companies that source biofuels from regions that have historically had land use change issues. The approach is in line with the Global Policy Statement of SAFUG on ILUC[6].

UN Sustainable Energy for All Initiative (SE4All)

RSB and the UN Food and Agricultural Organisation (FAO) are chairing the Sustainable Bioenergy Group (SBG) of SE4ALL (see article page 166). This coalition aims to speed up the development and deployment of sustainable bioenergy in order to contribute to meeting the SE4ALL goals of doubling the global use of renewable energy and ensuring universal energy access by 2030. Supported by Novozymes and the Inter-American Development Bank (IDB), SBG members include Bloomberg New Energy Finance, KLM, and the United Nations Foundation.

"RSB sees SE4All as a key framework to promote sustainable bioenergy at scale and believes that it will lead to the advancement of sustainable production on the ground supporting rural development, workers' rights, biodiversity protection, and reduction of greenhouse gas emissions, in line with international best practice outlined in the RSB standards," said RSB Chair Barbara Bramble.

Figure 2. KLM in flight, Photo Credit: KLM.

Conclusion

RSB's active engagement with aviation industry leaders has led to a growth in certification and membership. This demonstrates the aviation industry's interest in reducing its global footprint, not just for CO_2 emissions, but also for other environmental and human aspects – from livelihoods of smallholders, to conservation and biodiversity.

Now there are more resources and support available to the aviation industry than ever before. Through new advisory services, RSB can help aviation companies more efficiently implement the systems necessary to achieve certification in a way that aligns with their existing business practices. Investors can also receive RSB guidance for assessing and mitigating risks before making decisions in bio-based aviation projects. These are important steps to continue moving forward towards sustainable aviation.

RSB's continuing commitment to linking smallholder farmers to aviation markets and the aviation industry's uptake of advanced biojet fuels, and support of the RSB standard, bode well for the development of truly sustainable biofuels.

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SE4ALL SUSTAINABLE BIOENERGY GROUP: PARTNERING TO PROMOTE SUSTAINABLE AVIATION BIOFUELS

BY GERARD J. OSTHEIMER (SUSTAINABLE ENERGY FOR ALL)

Aviation and Climate Change

The Aviation Sector is showing tremendous leadership in addressing climate change. The International Civil Aviation Organization (ICAO) adopted aspirational goals of 2 per cent annual fuel efficiency improvements and carbon neutral growth from 2020 and a " Basket of Measures" to reduce international aviation CO_2 emissions. The aviation industry, through the Air Transport Action Group, committed itself to the ambitious goals of carbon-neutral growth from 2020 onwards and a subsequent reduction of net aviation emissions by 50% by 2050, relative to 2005 levels. ICAO reports progress on all elements of its "basket of measures", including aircraft technologies, operational improvements, sustainable alternative fuels and a global market-based measure. While improvements in aircraft technologies and operations are expected to contribute to reducing emissions, it is expected that the necessary deep cuts will come from the use of Sustainable Low Carbon Fuels that provide significant net reductions in CO_2 emissions relative to fossil-based aviation fuel.

After years of Research & Development investments, technological advances and the development of numerous strategic partnerships between airlines and fuel producers, sustainable aviation biofuels are emerging as a viable way to de-carbonize the aviation sector. The ICAO Sustainable Alternative Fuels (SUSTAF) Experts Group recognized the potential for Sustainable Aviation Biofuels but also recognized that the nascent sector needs to:

- Establish robust biomass feedstock supply chains;
- Ensure that the biomass feedstock is produced in an environmentally, socially and economically sustainable manner;
- Attract the necessary investment to build the first production facilities;
- Put in place policies that promote the use of Sustainable Aviation Biofuels; and
- Improve fuel production technologies by investing in Research and Development so as to achieve price parity with fossil-based aviation fuels.

Overcoming the complex, inter-dependent challenges of creating a vibrant, sustainable aviation biofuels industry *de novo* requires extensive participation of all stakeholders, including government support through stable, forward-looking energy policies and legislation. Establishing and maintaining such policies and triggering investment has proven to be a difficult task in mature aviation markets. Creating a viable biojet fuel supply industry in developing countries requires considerable international support, although several have the climate and biomass resources suitable for producing sustainable aviation biofuels at scale. If sustainable aviation biofuels could be produced in these countries, then the combination of global climate change mitigation benefits and local socio-economic benefits could generate a valuable "Win-Win" outcome. This is what SE4ALL is seeking to support.

SUSTAINABLE ENERGY FOR ALL

Sustainable Energy for All

The Sustainable Energy for All initiative (SE4All) is a multi-stakeholder partnership between governments, the private sector, and civil society that was launched by the UN Secretary-General in 2011. SE4All has three interlinked objectives to be achieved by 2030:

- Ensure universal access to modern energy services;
- Double the global rate of improvement in energy efficiency; and
- Double the share of renewable energy in the global energy mix.

SE4All leverages the global leadership and unprecedented convening power of the United Nations and the World Bank to assemble an unparalleled network of leaders from all sectors of society into a partnership that can transform the world's energy sector and contribute to advancing the 2030 Agenda for Sustainable Development adopted by the United Nations in 2015. Especially, we are committed to Sustainable Development Goal 7: "Ensure access to affordable, reliable, sustainable, and modern energy for all" and "to increase substantially the share of renewable energy in the global energy mix by 2030".

SE4All seeks to mobilize stakeholders around best practices, supports the adoption of innovative solutions and the creation of the conditions that will enable a massive scale-up of private investment in energy access and clean energy. As of 2016, SE4All has connected development agencies, development finance institutions, civil society organizations and multilateral institutions, such as the International Renewable Energy Agency (IRENA), into a powerful collaborative network capable of facilitating renewable energy projects in developing countries across the globe. Importantly, the SE4All community recognizes that only by harnessing the power of the private sector will renewable energy be deployed at the scales necessary to impact the global energy mix.

Se4all Sustainable Bioenergy High Impact Opportunity

In response to the UN Secretary General's call for the Private Sector to partner with SE4All, the global biotechnology company Novozymes catalyzed the creation of an open, voluntary partnership of likeminded stakeholders committed to promoting sustainable bioenergy solutions so as to assist SE4ALL in reaching its goals of universal energy access and doubling the use of renewable energy. The SE4ALL Sustainable Bioenergy High Impact Opportunity (HIO) was launched in May 2015. The HIO Founding Members are Bloomberg New Energy Finance, Carbon War Room, IEA Bioenergy, KLM/SkyNRG, Novozymes, Roundtable on Sustainable Biomaterials, UN Food and Agriculture Organization and UN Foundation. Of SE4ALL founding members, the Carbon War Room, SkyNRG and RSB are particularly active in promoting Sustainable Aviation Biofuels. Their work is also described in this publication (Chapter 4).

Several types of bioenergy projects are being promoted, including:

- on-farm bioenergy production to boost agricultural yield and reduce post-harvest losses;
- distributed electricity production using sustainable biomass from forestry and agriculture coproducts;
- electricity and fuels from municipal solid waste (MSW);
- ethanol for clean cooking and transportation;
- and sustainable aviation biofuels.

Already, the HIO is actively collaborating with its SE4All partners, such as IRENA and the Regional Hubs, to up-scale bioenergy development through knowledge enhancement and information sharing, policy support and deployment support. Additionally, the HIO is developing means of financing sustainable biomass power projects and renewable fuels projects across the globe.

Below50: A Public-Private Partnership to Promote Low Carbon Fuels

The Sustainable Bioenergy HIO moved a step forward in partnering with the World Business Council for Sustainable Development to create *Below50*, which is a global collaboration of forward-thinking companies that will grow the global market for the world's most sustainable fuels and accelerate the shift away from fossil fuels so as to achieve a carbon neutral transport sector.

The partnership was launched on 1 June 2016. Below50 is to be composed of companies that span the entire transportation fuel value-chain including fuel producers, investors, equipment manufacturers and end-users. Below50 is well suited to create linkages between aviation fuel consumers such as airlines and biojet fuel producers. Below50 is designed to:

- Increase the number of companies choosing Below50 fuels;
- Create inter-sectoral business-to-business opportunities across biofuel supply chains;
- Demonstrate that Below50 fuels make good business sense; and
- Address legislative and financial barriers to sourcing Below50 fuels.

Any company that produces, uses or invests in alternative fuels that are at least 50% less carbon intensive than conventional fossil fuels can join below50. They must publicly commit to the campaign, provide evidence of production, use, or investment in below50 fuels, and disclose their progress towards achieving promoting uptake of below50 fuels. Low carbon fuels is a major business opportunity, with the market for sustainable fuels estimated to reach $185 billion in the next five years. Sustainable fuels now make up only 3% of transport fuels, but this figure must grow to 10% by 2030 to meet economic growth and help keep global warming below 2 degrees.

Overall, Below50 wants to create a paradigm shift in the low carbon fuel sector, reach new customers and create new markets.

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AVIATION'S CARBON FOOTPRINT REDUCTION THROUGH SUSTAINABLE ALTERNATIVE FUELS

BY THOMAS RÖTGER (INTERNATIONAL AIR TRANSPORT ASSOCIATION)

Progress To-Date

The progress achieved over the last years in the development and deployment of sustainable alternative fuels for aviation (SAF) has been impressive. Before the first biofuel test flights in 2008, few experts would have believed that regular flights on biofuels would become a reality, and that within just eight years, we would see the first continuous SAF supply for airlines and airports.

The impressive achievements in SAF technology and supply development have clearly been motivated by the commitment to reduce aviation's environmental impact and especially its carbon footprint. This is supported by the entire aviation industry, governments and ICAO.

Despite significant developments in aircraft technology, and operational and infrastructural fields, the fuel efficiency improvements achieved by these means will likely not be enough to keep up with air traffic volume growth which is projected to continue at 4% to 5% annually in the coming decades. De-carbonization of air transport through the use of SAF is therefore an essential part of the strategy to achieve carbon-neutral growth from the year 2020, and the long-term goal of 50% emissions reductions by 2050 compared in comparison to 2005 levels[1].

So far, there have been two important development phases[2]:

1. 2008-2011: the test flight phase, starting with the first flight powered by a SAF blend by Virgin Atlantic in 2008, followed by an intense series of other flights using a variety of fuels from different feedstocks.
2. 2011-2015: a phase of over 2000 commercial flights powered by SAF blends, operated by 23 airlines across the globe; these started immediately after the certification of HEFA fuels for commercial flights in July 2011.

All these test and demonstration flights were carried out by individual aircraft operating on a few city-pair routes, with segregated and closely monitored fuel supply. However, by early 2016, we had reached the moment of transition - from test and demonstration flights to commercial deployment - with two major milestones recently achieved:

- On 22 January 2016, Oslo Airport started regular supply of a SAF blend through its existing common fuel distribution system. This is the first time an airport has made SAF available to all refueling aircraft, relying on existing infrastructure[3].
- On 11 March 2016, the SAF producer AltAir started regular SAF supply for United Airlines flights out of Los Angeles International Airport. These companies entered into an initial three (3) year offtake agreement at a volume of 15 million gallons (roughly 15,000 tonnes per year). This was the first in a series of– SAF supplier long-term offtake agreements with a number of airlines that was concluded in recent years[4].

Thus, regular SAF supply for commercial flights has become a reality. Various other airlines and airports are preparing similar supply chains for the coming years. Nevertheless, successful large-scale commercial deployment will depend strongly on favorable energy policy and legislation incentivizing production and use of SAF.

Technical Progress

Aviation is a global business and some airlines operate flights to/from more than a hundred countries. Therefore, it is essential that jet fuel offered anywhere in the world is compatible with the entire commercial fleet operating worldwide. Also, alternative jet fuels must be able to use the existing fuel distribution infrastructure, as building up a parallel infrastructure would be prohibitively costly. Consequently, only "drop-in" alternative fuels can be accepted, i.e. fuels which: can be blended with conventional jet fuel over reasonably wide percentage ranges, can use the existing fuel distribution system, and do not require adaptations of the engines or aircraft fuel system. The "drop-in" quality is likely to be essential for alternative jet fuels over the next few decades. The technical standards organization ASTM International has created standard D7566[5] for the certification of alternative jet fuels in this context. The physical and technical requirements that an alternative fuel must meet are essentially the same as for conventional jet fuel, and once a fuel is certified under D7566, it is considered as certified jet fuel (i.e. meeting the general jet fuel standard ASTM D1655), and can be used in the same way as conventional jet fuel without restrictions.

So far, three different SAF production pathways have been certified under the ASTM standard D7566, namely:

- Fuels produced by the Fischer-Tropsch process from any kind of biomass or other carbon-containing feedstock (2009).
- Fuels from vegetable oils or animal fats by the HEFA (hydrogenated esters and fatty acids) process (2011).
- Synthesized Iso-Paraffinic (SIP) fuels from sugars, also known as DSHC (direct sugar-to-hydrocarbon) (2014).

Six other processes are currently undergoing the ASTM

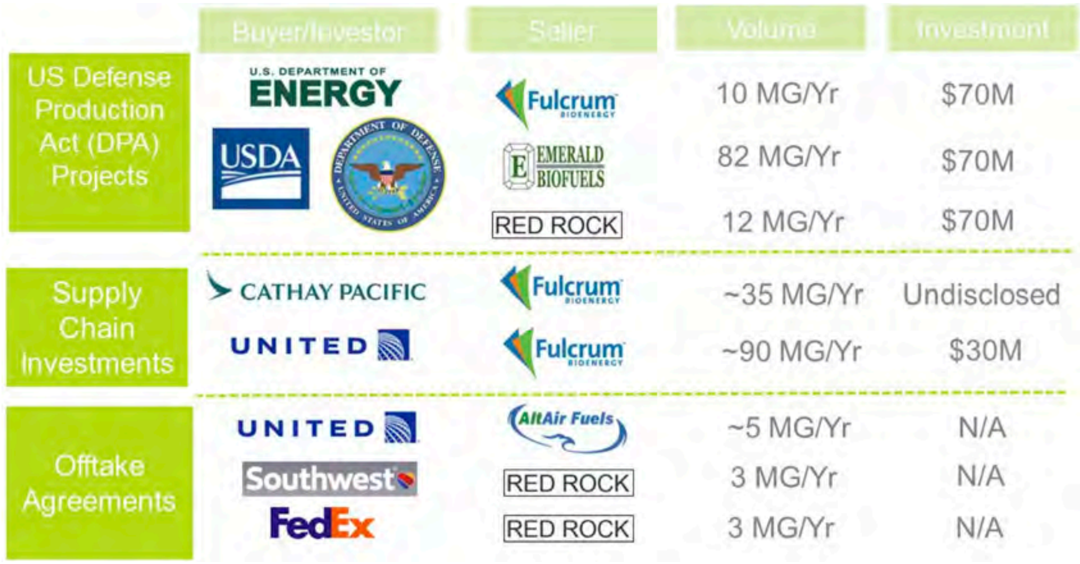

Figure 1. Long-term SAF offtake agreements[13].

certification process[6] and twelve more are in the preparation for ASTM certification. A very promising option among these is renewable (or "green") diesel[7], a drop-in replacement for fossil diesel, made from vegetable oils and animal fats using a similar process as for HEFA jet fuel. As this consists of a slightly different mix of hydrocarbons than jet fuel, certification would be limited to relatively low blends (probably around 10% to 15%). It has the advantage of being a product that is already available in large quantities for the automotive market, which would allow for a significant increase in the amount of SAF available in the short-term.

Each of these processes uses different kinds of feedstocks and with an increasing choice of process pathways. As such, a wide variety of feedstocks from different climatic zones will be usable, including dedicated crops, as well as residues from agriculture, forestry and animal origin, and also municipal and industrial wastes. In particular, pathways using cellulosic and ligno-cellulosic material will allow the use of abundant and cheap agricultural and forestry residues, which could offer the potential to reduce production costs for SAF.

ICAO's Alternative Fuel Task Force conducted a study, led by MIT and IATA, to estimate the potential production of SAF in the short-term (to 2020) and the long-term (to 2050). It found that up to 6.5 Mt/year of alternative jet fuel (2%-3% of global jet fuel demand) could be made available by the year 2020, assuming that renewable diesel is approved by ASTM.

> 6.5 Mt/year of alternative jet fuel (2%-3% of global jet fuel demand) could be made available by the year 2020, assuming that renewable diesel is approved by ASTM.

In the longer-term, the methodology involved a three-stage iteration, by assessing:

1. The constrained primary bioenergy potential;
2. How much of that bioenergy could be feasibly and economically achieved;
3. What would the ultimate jet fuel achievement be under a range of assumptions such as energy demand, finished product economics, and societal choices?

The analysis delivered a wide range of results with some scenarios showing almost no CO_2 reduction from alternative fuels, while other more favorable scenarios demonstrated that over 100% of expected 2050 international aviation jet fuel demand could be satisfied by alternative jet fuel. The clear message from this work is that, while technological feedstock yield improvements, economics and societal choice will be important, and effective and enabling policy will play a pivotal role in the ultimate outcome.

National and International Projects and Initiatives

Numerous stakeholders have to work together for the realization of SAF deployment. In addition to airlines and SAF producers and suppliers, there are numerous other players including: producers of agricultural and forestry feedstock, airports, research institutions, as well as various governmental agencies, such as aviation authorities, agencies, and ministries for transport, energy, environment and agriculture. Partnerships and joint initiatives for SAF development and deployment have been created in many countries around the globe, ranging from simple bilateral project partnerships to large multi-stakeholder associations bringing together all required expertise in a country or region and set up for long-term cooperation. A comprehensive list of these initiatives can be found in ICAO's GFAAF database[8].

As already mentioned, bilateral partnerships between airlines and SAF suppliers comprising long-term offtake agreements are powerful instruments to establish certainty of demand and to increase confidence in the stability of the alternative fuel market for aviation. **Figure 1** shows the bilateral agreements publicly announced as of early March 2016. Following the supply agreement between AltAir and United Airlines, several other partnerships are expected to start operations in the next few years. The largest of these is expected to reach 90 million gallons (270,000 tonnes) per year over 10 years.

Broader partnerships are needed that ensure SAF supply to entire airports, or "bioports", such as Oslo airport, which has been operational since January 2016. Several bioport initiatives have been launched involving cooperation among the airport, one or several major airline operators, SAF suppliers (often a trader purchasing SAF at different sources to ensure a sufficient continuous supply), and governmental institutions. A good example of this is the Bioport Holland project in Amsterdam[9]. The Canadian GARDN initiative has started a project aimed at implementing a bioport fuel supply trial at Montréal airport[10].

Multi-stakeholder associations which gather together all relevant partners from industry and government for the development and deployment of SAF have been founded in various countries. Most of these follows the example of CAAFI (Commercial Aviation Alternative Fuels Initiative)[11] in the US, but adapted to the specific situation in each country or region. The number of such initiatives is continuously increasing, in particular in countries where aviation plays an increasingly key role and in countries with favorable conditions for biofuel feedstock production. Such countries, often located in tropical regions, are interested in creating new opportunities for the local (often rural) economy (e.g. Indonesia, Malaysia, South Africa). A selection of the most relevant initiatives is listed in **Table 1**.

The Sustainability Challenge

The main impetus for airlines to use SAF is to make aviation more sustainable. Therefore most airlines that purchase SAF set robust sustainability requirements to their suppliers. As an example, all members of the Sustainable Aviation Fuels User Group (SAFUG) have signed a pledge supporting strict sustainability criteria, consistent with internationally recognized standards, such as the RSB.

A variety of regulatory and voluntary sustainability standards for biofuels is in use today[12]. Regulatory standards, such as the EU RED and the US RFS, are the basis for public incentives and for counting specific fuels towards renewable fuel or energy targets. Many biofuel producers have their products certified under voluntary standards, which usually cover a wider range of criteria, to demonstrate compliance with a wide range of environmental, social and economic sustainability criteria (see article page 163).

International aviation is very interested in global harmonization of sustainability standards to facilitate SAF purchases in different countries and recognition under different incentive schemes. With the development of ICAO's Global Market-based Measure (GMBM), which IATA thinks should give some recognition to the emissions benefits from SAF under the GMBM, it becomes necessary to define a globally harmonized set of sustainability criteria. CAEP will work on this task in its next work cycle (2016-19) in order to have an instrument ready for application at the planned entry into force of the GMBM in 2020.

The Economic Challenge

Despite the remarkable advances in the development and deployment of SAF over the last few years, the high cost of production has so far presented a major obstacle towards large-scale commercial implementation.

Long-term offtake agreements between airlines and SAF producers, such as those shown in **Figure 1**, give producers and their investors and financiers the necessary certainty for continuous demand over a longer period, which has a positive effect on loan conditions for the construction of production plants.

Consequently lower production and sales prices can be reached, approaching competitiveness with conventional jet fuel, if economies of scale and demand certainty are combined with public incentives, such as co-funding or loan guarantees for SAF production plants and a system of tradable certificates for sustainable fuels. Although competition with current low oil prices has recently made SAF purchases more challenging, it is widely recognized that engagement in SAF is a long-term investment and should not be subject to decisions based on short-term oil price fluctuations.

Need for Policy Support

Considering the important benefit for the environment, the use of renewable transport fuels is stimulated in many countries by various policy instruments such as tax rebates and blend obligations, as well as loan guarantees and other investment aids for production plants.

However, many of these incentive schemes have been tailored for land transport modes and do not directly apply to sustainable aviation fuels. Therefore, biomass or biofuel producers might be incentivized to sell their product to the land transport modes rather than the aviation market. Regulations that create a level-playing field between both sectors are vital to ensure that aviation receives its fair share of available biomass and finished fuel.

There is also growing awareness by policy makers that, contrary to land transport, aviation has no alternative to liquid hydrocarbon fuels in the short- to mid-term, and should be considered as a preferred user of sustainable fuels.

As mentioned earlier, the potential for SAF availability until 2050 strongly depends on political and economic framework conditions. CAEP has launched a study to compare the effectiveness of different policy instruments to incentivize SAF commercialization, which is intended to support governments in a growing number of countries to optimize the consideration of aviation in their renewable energy policies.

Initiative	Country/region	Website (or if missing, relevant info)
CAAFI	US	www.caafi.org
MASBI	US Midwest	www.masbi.org
SAFN	US Northwest	http://climatesolutions.org/programs/saf/resources/safn
BioFuelNet	Canada	www.biofuelnet.ca
Plan de Vuelo	Mexico	http://bioturbosina.asa.gob.mx/es_mx/BIOturbosina/Plan_de_Vuelo
ABRABA / PBB/UBRABIO	Brazil	http://cdieselbr.com.br/, www.ubrabio.com.br
Biofuels Flightpath	EU	http://ec.europa.eu/energy/en/topics/renewable-energy/biofuels/biofuels-aviation
aireg	Germany	www.aireg.de
NISA	Nordic	www.cphcleantech.com/nisa
Bioqueroseno	Spain	www.bioqueroseno.es
Bioport Holland	Netherlands	e.g. http://www.greenaironline.com/news.php?viewStory=1904
AISAF	Australia	aisaf.org.au
ABRETF	Indonesia	e.g. http://www.core-jetfuel.eu/Shared%20Documents/Sayuta_Senobua_Aviation_Biofuel_Program_Indonesia.pdf
INAF	Japan	e.g. http://www.greenaironline.com/news.php?viewStory=1958
SEASAFI	South East Asia	e.g. http://www.greenaironline.com/news.php?viewStory=1739
Fuel Choices Initiatives	Israel	www.fuelchoicesinitiative.com

Table 1. Selection of Multi-Stakeholder Sustainable Aviation Fuel Initiatives[14]

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3. e.g. http://www.airport-world.com/news/general-news/5405-oslo-airport-becomes-first-gateway-in-the-world-to-offer-biofuel-to-airlines.html
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12. http://www.ecofys.com/en/project/assessing-sustainability-standards-and-accounting-for-biojet-fuels/
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14. IATA Sustainable Aviation Fuel Roadmap, Chapter 2 (http://www.iata.org/whatwedo/environment/Documents/safr-1-2015.pdf)

FLYING GREEN - MORE THAN JUST A CAMPAIGN

BY PEDRO SCORZA (GOL)

Prompted by GOL's adoption of the Brazilian Greenhouse Gas (GHG) Protocol Program, we started a corporate program in 2011 to reduce the carbon footprint of our operations. We had learned how to measure our GHG emissions, and time have come to exert control over these emissions. In this learning curve, it was understood the decisive role of biojetfuel in the mitigation of CO_2 emissions, and that we would have to work with renewable fuels, in conjunction with the other CO_2 mitigation measures, to reach our corporate sustainability goals, the voluntary goals of IATA and the aspirational goals of ICAO.

A momentum was being created with the preparations for the RIO+20 Conference and the natural Brazilian focus on biofuels. This led GOL to take part in the *"Flightpath to a Sustainable Future – The ICAO Rio+20 Global Initiative"*, bridging the fourth segment of the low carbon flight from Montreal, Toronto, Mexico City, Sao Paulo into Rio+20. On June 19th, 2012, at 12:40 pm, the first experimental GOL "green" flight 9290, fueled with a blend of biojetfuel made of inedible corn oil and used cooking oil, departed from the city airport of Sao Paulo, bound for the Rio+20 conference. On board, the ICAO Secretary General and his delegation, Brazilian aviation authorities, as well as major supporters and players in the aviation segment. The InterAmerican Development Bank was one of the key partners that made this event happen.

Building on this experience and the launch of the *Plataforma Brasileira de Bioquerosene* at Rio+20, a formal structure to support biojet fuel use for GOL flights was established in August 2013. It gathered the key stakeholders of the industry (Boeing, IADB, UBRABIO. Amyris, ABEAR, universities, research centers, producers, among others). A four-year plan was adopted for the implementation of the "from research to flight" integrated value chain concept, based on multiple sustainable feedstocks, and multi-process bio refineries.

The efforts of the *Plataforma Brasileira de Bioquerosene* culminated with the authorization to operate commercial flights in Brazil using a biojetfuel blend.

To give visibility to the biojetfuel program, low carbon flights were used to connect with the key sports events in Brazil, such as the Copa América (2013) and the World Soccer Cup (2014) in Brazil, which was the opportunity to launch the "Flying Green Programme". Rio de Janeiro International Airport was selected as the base for this Program because it offered appropriate infrastructure, logistics, blending and fit-for-purpose certification for the blend. In addition, it is a major hub for the destinations relevant to the tournament, thus reducing the additional pressure of the increased flight volume during the World Cup.

Several new operational procedures that had never been undertaken by GOL or BR Aviation, the fuel distribution company, were incorporated into the special "Flying Green Program". This was done to allow for the expeditious fueling of specific "green" flights, in spite of the new procedures.

We faced a new logistic challenge due to Brazilian regulations, which led us to perform segregated fueling operations: the percentage of biofuel in the blend had to be tracked at all times, in order to allow for possible fiscal incentives linked to the volumes of biofuel used. This became a barrier against streamlined operational flow, demanding special procedures to keep track of the neat percentage and a segregated operation which goes against the drop-in concept, essential to the aviation industry.

Forced into segregated operations, tank trucks were needed rather than pumps to perform fueling independently from the hydrant fueling, posing the challenge of fueling the planes for "green" flights in different slots, without delay. Punctuality is an operational cornerstone at GOL, and despite the added efforts required to perform the segregated operations, all flights during the World Cup were fueled in a timely manner.

Furthermore, the main objective of this effort was to demonstrate to the public and authorities that renewable fuels are an

GOL Linhas Aéreas Inteligentes S.A is a Brazilian airline based in São Paulo, Brazil. The company is the largest low-cost airline in South America and the largest Brazilian airline company in number of passengers transported.

According to the National Civil Aviation Agency of Brazil (ANAC), between January and December 2015 GOL transported 35 million passengers and had 35.9% of the domestic and 13.6% of the international market share in terms of passengers per kilometer flown, making it the second largest airline in Brazil, after TAM.

attainable goal, and not just a dream. The challenge became to explain to our passengers what we were doing something new and different in a way that they would understand. To do this, a carefully planned on board communication campaign was undertaken for every "green" flight. Thus marketing logistic had to be inserted into the new operations and fueling logistics, while continuing to provide a high level of client services.

The Flying Green campaign was kicked off on International Environmental Day (June 5th 2014). It was a low carbon flight using HEFA (hydroprocessed esters and fatty acids) blend that took off from the Rio de Janeiro Airport.

The first low carbon flight from the International Airport of Belo Horizonte to Brasilia departed on June 6th, 2014. It was the key event of the launching of the *Plataforma Mineira de Bioquerosene e Renováveis*, a joint effort of GOL and the Minas Gerais State Government to establish the first highly integrated "from research to fly" biojetfuel value chain in Brazil.

The Flying Green Program during the 2014 World Cup allowed GOL to transport more than 47,000 passengers in 364 low-carbon flights domestic flights, including the chartered flights of the Brazilian Soccer Team, with GOL as the official carrier. It was the first World Cup involving low-carbon flights, and there was significant media coverage of the efforts made by the GOL operational team in organizing and implementing the program. It is seen as a first step towards the long-term challenge of introducing biojetfuel to mitigate the GHG emissions of the aviation sector, as proposed by ICAO and IATA.

Later the same year, GOL and Amyris, with the support of Boeing and IADB, operated the first international regular passenger flight using SIP (synthesized iso-paraffins) produced by Amyris in Brazil. It departed from Orlando, Florida and flew to Sao Paulo, via Santo Domingo. The experience of the segregated fueling procedure pioneered at the World Cup was replicated in this first ever international low-carbon flight by a Brazilian carrier originating in the USA.

These initial successes have motivated GOL to address the huge challenge of sustainable biomass production, the starting point of the integrated value chain. The current price of fossil oil around US$ 50 a barrel poses an additional economic barrier for renewable fuels, increasing the need for a synergetic collaborative action involving all stakeholders to promote the highly integrated value chain concept. It must be optimized logistically, with a competitive fit-for-purpose distribution cost in the different airports of Brazil.

Brazil is a country of continental dimensions, and 90% of GOL's operations are domestic flights which serve more than 50 airports. GOL is driving the implementation of the *Plataforma Mineira de Bioquerosene e Renovaveis* with the State of Minas Gerais government and local municipalities, since the International Airport of Belo Horizonte, CNF, is both a major domestic hub for GOL, and the site of its Maintenance Platform.

The objective going forward is to promote sustainable Green Economy projects through regional biomass production. This will be done by family farmers and agribusiness in the State of Minas Gerais to feed into a biorefinery in the Metropolitan area of Belo Horizonte for a large scale integrated value chain proof of concept. This pilot value chain is designed to demonstrate the technical and economic viability of the biofuel and renewables program for the de-carbonization of the aviation sector and how such a project can promote socio-economic development.

Results of the domestication program of the Macauba (*Acrocomia aculeata*), a Brazilian native palm, have been encouraging. The program is being conducted by the Federal University of Viçosa, EPAMIG, and EMBRAPA (a leading agricultural research institution in Brazil). This prolific oil bearing native palm was selected as a strategic biomass alternative that integrates both family farming and agribusiness. The Ministry of Agrarian Development is highly interested in developing Macauba as an alternative to diversify the feedstock for biofuels, aiming at the inclusion of family farmers in the production efforts. The Round Table on Sustainable Biomaterials (RSB) is already establishing certification evaluation for small land holders engaged in the cultivation of Macauba in the Montes Claros region of Minas Gerais.

Being a native species, Macauba can be used to recuperate river bank areas to stimulate water production. It can also be used in recovery of Permanent Protection Areas and Legal Reserve areas (under the Brazilian Forest Code, all agricultural properties must reserve a minimum of 20% of land for legal reserve conservation). These types of areas could use the Macauba plant for the reforestation projects, thus contributing to the Brazilian Nationally Determined Contribution under the UNFCCC Paris Agreement of a reforestation goal of 12 million hectares, without indirect land use change issues.

The Ministry of Agrarian Development will be implementing 30 demonstration units in Minas Gerais, with family farmers intercropping Macauba with cash crops in six regions of the State of Minas Gerais in 2016 to start the Macauba value chain. Additional concrete actions will include using Macauba in the recuperation of the Permanent Protection Areas and Legal Reserves of the Rio Doce Basin.

Conclusion

In the longer-term, GOL expects that all its efforts in developing and using sustainable alternative fuels will eventually lead to the carbon neutral growth of its operations sometime between 2023 and 2025, thus contributing to the industry goal for international operations.

GOL has invested much in this biojet fuel development as an important part of its corporate history. The next steps on this path are expected to confirm the participation of GOL and the Brazilian Biojet fuel Platform as important players in the global history of biojetfuel development.

THE E-FAN PROJECT

BY AIRBUS GROUP

From the A320 family, to the superjumbo A380 and the newest member of the Airbus commercial fleet, the A350 XWB, Airbus Group and its divisions have endeavoured to remain at the forefront of innovative R&D into developing the sustainable aviation of the future.

Alongside innovative technological R&D into areas such as biofuels from renewable resources, lightweight materials and designs aimed at reducing aircraft weight and fuel consumption, Airbus Group has established an E-Aircraft Roadmap to guide its development of electric and hybrid propulsion systems of tomorrow – today. An all-electric two-seater technology demonstrator called the E-Fan is one of the key trailblazers along our path to electric flight and aviation's next frontier.

The E-Fan project originated during the 2011 Paris Air Show as a follow-up to the initial cooperation of Airbus Group Innovations with Aerocomposites Saintonge on the Cri-Cri – the world's first fully-electric four-engine aerobatic aircraft. Using the Cri-Cri as a flying laboratory, numerous performance tests allowed engineers to gain experience with the integration of batteries and energy management, while also focussing on energy recovery by varying the propeller pitch.

The E-Fan technology demonstrator was developed initially as an all-electric, two-seater aircraft with covered fan engines. Small electric aircraft are seen as a key step towards introducing electric propulsion on larger airplanes – up to the size of a 100-seat-category regional airliner. As a highly innovative technology flying testbed, the E-Fan demonstrator is stimulating research in electric propulsion and also helping to promote the certification of electrical flight concepts.

The E-Fan's two electric motors deliver a combined power of 60kW, each driving an aft-mounted ducted, variable pitch fan. Electrical energy for these motors comes from the aircraft's battery system, for which capacity has been increased by 60 percent since its first flight in 2014.

In its original configuration the E-Fan utilised a series of lithium-polymer batteries located inside the wings, where fuel tanks would be on a traditional aircraft. The E-Fan team has since changed to a more powerful lithium-ion battery system, which was a key upgrade that enabled the technology demonstrator aircraft's flight across the English Channel. Comprising 2,982 cells with a capacity of 2.8 amperes per hour each, the lithium-ion battery system retains the same location as the previous lithium-polymer cells with E-Fan's wings.

With its crossing of the English Channel in July 2015, the E-Fan demonstrator became the world's first all-electric, two-engine aircraft to take off by its own power to cross the Channel. This historic flight followed in the footsteps of one of Airbus Group's "founding fathers," Louis Blériot, who crossed the Channel in 1909, showing that the pioneering spirit and ingenuity demonstrated by Blériot and the other early aviators is still alive today. We hope that this flight and the E-Fan project will capture the imagination of the next generation of aviators and engineers.

But it didn't just prove the viability of electric flight – it also set the stage for the next project phase: launching the commercial production of an all-electric, two-seat E-Fan 2.0. The E-Fan project has allowed the Airbus Group to perform extensive characterisation and testing of the electrical propulsion unit and other technical parameters for certification purposes ahead of industrialisation of the E-Fan 2.0 in 2018.This ambitious project

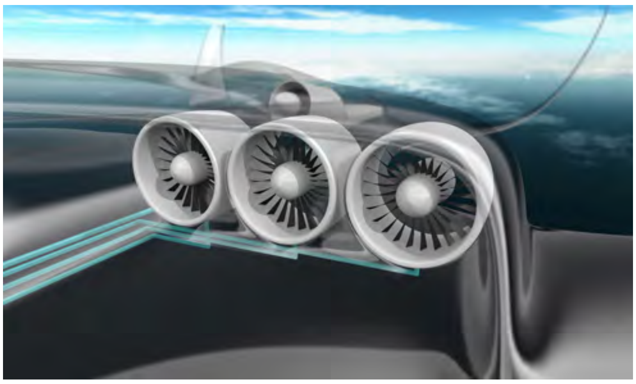


Figure 1. Airbus E-Thrust e Concept view B1

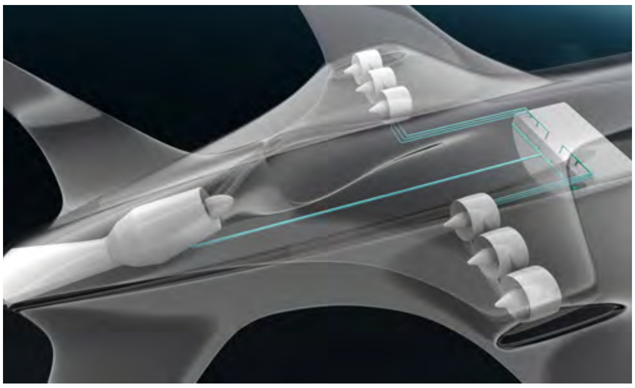


Figure 2. Airbus E-Fan

aims to achieve technology breakthroughs in several areas, such as energy storage of 180 Wh/kg, adapted for a charge regime of less than one hour. It also brings together partners from across the industry and research sector, working together with Airbus on a common goal of next generation of flight with minimal impact on the environment.

Electric and electric-hybrid flight represent some of the biggest industrial challenges of our time, aiming at zero-emissions aviation.

Airbus Group is committed to meeting the environmental standards set by ICAO for noise and emissions and there are strong incentives for the Group and its divisions not only to develop innovative, eco-efficient propulsion and lightweight material solutions – but ultimately bring them to market quickly as more stringent carbon emissions regulations come into effect.

Meeting the ambitious environmental goals set for aviation by the European Commission's Flightpath 2050, which calls for a reduction of aircraft CO_2 emissions by 75%, NOx emissions by 90% and noise levels by 65% compared to year 2000 levels is another key driver.

The E-Fan project is just one element of our overall E-Roadmap: April 2016 saw the official ground-breaking ceremony on the E-System House at the Group's site to the south of Munich. The E-System House is set to go online in 2018, and will focus on R&D into the development of technologies for electric and hybrid aircraft propulsion. This internal research and development facility will be jointly operated by Airbus Group and its three divisions. April 2016 also saw Airbus Group join forces with Siemens in a collaboration aimed at developing hybrid-electric propulsion systems for different aircraft architectures and sizes in another step towards emissions free aviation.

Figure 3. Airbus E-Fan into graphics

Figure 4. Airbus E-Fan Bleriot XI comparison

COCHIN INTERNATIONAL AIRPORT - WORLD'S FIRST SOLAR-POWERED AIRPORT

BY P.S. JAYAN (COCHIN INTERNATIONAL AIRPORT)

Cochin International Airport, India's first airport built under a public-private-partnership (PPP) model, has scripted another chapter in aviation history by becoming the first airport in the world that operates completely on solar power. The 12 MWp solar power plant was inaugurated by Hon Chief Minister Mr. Oommen Chandy, on 18 August 2015. It comprised 46,150 solar panels laid across 45 acres of land near the air cargo complex. Now, Cochin Airport will have 50,000 to 60,000 units of electricity per day available to power all of its operational functions, making the airport "absolutely power neutral".

Cochin International Airport Limited (CIAL), which has always adhered to the philosophy of sustainable development, ventured into the Solar PV sector in early 2013 by installing a 100 kWp solar PV Plant on the roof top of the arrival terminal block. This was a first in the field of grid-connected solar PV in the State of Kerala. The plant contains 400 polycrystalline modules of 250Wp, with five 20kW capacity *Refu-sol* made string inverters. After the successful commissioning of this plant, CIAL installed a 1 MWp solar PV power plant partly on the roof top and partly on the ground in the aircraft maintenance hangar facility. This plant was includes 4,000 monocrystalline modules of 250Wp, with 33string inverters of 30kW capacity. This plant is the first Megawatt scale installation of a Solar PV system in the State of Kerala.

Both these plants are equipped with a remote monitoring systems. Since commissioning, these plants have saved more than 550Mtonnes of CO_2 emissions, thus contributing significantly to the efforts of CIAL to reduce environmental degradation.

Inspired by the success of the above-mentioned plants, CIAL has decided to set up a larger scale 12MWp solar PV plant as part of its green initiatives. This will be built in an area of about 45 acres near the international cargo terminal. and will include PV modules of 265Wp capacity, and inverters of 1MW capacity. It generates around 48,000 units of electricity per day, which along with the electricity generated from the existing 1.10 MWp plants, would be sufficient to meet the power requirements of the airport. This is a grid connected system without any battery storage. A power banking module has been worked out with the Kerala State Electricity Board (KSEB); wherein, CIAL gives as much power it produces (during day time hours) to the KSEB grid and "buys back" the power from KSEB when needed (especially at night). This plant will produce 18 million units of electricity from the sun annually– enough to power 10,000 homes for one year.

Over the next 25 years, this green power project will replace the need for carbon dioxide emissions from coal fired power plants by more than 300,000 tons, which is equivalent to planting 3 million trees, or not driving a motor vehicle(s) 750 million miles.

Solar Capacity To Be Doubled

In November 2015, the CIAL board of directors decided to double the airport's solar capacity in to accommodate the needs of the new international terminal, which is currently under construction. It is expected that the power consumption needs of the new complex will be approximately 100,000 units of electricity per day.

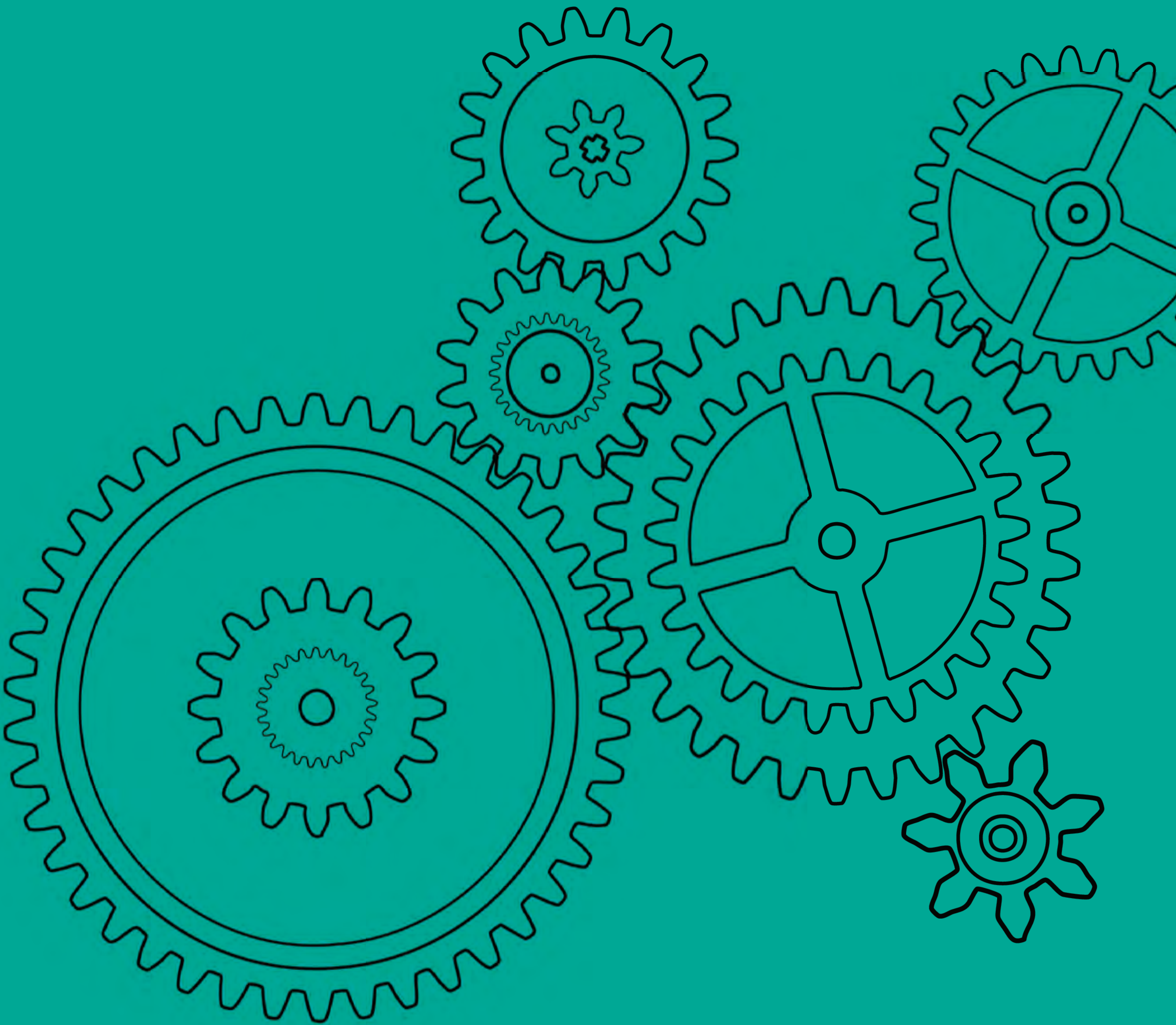
In the next 25 years, this project would have avoided 300,000 tons of CO_2, which is equivalent to planting 3 million trees.

CIAL's decision to install more panels is to meet that demand and retain its unique status as a fully solar energy-powered airport. At present, the solar power project comprising 46,000 panels is spread over 45 acres alongside the cargo complex. Another 10,000 plus panels would be installed in the remaining space here to generate an additional 2.40 MW power.

Panels to be installed atop the building housing hangar would help generate 3 MW and those to be laid above the new park are expected to bring another 1 MW to the airport's power pool. Generation of another 7 MW through panels to be installed over the three km-long irrigation canal would take the total installed capacity to 26.50 MW.

CHAPTER 5

STATE ACTION PLANS



OVERVIEW

BY JANE HUPE, DEPUTY DIRECTOR ENVIRONMENT, ICAO

Since the 37th Session of the ICAO Assembly in 2010, ICAO has encouraged its Member States to voluntarily submit their Action Plans for emissions reductions from international aviation. In 2013, the 38th Assembly decided to further encourage ICAO Member States to submit their Plans, to update those submitted in 2012, to share their content on the ICAO public website and to cooperate with other States for their submission in June 2015.

Thus, for the past six years, ICAO has been working on a comprehensive strategy to strengthen national capacities on environment and, specifically, to reduce the impact of the international aviation on climate change.

All of the ICAO Member States wanted to take action, but some were not sure how. ICAO has therefore put in place an integrated strategy to support the States willing to take action. This included developing and promoting guidance, technical material, and offering capacity-building to facilitate the development of State Action Plans[1] on CO_2 emissions reduction activities. By June 2016, 94 ICAO Member States representing 88 per cent of international traffic voluntarily developed and submitted an action plan to ICAO, reaching the target of 50 per cent more action plans submitted in comparison with the last triennium (Figure 1).

ICAO Buddy Programme

One of the key elements of the ICAO strategy is forming partnerships to facilitate the development of Member States' Action Plans to reduce aviation emissions. It encourages States that submitted their action plans to build partnerships with other Member States that did not. The "Buddy Programme" is an instrumental step to enhancing the submission of State's Action Plans and to make sure that all avenues are explored to multiply their environmental benefits. It is increasingly gaining momentum amongst ICAO Member States. ICAO developed a sample agreement for direct use by States, in order to facilitate the establishment of such partnerships (**Figure 2**). ICAO has also been working directly with individual States and national action plan focal points to provide tailored, individual assistance to facilitate the preparation of action plans. Since September 2014, 400 contacts have been made with national action plan focal points.

Figure 1. 94 States have submitted an action plan (June 2016)

ICAO STATES' ACTION PLAN BUDDY PROGRAMME

BUDDY PARTNERSHIP

BETWEEN

.... (ICAO Member State A)

AND

.... (ICAO Member State B)

FOR THE PREPARATION OF STATES' ACTION PLANS ON EMISSIONS REDUCTION

ICAO States' Action Plans are an essential tool to define and implement States' actions to reduce CO_2 emissions from international aviation. Additionally, it is a valuable instrument for ICAO to measure the achievements made by States regarding the global aspirational goals to reduce international aviation emissions. In spite of the progress already made by some States, many still need assistance to elaborate and submit their action plans. Aligned with the ICAO Assembly Resolution A38-18 Paragraph 13, this Buddy Agreement is created to facilitate the establishment of partnerships between ICAO's Member States in order to assist each other to this end.

This Buddy agreement is made between *ICAO Member State A*, and *ICAO Member State B* collectively referred to as Buddy Partners. It is a non-legally binding collaboration to be implemented in good faith by the Partners.

1. **Objective and Scope:**

This Buddy Agreement in respect of ICAO States' Action Plan Buddy Programme aims to establish the model framework by which ICAO Member States can help other Member State(s) to prepare and submit their States' Action Plan. It aims to facilitate the development of international cooperation among ICAO Member States. The scope of this Buddy Agreement could include, but is not limited to, *[training, site visits, ICT tours, capacity building, exchange of relevant information, workshops, technical meetings or financial assistance*].

[In this paragraph States should define their cooperation. They could use as examples the actions defined below]

2. **ICAO's role:**

ICAO will keep a registry of these agreements and can be called upon by the Partners to facilitate the establishment of this Partnership, through the provision of technical expertise and/or facilitating the discussions and implementation of this agreement.

Figure 2. ICAO Buddy Programme agreement

ICAO-European Union Joint Assistance Project

Another important element of the strategy is to facilitate access to financial resources to enable the development of action plans and /or the implementation of measures to reduce CO_2 emissions.

In 2013, ICAO established the first partnership to develop and implement action plans with the European Union: a joint assistance project on capacity building for CO_2 mitigation from international aviation in 14 selected States, 12 of them from the African region and two from the Caribbean region (**Figure 3**).

The main objectives of the ICAO-European Union project are to support the development of voluntary action plans; set-up Aviation Environmental Systems (AES) to collect data; build emission inventories and monitor CO_2 emissions from aviation; and implement measures to reduce aviation emissions.

This first of its kind partnership on environment and aviation demonstrates that the impact of the States' Action Plans goes far

Figure 3. The architecture of the ICAO-European Union joint assistance project

beyond initial expectations. It is rare to see an initiative with such a multiplier effect. This project has triggered powerful synergies to address the environmental issues at the national level in all the beneficiary States, which have established National Action Plan Teams to bring all aviation stakeholders around the table. The establishment of these teams has changed the way the States work toward environmental objectives. Action Plans are the result of an inclusive process that involves all the national stakeholders: civil aviation authorities, ministry of environment, ministry of transport, airports, airlines, air navigation services providers, and fuel suppliers, amongst others, each one contributing within their areas of expertise.

The project has enabled a shift in institutional culture regarding the environment in the selected States. Environmental action on aviation, that was not seen as a priority in the past, has now become increasingly relevant for these States, which have taken ownership, greatly increased awareness of environmental issues, and are enthusiastic to undertake concrete action.

The presence of ICAO through the local project offices and on-site missions (**Figure 4**) has been essential in engaging the civil aviation authorities of the selected States and for the commitment of all the relevant actors toward the common goal of environmental protection. In less than a year, the ICAO Secretariat project team visited each of the 14 selected States, encouraging them to work with the members of the National Action Plan Teams to complete the collection of historical data, prepare the baseline scenarios, and facilitate discussions on the potential mitigation measures available for the States to reduce fuel consumption and emissions from international aviation.

Figure 4. Meeting the team , a working group meeting in Santo Domingo, Dominican Republic

Aviation Environmental Systems: Automatic Emissions Monitoring

Prior to the implementation of the ICAO-European Union Project, none of the beneficiary States had an emissions monitoring system in place and therefore they were not able to efficiently collect and monitor CO_2 emissions from the aviation sector. The Aviation Environmental System (AES) is a monitoring, reporting and verification (MRV) tool, developed under the project and installed in all the selected State. It supports the automated collection and monitoring of data, providing the beneficiary States with the ability to assess, monitor and report CO_2 emission reductions obtained through the progressive implementation of the mitigation measures included in their Action Plans. In light of the success of this tool, many other Member States have shown interest and have requested ICAO to help them to integrate the AES into their existing monitoring systems as soon as possible.

Selection and Implementation of Measures

The ICAO-European Union project is currently entering its CO_2

mitigation phase, with the establishment of a series of pilot projects to reduce fuel consumption and emissions from aviation. These pilot projects will consist for example, of the installation of solar panels connected to an electric Pre-Conditioned Air unit and Ground Power Unit in two international airports of the selected States. This will enable the use of clean energy technology for the provision of ground support to the international operations at these airports and will therefore reduce fuel consumption and CO_2 emissions.

The project will also fund feasibility studies for the development of a sustainable alternative fuel production chain for the aviation sector in the beneficiary States, that could become instrumental for the States to mobilize further political and financial resources, should they wish to pursue the production and use of alternative fuels.

The results of the pilot projects will become practical examples of concrete actions to reduce CO_2 emissions. The availability of further financial contributions from donor States and international organizations would enable ICAO to replicate these projects in other States that require assistance to implement their action plans and to establish robust emissions monitoring systems. By doing so, other States will be able to also benefit from these capacity building activities and tools which have proven successful in addressing climate change in the aviation sector. Further financial and technical assistance will be crucial in environment to ensure that “No country is left behind” (see articles page 182 and page 184).

ICAO-UNDP-GEF Global Capacity-Building Project

Partnership was also established with the United Nations Development Programme (UNDP) with financing from the Global Environment Facility (GEF) to undertake a Global Capacity Building project – including the implementation of a pilot project on renewable energy in Small Island Developing States (SIDS) (see article page 191).

The ICAO-UNDP-GEF project is underpinned by the willingness to realize incremental CO_2 emissions reductions arising from the implementation of international aviation mitigation measures in developing countries and SIDS. This objective will be attained through the delivery of unique guidance material:

- on governance, in order to support States establish an effective organization within their administration for CO_2 mitigation activities in aviation;
- on the financing of clean energy projects for aircraft (drop-in sustainable alternative fuels) and airports; and
- on the cost-benefit assessment of the implementation of different mitigation measures.

A key component of the project is the implementation of a pilot project, which could be replicated in other SIDS, thus multiplying environmental benefits.

Norman Manley International Airport in Kingston and Sangster International Airport in Montego Bay, Jamaica, will be the testbeds for the implementation of clean energy projects. Different financing approaches are expected to be used. This experience will directly benefit the development of the solar energy component of the Guidance Material on financing and implementation of clean energy projects.

Again, the experience gained in the implementation of these pilot projects can be easily applied to other SIDS. This the practicability and the replicability of the model – financing, institutional approach, technology etc. - that allows for the maximization of environmental benefits. In addition, States can further use their own GEF national allocations for the implementation of similar projects at their airports.

Conclusion

The States’ Action Plan initiative fosters a highly cooperative culture in support to the establishment of inclusive and effective multi-stakeholder partnerships (SDG 17), while contributing to combatting climate change (SDG 13). States Action Plans also trigger technological or operational innovations, leading to more efficient infrastructure (SDG 9). Last but not least, knowledge-sharing is encouraged through the dissemination of good practices. The good practices promoted as part of the capacity-building activities contribute to the development of sustainable alternative sources of energy (SDG 7) and to creating new economic opportunities for local communities (SDG 8).

Going forward and building on the strong experience gained with its current two assistance projects, the potential for cooperation with other United Nations agencies and international Organizations continue to be explored, so that synergies are realized to the benefits of ICAO Member States and their sustainable development.

Sustainable Development Goals

References

1. http://www.icao.int/environmental-protection/Pages/ClimateChange_ActionPlan.aspx

THE DEVELOPMENT OF BURKINA FASO STATE ACTION PLAN

BY SALIFOU ZANGA (NATIONAL CIVIL AVIATION AGENCY, BURKINA FASO)

Burkina Faso is a Sahelian country located in the heart of West Africa, without a sea coast. Therefore, the most developed means of transportation are buses and trains, connecting it to the six neighboring countries of Côte d'Ivoire, Mali, Niger, Benin, Togo, and Ghana.

Alongside these means of transportation, there are a large number of air passengers. In fact, more than 13 international airlines and one national airline are operating from and to Burkina Faso.

Air Burkina, the national carrier, started its flights in the 1960s with small piston engines aircraft. It has contributed to opening up the country through its domestic flights, landing all over in Burkina Faso, formerly known as "Upper Volta".

Nowadays, the airline is using two Brazilian Embraer ERJ170 and is planning in the nearest future (in the next 5 years) to diversify its fleet in order to meet a fast growing demand.

Statistics show that Air Burkina carries between 25 and 30% of passengers from the departure and arrival airports of Ouagadougou and Bobo-Dioulasso, the two international airports.

Passenger traffic has experienced a fairly steady increase between 2004 and 2013, a traffic decrease in 2014 and 2015 and a slight recovery from the last quarter of 2015. The most significant traffic growth was observed in 2012 with an increase of more than 12%, and the lowest rated traffic in 2015 with a decline of about 10%.

On average, 500.000 passengers transit annually through Burkina Faso and 6.000 tons of freight upon arrival and departure.

To manage the civil aviation sector's activities, the Government of Burkina Faso has created the National Civil Aviation Agency, with statutory powers to regulate and supervise safety and security. To achieve this, the civil aviation sector is working jointly with State or private organizations in Burkina Faso, which are:

- the Agency for the Safety of Air Navigation in Africa and Madagascar (ASECNA);
- the National Delegation for Aeronautical Activities (DAAN);
- the Administrative Board of ground handling Services (RAC-GAE);
- the national carrier, Air Burkina.

Like most African countries, it is in 1960 that Burkina Faso was proclaimed independent and as an independent State, Burkina Faso ratified the Chicago Convention in 1962, marking its commitment to participate in the safe and orderly development of the international civil aviation.

To show its commitment to ICAO policies, Burkina Faso has voluntarily adhered to the objectives of Resolution A38-18 adopted at the 38th session of ICAO Assembly, including the development and submission of an action plan on international aviation CO_2 mitigation activities.

Action Plan and Assistance

With that willingness, Burkina Faso is one of the 12 States in Africa selected to receive the support from the ICAO-European Union joint Assistance project "Capacity building for reducing CO_2 emissions from international aviation". This project was funded with 6.5 million Euros in fourteen States: twelve in Africa and two in the Caribbean. Starting in January 2014, the project is scheduled to be completed in June 2017.

At this point, Burkina Faso has met its commitments as part of the project:

1. two focal points from the Civil Aviation Authority were officially appointed by Burkina Faso to be trained with the necessary tools to carry out an action plan;
2. a national action plan team, a multidisciplinary team of 16 members, was constituted to develop the action plan; in addition to the civil aviation authority representatives, it is composed of airline, airports, and air navigation service providers representatives.
3. the first action plan of Burkina Faso was sent to ICAO in December 2015. The Action Plan of Burkina Faso is available on the ICAO public website[1].

To achieve its objectives, Burkina Faso has benefited from the support of ICAO experts and from the Action Plan and Assistance seminars organized by ICAO.

Challenges

More than two years after the project inception, Burkina Faso can already draw some lessons from the process. Indeed, looking back, some difficulties have paved the way of the development of the plan.

One of the major challenges was mastering calculation tools available to the States (ICAO Fuel Saving Estimation Tool, ICAO Carbon calculator, Environmental Benefit Tool).

Another challenge was related to the organization of the national action plan team meetings: meeting regularly with 16 experts from several ministries has not been easy. However, this logistics hurdle was overcome by the use of Information and Communications Technology (ICT) and on-line file exchanges enabled the team to work in an orderly and rational way.

Summary of Burkina Faso Action Plan

The action plan for the reduction of CO_2 emissions from international aviation is built on three pillars:

1. presentation of the civil aviation environment of Burkina Faso;
2. reduction measures adopted and the quantification of expected results;
3. needs for assistance.

The first pillar has been presented above. Regarding the second pillar, Burkina Faso has identified 12 measures in its Action Plan to help reduce emissions from international aviation:

1. Purchase of new aircraft;
2. Measures to improve taxiing;
3. Continuous Descente Operations (CDO);
4. Continuous Climb Operations (CCO);
5. Single engine taxi;
6. Engine wash;
7. Aircraft wash;
8. Construction of taxiways;
9. Installation of fixed electrical ground power and pre-conditioned air allow aircraft Aircraft Power Unit (APU) switch-off;
10. Reduce distance travelled;
11. Conversion of support equipment to use cleaner fuels (biodiesel)
12. Studies on the use of alternative fuels in civil aviation

This last measure aims to use the high production potential existing for bio fuel in Burkina Faso. An operating factory already exists and produces bio fuel from jatropha for local and sub regional consumption.

> The implementation of all the mitigation measures identified in the action plan of Burkina Faso has the potential to reduce over 23% of the average CO_2 emissions from aviation between 2016 and 2025.

In 2014, the CO_2 emissions from international aviation were 19.003 tons. These calculations did not take into account the co-benefits associated with the implementation of measure N°3 and N°4 (CCO and CDO) and N°9 (reducing the use of ground power unit).

In order to strengthen national capacities to monitor and report the aggregated CO_2 emissions data, ICAO, through funding from the ICAO-European Union Assistance Project, provided the National Civil Aviation Agency with ICT equipment and a software (Aviation Environmental System). The software is compatible with ICAO database systems and ICAO Environmental tools and aims at collecting emissions data. The National Civil Aviation Agency has already reported to ICAO the emissions data of January and February 2016.

To summarize, Burkina Faso is proud to be part of this ambitious joint assistance ICAO-European Union project and will especially, let other countries of Western Africa, and why not of the entire African continent, benefit from its experience and from the positive results that will come from participation in this project, as part of the ICAO “Buddy Programme”.

This project gives Burkina Faso the opportunity to pave the way in this area, to strengthen the regional cooperation and to trigger interest in neighbouring national civil aviation authorities to get more involved on CO_2 emissions reductions at their national level.

It is to be noted that some measures are under implementation (washing of engines, washing of aircraft, reducing distances) and others (CDO, CCO, constructions of additional roads and feasibility studies for the use of bio fuel) could not be implemented without the support of the international community.

By providing Burkina Faso with IT equipment and the AES, the ICAO-European Union joint assistance project has enabled the State to report to ICAO, their expected trend for fuel consumption and associated CO_2 emissions. In addition, the AES will provide airlines with real data on fuel consumption, which airlines can use to perform more efficient operations and realize economic benefits.

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TRINIDAD AND TOBAGO ENVIRONMENTAL PROJECT: ICAO-EUROPEAN UNION ASSISTANCE PROJECT ON CAPACITY BUILDING

BY RAMESH LUTCHMEDIAL (CIVIL AVIATION AUTHORITY, TRINIDAD AND TOBAGO)

Background

Trinidad and Tobago is a twin Island Republic with two (2) international airports, namely the Piarco International Airport, Trinidad and the ANR Robinson Airport, Tobago.

Trinidad and Tobago is governed by its Environmental Management Act. The Act is an umbrella piece of legislation incorporating important environmental policy statements of the Government of Trinidad and Tobago, a blueprint for the further development of environmental policy and legislation, and a monitoring and enforcement mechanism.

Under the ICAO Convention, the Government of the Republic of Trinidad and Tobago has responsibility for the provision of Air Navigation Services within an airspace, known as the Piarco Flight Information Region (FIR). The Piarco FIR is approximately 750,000 square miles, that includes the airspace over the entire group of Eastern Caribbean islands from north of Antigua to south of Trinidad and stretching eastward to halfway across the Atlantic. The volume of aircraft movements within the Piarco FIR averages in excess of four hundred (400) movements per day during busy periods.

As aviation activity in the Piarco Flight Information Region (FIR) increases, the pressure on aircraft operators, airports, and air traffic management to increase capacity while achieving an environmentally sustainable air traffic system is intensifying.

The need to address the adverse environmental impact of aviation is on the agenda of the international air transport industry and it is embedded in the historic Port Of Spain Declaration. This Declaration was signed by twenty one (21) States in the North American, Caribbean and Central American (NACC) Regions in April 2014. It commits States in the NACC Region to achieve harmonisation and integration of the ATM system, taking into account, inter alia, the need to minimise any adverse environmental impact.

Development of the First Action Plan on Emissions Reduction for Trinidad and Tobago (APERTT) 2012 and the Award of the ICAO-European Union Assistance Project on Capacity Building

In 2012, the Trinidad and Tobago Civil Aviation Authority (TTCAA) participated in a number of Environmental Seminars both at ICAO Headquarters in Montreal, Canada and through the International Air Transport Association (IATA). The ICAO seminars provided the training and knowledge required for Trinidad and Tobago to develop its first Action Plan on Emissions Reduction (APERTT). This Action Plan was submitted to ICAO in December 2012.

The objective of the first APERTT was to construct a plan to reduce CO_2 emissions for the Caribbean Region. This proved to be a significant challenge since the Region consists mostly of Small Island Developing States (SIDS) and resources were difficult to assign.

Notwithstanding this challenge, Trinidad and Tobago proceeded with the development of the APERTT 2012, which only included mitigation measures relevant to the Piarco FIR and its national airline, Caribbean Airlines Limited.

ICAO used the State's Action Plans of Trinidad and Tobago as a tool to identify funding for environmental projects. In January 2014, ICAO announced that Trinidad and Tobago is one of fourteen (14) countries that will benefit from the first **ICAO-European Union joint Assistance Project on Capacity Building - CO_2 Mitigation from International Aviation.**

The major objectives of the ICAO-European Union Assistance Project on Capacity Building are:

- **i.** Development of an Action Plan for Trinidad and Tobago – Aimed at improving capacity of the National Civil Aviation Authority to develop an Action Plan on Emissions Reduction from International Aviation.
- **ii.** Development and Installation of an Aviation Environmental System (AES) – information technology software and hardware for the efficient CO_2 emissions monitoring for international aviation.
- **iii.** Implementation of the Mitigation Measures – Prioritize mitigation measures identified, evaluated, and implemented.

The Project "kick-off" Seminar for the Caribbean was held in the Dominican Republic in December 2014. However, Trinidad and Tobago had started work on the Project in June 2014, prior to the kick-off seminar. The seminar strengthened the understanding and commitment of the national focal points towards the project and set-up the grounds for the implementation of the milestones and project expected results for 2015.

The important milestones for the first six (6) months of the project included:
- the capacity building Seminar in 2014
- the establishment of a functional National Action Plan Team (NAPT)
- on-site support missions by the project consultants;
- development of the Aviation Environmental System (AES) prototype; and
- the calculation of the emissions baseline for the State Action Plan.

Development of the Second Action Plan on Emissions Reduction for Trinidad and Tobago (APERTT) 2015

In the first eighteen (18) months under the project, Trinidad and Tobago made significant strides in building capacities with various government agencies and stakeholders. One of the major lessons learned from the development of the first APERTT 2012 was the lack of a coordinated approach by all stakeholders to establish mitigation measures in their respective areas. This lesson was used in the development of the second APERTT 2015 and as a result the National Action Plan Team, namely the Aviation Environmental Working Group (AEWG), was established, consisting of:

i. Trinidad and Tobago Civil Aviation Authority (TTCAA)
ii. Airports Authority of Trinidad and Tobago (AATT)
iii. Caribbean Airlines Limited (CAL)
iv. The Ministry of Planning and Development (MPD)
v. The Environmental Management Authority (EMA)
vi. National Petroleum Marketing Company Limited (NP)
vii. Airline Ground Handlers: Swissport and Piarco Air Services Limited

The APERTT 2015 included six (6) main mitigation areas to reduce CO_2 emissions from International Aviation. These are:

a) Aircraft Technology and more efficient operations
b) Research on Alternative Fuels
c) Air Traffic Management and Infrastructure use
d) Airport Improvements
e) Complementary Measures (Regulatory / Economic)
f) Monitoring and Data resources

The APERTT 2015 also included a **Carbon Low Emissions Program (CLEP)**. The CLEP has twenty seven (27) new measures to support CO_2 emissions reduction. It is estimated that this program will reduce 20,000 tonnes of CO_2 from International Aviation each year from 2018. The CLEP will support the regional efforts of Air Traffic Management in the Piarco FIR and will generate Research, Partnerships and Complementary measures to develop long-term strategies for Trinidad and Tobago.

The Baseline

Through the establishment of the AEWG, a baseline was established using the traffic data in Trinidad and Tobago from 2012 to 2014. This was a major challenge for Trinidad and Tobago since the national airline, Caribbean Airlines Limited, needed assistance and guidance to collect and use the appropriate data. Under the ICAO-European Union Assistance Project, ICAO conducted mission visits to Trinidad and Tobago and worked with every stakeholder under the Project to ensure the objectives were met. The mission visits delivered major results for Trinidad and Tobago.

Impact on the State and the Expected Results

Under the ICAO-European Union Assistance Project, Trinidad and Tobago has produced a robust Action Plan to reduce CO_2 Emissions from International Aviation for the State and the Piarco FIR. The project has tremendously strengthened the national Aviation Environmental Working Group (AEWG) along with other Government Agencies and stakeholders. With improvements to the monitoring processes and CO_2 reporting in the Piarco FIR, Trinidad and Tobago will be able to take appropriate mitigation actions to support the development of a cleaner, more efficient and sustainable aviation system aligned with national policies and strategies.

In 2015, the Trinidad and Tobago Civil Aviation Authority introduced the Air Traffic Flow Management (ATFM) concept for the Piarco FIR. The introduction of ATFM is a very important measure in the short-term to mid-term, due to the neighbouring FIR's being oceanic airspace, San Juan FIR (Puerto Rico), Maiquetia FIR (Venezuela) and Brazil, all with high and ever increasing traffic flow.

The ATFM is a key instrument to improve collaborative decision making (A-CDM) and will support the reduction of fuel consumption caused by delays and other related situations such as weather, airports capability, and other factors that limit the efficiency of the airspace.

> The implementation of the mitigation measures in the action plan of Trinidad and Tobago will contribute to the reduction of CO_2 emissions by an average of 22,800 tonnes per year for international flights performed by the national airline, Caribbean Airlines Limited (CAL)

The implementation of the mitigation measures in the APERTT will contribute to the reduction of CO_2 emissions by an average of 22,800 tonnes per year for international flights performed by the national airline, Caribbean Airlines Limited (CAL). A reduction of 5,027 tonnes of CO_2 per year will be achieved from the domestic flights performed by CAL as co-benefits.

The basket of measures selected for Trinidad and Tobago will contribute to and support the reduction by at least 6,480 CO_2 tonnes per year from international operations performed by other international airlines in the State and the FIR.

Next Steps

- The present operations of the national airline, Caribbean Airlines Limited, are being reviewed, with a focus on improving efficiency of aircraft operations.
- Research, Feasibility Studies, and Cost Benefit Analysis on the use of alternative fuels in the aviation sector will commence by June 2016 as an aspirational goal for Trinidad and Tobago.
- Energy audit and feasibility studies at the Trinidad and Tobago International Airports will be conducted with an aim towards solar energy. Ground operations will also be studied aimed at improving all areas of airport operations.
- The establishment of an Environmental Unit within the Trinidad and Tobago Civil Aviation Authority will lead the State's efforts to increase the safety and capacity of the global aerospace system in an environmentally sound manner. It will also lead the strategic policy and planning efforts for environmental sustainability on international aviation.

Conclusion

Leadership in any industry is underpinned by strategic management, innovation, and operational excellence. The aviation industry is no exception. The Trinidad and Tobago Civil Aviation Authority recognises that these characteristics are critical to not only maintaining a leadership role in the Caribbean but also in driving its international presence. Trinidad and Tobago is on the flight path to maintaining environmental sustainability within its aviation system. Trinidad and Tobago is ready to assist the SIDS in the Region to promote environmental sustainability, as part of the ICAO "Buddy Programme".

THE CENTRAL AMERICAN ACTION PLAN FOR THE REDUCTION OF EMISSIONS FROM INTERNATIONAL CIVIL AVIATION AND ITS UPDATE

BY GIOVANNI TOBAR (CIVIL AVIATION AUTHORITY, GUATEMALA)

The 37th Session of the ICAO Assembly in 2010 took an important step forward in addressing the topic of greenhouse gas emissions from international civil aviation. Resolution A37-19 sets an important precedent by providing a scenario of global targets to stabilize CO_2 emission levels in the international civil aviation sector.

The Central American region has fully recognized the efforts undertaken by ICAO to make progress in reducing greenhouse gas emissions from international air travel. The Voluntary Action Plans for CO_2 Emissions Reductions represent a significant strategy because it allows mitigation measures to be adopted in the short and medium term, that have many long-term benefits in terms of emissions reduction. This, in turn, allows States to establish proactive measures and actions in accordance with their own capacities and territorial conditions.

Within this context, the 96th Meeting of the Civil Aviation Directors General for Central America and Panama (DGAC/CAP/96), held in Mexico City from 22 to 25 May 2012, made a significant commitment for the region. It was proposed that the Central American States (Belize, Costa Rica, El Salvador, Guatemala, Honduras and Nicaragua) should develop a joint action plan to tackle CO_2 emissions. The State of Guatemala was delegated as the Coordinating State to work collaboratively with the nominated focal points from each Central American State. to develop a plan, which will systematically define the main strategies in line with ICAO's aspirational goals.

The first Action Plan for the Reduction of Greenhouse Gas Emissions from International Civil Aviation in the Central American region, entitled CAAPER, was thus submitted within the framework of the 38th Session of the ICAO Assembly.

The tri-annual update of the abovementioned Plan is currently in the process of being reviewed and approved. This is taking place in three main areas: Support Strategies, Reduction Measures, and Complementary Programmes These include strategies such as institutional strengthening, the promotion of technology, infrastructure modernization, operational improvements, development of incentives, the promotion of research and development, the development of offsetting programmes, and other voluntary action.

The production of the initial document and its updated version have both illustrated once again the strengthening of Central American integration processes and the region's positive contribution to dealing with the phenomenon of global climate change in a responsible way.

It is important to clarify that the States in this region are developing countries that are extremely vulnerable and sensitive to the phenomenon of climate change. Therefore, voluntariness and recognition of States' specific capacities and special circumstances have been considered as key elements, alongside other principles, which urge States to step up their environmental protection and conservation efforts for future generations.

The sharing of air navigation services is enabling Central American countries to take measures to reduce emissions generated by operations in any of the given States. Joint strategies are also being implemented with a goal of contributing to the reduction of emissions from all operators, including those who use the upper airspace, even if they do not land in the region's airports.

CAAPER, in turn, has facilitated the development of the Central American region's potential to reduce emissions through different procedures such as Performance-Based Navigation (PBN); the Central American Air Navigation Agency (ACNA) has already projected a reduction of approximately 25,257 CO_2 tonnes in the region between 2015 and 2019 thanks to the implementation of these procedures. Moreover, implementing the various strategies established by CAAPER will allow for an estimated reduction of up to 42,375.15 CO_2 tonnes by 2019. This all brings added value to the document produced by Central American States which, in accordance with the baseline developed therein, have determined that the region only accounted for 0.583% of the total anthropogenic emissions from aviation in 2014[1].

All of the above clearly highlights the need to call on the aviation community to provide solid, sustainable, transparent, predictable and additional resources to accompany the development of this

Action Plan and the implement of the mitigations measures to reduce CO_2 emissions from international aviation, as well as a call to those other countries and/or regions with similar or higher levels of vulnerability to climate change than the Central American region.

The implementation of the mitigation measures identified in the CAAPER Action Plan will allow for an estimated reduction of up to 42,375.15 CO_2 tonnes by 2019.

The Central American Action Plan for the Reduction of Emissions from International Civil Aviation and its update are a reflection of both the region's good faith and commitment to the global environment and the region's contribution to the vision of promoting an economically, socially and environmentally sustainable aviation.

References

1. It is estimated that aviation generated a total of 717.8 Mtonnes of CO_2 in 2014, according to data from the Global Carbon Atlas.

THE DEVELOPMENT OF SPAIN'S ACTION PLAN: BENEFITS AND LESSONS LEARNED

BY ALFREDO IGLESIAS (STATE AVIATION SAFETY AGENCY, SPAIN), RAUL MARTIN (SENASA), JULIA MUNICIO (SENASA)

Introducing the Action Plan of the Aviation Sector in Spain

Spain is a member of the European Union and is fully committed to the policies and objectives of ICAO. In this respect, Spain has developed and submitted its Action Plan for emissions reduction of the Aviation Sector in 2012, as well as its update in 2015.

In addition, Spain is a member of the European Civil Aviation Conference (ECAC), which is an intergovernmental organization dealing with civil aviation, which among other activities supports ICAO's efforts to address climate change. ECAC decided to create the Aviation and Climate Change Action Plan Expert Group (ACCAPEG), which contributes to the ICAO objectives through the elaboration of a common section in the Action Plans for its 44 Member States, including a baseline of the emissions from international aviation and an assessment of the benefits obtained through the supranational measures.

In this context, and recognizing the individual value of each Member State preparing and submitting their Action Plans on international aviation emissions reduction activities to ICAO, Spain developed its Action Plan in 2012 and updated it in 2015. Spain's Action Plan includes both national and supranational voluntary measures, designed to improve fuel efficiency and reduce the carbon footprint of the international aviation sector, which therefore contributes to the ICAO global aspirational goals of 2 per cent annual fuel efficiency improvement and carbon neutral growth from 2020, established in 2010.

Challenges in the Development of the Spanish Action Plan

In the case of Spain's Action Plan for international aviation, the technical team responsible for the development of the Plan has identified different challenges along the process.

First, the technical team needed to familiarize itself with the different steps for the elaboration of the Plan. This process allowed the team to communicate the expected deliverables and positive outcomes linked to the initiative to all of the parties involved. The direct support offered by ICAO has been useful in overcoming this challenge. Indeed, ICAO organized Action Plan seminars for all focal points and made available tools for the calculation of CO_2 emissions, as well as supporting documentation. All these tools and guidance documents have provided the support needed to elaborate the action plan. Spain attended the Action Plan seminar held in Warsaw in March 2015, receiving training about the development and the objectives of the Plans. Then, a key challenge in the elaboration of the action plan was to secure the voluntary collaboration of all the Spanish international aviation stakeholders. These stakeholders were organized in different working groups, and were informed about the commitment of Spain to elaborate such an action plan, together with the expected benefits resulting from the publication of the plan. The description of these benefits included the selected mitigation measures and initiatives toward the reduction of CO_2 emissions from international aviation.

As a consequence of the formalization of these working groups, the technical team responsible for the elaboration of the action plan cooperated with a number of relevant entities in international aviation, such as Spanish airlines (Iberia, Air Europa, Swiftair, etc.), the airport operator AENA S.A., and the air navigation service provider ENAIRE. In addition, statistical information from the National Institute of Statistics (INE) and outputs from the main collaborative projects among different companies of this sector were considered.

Overall, feedback received from the different parties involved in the process of building the action plan was very positive. In some cases, some stakeholders were reticent to provide information, due to the confidentiality of some of the data needed to develop the plan. However, the confidentiality terms under which the action plan was developed allowed for these data to be provided to the action plan team. They were populated in a way that did not enable to use them in a commercial context.

During the third phase of the development of the action plan, the challenge was to carry out the calculations to elaborate the reference scenario from 1994 until 2014 and the associated forecast from 2015 to 2050 of the international Revenue-Ton-Kilometers (RTK), the fuel consumption and the CO_2 emissions from international aviation in Spain.

Information for the Spanish reference scenario and the quantification of the measures came from two groups:

- The first group developed the international baseline of the emissions from international air transport that was reported to the ECAC Member States and developed by EUROCONTROL. This includes the information from the supranational measures, or the measures involving various countries at the same time;
- The other group developed the national baseline from

international air travel departing from Spain using the Spanish Model for Quantifying Air Transport Emissions (MECETA). MECETA is able to calculate the fuel consumption and emissions for the Landing and Take-Off and cruise phases, adjusting the ICAO certified values for the times in mode and applying the power engine's reduction during take-off. At the same time it adjusts the fuel consumption to the real values through cruise curves.

The implementation of the measures provided by the collaborative entities, the evolution of the international RTK, the fuel consumption, and the CO_2 emissions were reported by the stakeholders and subsequently included in the action plan. It is to be noted that the calculation was difficult due to the uncertainty derived from the evolution of some of the measures. Another challenge was the precision of the information received, which did not allow the technical team to get to the level of precision required to develop a forecast until 2050. Instead, this forecast was limited to the period from 2015 to 2030.

Benefits Related to the Action Plans

Beyond the collaborative benefits related to the Action Plans at a national and international level, the aim of the action plan is to evaluate the present and future implementation of the different mitigation measures selected.

The mitigation measures are selected from a range of measures, which include regulatory and economic measures, or the use of alternative fuels. They also include measures linked to air traffic management and operations, the development of new technology for aircraft or improvements at airports. All these measures lead to quantitative and qualitative benefits. In addition, the action plan can also be used to showcase the associated co-benefits, which are the benefits generated by the implementation of the mitigation measures that have a positive impact beyond international aviation emissions. All these measures favor the sustainability of aviation.

The quantitative benefits derived from the action plan are the identification and implementation of measures to reduce fuel consumption and its associated CO_2 emissions, in line with ICAO aspirational goals for international aviation.

The implementation of the measures described in the Plan also leads to **qualitative benefits** as these measures provide more visibility to the actions carried out by aviation stakeholders to addressing climate change. Importantly, it also opens opportunities for cooperation between different stakeholders, engaging the industry, the financial institutions, and other international organizations in exchanging best practices information, within the ICAO frame, and thus accelerating the financing processes and consolidating alliances between different States.

The collaboration between Spain and Ukraine in 2012 leading to the submission of Ukraine's Action Plan, is an example of this engagement. The more successful the action plan initiative is, the greater the ability ICAO has for extending the benefits of measures to all regions and States. This assists in reducing the legal, security, economic, and institutional barriers to the implementation of new initiatives.

Beyond the qualitative and quantitate benefits already mentioned, there are also the **co-benefits** produced in parallel to the main goals of the action plans. These co-benefits can include the reduction of noise nuisance due to the design of new routes or the penetration of new technologies. They also cover the reduction of emissions impacting the local air quality, and reduction of emissions from domestic aviation.

Evolution of the Action Plan

The Action Plans are live documents. They have to be updated every three years to take into account the constant evolution and the environmental benefits resulting from the implementation of the selected mitigation measures. The compilation of the environmental progress achieved with the implementation of the plan provides information on the CO_2 emissions reductions.

These CO_2 emissions reductions are then compiled with the aim of evaluating the progress leading to the achievement towards the ICAO global aspirational goals. Spain is making significant efforts to reduce emissions and such is reflected in the National Inventories of Emissions from Aviation. Spain developed a set of corrective measures that could be implemented in the event that the objectives planned were not achieved. Such measures range from: new assignments or cuts in budgetary resources, review of tasks, etc., as well as new cooperation between States in the development of analytical models for the prediction of the evaluation of the impacts of aviation.

For Spain, the action plan on CO_2 Emissions Reduction activities is recognized as a collaborative and useful tool that involves various stakeholders in the fight against climate change led by ICAO, within the international air transport sector.

ICAO, UNDP AND GEF –PROGRESSING THE GLOBAL CLIMATE AGENDA TOGETHER

BY ICAO SECRETARIAT

In March 2015, ICAO formed a partnership with the United Nations Development Programme (UNDP) with financing from the Global Environment Facility (GEF), in order to design and implement a pilot project demonstrating CO_2 emissions reductions in international aviation.

Under of the design elements of this pilot project, ensuring a high level of replicability for developing States and Small Developing Island States (SIDS) was considered as being critical. The administrative and financial modalities of the pilot project should be easily reproduced. Indeed, individual States would be able to easily implement similar projects using a variety of possible financing mechanisms, including their own GEF national allocation, if they wished to do so. These States would also have access to specific guidance developed on the administrative, financial and technical components of the pilot project to implement their own CO_2 emissions reduction project.

ICAO and UNDP agreed on the design elements of their joint project, they then had to decide which mitigation measure they would showcase. After a thorough assessment of the options available and based on an in-depth understanding of the needs of developing States and SIDS, it was decided to implement a "solar-to-gate" project.

Indeed, after landing at the airport or prior to departing for another flight, an aircraft has to keep a number of on-board system functionalities running. Air conditioning and heating are the most commonly experienced of these functionalities by passengers. Thus, aircraft need energy when they are parked on the ground. Aircraft are equipped with an Auxiliary Power Unit (APU), in general located at the aircraft tail. APUs generate the electricity required to keep the essential on-board systems. This energy can come from the kerosene loaded on-board the aircraft or from a diesel generator connected to the aircraft when it is at the airport gate. The objective of the ICAO-UNDP-GEF pilot project is to substitute the use of kerosene or diesel with electricity from a clean, renewable source. Hence, the willingness to bring solar energy to the aircraft, when parked at the airport gate.

To bring this concept to life, the following three components are covered by the pilot project (see **figure 1**):

1. The installation of solar panels;
2. A convertor to transform the solar energy into electricity; and
3. The acquisition of an electric Pre-Conditioned Air (PCA) unit and an electric Ground Power Unit (GPU). The PCA and GPU are available at the gate and can replace fully the use of the APU, as soon as they are connected to the aircraft.

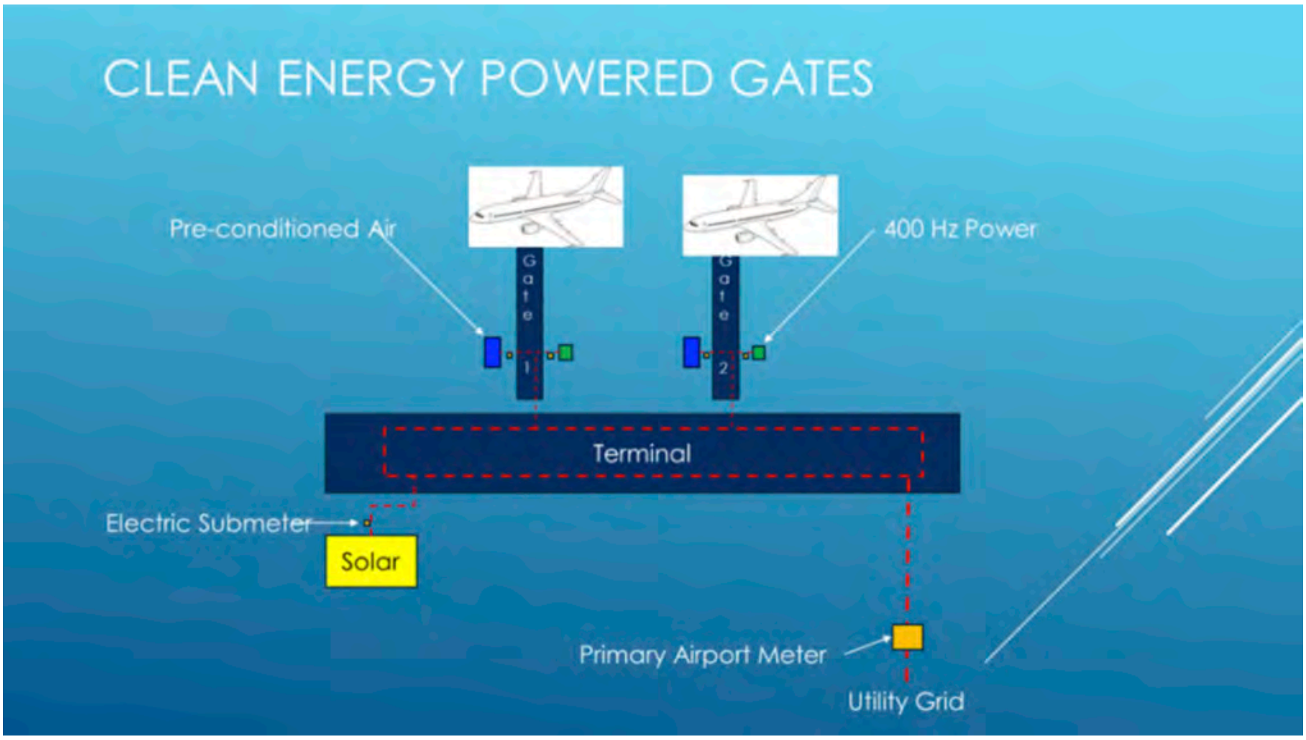


Figure 1. The components covered by the pilot project

Figure 2. Consultation with main partners (from left to right: Ms. Jane Hupe, Deputy Director Environment, ICAO , Ms. Laurence-Chounoune, Deputy Resident Representative and Mr. Pouezat, Resident Representative, UNDP Jamaica, Bahamas, Bermuda, Turks & Caicos and Cayman Islands in Kingston, Jamaica).

Last but not least, decision had to be made on where to implement the pilot project. Initially, it was foreseen to identify one international airport in Jamaica as implementation site. Following a detailed analysis by leading experts in the field of renewable energy and aviation and a series of consultations, it was found possible with the same budget to implement smaller scale projects at two airports, thus giving the opportunity to promote two different business models. In one case, all three components of the project will be financed by the GEF project budget itself, in the second case, the solar panel component will be installed on a cost recovery basis, thus stimulating partnerships between the public and private sectors.

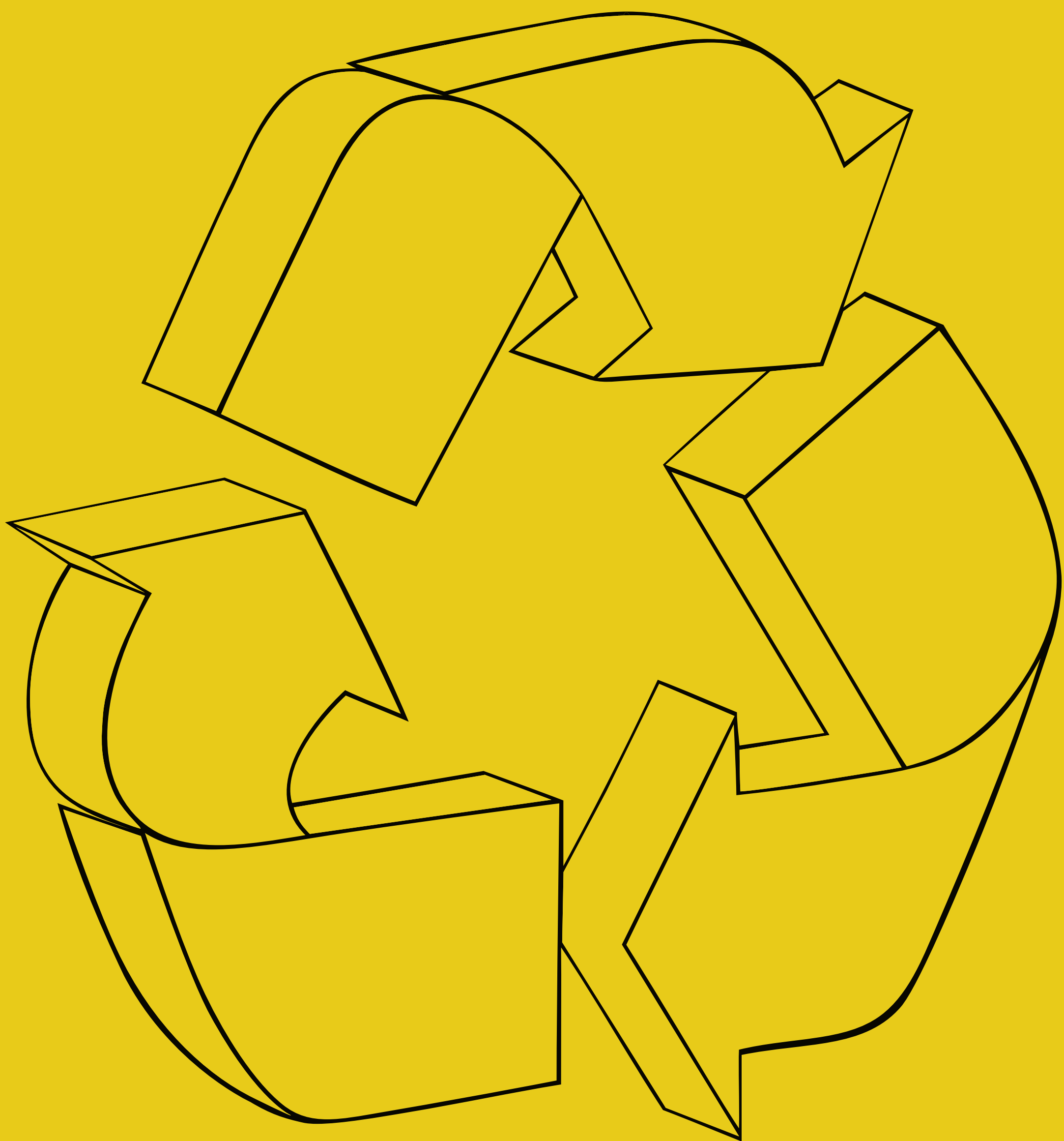
"This initiative by ICAO/UNDP is welcomed by the Ministry of Transport, and the entire Government of Jamaica. The Government pledges its support in this venture, and looks forward to the commencement of this emissions saving project", says LM Henry, Minister of Transport and Mining of Jamaica.

"Jamaica Civil Aviation Authority on behalf of the Government of Jamaica is committed to provide the necessary support to the project," says Nari Williams-Singh, Director General of Jamaica Civil Aviation Authority.

"The successful outcome of this project is vital not only for Jamaica, but for the whole Caribbean region," says Cleonie Williams, an office manager at Caribbean Aviation Safety and Security Oversight System (CASSOS).

CHAPTER 6

AIRCRAFT END-OF-LIFE AND RECYCLING



THE AIRCRAFT LIFE-CYCLE: "REDUCE, RE-USE, RECYCLE"

BY ICAO SECRETARIAT

In October 1987, the World Commission on Environment and Development, also known as the Brundtland Commission, released a report aimed at providing "a global agenda for change". This report, *Our Common Future*[1] gave life to and provided a definition for "sustainable development", integrating environment and development under one umbrella, stating that "Humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs." Since, sustainable development has become central to the activities of the United Nations, and reached its culmination in September 2015 with the adoption of the UN Sustainable Development Goals.

A number of sectors have embraced the concept of sustainable development, deploying the socio-economic benefits of their products and services, while striving to minimize their impact on the environment. This "clean production" approach has increasingly expanded to goods' and services' entire life-cycle and issues such as waste reduction, energy and water efficiency, water quality and eco-design are fundamental to an environmentally sustainable and economically sound production chain. The linear approach to manufacturing "take, make, dispose" is evolving toward greater consideration for the origin of the input material, the impact of the manufacturing process on the environment and the treatment of end-of-life products. Aviation is no exception and the environmentally-sound management of the aircraft life-cycle is gaining traction, leading to the multiplication of partnerships and best practices in the sector, as illustrated in this chapter.

For aviation, such considerations are of greater relevance now, as an increasing number of aircraft are expected to leave service. Some studies show that some 17,000 commercial aircraft will be retired from service by 2030.

Some 17,000 commercial aircraft will be retired from service by 2030.

Environmental Sustainability Across the Aircraft Life-Cycle

Between the inception of an aircraft research programme and the aircraft's actual entry into service, some of the most forward-looking innovations can be embedded into new aircraft designs. Indeed, aircraft manufacturers are continually bringing new products to the market that would decrease the environmental footprint of aircraft operations. Today's innovations, such as advanced materials or 3-D printing, can be real game changers for the sector.

The use of leading-edge technologies and advanced materials have a significant CO_2 emissions reductions potential. For example, aircraft weight reduction measures enable Bombardier's C Series aircraft to deliver over 20% fuel burn benefit, which can reduce CO_2 emissions to 6,000 tonnes annually. In a similar vein, Airbus considers that in the long-term, 3D printing can reduce aircraft weight by more than 1,000 kg per aircraft. It is anticipated that 3D printing on a large-scale could be in place by 2018.

Aircraft manufacturers are also reducing the environmental impact of their manufacturing process. This strategy includes better control of waste material and a decrease in energy consumption at their manufacturing facilities.

Again, 3D printing appears to have significant potential. For a single spare part, the time, cost and waste savings linked to the use of 3-D printing are considerable, and can bring about reductions in raw material waste as high as 95%. Aircraft parts are not directly cut in raw material sheets, which would create scrap material, but stem from the conglomeration of the exact amount of raw material needed to manufacture the piece.

The use of new technology is also associated with new challenges, and this is when recycling and aircraft end-of-life management come into play. While waste savings are important, the ability of the sector to re-use and recycle aircraft parts and to adapt these practices to the new materials used in aircraft manufacturing, such as composite materials, are equally as valuable.

The Aircraft Fleet Recycling Association (AFRA) has announced that 400 to 600 aircraft will be dismantled each year until 2017 and it is expected that the entry into force the new ICAO CO_2 standard for aircraft will intensify this trend. The objective of AFRA is to ensure that this process is carried out in compliance with state-of-the-art practices (see related article page 196). However, important challenges lie ahead, beginning with the lack of awareness on environmental best practices in this area.

The Way Forward

A paradigm shift is needed to conceive of the life-cycle of the aircraft in its entirety and to extend the concept of environmental sustainability beyond the production and utilization of aircraft.

ICAO and its partners will aim to support this paradigm shift and to provide best practices on the use of material, as well as information on environmental risks during the dismantling and recycling process. The ICAO Committee on Aviation Environmental Protection (CAEP) will establish a first diagnosis of the issues connected to aircraft end-of-life to make sure that they are addressed by the relevant bodies, including safety and security. This should contribute to strengthening the full life-cycle approach to aircraft manufacturing.

From cradle-to-grave and to cradle-to-cradle, a case is being built on a daily basis by those who work hard to limit the aircraft environmental impacts, after those aircraft have completed their service in the development of international aviation.

Of course, to address emerging issues such as aircraft recycling and dismantling, it is imperative that ICAO establishes relevant partnerships with the experts in the field. By the time of publication of this report, ICAO and AFRA should have formalized their willingness to strengthen their cooperation.

Sustainable Development Goals

References

1. World Commission on Environment and Development (1987). Our Common Future http://www.un-documents.net/wced-ocf.htm

AFRA – LEADING THE WAY IN SAFE AND SUSTAINABLE AIRCRAFT END-OF-LIFE MANAGEMENT

BY LAURA DWULET (AIRCRAFT FLEET RECYCLING ASSOCIATION -AFRA)

With increasing focus on environmental and operational issues related to aircraft end-of-life and related practices, procedures, and safety and environmental concerns, the Aircraft Fleet Recycling Association (AFRA) is uniquely positioned as the only international trade association focused on aircraft disassembly, recycling, and end-of-life solutions. AFRA seeks to build awareness and endorsement of the AFRA Best Management Practice (BMP) guide that helps assure that facilities operate in a safe and environmentally responsible fashion, and accredits companies that meet the minimum best practices.

In a recent study conducted in partnership with TeamSAI, AFRA estimated that between 1,200 and 1,800 aircraft will be torn down or dismantled over the next three years (2014-2016)1, and that a key challenge is to recycle and disassemble these materials in a way that is environmentally responsible. Not all end-of-life aircraft owners are considering environmental performance when looking for a disposal provider, and not all customers are aware of the risks of end-of-life aircraft in the field of aviation safety and environment, and the effect of that on value. AFRA strives to ensure responsible handling of materials, jobsites, and the safety of aircraft disassemblers and the flying public.

Between 1,200 and 1,800 aircraft will be torn down or dismantled over the next three years (2014-2016).

About the Aircraft Fleet Recycling Association (AFRA)

AFRA is the leading global organization for developing and promoting the safe and sustainable management of end-of-life aircraft and components. AFRA was founded in 2006 at Chateauroux, France with the mission to organize and present an industry perspective on aircraft sustainability via the development and recommendation of best practices and technologies for the management of the world's older aircraft fleet. It is essentially a membership-based global collaboration meant to elevate industry performance and to increase commercial value for end-of-life aircraft through safety (aviation and labor), environmental responsibility, business practices, technology advancements, and regulatory engagement.

AFRA currently has 68 member companies, from almost 20 different countries, and is headquartered in Washington, DC. AFRA offers four different membership categories, and its members include aircraft disassembly companies, material recycling companies, air centers, OEMs, lessors and airlines, and research institutes.

Reducing the Environmental Footprint of the Sector

Core values of the Association are quality, safety, environmental stewardship, and collaboration. AFRA aims to ensure that its BMP-accredited members: meet or exceed industry standards, protect the safety of employees, place communities and passengers first, protect the environment and reduce the industry's impact on critical resources through the product lifecycle, and strive to include all aviation stakeholders in all AFRA-sanctioned activities.

In practice, AFRA works toward realizing these values by: maintaining and encouraging industry recognition of, and participation in, its accreditation program and BMP; engaging its members in key projects and initiatives; and entering into working partnerships with aligned organizations.

AFRA Accreditation and the BMP Guide

AFRA's guide titled "*Best Management Practice for Management of Used Aircraft Parts and Assemblies and for Recycling of Aircraft Materials*" (BMP) is the global standard for environmentally responsible aircraft disassembly and recycling. The document represents a collection of recommendations concerning best practices for the management of parts that are removed from aircraft, engines, or other assets during the *disassembly* of an asset at the end of its service life. It also provides guidelines for the *recycling* of parts and materials that are recovered from aircraft, engines, or other assets during the recycling of an asset at the end of its service life.

The document provides guidance on employing Best Practices, which are auditable standards. The purposes of the BMP guidelines are to: increase and sustain the value of end-of-life assets, grow BMP awareness, increase the number of aircraft dismantled and recycled according to BMP, and to improve the recycling rate of the current fleet. AFRA accreditation is available for Association members as well as non-member companies. Companies can choose to be accredited for disassembly, recycling, or for dual accreditation.

Our Place in the Market

Between 40% and 50% of the weight of most dismantled aircraft is returned to the parts distribution pipeline. AFRA members estimate disassembly of between 400 and 600 aircraft per year through 2017, with those numbers likely to increase beyond that. Those estimates are based on both the age of aircraft in circulation, as well as on publicly available statistics on new orders placed with major aircraft manufacturers. Of course, as with any industry, world economies play a vital part in the decision to take aging aircraft out of service. In the last worldwide recession, AFRA members across the globe saw the availability of aircraft to be disassembled and recycled drop substantially, while the past few years have seen a slow but steady increase.

Between 40% and 50% of the weight of most dismantled aircraft is returned to the parts distribution pipeline.

We have also seen saturation in the marketplace of companies engaged in aircraft disassembly and recycling, which can bring into question the viability of many of the smaller shops, which would be based almost solely on the availability of aircraft to recycle. The more planes there are, the more room there is in the industry, but it is safe to say that based on the current landscape the industry will be operating at or above capacity for some time to come.

Many of the companies engaged in aircraft recycling are accredited by AFRA and working to its Best Management Practices for both disassembly and recycling. The increase in aircraft owners specifying AFRA BMP in their disassembly and recycling requests for proposals (RFPs) is a major step in the right direction.

Key Initiatives and Partnerships

AFRA was founded in 2006, so it is now entering its tenth year as the global organization for developing and promoting the safe and sustainable management of end-of-life aircraft and components. In that relatively short time, the Association has developed a sound membership and has accredited various companies for aircraft disassembly, recycling, or both, in accordance with its Best Management Practices.

Some recent statistics of interest regarding aircraft end-of-life based on feedback from AFRA members worldwide include:

- Average parts value per aircraft is estimated between $1-3 million.
  - Engines have most value.
  - Can have no value if records of aircraft are not available.
- Total tear-down/dismantling market is estimated to be $80 million per year.
- Recycling /dismantling cost for certain aircraft may exceed parts value.
  - Customers are likely to seek low-cost providers.
- To manage and reduce the overall environmental impact, while increasing end-of-life value at the disassembly phase…
  - Better performance = higher cost = higher component value.
- Users are increasingly recognizing AFRA standards.
- Airlines such as Delta, Cathay Pacific and ANA are referencing the AFRA standards or the use of the AFRA BMP in their RFPs.
- FAA, SFO Airport, and US DOD have referenced AFRA standards in their RFPs.

As an international organization, AFRA is focused on continuing to grow its membership among companies engaged directly in aircraft recycling. It also places a high priority on targeting those companies and organizations with a specific interest in the industry, such as aircraft manufacturers, parts distributors, industry suppliers, research organizations, and other stakeholders. Additionally, the AFRA membership is collectively interested in promoting the industry through targeted outreach that speaks to the importance and value of its BMP, as well as to educate aircraft owners about the decision-making process regarding aircraft end-of-life.

Beyond those, AFRA is involved with a number of related associations and industry influencers and stakeholders, which have a mutual interest in ensuring the safe and responsible disassembly and recycling of aircraft. These groups believe that specific attention must be paid to the safety of those individuals who perform the work, the environment in which the process takes place, and the responsible distribution of parts or recycling of the remaining materials from the process.

Over the next three years, AFRA would like to see a marked increase in aircraft owners asking for AFRA accreditation in their disassembly and recycling RFPs. Increased participation of disassembly and recycling companies in AFRA is also sought so that they will become will become part of the discussion.

The participation of many companies and organizations at the industry level will foster discussion and action on how all players can continue to improve practices and processes collectively. It will also encourage more companies to take the next step and work towards AFRA accreditation.

AFRA plans to continue to expand its outreach and engagement with key industry stakeholders to educate and inform them about the AFRA organization, aircraft disassembly and recycling, and AFRA's Best Management Practices. There are also many opportunities to engage with other segments of the industry where there is a complementary interest in the safe and successful disassembly and recycling of aircraft. Among the groups AFRA is actively engaged with are: ISTAT (International Society of Transport Aircraft Trading - Americas and Europe), ATAG (Air Transport Action Group), ICAO (International Civil Aviation Organization), IATA (International Air Transport Association), ASA (Aviation Suppliers Association), UK Environment Agency, EASA (European Aviation Safety Agency), and the FAA (Federal Aviation Administration). It is AFRA's hope to receive input and guidance from these and other groups that supports AFRA Best Management Practices as part of the aircraft end-of-life decision tree.

Conclusion

The Aircraft Fleet Recycling Association's robust best practices accreditation program, as well as its international outreach and initiatives with government agencies and NGOs to promote industry best practices, help ensure that aircraft disassembly, recycling, and end-of-life solutions are implemented with the highest level of integrity.

Reference

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THE FUTURE OF SUSTAINABLE, END-OF-LIFE AIRCRAFT MANAGEMENT

BY JULIEN DEZOMBRE (BOMBARDIER), KAHINA OUDJEHANI (BOMBARDIER)

Sustainability is fundamental to how Bombardier conducts its business. As an organization, we adhere to a Product Innovation Lifecycle to ensure the innovations we incorporate into our products at every stage meet and exceed customer expectations as well as produce the most sustainable and high-performing solutions, while mitigating the risks of new technology integration.

The Bombardier C Series commercial aircraft family has been developed following this innovative approach. The first aircraft, the CS100, is scheduled to enter into service in the second quarter of 2016 with SWISS. Later in 2016, a CS100 Environmental Product Declaration (EPD) document, an industry first, will be published.

As a responsible manufacturer of both commercial airliners and business jet aircraft, Bombardier has established a dedicated Ecodesign Program to integrate environmental concerns during all lifecycle stages of each new aircraft program, from the design phase to end-of-life (EoL), as illustrated below.

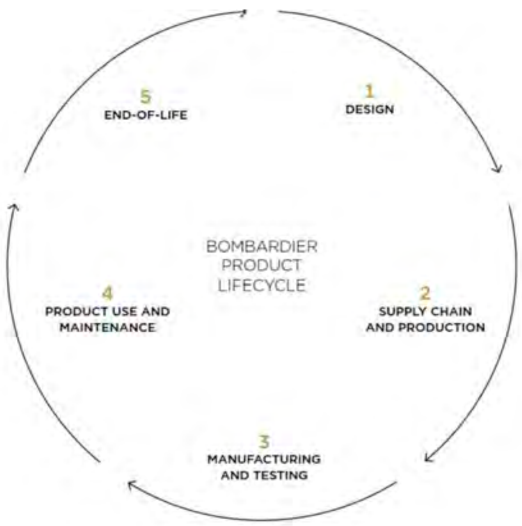


Figure 1. Product Lifecycle

Figure 2. Routes to improve End-of-Life management

Bombardier has established an End-of-Life program to support its corporate objective that all new products be 100 per cent recoverable by 2025. This program is focused on developing more efficient dismantling operations, maximizing the value of materials, and increasing the recoverability of 20 to 25 per cent of the materials that are discarded today, while reducing their overall environmental impact.

The rapid growth of air traffic over the last few decades has resulted in a high number of aircraft entering in service. However, whether for technical or economic reasons, many of these aircraft will retire from service over the next 20 years; in its 2015 Commercial Aircraft Market Forecast, Bombardier believes that 5,000 aircraft in the 60- to 150-seat categories will retire by 2034.

The storage of aircraft parked on airport grounds worldwide either waiting for a potential return to service or a tear-down operation has been considered the only option for a long time. Today however, this solution is no longer socially or environmentally acceptable for it can potentially create environmental issues, such as the release of pollutants from aircraft materials during dismantling as well as the unattractive view it forces on neighbourhoods surrounding the airport.

The aerospace industry, along with aircraft dismantlers, have looked at implementing a safe and sustainable solution for the management of the EoL of aircraft. In fact, the Aircraft Fleet Recycling Association (AFRA), in which Bombardier is actively engaged, assembled a team representing aerospace manufacturers, recyclers and dismantlers to provide their recommendations concerning best practices for the management of EoL.

Today, it is generally recognized that 80 to 85 per cent of an aircraft can be recycled. One objective for the different parties involved in EoL management is to address new challenges that can include developing more efficient dismantling operations, maximizing the value of materials, and increasing the recoverability of materials being discarded today.

Today, it is generally recognized that 80 to 85 per cent of an aircraft can be recycled.

For example, aluminium is literally used everywhere in current-general aircraft: in the fuselage, in the trims, in wing panes and many other locations. One of the most widely used alloys in aviation is the alloy known as 7075 which consists of aluminium, zinc, magnesium and copper. However, during the current recycling operation, alloy 7075 is usually mixed with other metals, thereby lowering both the final value and the end application of this valuable recycled aluminium (**Figure 4**).

The introduction of advanced materials to lighten structures - such as the increasing use of carbon fibres composites - is also a growing challenge for EoL management. Finding innovative solutions to recycle and reuse these carbon fibre materials must be part of the way forward.

Bombardier has led a research and development project, in collaboration with other industry partners and Canadian universities, to find new ways to increase the recyclability and recoverability of metals and maximize the value of the high quality aluminium alloys while also reducing the environmental footprint of the recycling operation.

Funded through the Consortium for Research and Innovation in Aerospace in Québec (CRIAQ), Canada, this project started in October 2011 and was completed in December 2015, with these outcomes:

Figure 3. Bombardier CRJ100 tear down

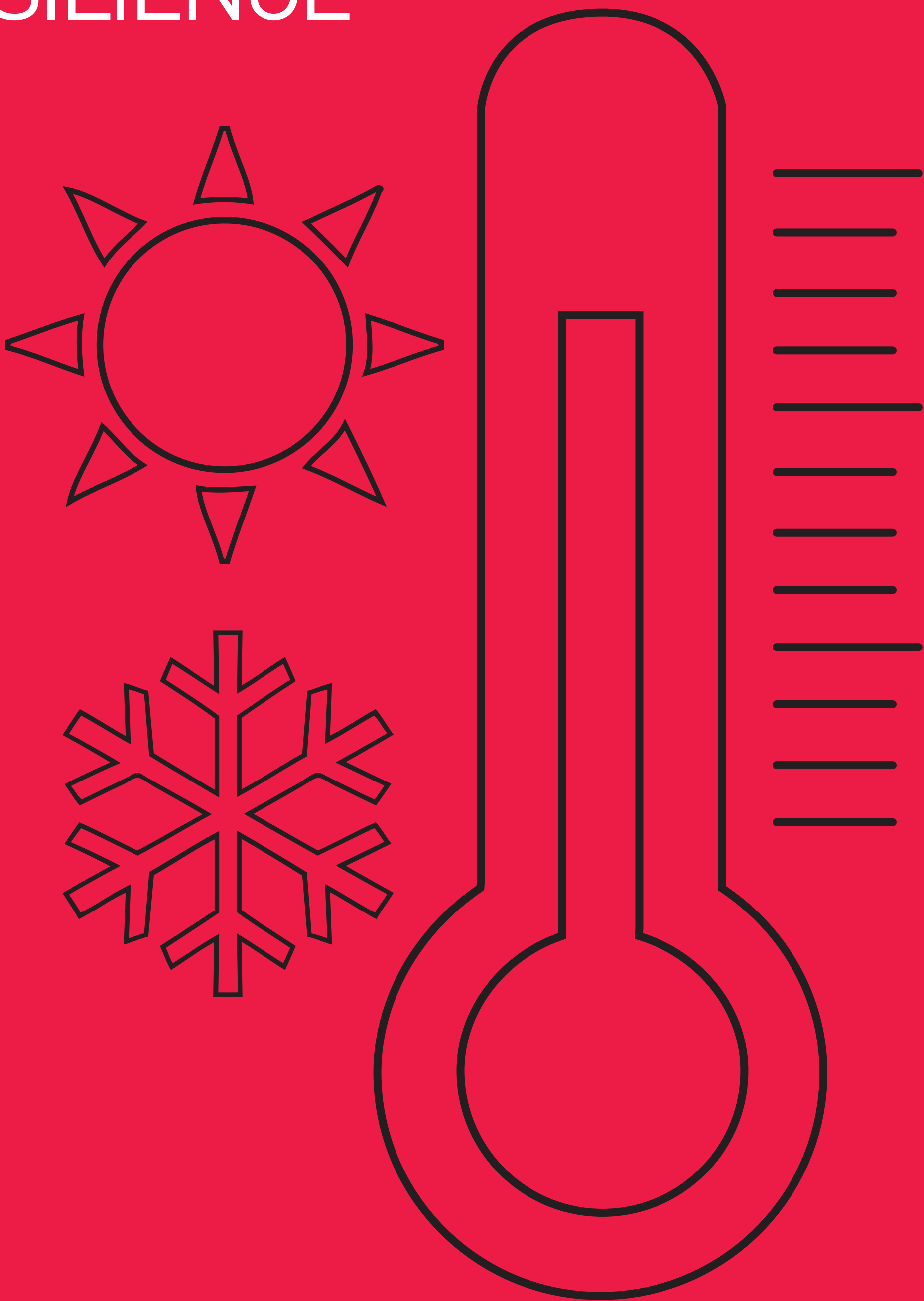
- Recommendation of new ways to optimize aircraft dismantling while reducing environmental and safety risks;
- Improvement of recyclability rates and material valorization (e.g. improve segregation based on the type of alloys and increase the value of recyclable materials);
- Assessment of potential environmental impacts related to EoL operations; and
- Integration of lessons learned in aircraft design to improve the design for EoL.

The consortium also has worked with Industrial Design students at the Université de Montréal to re-design leftover aircraft material into potentially commercially viable items such as bicycles, clothes, etc. Known as up-cycling, it aims to identify / demonstrate solutions to discarding non-recyclable material into landfill.

Figure 4. Re-designed leftover aircraft material

CHAPTER 7

CLIMATE CHANGE ADAPTATION AND RESILIENCE



CLIMATE ADAPTATION AND RESILIENCE IN INTERNATIONAL AVIATION

BY ICAO SECRETARIAT

Since the 2013 edition of the ICAO Environmental Report, the question of how to adapt to climate change has become prevalent within international organizations, governments and business. The landmark Paris Agreement adopted in December 2015 formulizes a long-term goal of keeping the increase in global average temperature to well below 2°C above pre-industrial levels. It also aims to strengthen societies' ability to deal with the impacts of climate change.

Indeed, following the last scientific findings from the IPCC, greenhouse gases released in the atmosphere since the beginning of the industrial area are already warming the planet, inducing climate impacts. These impacts are different depending on the world regions and affect physical, biological and human systems at local level (Figure 1), forcing societies to develop tailor-made adaptation strategies.

As far as international aviation is concerned, the understanding of climate change impacts has reached different levels of maturity, depending on whether the impacts are to the physical infrastructure (e.g. airport buildings, apron, control tower, energy grid), ground operations or wether en-route operations are considered. However, predictions on the magnitude of sea-level rise by 2100 imply that the infrastructure of the world largest international airports could be affected, thus putting international aviation services at risk. This chapter provides an overview of these impacts, while highlighting the need for further research on the local effects of climate change on aircraft and airport operations (see articles page 205 and page 208).

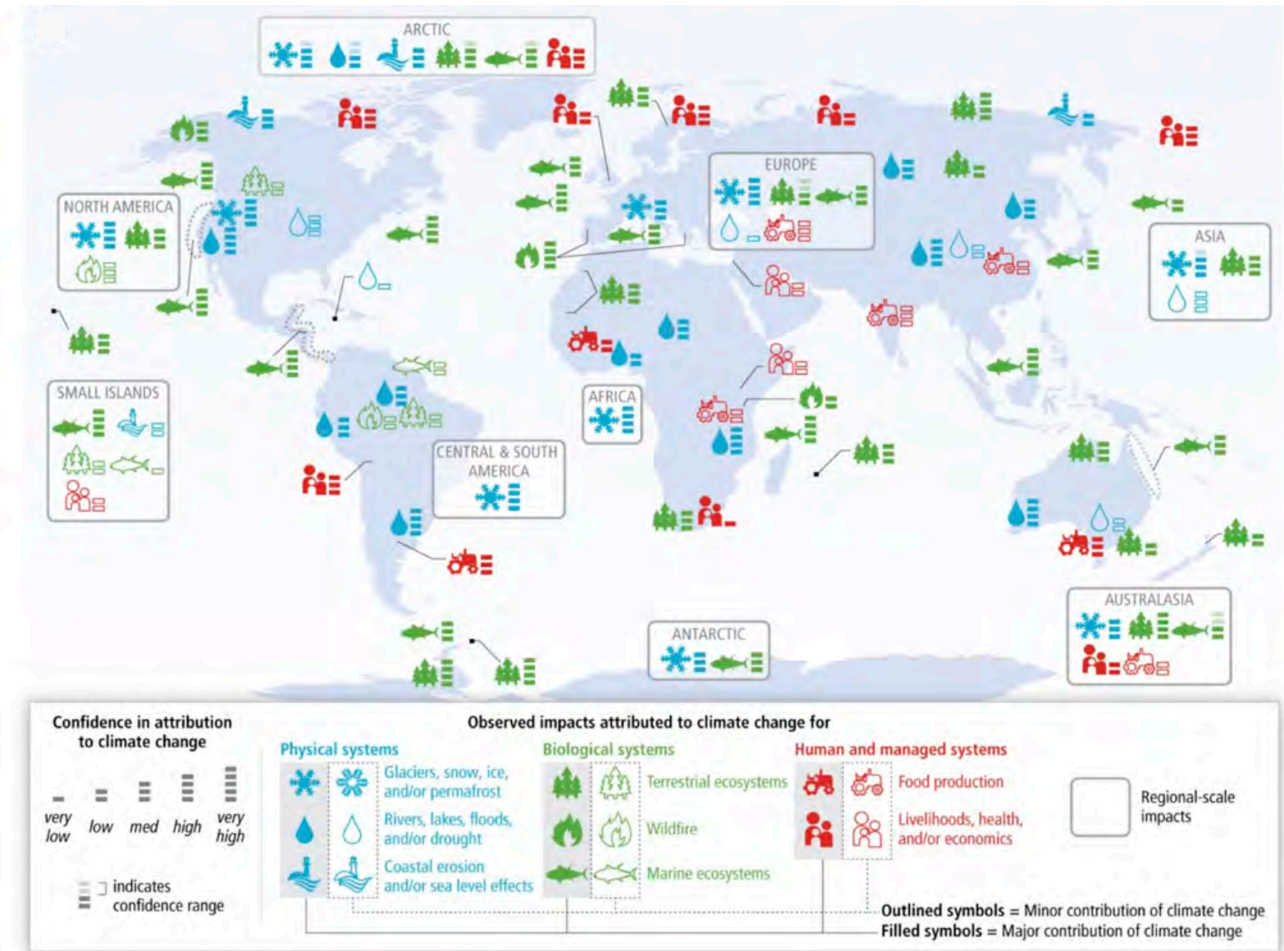


Figure 1. Global patter of observed climate change impacts (source: IPCC Working Group I, 5th Assessment Report, Summary for Policymakers)

Climate Adaptation and ICAO

During the last triennium, ICAO initiated research activities on the impacts of climate adaptation on international aviation at the request of its Member States. The ICAO Committee on Aviation Environmental Protection (CAEP) Impact and Science Group reviewed the projected impacts of climate change on aviation and research was carried out to better understand the possible effects of climate change on air navigation services over the North Atlantic. In 2016, it was decided that as part of its work programme, CAEP would conduct the necessary research and get an understanding of the environmental impacts of climate adaptation. Any other issues identified during the process would be directed to the relevant ICAO panels.

In addition, mindful of the need to develop aviation-specific guidance on climate adaptation during airport planning, ICAO has included a new Chapter on Climate Adaptation and resilience in the ICAO Airport planning Manual, Part 2 (Doc 9184). For the first time, climate change impacts were included in airport planning considerations, alongside with aircraft noise, which have historically been the main environmental concern around airports. Therefore, the updated ICAO Airport Planning Manual, Part 2 is considered as the first building block of a wider climate adaptation synthesis to be conducted by the ICAO Committee on Aviation Environmental Protection.

Although the scientific basis driving climate adaptation strategies should continuously be refined and updated to ensure that action is timely and heads in the right direction, the observation of severe impacts has already led operational stakeholders and governments to take initial steps towards better preparedness, designing a pathway for climate change adaptation in aviation. Brisbane Airport in Australia and the network of airports operated by Avinor in Norway illustrate possible such initial adaptation actions (see articles page 211 and page 214).

The experience gained by States, airport operators, ANSPs and aircraft operators multiplies the opportunities to exchange good practices on adaptation and enhance cooperation. ICAO can play a role in proposing a common approach to risk assessment and possible practical solutions.

Financing

The implementation of these solutions is bound to resource availability. A global study conducted by the World Bank and released in 2008 estimated that between 2010 and 2050, the cost of adapting to an approximately 2 degree Celsius warmer world by 2050 would be in the range of USD 70 billion to USD 100 billion a year[1]. In 2014, the United Nations Environmental Programme (UNEP) provided a revised estimate of these costs in its *Adaptation Gap Report*[2], based on new national and sector-specific studies. According to this study, the costs of adaptation for Least Developed Countries would approximate USD 50 billion per year by 2025/2030 and could reach US$100 billion per year by 2050. This poses the question of adaptation financing, as the *Adaptation Gap Report* also highlights that Least Developed Countries and Small Island Developing States are likely to have far greater adaptation needs than developed countries.

While adaptation measures in aviation may rank from low-resource options (e.g. training and raising awareness) to resource-intensive ones (e.g. relocation of airport), some vulnerable States need external financing to implement their adaptation strategies. International multilateral funds, bilateral funds and private capitals are available to facilitate access to adaptation financing, should it be through development funds or funds targeting support activities to climate adaptation. The organizations below provide funding to climate adaptation programme development and implementation (**Table 1**).

Fund	Purpose	Administered by
Pilot Programme for Climate Resilience	It aims to integrate climate resilience into States' development strategies and to support the implementation of their plans.	Climate Investment Funds
Least Developed Countries Fund	It finances the development and implementation of the National Adaptation Plan Actions (NAPAs).	Global Environmental Facility
Special Climate Change Fund	Finances projects relating to: adaptation; technology transfer and capacity building; energy, transport, industry, agriculture, forestry and waste management; and economic diversification.	Global Environmental Facility
Adaptation Fund	Finances concrete adaptation projects and programmes in developing countries and in countries that are particularly vulnerable to the adverse effects of climate change.	Adaptation Fund Board
Green Climate Fund	It funds low-emission and climate-resilient projects in developing countries, through the mobilization of financial resources from advanced economies.	UNFCCC
Global Climate Change Alliance+	Acts as a platform for dialogue and exchange of experience and provides technical and financial support to increase developing countries' capacity to adapt to the effects of climate change	European Commission

Table 1. Funding Sources for Climate Adaptation Projects in Developing Countries

The Way Forward

It is noteworthy that early responses to climate risks are more cost-effective than *ex post* remediation actions. Integration of climate adaptation considerations into existing aviation infrastructure development plans should be systematically considered, with a view to designing and building an adaptive aviation system. Resources are scarce and therefore, the priorities and timing for action need to be refined with more in-depth research of the impacts of climate change on aviation. This is exactly what ICAO is pursuing through CAEP.

ICAO's role is to support States in this endeavor in providing concrete guidance to the States that need it most.

The inclusion of a new chapter on Climate Adaptation in the ICAO Doc 9184 *Airport Planning Manual, Part 2* is an effective vehicle for disseminating information and for raising awareness on possible risk-assessment and adaptation actions amongst airport planners and developers (see article page 60).

While adaptation strategies will have to be integrated into all aspects of States' economic and social development plans, the most effective approach to limit the costs of adaptation is to limit climate change, through comprehensive mitigation actions. ICAO is committed to pursuing the implementation of its basket of mitigation measures, with a view to achieving global aspirational goals for CO_2 emissions.

Showing leadership on both fronts supports the United Nations Sustainable Development Goals, and contributes to a more resilient planet in a manner that fosters the socio-economic development of the most vulnerable communities.

Sustainable Development Goals

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2. UNEP 2014. The Adaptation Gap Report 2014. United Nations Environment Programme (UNEP), Nairobi

THE IMPACTS OF CLIMATE CHANGE ON AVIATION: SCIENTIFIC CHALLENGES AND ADAPTATION PATHWAYS

BY DR. HERBERT PUEMPEL (AUSTROCONTROL) AND DR. PAUL D. WILLIAMS (UNIVERSITY OF READING)

The International Civil Aviation Organization (ICAO) reached out to the climate science community almost 20 years ago in an effort to seek suitable mitigation measures to reduce the emissions of carbon dioxide (CO_2) and other atmospheric pollutants from aviation activities worldwide. The Organization adopted a comprehensive strategy to address international aviation CO_2 emissions, which culminated in the adoption of a CO_2 Standard in 2016. Emission reduction efforts such as market-based measures, operational changes, and technological improvements have significantly reduced fuel burn and thus CO_2 emissions from aviation over the past four decades. Going forward, operational measures such as new air traffic management (ATM) systems (e.g., NextGen, SESAR, CARATS, etc.), as well as new technological developments, have the potential to continue reducing the CO_2 emissions from aviation. Nevertheless, the robustness of aircraft and indeed the robustness of the entire aviation system should be monitored carefully, as the sector will have to prepare for the more extreme meteorological conditions that are expected in the future as the climate continues to change.

Adaptation to Climate Change: The Scientific Issues and Challenges

The scientific case for global climate change has been well established and rests on a firm understanding of the physical processes involved that drive up the temperatures in the lower atmosphere. The consequences of global climate change for aviation will be summarized in the following paragraphs. A schematic summary of some of the possible impacts is shown in **Figure 1**.

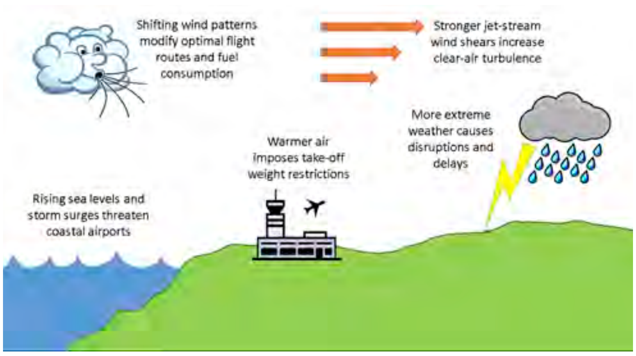

Figure 1. A Schematic Summary of Some of the Possible Impacts of Climate Change on Aviation.

Large-Scale Phenomena

Higher Temperature Maxima

Higher temperature maxima at ground level result in significant decreases in air density, reducing the lift force on the wings of departing aircraft. This reduction in lift could have severe consequences for aircraft take-off performance, where high altitudes or short runways limit the payload or even the fuel carrying capacity. These effects will require more detailed analyses for different geographic regions, with major concerns for high altitude airports in subtropical regions. The already established method of scheduling long-haul departures for the cooler evening and night hours will in some areas (e.g., Middle East, Central and Southern American high altitude airports) be affected further by the reduced cooling overnight where high cloud is often present. In these cases, the non-CO_2 effect of contrail-related cirrus clouds may have to be considered as an additional factor, potentially reducing the unproblematic hours of operation even further in some regions.

Rising Sea Levels

The rise in globally averaged sea level, through increased melting of ice sheets and glaciers and also thermal expansion of the oceans, is well understood and documented. Coupled with rising sea levels, storm surges linked to more intense extra-tropical cyclones may threaten the viability of low-lying airports at coastal locations unless protective measures are taken. These effects are likely to be exacerbated through very intense precipitation episodes linked to these storms, which can lead to excess flooding where run-off collides head-on with storm tides (e.g. the extreme floods in Myanmar during Tropical Storm Nargis in 2008). Planning of new airports in such regions will require hydrological, climatological, and technical expertise.

Jet Stream Changes

The response of the atmospheric jet streams to climate change is an area of active research in the scientific community. In essence, the mid-latitude jet stream in each hemisphere is created and sustained by the temperature difference between the cold poles and the warm tropics. Climate models, satellite observations, and physical theory all suggest that this temperature difference is changing in a complicated manner; it is decreasing at ground level because of amplified polar warming associated with melting sea ice, but it is increasing at flight cruising levels because of lower stratospheric cooling. One possibility is that changes in the prevailing jet stream wind patterns may modify optimal flight routes, journey times, and fuel consumption. Another possibility is that increased shear within the jet streams at cruising levels may reduce the stability of the atmosphere and increase the likelihood of clear-air turbulence breaking out.

Understanding Other Effects

For many of the above effects, a clear signal is apparent from both climate models and observed trends over the last 30 years, and the signal is consistent with our physical understanding of the climate system. Other questions, such as the interactions between various climate impacts, will clearly require a significant research effort and multi-disciplinary collaboration.

The scientific understanding of other effects is gradually increasing over time. An in-depth analysis of the El Niño-Southern Oscillation (ENSO) from the latest generation of climate models appears to support the evidence from paleo-climatological studies, pointing to an increase in the severity of El Niño during warmer climate episodes in the past. More extreme El Niño events will affect many regions of the world directly or indirectly, e.g. by exacerbating extreme droughts and heat waves in Australia and exacerbating massive floods in the West Coast of North and Central America. All of these extreme situations will have a significant negative impact on all forms of transport, including aviation.

Further Research Efforts

The role of seasonal, inter-annual, and decadal cyclic variations such as ENSO, the North Atlantic Oscillation (NAO), the Pacific Decadal Oscillation (PDO), and other recurring phenomena requires significant further research efforts. Given the overwhelming amount of data resulting from climate model runs, the initial approach to understanding future climate states was the analysis of a new quasi-equilibrium state valid for the end of the century. This state was described in latitudinal and regional means over extended periods of time, to isolate the sometimes conflicting signals between different models. Many climate models exhibit noticeable biases in some regions and variables (e.g. in the Equatorial Pacific Ocean temperatures) when compared with the current observed climate.

A Future Mean State

Adaptation measures being considered by societal and industrial sectors such as transport, and in particular aviation, need to address not only a future mean state for climate, but also the variable local and regional weather extremes likely to occur over the coming decades. Such extremes may already be exhibiting typical conditions that were only expected for the end of this century.

In order to provide robust scientific advice to stakeholders, the scientific community will need to address typical scenarios and try to describe impacts linked to these scenarios. As an example of such scenarios, we may consider the emerging evidence of a sequence of high-amplitude, low wave number regimes in the jet stream wind pattern (e.g. over the East Atlantic and Europe) in non El Niño years. This could well lead to the paradoxical occurrence of intense snowfall and low winter temperatures over large areas of Europe, contrasted by a significant northward displacement of the westerly jet streams, with very mild temperatures during the extreme El Niño years. These are probably closer to what the earlier, average-based predictions gave (i.e. high rainfall and strong winds over Northern Latitudes, and drought in the Mediterranean region).

Small-Scale Phenomena

Scientific research into the impacts of climate change on aviation encounters the inevitable problem that many high-impact weather phenomena are linked to space and time scales well below those resolved by current computer models of the atmosphere. Such phenomena typically include: low-level wind shear; hail and lightning strikes; clear-air turbulence and mountain wave turbulence; convective turbulence and turbulence near thunderstorm tops; icing; and low visibility. Intelligent ways of downscaling, statistical post-processing, and advanced conceptual models, will all be needed to obtain statistically reliable results.

Clear-Air Turbulence

Improving our physical understanding of the generation of small-scale processes can help. For example, although Clear-Air Turbulence (CAT) occurs on the micro-scale, the wind shear that generates CAT is driven on a much larger scale, and is potentially resolvable by the current generation of weather and climate models. More basic scientific research is needed to improve our understanding of these small-scale effects. This research will require better atmospheric observations and would benefit from access to operational turbulence data from aircraft.

Airframe Icing

The phenomenon of airframe icing is traditionally seen as a problem mostly by the general aviation and commuter aviation sectors, which operate aircraft with limited engine power and rudimentary anti-icing devices. Nevertheless, icing needs to be better understood to be able to predict future scenarios. The presence of large super-cooled droplets at a temperature range of between -4°C and -14°C depends on a number of conditions, including: availability of large amounts of water vapor, meso-scale bands of intense updrafts, and a limited concentration of suitable aerosols to prevent the formation of many small droplets.

The general warming trend and the increase of moisture in some latitude bands, with a generally more active dynamic flow, all tend to point to an increased chance of occurrences of conditions favorable to icing, and also to an extension of the upper limit of icing layers due to the higher temperatures. This suggests a need to have a fresh look at the current regulations for twin-engine aircraft operations over oceanic airspace, as cabin pressure loss or the loss of power in one engine would force such aircraft to fly at levels still affected by icing (i.e., in the range between FL130 and FL160). On the other hand, high-altitude icing is also likely to increase with more intense cumulonimbus (CB) clouds and a rise of the tropopause due to the higher temperatures and higher moisture of tropical air masses.

Sand and Dust Storms

The likely increase in occurrence and intensity of sand and dust storms caused by both longer drought periods and potentially stronger winds in the sub-tropical latitudes will require a thorough analysis of its impacts on the safety and regularity of flights in these regions. There is emerging evidence that the drive to achieve higher engine efficiency to reduce fuel consumption has pushed the operating temperatures in the combustion chambers of the most modern engines towards temperatures in excess of 1600°C. At these temperatures, the silicates contained in typical sand and dust storms will melt and thus affect the performance and maintenance requirements of jet engines.

Risk Management Considerations

In summary, a multi-disciplinary research effort by scientists, meteorologists, climatologists, engineers, biologists, and epidemiologists is needed to understand better the impacts of the changing climate on the entire aviation system, including aircraft and infrastructure. Thereafter, dedicated guidance material by ICAO could target climate adaptation correlated issues, based on models of best practice. Such guidance material would aim to support the risk management activities of all stakeholders, including operators and pilots, airport managers, aircraft manufacturers, governments, and regulators. It will be important for that guidance material to be regularly revised and updated, to keep it in sync with the evolving and non-stationary climate statistics.

ADAPTING AVIATION TO A CHANGING CLIMATE

BY RACHEL BURBIDGE (EUROCONTROL)

We know that the climate is changing and that we should expect impacts such as higher temperatures, sea-level rise and greater weather extremes. This will require all sectors of society to take action to adapt and develop resilience to such impacts, including the aviation sector. But what will be the specific risks for our sector? And how can we assess and take action to address them?

The general climate change impacts which we can expect are reasonably well-established, although they will vary according to climate zone, and there remains less certainty as to how they will evolve at the local scale. This translates into a range of potential risks for aviation, which will also vary according to geographical location and type of operations. Several papers and reports have already set-out in detail the key impacts which aviation may experience from a changing climate (see article page 205).

In general (see **Figure 1)**, we can expect impacts such as changes in precipitation temperature and wind patterns, increased frequency of storms, and sea-level rise and storm surges, not to mention less obvious impacts such as increased clear air turbulence and changing wildlife migration patterns. This translates into a range of potential impacts for aviation operations and infrastructure such as temporary or permanent flooding of infrastructure, changes to aircraft performance or reroutings to avoid weather systems (**Figure 1**), some of which, may actually increase aviation's environmental impact.

At the same time, as climate impacts are expected to become more severe, traffic is growing, with some regions expecting to see up significant growth in coming years. This is an issue, not just because the impacts of disruptive events such as convective weather or heavy precipitation can be exacerbated when capacity is constrained, but because disruption in one part of the global network can have a knock-on effect for the network as a whole. Therefore, it is essential to make sure that locations which may experience both high growth in demand and significant impacts from climate change have the information they need to identify and address those effects.

However, this is an emerging issue, which we are still working to understand, and up until now there has been limited information available. Therefore in 2014, EUROCONTROL worked in collaboration with a group of 7 air transport organisations ACI EUROPE, AENA, London Heathrow, Avinor, DGAC/STAC, NATS, and Manchester Metropolitan University, and in consultation with IATA, to develop some awareness material on adapting aviation

Climate risk	Impact	Actors
Precipitation change	▪ disruption to operations e.g. airfield flooding, ground subsidence ▪ reduction in airport throughput ▪ inadequate drainage system capacity ▪ inundation of underground infrastructure (e.g. electrical) ▪ inundation of ground transport access (passengers and staff) ▪ loss of local utilities provision (e.g. power)	
Temperature change	▪ changes in aircraft performance ▪ changes in noise impact due to changes in aircraft performance ▪ heat damage to airport surface (runway, taxiway) ▪ increased heating and cooling requirements ▪ increased pressure on local utilities e.g. water and power (for cooling).	
Sea-level rise	▪ loss of airport capacity ▪ impacts on en-route capacity due to lack of ground capacity ▪ loss of airport infrastructure ▪ loss of ground transport access	
Wind changes	▪ convective weather: disruption to operations ▪ convective weather: route extensions ▪ jet stream: potential increase in en-route turbulence ▪ local wind patterns: potential disruption to operations and changes to distribution of noise impact	
Extreme events[2]	▪ disruption to operations, route extensions ▪ disruption to ground transport access ▪ disruption to supply of utilities	

Figure 1. Overview of some key climate risks for aviation

to a changing climate. The outcome was a factsheet, which can be downloaded from www.eurocontrol.int/resilience.

The factsheet starts with an overview of some of the key climate impacts for aviation (**Figure 1**). Although this is by no means an exhaustive list, it is an introduction to the types of impacts organizations might need to consider. It then provides a checklist of questions for beginning to assess whether your organization is vulnerable to the impacts of climate change. Again, this is not an in-depth guide for carrying out a risk assessment – there is more detailed information out there on that - but it is a starting point for thinking about a climate change risk assessment. The factsheet also provides a set of case studies from organizations who are already taking action to adapt to climate change and gives examples of what they are doing and how they are doing it. Finally, it provides a list of resources where you can you get further information on both risks and impacts and more detailed advice on how to carry out a climate change risk assessment.

One of the key objectives of the factsheet is not only to raise awareness of possible risks but also to highlight the potential need to carry out an assessment of potential vulnerability to climate change impacts. This will be considered below.

Climate Change Risk Assessment: What to Ask?

If an organization wants to decide whether and to what extent adaptation actions may be required, undertaking a review of possible climate vulnerabilities is a good place to start.

The Adapting Aviation to a Changing Climate factsheet identifies an initial set of high-level questions to ask when considering an airport climate change risk assessment (**Figure 2**). The purpose of these initial questions is to help an organization decide whether it has sufficient reason to warrant a full assessment.

The first key question to ask is how the climate will change in the local area. Understanding this is fundamental as it highlights the key areas where adaptation actions may be required. Following this, it needs to be identified who within the organization would have responsibility for adaptation action – and this could be more than one person or department. Climate impacts could affect operations, safety and infrastructure therefore it is important to make sure all of the necessary people are involved.

When it comes to initiating an actual climate impact assessment, organizations may already have risk assessment methodologies in place or national guidelines could be available. Alternatively, airports could use or adapt an existing methodology developed for climate change impact assessment by another airport. At least four proven examples are currently available from the Airport Cooperative Research Programme, London Heathrow, the French Directorate General of Civil Aviation (DGAC) and Avinor, the Norwegian airport operator and ANSP.

Finally, once an assessment is initiated, it is important to keep in mind that not only the climate vulnerability of the infrastructure but

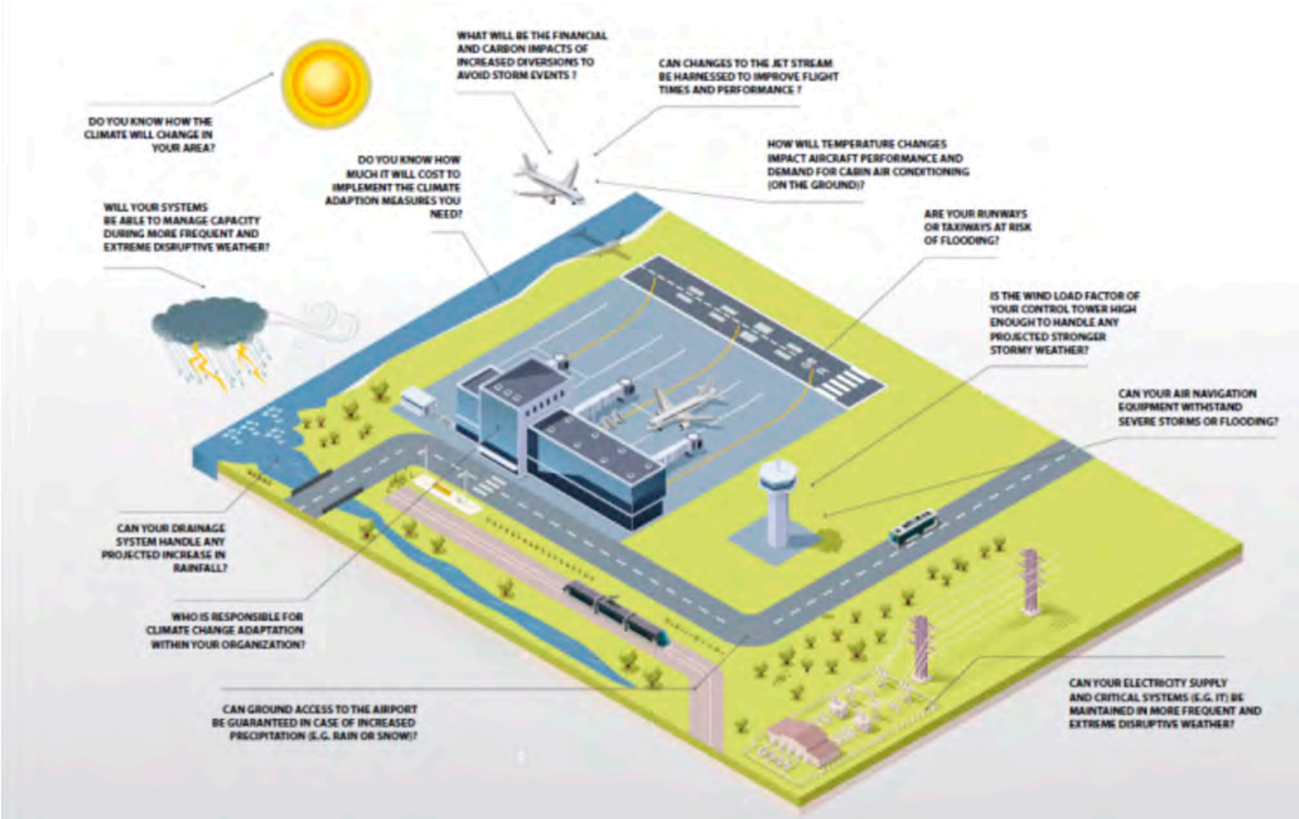

Figure 2. Climate change risk assessment: initial questions to ask

also potential operational and business risks should be assessed, and that not all impacts (e.g. ground transport access or utility supply) may be entirely within the control of the airport itself.

Key priorities for building aviation climate resilience

In September 2015 EUROCONTROL and Manchester Metropolitan University organized a workshop on Adapting Aviation to a Changing Climate. The 30 participants, representing industry, regulators and academia, identified four key priorities for action to develop climate change resilience for the European, and global, aviation sector (**Figure 3**).

Figure 3. Key priorities for building aviation climate resilience

Priority 1: Understanding the problem

- Review and frame the challenge from a holistic sectoral perspective: identifying the key potential impacts for each stakeholder and the network as a whole.
- Identify what knowledge of those impacts already exists and where are the knowledge gaps: identify research priorities.

Priority 2: Assessing the problem

- Develop a generic impact matrix from a common baseline e.g. a 3°C temperature rise and Xm of sea-level rise: challenging but essential to ensure that adaptation actions are coordinated and effective.
- Use compatible risk assessment methodologies to facilitate the development of harmonized local and network resilience measures.

Priority 3: Actions to Adapt

- Identifying operational measures and infrastructure measures to build resilience to increased disruption and changing baseline conditions.
- Identify win-win and no-regrets measures (e.g. measures that address other issues but that also promote resilience).
- Be aware of trade-offs, especially where environmental improvements may introduce vulnerabilities.

Priority 4: Communicate and collaborate

- Communicate and collaborate, regionally and globally.
- Collaboration and coordinate knowledge and research from other regions and sectors.
- Raise awareness and disseminate best practices.

So, what is next?

We now have a reasonable qualitative understanding of the implications of climate change for the aviation sector and the high-level actions which we need to take to address them. However, uncertainties remain and so far little work has been done to quantify what climate change implies from an operational perspective.

Moreover, we need to remember that we are a diverse and global sector, yet a vulnerability in one part of the network can impact the network as a whole. Therefore we not only need to identify and address our individual needs, but to work together as a global sector, particularly through ICAO to learn from each other, collaborate and communicate, and build partnerships for action.

The global aviation sector is making significant efforts to reduce its contribution to climate change by increasing its operational efficiency. Let's not jeopardise the benefits of those operational improvements by not being able to deal with future climate conditions.

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ADAPTING AIRPORTS TO A NEW CLIMATE

BY OLAV MOSVOLD LARSEN (AVINOR)
AND KRISTIN FJELLHEIM (AVINOR)

In five consecutive reports since 1990, the International Panel of Climate Change (IPCC) has documented that global climate is changing. The latest report states: "Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased"[1]. There is virtually no doubt that even if we could eliminate all of humanity's carbon emissions this afternoon the delay in the atmospheric response would – according to scientific projections – make the future climate significantly different from that of today.

Both in the near-term (2030-2040), and the longer-term (2040 onwards), the global mean temperature is projected to rise, but how much depends on the extent to which carbon emissions are mitigated. In general, there will be more extreme weather; dry regions will be drier and wet regions will be wetter. The temperature increases will be more pronounced closer to the poles, but there will be more days with heat extremes all over the globe. Many regions will see more precipitation, and also more very intense rainfalls and flooding, while other regions will see a decrease in rainfall, causing drought and water restrictions. Sea level rise, extreme precipitation, cyclones, and storm surges will affect coastal airports more often than today. These changes will happen gradually, but we have already seen extreme weather events that provide a glimpse of what will be "the new normal". Adapting to the future climate will be location- and context-specific, with no single approach for reducing risks appropriate across all settings[2].

Many airports throughout the world have extensive programs to reduce their emissions of Green House Gases (GHG) and programs such as Airport Carbon Accreditation[3] are gaining ground. But what about the other half of the equation? How will climate change affect airports and what can be done to make airport infrastructure more resilient to the future climate and to ensure safe and reliable operations?

Norway

Most of Avinor's 46 airports are scattered along the rugged Norwegian coastline. Twenty of them are quite exposed and several have runways less than 4 meters above sea level. No two airports are the same, and while risks can be identified at a high level according to climate zone and geographical location, the specific impacts each one will have to deal with may vary greatly according to operational and infrastructure characteristics.

Forecasting always implies a degree of uncertainty. Climate change at Norway's latitudes comes with huge seasonal, local and regional varieties but the future will generally be "warmer, wilder, and wetter". In the case of Avinor, "warmer" means, that the winter season will be shorter at all the airports and some airports will have to deal with troublesome +/- zero degrees-weather more often; less often at other airports. In this temperature range, snow melts and rain freezes, with possible reduced friction and slippery operational conditions as an outcome. Increased precipitation and freak rains challenge the drainage of runways, aprons, buildings and other infrastructure alike. In winter "wetter" could imply more heavy snowfalls with a risk of reduced punctuality and regularity. "Wilder" means more extreme weather events, storms and storm surges impacting traffic, causing delays, and potentially damaging infrastructure.

Cooperation

Avinor has been looking into climate adaptation strategies since the turn of the century. Within the government's National Transport Plan (NTP), an initiative of the Norwegian Ministry of Transport and Communications carried out every four years, Avinor along with the three transport directorates (road, rail and coast) have been asked to plan the national transport infrastructure. This created an awareness since quite early on of the overall risks, and what to expect in the future. It also showed that, compared with other modes of transport, aviation has the resources and capabilities needed to meet the challenges. Because airspace and runways are constantly monitored, airports can be closed if weather requires, thus limiting the level of risk to life and health. Furthermore, there is only a small risk of landslides and avalanches at airports. The same cannot be said for rail and road.

So, the point of departure for a robust "plan/do/check/act approach" was in place more than a decade ago. Ideally, the next stage should have been a thorough risk assessment of the overall situation at Avinor's airports and other critical infrastructure, identifying vulnerabilities and strengths, acknowledging the differences between airports, and analyzing how climate change would impact Norwegian airports differently in different regions.

Jump Start

However, we were forced to jump start things at the "do" part of the process when new legislation in 2005 required that safety areas at the sides and ends of runways at several airports had to be expanded. Climate change became a real issue for us when we realized the implications of the fact that the seabed close to the runways in question was, in some places, very deep and that it would have a huge impact on the "storm proofing" of the safety areas. In collaboration with technical experts we had to look into the "wilder" aspects of climate adaptation. Projections of future sea levels, wind directions, wave directions and – in some instances – the underwater topography, were all taken into account to calculate the size, shape, and amount of rock fill needed to make robust safety embankments which would be able to withstand future storms.

Although Avinor has been aware of climate change and adaptation issues for some time, new legislation and real world projects forced it to take climate change into consideration during the planning and execution phases of a number of fairly large airport construction projects between 2006 and 2013. This evolved into Avinor creating its own set of internal guidelines for dimensioning criteria for safety areas at runways close to the sea, as well as strengthening requirements for potential new runways. As a result, they now have to be constructed at least 7 meters above sea level.

Another example of this is the water and drainage master plan carried out in the planning phase (2008-2009) of the terminal expansion and the related work on the apron at Oslo Airport (to be opened in March 2017). The study revealed that is was necessary, and thus it was decided, to add fifty per cent drainage capacity compared with the 1990s, when the airport was constructed.

Risk Assessment

In 2014, Avinor finally started the process of undertaking a systematic risk assessment of all of its airports, including connected navigation systems and surface access to the airports. A simplified version of the Heathrow methodology[4] was used as a starting point.

Many airport challenges have been fairly easy to define and identify, and they include drainage issues, wind issues, and flooding issues. But the risk assessment has also revealed air navigation service challenges (Avinor is also the national provider of air navigation services). For example, the electricity supply to navigation equipment at some of low-lying airports, is placed on the floor in their shelters. This is not a good idea when the airport is at risk of flooding, so this will be rectified. Other navigation infrastructure could also be vulnerable at times of storms and blizzards.

As far as the "warmer" challenge is concerned (which is relevant even in Norway), the risk assessment made Avinor question whether the cooling capacity in the server rooms at some of the northernmost airports is sufficient to withstand future forecast summer high temperatures. When it comes to air traffic management, a positive finding is that the transition to satellite based navigation will reduce the vulnerabilities mentioned above. Norwegian airports are used to handling fairly extreme winter conditions, but "wilder" winter weather could impact punctuality and regularity.

A 50 per cent drainage capacity was added as part of the terminal expansion of Olso Airport, compared with the initial airport drainage capacity decided in the 1990s.

A main variable is, however, hard to predict: the position of the North Atlantic jet stream which could impact local wind directions and thus cause cross winds at the runways more often than today. As a result of this uncertainty, it was recently decided in the master plan process at Stavanger Airport to keep the secondary cross runway as there has been a clear tendency towards changing wind directions over the last few years. The alternative was to have two parallel runways.

20-20 Hindsight

With the benefit of 20-20 hindsight, it is now clear that Avinor should have carried out the risk assessment a lot earlier. Based on that experience, the clear advice to others in the aviation industry is to proceed as soon as possible with this process. Appoint someone in the organisation to be responsible for climate change adaptation and carry out a risk assessment! Most airports already have risk assessment methodologies in place or there could be national guidelines that can be used. Use the one you are familiar with and it will be easy to communicate in your organisation.

Fortunately, the literature on aviation and climate change adaptation is steadily growing. ICAO has dedicated one chapter in each of its two latest Environmental Reports (2010 and 2013) to the issue. In the US, FAA supported by Airport Cooperative Research Program (ACRP) has been working on these issues for several years as evidenced by its report: "Airport Climate Adaptation and Resilience"[5], and the newly released report 147 on "Climate Change Adaptation Planning: Risk Assessment for Airports" which also includes an electronic risk assessment tool[6]. In Europe, EU and national authorities are publishing a steady stream of reports and recommendations. Since 2008, Eurocontrol has taken lead role in the aviation industry and included future climate change in their "Challenge to growth" reports. Eurocontrol also provides a very useful website[7] with a list of suggested literature and other information most relevant to the aviation industry. Examples of aviation reports online include the comprehensive climate change risk assessments carried out by NATS (the UK Air Navigation Service Provider)[8] and Heathrow Airport[9].

Buildings

Avinor has about 1.2 million square meters of building infrastructure of all types (e.g. terminals, operations buildings, hangars, office buildings, parking houses, etc.) spread out over more than 50 locations in the country. Although most of the buildings still have many years left before the end of use, many have recently come under scrutiny in terms of climate adaptation.

Adding to the cooperation activities mentioned above, Avinor recently joined a center for research based innovation relating to climate adaptation solutions involving the other transport directorates, Norwegian financial institutions, industry, and academia[10]. This gives it a sneak peak into future climate adaptation measures and solutions. It also provide it with the opportunity to influence the research areas. As an example, Avinor's involvement has resulted in more research on solutions for existing buildings.

Avinor is also a property developer that builds new buildings and expands existing ones. In this process there are several elements to consider and it is easy to forget climate adaptation as it is not yet a well-established subject in the building industry. Avinor has tried to solve this by including climate adaptation issues in the requirements specification for these types of projects. These require that the building and the choice of materials must be evaluated in accordance with the local climate and the future predicted amount of precipitation, wind, and extreme weather, as well as having a sustainability focus. The concept of "building for a changing climate" but also changing user behavior is becoming more prominent. For example, the new requirement specifications state that the location and orientation of the buildings must be considered with regards to future precipitation and wind directions.

The ideal situation is that climate changes and climate impact factors be included in the lifecycle cost analysis so that any new buildings, and maintenance of existing buildings, will be both adapted to a changing climate, and climate impact will be minimized. Through a new strategy for maintenance of buildings and infrastructure, the lifecycle perspective will become more prominent in Avinor. By including climate change in the lifecycle cost calculations, many of the climate adaptation measures that might seem costly at the outset, will in fact reduce the lifecycle costs of the project.

Conclusion

Climate change is here to stay, and there will be significant regional and seasonal variations. There is thus no single approach to be taken. This article has provided some examples from the perspective of a Northern European airport operator's climate challenges and adaptation activities. Avinor's experience is that minor adaptation investments in already planned and/or ongoing projects can save on future resources.

Aviation is an extremely risk averse business. Climate change poses a new set of risks that airports need to assess properly. The last decades have provided a glimpse of the future climate, but the main effects will be more evident three or four decades from now, and onwards. There is thus no reason to panic, but much of the airport infrastructure erected today will be there in the new climate. A rational response at all airports is therefore to carry out risk assessments of existing and new infrastructure in order to think ahead, reduce risks, minimize life cycle costs, and ensure the reliability and regularity of the aviation sector.

Furthermore, aviation is dependent on all elements of the network to be fully functioning. All actors in the aviation industry should carry out risk assessments – which is not difficult – and decide if action is required.

It makes little sense to have islands of resilience in an ocean of vulnerabilities.

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BRISBANE AIRPORT'S NEW PARALLEL RUNWAY PROJECT - CLIMATE CHANGE ADAPTATION MEASURES

BY KARYN RAINS (BRISBANE AIRPORT)

Located around 14kms north-east of the Brisbane central business district, the Brisbane airport is situated on a 2700 hectare precinct which accommodates a range of activities including domestic and international terminals, aviation and business operations, and by virtue of its size and geometry enjoys large buffer zones providing a barrier between airport operations and surrounding communities.

To alleviate growing passenger and air traffic congestion, and to accommodate future growth, planning for a second runway at Brisbane Airport has been underway for over 20 years. Major infrastructure projects such as this require extensive site surveys and design studies; are subject to numerous legislated planning conditions and approvals; involve detailed stakeholder engagement; and, pose a range of construction and operational challenges.

In 2007 the Brisbane Airport New Parallel Runway project was approved by the Australian Government following the completion and acceptance of a comprehensive Environmental Impact Statement (EIS) and Major Development Plan (MDP).

The project involves construction of a new runway, and associated infrastructure, on a low lying coastal area, parallel to Brisbane Airport's existing runway. The proposed runway site is currently subject to inundation during high tide, flood events and at risk to future climate change impacts such as storm surge and sea level rise. As such, climate change impacts were considered in the planning and design for the ongoing continuity and long term viability of operation of the new runway.

Impacts/Risks Addressed

Given the sub-tropical location of the site, and its proximity to the coast, the key climate change related risks were identified as sea level rise, storm surge from increased cyclones and other low pressure events, local/regional flood events and increase in average temperatures. Specifically, there were a number of key design and planning decisions for the NPR where consideration of climate change and other related stakeholder issues featured.

Specifically, these were:

- Project go / no go decision: As part of the design process for the NPR, alternatives to building a new runway were considered. After evaluation of the options available to address the airport's current operating constraints and future growth projections, construction of the NPR was found to be the most appropriate option.
- Runway placement and layout: Six options were considered. Each option presented a range of issues for assessment, including cost, operating and safety standards, noise restrictions, environmental impacts, and climate change resilience.
- Runway height: The height above sea level of the runway became the major climate change related design issue. The final design had to take account of historic and projected severity and frequency of sea level rise, storm surge and local/regional flood events. Based on the available evidence a design decision was then made to take account of the level and likelihood of the risk (e.g. sea level rise) and the cost of mitigation (e.g. raising the height of the runway).

Information & Knowledge Gaps

In considering the impacts of climate change on the proposed runway the project drew upon information and expertise from across a range of scientific and engineering sources. Initial considerations for flood and storm tide surge modelling were derived from the findings of a multi-agency investigation which assessed the magnitude of the present and future ocean threats from tropical cyclones in Queensland and the vulnerability of coastal communities to extreme winds (Queensland Government 2004).

Response Strategy

From the early stages of the project, BAC's New Parallel Runway project team were fully aware of the need to consider future climate change impacts in the design, construction and operation of this major asset and the role that engagement with key stakeholders would play in the design and approval process.

Climate Change Impacts

Given the vital importance of the infrastructure and its long term operating life the design response to potential climate change impacts was as follows:

- Sea level rise and increased frequency of cyclonic events was addressed by incorporating a 400mm allowance plus 500mm additional wave set up freeboard in the hydrological modelling in accordance with research available at the time for the Queensland coast.
- Consideration of temperature increases in future decades was automatically accounted for in the ultimate length planning for both the existing main runway and for the new runway, each of which has significant additional lengths available to be added in the future.

In the preliminary design developed in 2005 the minimum design level for the NPR based on a 1% Average Exceedence Probability (AEP) design storm tide level was determined to be 2.4m AHD or 3.53m Airport Datum (AD). This consisted of:

- Existing storm surge level of 1.5m AHD;
- Climate change increase of 400mm (including 300mm sea level rise and increased cyclone frequency); and
- Wave set up freeboard of 500mm.

Additional design considerations

In addition to the storm tide, climate change and freeboard allowance, a further design consideration influenced the final design elevation for the NPR. BAC decided that it would be preferable to select a minimum design to be the same as the existing runway (5.2m AD) so as not to have an undesirable incline (gradient) along the linking taxiways and links into adjoining aprons. This design feature minimises aircraft fuel burn during taxiing between the NPR, the existing runway system and existing aircraft terminals. In addition to decreased fuel burn a runway elevation higher than 3.53m AD provides further enhancement of protection against future climate impacts.

In addition to the height of the NPR other climate change impact related measures include construction of tidal channels and the installation of a new sea wall along the northern boundary of the airport, and allowance for a future runway extension to 3600m if it is determined that additional runway length is required for aircraft operations due to temperature increase.

Updated Research

To further substantiate the proposed runway height to account for newer research, in 2009, BAC engaged the Antarctic Climate and Ecosystems Collaborative Research Centre (ACE CRC) based in Tasmania Australia to evaluate the runway height specifications using the latest climate and sea level data available. Using a customised sea-level calculator the ACE CRC provided updated assurance of the runway design level (5.2m AD) describing it as 'strongly precautionary'.

Stakeholder Engagement

Given the profile and complexity of the New Parallel Runway project, a key factor in progressing the design and approval of the project was engagement with a broad range of stakeholders. A 22-month stakeholder engagement process was undertaken culminating in late 2006 when BAC released for public comment the New Parallel Runway Project Environmental Impact Statement and Major Development Plan (EIS/MDP).

At the conclusion of the consultation period BAC had received 196 public submissions. Of the submissions received, three specifically questioned whether the proposed runway design adequately took account of the long-term impacts of climate change and sea level rise. In responding to the climate change issues raised in the engagement process BAC drew upon research and design data applied in the modelling and the final design specifications for the runway height and other supporting measures.

Implementation Phases

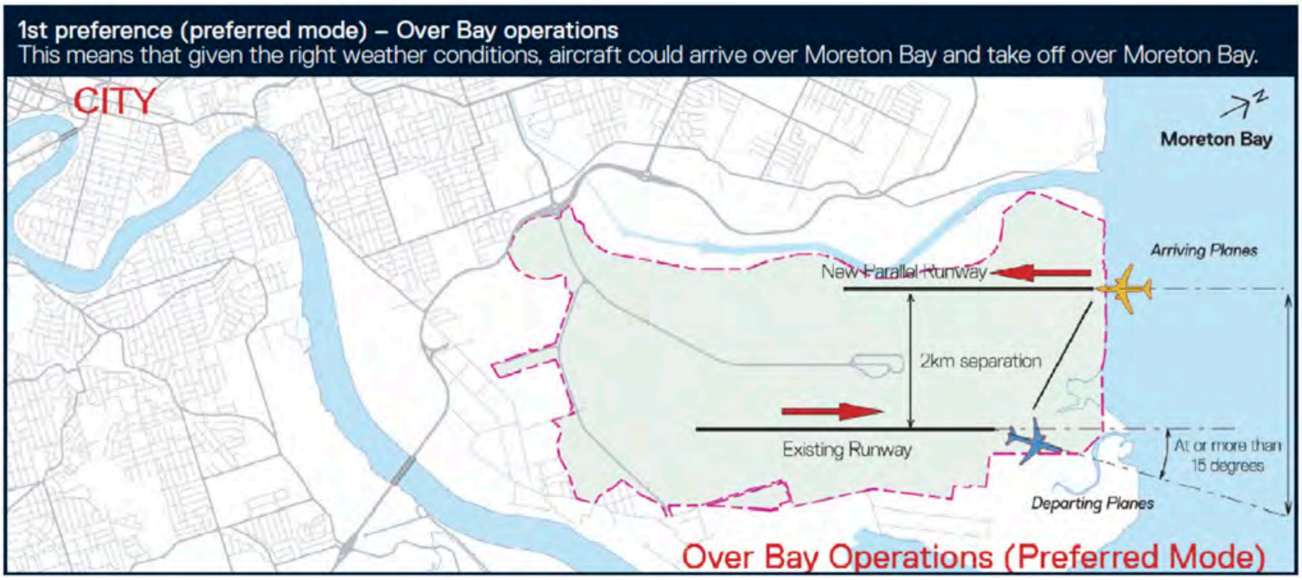
The project has progressed through the usual climate change adaptation phases: Assessment & Research / Engagement / Decision Making / Planning / Construction. The ground preparation works (including the early civil works and dredging and reclamation works) were completed in 2015 and the site is currently consolidating under the placement of nearly 11 million cubic metres of sand and an extensive array of vertical wick drains. The performance of the ground strength and elevation improvements is set to allow pavement and airfield construction to commence in 2017 with the runway targeted to be operational in 2020.

How Does the Project Contribute to Reducing the Environmental Footprint of the Sector?

The New Parallel Runway system will be operated to maximise operations over Moreton Bay in order to minimise noise impacts to local communities. Parallel runways provide the best opportunity to maximise the number of aircraft that can fly into and out of an airport. Upon opening the dual parallel runways will be used in a number of ways, commonly referred to as 'modes of operation'. Each mode of operation is allotted a hierarchy of 'preference'. With two parallel runways in operation the preference will be to use Over Bay operations, in the first instance (see diagram below), particularly in the noise sensitive night hours, then 19 parallel, and then 01 parallel operations respectively.

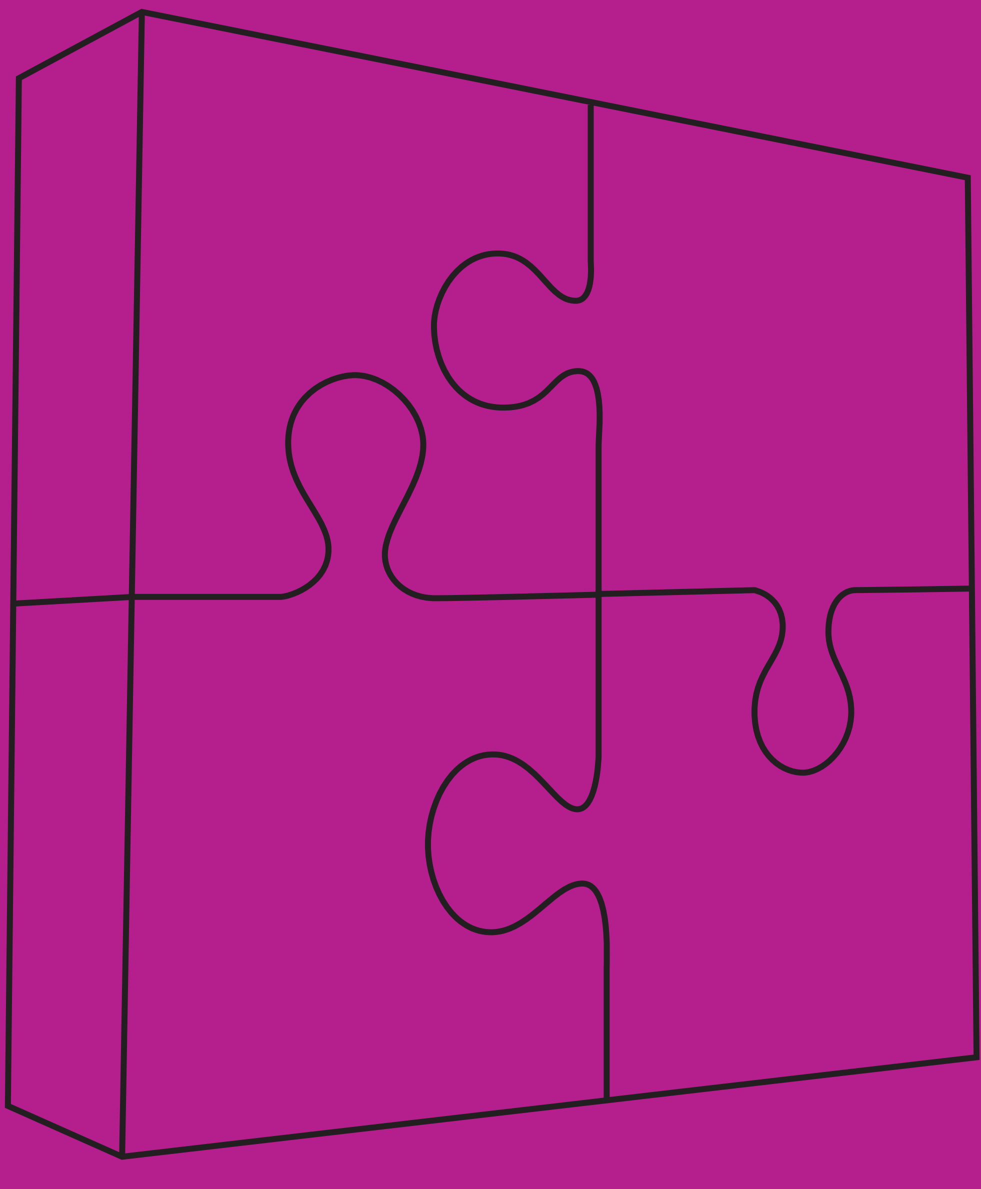
The Way Forward

With the NPR site currently achieving predicted ground settlement rates, commencement of pavement and airfield construction is expected to start in 2017. This will involve the removal of excess sand once final ground settlement levels have been achieved; pavement laying for the new 3300m runway and 12 km of taxiways; installation of airfield infrastructure; and introduction of the new approach and departure paths. The NPR will be commissioned and operational in 2020.



CHAPTER 8

PARTNERSHIPS



MESSAGE FROM BAN-KI MOON

SECRETARY GENERAL OF THE UNITED NATIONS

International aviation creates a worldwide network of connectivity, driving economic growth, social development and cultural understanding. Our challenge is to continue reaping its many benefits in a low-carbon manner while enabling it to respond to the disruptions caused by climate change.

This new edition of the International Civil Aviation Organization Environmental Report offers vital information for rising to this challenge at a pivotal moment for global efforts to achieve sustainable development.

The world now has two mutually reinforcing plans for progress: the 2030 Agenda for Sustainable Development, our blueprint for transforming our world, and the Paris Agreement on climate change, which sets forth the way to limit global temperature rise well below 2 degrees Celsius.

International aviation can make major contributions to the success of these twin endeavours. This edition of the ICAO Environmental Report shows how air transport is well on its way to carrying out forward-looking solutions – and sets out the strategic path for even greater progress.

Aviation is driven by innovation, putting it at the forefront of new approaches to advanced materials, alternative fuels and new forms of collaboration that deliver more effective and environmentally friendly operations.

The leadership of ICAO is critical. Just a few weeks after the conclusion of the Paris Agreement, ICAO announced that its Committee on Aviation Environmental Protection had unanimously recommended a new standard limiting aircraft CO_2 emissions – a move that was widely welcomed.

I commend this report to all those interested in ushering in a more sustainable future.

CREATING OPPORTUNITIES FOR THE AVIATION SECTOR THROUGH SUSTAINABLE DEVELOPMENT

BY ERIK SOLHEIM, EXECUTIVE DIRECTOR UNITED NATIONS ENVIRONMENT PROGRAMME (UNEP)

The aviation sector perfectly illustrates why the world needs an integrated approach to the social, economic and environmental dimensions of sustainable development and why it must shift to an inclusive green economy that can underpin them.

The sector supports some eight million jobs and eight per cent of the global economy, bringing important international market access to developing nations, relief aid to crisis zones and research data to scientific communities. However, the demand for air transport continues to double every 15 years, with around six billion passengers a year expected by 2030. While we know the sector already accounts for two per cent of man-made CO_2 emissions, we don't yet understand the full environmental impact of all emissions, technologies and materials, including some of those being used to replace chemicals being phased out in line with the latest environmental regulations.

ICAO has already played a crucial role in supporting sector-wide efforts to reduce the fuel burn and CO_2 emissions of air transport operations by more than 70 per cent and noise by more than 75 per cent in the last 40 years. It will be just as crucial in redoubling those efforts to ensure sustainable development by further improving fuel efficiency by two per cent per year and achieving carbon neutral growth from 2020.

Some of the mechanisms to achieve this, which are highlighted elsewhere in this report, are already gathering momentum. However, UNEP can see several potential areas to help governments, authorities and various private sector industries rapidly improve environmental performance and reduce the impact on climate change.

For example, scaling up new generation sustainable biofuels and other alternative energies, like fuel cells and solar power, would reduce emissions from air and ground operations, while decarbonizing the economy and encouraging investment in newer, more eco-efficient aircraft; full deployment of available technology such as the SESAR and NextGen systems for air traffic management, in the context of ICAO's Global Air Navigation Plan would cut emissions, noise and congestion; and accelerating the research, development and safe implementation of new technologies, such as additive layer manufacturing and biomimicry structural designs, would reduce environmental impact of existing air transport networks and support the transition to a more integrated multi-model system.

In fact, a new report from IATA and SEO Amsterdam Economics Research indicates that even just improving air traffic management - even just in Europe - could boost the economy by some EU245 billion by 2035[1], while tripling capacity and reducing environmental impact by 10%. Not only could that support sustainable development on many fronts, but much of the transition could potentially be funded by reinvesting the estimated $7 billion a year the sector pays in emissions related taxes and charges.

Such examples provide just a small taste of why the ten links between ICAO's Strategic Objective on environment and the 2030 Agenda also offer considerable opportunities for the transport, energy, building and financial sectors.

I hope this report will encourage public and private sector decision makers to strengthen policies for energy, infrastructure and education; to encourage regulatory, financial and industrial co-operation; and to ensure that wider access to the benefits of aviation allows social, economic and environmental progress go hand in hand.

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MESSAGE FROM CHRISTINA FIGUERES

EXECUTIVE SECRETARY OF THE UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE (UNFCCC)

The year 2015 will go down in history as the year that governments of the world came together and set a new, transformative development agenda. With the adoption of the Sustainable Development Goals in September and the Paris Agreement in December, governments set a course for socially and environmentally responsible growth.

Now, all investment, enterprise and governance must be carefully considered to transform growth and bring it in line with the vision laid out in these agreements. This is a paradigm shift that requires action across all facets of the economy. Every sector must contribute to reducing emissions and increasing resilience.

The Paris Agreement enshrines a clear long term goal that guides this transformation – the determination to limit warming to less than 2 degrees Celsius, with a stated aim of keeping rise as close to 1.5 degrees as possible. Understood as an emissions pathway, this means restoring the balance between emissions and the planet's absorptive capacity in the second half of the century.

Achieving this goal must be marked by a peak of global emissions and a steep decline immediately after. This peak must happen soon, which will only happen through urgent action by all – every country, every community, every company.

One of the first steps towards meaningful contributions from every industry is an honest assessment of current environmental responsibility and sustainability actions. Through understanding and awareness of how our activity impacts the environment, and in particular the climate, we can curb emissions and adapt to impacts built into the climate system.

The ICAO 2016 Environmental Report is a crucial step that allows aviation to produce policy that leads to peaking emissions in the industry. This report allows for informed policy decisions based on sound science.

International aviation, led by ICAO, has already laid the foundations for this work. Through the Basket of Measures, through the recently adopted CO_2 standard, and through the work on developing a new market-based measure, international aviation is well positioned to peak the sector's emissions within the next few years.

Coherent and cohesive policy applied across international borders is a necessity for an industry that thrives on connecting countries. Through market mechanisms, research and development into new fuels and high efficiency operations in the air and on the ground, the international aviation industry will help nations meet their Paris Agreement contributions.

Clearly, there is ambition to address emissions through climate action within the industry. There is a long-term path that includes the Basket of Measures, new fuels and other technological innovations. In the near term, a market-based measure must be a cornerstone to build an ambitious climate target that connects aviation to global solutions.

The foundation and commitment for meaningful progressive climate action is in place. Commitment must now be followed by action. When ICAO's 39th Assembly meets in Montreal this September, ICAO member states have the opportunity to take action that matches stated ambition.

This opportunity for bold action integrates aviation into the global climate change solution space. I urge you to seize this opportunity, put in place your path to climate neutrality by 2020 and seek ambition that allows you to exceed that aspirational aim by peaking and declining aviation emissions even sooner.

The UNFCCC secretariat stands ready to support ICAO. We can and must work together to find solutions that spell success for the Paris Agreement.

Paris was a call to action for all. I am confident that aviation will be counted among those responsible for successfully putting the world on course to fulfilling the transformative vision that emerged in Paris – a resilient, climate-safe future.

INTERNATIONAL AVIATION AND CARBON MARKETS: FROM AGREEMENT TO ACTION

BY JOHN ROOME, SENIOR DIRECTOR, CLIMATE CHANGE, THE WORLD BANK GROUP

Climate change is a threat to the environment, the global economy, and future prosperity. As called for in the Paris Agreement of December 2015, there is an urgent need to keep global warming to below 2 degrees Celsius. To achieve this, bold action will be required by countries, societies and industries alike.

One of those bold actions would be a significant reduction in emissions of greenhouse gases from international aviation. To that end, the possible adoption of the Global Market-Based Measure (GMBM) by ICAO's 39th General Assembly is of great importance, not only to ICAO, its member states and the industry, but to the world. When implemented, the GMBM would allow the sector to achieve carbon-neutral growth from 2020 onwards. This would complement measures already being taken, such as technical and operational efficiency improvements. Not only would adoption of the GMBM demonstrate the commitment of the international aviation community to supporting the overall goals of the Paris Agreement – even though international aviation emissions were not included in the Paris Agreement – it would also be the first time an entire sector took global action to self-regulate its emissions of greenhouse gases. As such, it would be a major achievement.

However, building the infrastructure needed to comply with requirements under the GMBM will be a new and complex task for the aviation sector. The World Bank Group stands ready to support the efforts that will be made to implement it successfully. As a pioneer in the use of market instruments to mitigate climate change, the World Bank Group continues to play a leadership role in supporting future carbon markets and regulatory instruments, responding to the types of challenges that will be faced in implementing the GMBM effectively.

The World Bank Group is helping countries to design and implement a range of climate change mitigation policies at both the national and sector levels. This includes market-based carbon pricing instruments to help facilitate emissions reductions and investments in low-carbon infrastructure. The World Bank Group has extensive expertise in capacity building activities that are central to mechanisms under the GMBM, including designing and setting-up registries; monitoring, reporting, and verification systems; data collection and management tools; and regulatory frameworks for carbon markets.

Building the capacity of ICAO members and industry players to implement the GMBM starting in 2020 will require rapid action. The ICAO Secretariat started this work by organizing the Global Aviation Dialogues around the world in 2015 and 2016. These discussions have already identified areas where the World Bank Group, in partnership with ICAO, can extend expertise to stakeholders to ensure the GMBM's success.

The World Bank Group looks forward to helping ensure that members are ready to move forward with implementation of the GMBM in 2020.

MESSAGE FROM TONY TYLER

DIRECTOR GENERAL AND CEO OF THE INTERNATIONAL AIR TRANSPORT ASSOCIATION (IATA)

Partnership has always been at the heart of the air transport industry's strategy to manage and reduce its environment impact. Air transport is an interconnected industry which relies on cooperation across the value chain, and particularly with governments. Aviation needs smart regulations which can enhance the ability of the industry to drive social and economic growth.

Equally, the industry recognizes that its 'licence to grow' comes from being a good global corporate citizen. Strong, proactive voluntary action backed up by appropriate regulation is at the core of our sustainability agenda.

Accordingly, in 2009, the aviation industry set itself three global goals to address its climate impact: a short-term fuel-efficiency goal of 1.5% improvement per year to 2020; a mid-term goal to cap net CO_2 emissions through carbon-neutral growth from 2020; and a long-term goal to halve aviation CO_2 emissions by 2050.

Setting those goals was part of the industry's efforts to respond to the global challenge of climate change. A four-pillar strategy was developed to create a roadmap for delivering the goals. The pillars of new technology (including sustainable alternative fuels), better operations, improved infrastructure, and the implementation of a single global market-based measure have been recognized as providing a genuine roadmap towards a sustainable industry. For aviation, the most important thing is for the strategy to be applicable globally—because the efficient operation of the international aviation system is absolutely reliant on globally-agreed standards and systems.

Working in partnership with governments and across the whole aviation industry sector, there has been significant progress towards delivering on these commitments:

- Seven new, more efficient, aircraft types have entered service, with another three due to enter the fleet before 2020.
- Airlines have spent over $1 trillion buying these more fuel-efficient aircraft and over 8,000 of them have entered the world's fleet.
- Over 100 airports have installed solar power generation on-site and 156 are now part of the Airport Carbon Accreditation programme, representing over 32% of global passenger traffic.
- Improvements in air traffic management are helping to reduce emissions through measures such as performance-based navigation, air traffic flow management, shortening of routes and more flexible routings.

- We have tested, certified and flown over 2,200 commercial flights on sustainable alternative fuels and will have flown over 5,500 such flights by the end of 2016. Lower-carbon fuels are now being used on regular flights from at least two international airports with more airports and routes to follow.

In parallel with these practical developments, governments have been engaged in unprecedented multilateral policymaking activity in the sustainable development field.
In September 2015, the United Nations adopted the Sustainable Development Goals, which will help set the global development agenda for the next 15 years. Then in December last year, the world's governments adopted the historic Paris Agreement at COP21, delivering a genuine plan for global climate action. The air transport industry recognizes and welcomes these achievements. They lend a powerful impetus to the aviation industry's own sustainability agenda, which is progressing through a momentous year in 2016.

In February, working through ICAO, governments agreed on the world's first CO_2 efficiency standard for aircraft, supported by industry and environmental experts.

In June, airlines at the IATA Annual General Meeting overwhelmingly endorsed a resolution reaffirming the industry's commitment to the climate goals, and the need for a global carbon-offset scheme to help deliver carbon-neutral growth from 2020.

At this year's ICAO Assembly in September, we hope that governments will continue that spirit of consensus and adopt a global, mandatory carbon offsetting scheme to address the growth in aviation's emissions from 2020 onwards. Industry is fully supportive of these efforts as we believe that such a scheme is the most cost effective way to deliver on our climate commitments. We now urge governments to progress these discussions in a positive manner and to make the most of the historic opportunity we all have.

What is the vision underpinning the cooperation which has helped us to achieve all this? A common interest in our planet's future, balanced with a recognition that aviation is a force for good in this world, providing significant economic and social benefits, helping economies to grow, creating and supporting employment, and bringing people closer to their families and friends.

Looking to the future, it is clear the global carbon offsetting scheme for international aviation is not an end in itself. It is intended to be simply one additional tool in the basket of measures available to the sector. It will not make fuel efficiency any less of a day-to-day priority for airlines. Indeed, carbon-offsetting is regarded as an interim measure until new technologies, alternative fuels and propulsion systems reach maturity. The delivery of the four-pillar strategy in its entirety—including, crucially, vital improvements to air traffic management and airport infrastructure efficiency—is the only way the 2050 target can be met.

Most importantly of all, we need to continue the spirit of cooperation that has brought us to where we are today. Governments have an essential role to play in setting the policy frameworks that can incentivise work on developing more efficient technology, the commercialization of sustainable alternative fuels, better operational measures and improved infrastructure. In all of these areas, I hope that industry can rely on the support of governments for the adoption of initiatives that are in line with smarter regulation principles.

I hope that when we look back in years to come, 2016 will be seen not as an end point but simply the start of a period when the aviation industry efforts to earn its licence to grow took flight. And by reducing its environmental impact and enhancing its ability to provide economic and social benefits the world over, commercial air transport demonstrated beyond doubt its role as a force for good in the world.

MESSAGE FROM ANGELA GITTENS

DIRECTOR GENERAL OF AIRPORTS COUNCIL INTERNATIONAL (ACI)

Airports play a unique role in addressing adverse environmental impacts of aviation at a local level. Their experience in engaging with their communities is a successful example of cooperation in dealing with environmental issues. Airports are also the interface between aviation stakeholders and ground equipment operations, and therefore, they can work to improve not only their own environmental footprint, but also can contribute to the work being done by other stakeholders in this endeavor.

This engagement at the international level is performed through Airports Council International (ACI), the international organization representing the world's airports and the communities they serve. ACI has been actively cooperating with the International Civil Aviation Organization's (ICAO) environmental initiatives by creating synergies on several fronts:

- At the ACI 2015 World Annual General Assembly in Panama, the membership expressly supports ICAO's State Action Plans, Aviation System Block Upgrades (ASBU), the aircraft CO_2 emission standard, the development of sustainable alternative aircraft fuels and a global market-based measure.
- ACI's 2013 joint statement under the ATAG umbrella, together with ICAO, supports the need to cooperate to promote sustainable approaches to global aviation emissions reduction.
- ACI actively supports the industry's goal of becoming carbon neutral from 2020 and reducing aviation carbon emissions by 50% by 2050, and recognizes the leadership of ICAO in this process.
- ACI works through CAEP as an observer representing airport views at ICAO and contributing expertise on topics such as aircraft noise and community engagement, local air quality, airport planning, adaptation to climate change and greenhouse gas (GHG) management.
- ACI World and Regional Environment Standing Committees work independently on environmental and policy issues considered a priority for airports.
- ACI supports airport operator efforts to manage GHG emissions and other environmental impacts through training, conferences, workshops and the following specific initiatives:

1. ACI published the *Airport Greenhouse Gas Management Guidance Manual* in 2009 to assist airports in managing their carbon footprint.

2. ACI created the Airport Carbon and Emissions Reporting Tool (ACERT), an Excel spreadsheet enabling airports to calculate their greenhouse gas (GHG) emissions inventory. Moreover, the tool can be used without emissions or environmental expertise. ACERT was initially developed by Transport Canada and is widely distributed for free by ACI with the technical support of Zurich Airport. ACI has recently launched ACERT version 3.2, which includes new information on sewage and waste disposal.

3. *Airport Carbon Accreditation*, a four level accreditation program developed by ACI EUROPE, has now spread to all regions of the world. To date, 156 airports are accredited at one of the programme's four levels:
   Level 1: Mapping
   Level 2: Reduction
   Level 3: Optimization
   Level 3+: Neutrality

   The program has been a huge success, with participating airports across 51 countries representing 32.6% of worldwide passenger, or 2 billion passengers. Level 3 consists of engaging third parties to reduce their emissions, and reaching Level 3+ means that airports have offset their emissions and reached neutrality. ACI has signed an agreement with the United Nations Framework Convention on Climate Change (UNFCCC) at COP21 in Paris to further promote climate action through *Airport Carbon Accreditation*. ICAO is an official member of *Airport Carbon Accreditation's* independent Advisory Board.

4. In cooperation with CANSO, ACI recently published the *Guide to Managing the Impacts of Aviation Noise*. The publication is designed to assist both airport operators and air navigation service providers manage the impacts of noise while taking into consideration recent changes in airspace procedures.

As a global sector, aviation stakeholders necessarily have to combine efforts to address environmental impacts for the long-term sustainability of the industry. ACI is looking forward to identifying new areas of collaboration with ICAO to strengthen our already strong cooperation on common environmental objectives.

MESSAGE FROM DAVID F. MELCHER

PRESIDENT AND CEO, AEROSPACE INDUSTRIES ASSOCIATION AND CHAIR OF THE INTERNATIONAL COORDINATING COUNCIL FOR AEROSPACE INDUSTRIES ASSOCIATIONS (ICCAIA)

The year 2016 has been monumental for aviation and the environment. This February, ICAO's CAEP recommended an ambitious CO_2 emissions standard for commercial aircraft. This standard resulted from six years of committed work by a task force of experts from governments, industry and NGOs. In addition, we are hopeful that a global market-based measure is passed in order help solidify future industry commitments.

The aviation sector came together in 2009 and did something unprecedented and meaningful—voluntarily agreeing to significant cuts to CO_2 emissions, including carbon-neutral growth beginning in 2020 (CNG2020). Until that time, the aviation community had agreed to reduce emissions by 1.5 percent annually and to halve them by 2050 (as compared to 2005 levels). Fuel efficiency drives our industry, but environmental sustainability is also critical to customers and our membership.

The CAEP-endorsed CO_2 certification standard aims to reduce these emissions by encouraging the integration of fuel-efficient technologies into aircraft design and development. It is part of a broader set of actions aimed at tackling aviation's environmental impact. They include improvements in flight operations, deployment of biofuels and the reduction of noise and other emissions, together with the development of a carbon offsetting scheme for international aviation.

ICCAIA manufacturers have made great progress toward reducing our carbon footprint and will continue to achieve through continuous fuel efficiency improvements. Our industry is 80 percent more fuel efficient today than when the first jets were introduced. And the new standard will make certain that this impressive trajectory continues. The advanced technology that manufacturers incorporate in aircraft is a large part of the equation when it comes to reducing emissions from the aviation sector. We will ensure the technology will be ready.

Airlines, operators and governments across the globe are also key pieces to reducing our environmental impact. Operational procedures, incorporation of new satellite technologies into our air navigation system and other infrastructure improvements are critical to making sure airlines and other operators are as efficient as possible.

The continuous testing and deployment of biofuels is another ingredient to emissions improvement that will move us forward. There are now several possible sources of alternative sustainable jet fuels that have met rigorous safety standards for use as a jet fuel replacement. The technology is there, but we need to see more progress in developing scalability of biofuels before they can gain more traction in the commercial market and make a big difference.

Although aviation is a small contributor to climate change (only 2 percent of man-made CO_2, according to the Intergovernmental Panel on Climate Change), we continue to produce major improvements. We will also continue to make strides in reducing noise and other emissions, with the development of a non-volatile particulate matter (nvPM) standard under CAEP, and further the work done on supersonics. Policies and progress are continuing the correct way at ICAO – balancing environmental benefit, technological feasibility, economic reasonableness with consideration of interdependencies. ICCAIA has made lasting contributions to CAEP in setting global environmental standards on aircraft noise and emissions for over 40 years and will continue to do so.

MESSAGE FROM BY JEFF POOLE

DIRECTOR GENERAL, CANSO

CANSO, the Civil Air Navigation Services Organisation, is the global voice of air traffic management (ATM). Efficient air traffic management enables airlines and airports to provide the connectivity that drives economic and social development and provides access to markets. Importantly, ATM operational efficiencies help the aviation industry to meet its emissions reduction targets.

ATM has a vital role to play in reducing carbon emissions through operational efficiencies such as: enabling aircraft to fly the most efficient and shortest flight path rather than fixed routes; allowing aircraft to fly at the optimum altitude and speed over oceanic airspace rather than mandating a fixed speed and altitude; smoother arrival and departure flight profiles at airports rather than traditional stepped profiles; and reducing delays through collaborative decision making between ATM, airports and airlines.

States also have an important role to play in helping the industry reduce its emissions. States need to invest in ATM infrastructure, as this will improve the efficiency of the entire aviation system, reduce emissions and cater for future growth. Investment in ATM infrastructure not only benefits the environment, but acts as an enabler of aviation connectivity and development, bringing economic and social benefits.

ICAO's Aviation System Block Upgrades (ASBUs) serve as a catalyst for States to modernise their air navigation services. ASBUs give States a clear road map to achieve the necessary infrastructure improvements. They will improve aviation safety, enhance efficiency for airlines, and increase connectivity to boost GDP. CANSO is helping States and ANSPs implement the ASBUs through training courses, guidance materials and exchanging best practice.

We are working with States to harmonise airspace, so that a plane can fly using the most efficient operational route, thus saving emissions. Aviation transcends national boundaries, so airspace needs to be organised, and air navigation services delivered, in line with the operational requirement of airspace users rather than according to national borders.

Our goal is to enable planes to navigate seamlessly across national borders, selecting the most efficient routes. States can delegate service provision to other States and/or designate a service provider to provide service coverage for a larger airspace. This does not in any way diminish a State's sovereignty over its airspace. States also need to work better together to reduce airspace fragmentation across the wider region and free up military airspace.

In conclusion, the air traffic management industry is working hard to reduce emissions through operational measures, new technologies and more effective use of airspace. We look to States to play their part by investing in ATM infrastructure and working with each other to harmonise airspace.

MESSAGE FROM TIM JOHNSON

DIRECTOR OF AVIATION ENVIRONMENT FEDERATION, ON BEHALF OF THE INTERNATIONAL COALITION FOR SUSTAINABLE AVIATION (ICSA)

In 1998, a meeting between European and North American environmental organisations, committed to limiting and reducing the environmental impact of civil aviation, identified the need to have a voice at the International Civil Aviation Organisation (ICAO). While ICAO's Committee on Aviation Environmental Protection (CAEP) was already well established, its work had been brought to the attention of a wider, climate-focused audience after the Kyoto Protocol requested developed countries to pursue the limitation of the sector's greenhouse gas emissions working through (ICAO). Recognising the need for civil society to speak with one voice, the meeting created an umbrella organisation for civil society and the environment movement, the International Coalition for Sustainable Aviation (ICSA). Shortly after its formation, ICSA was recognised formally by ICAO as an observer organisation to CAEP.

Since this date, ICSA members have been engaging continuously in the CAEP process, participating actively in its working group and plenary meetings, and co-leading some of its activities on enhancing the ICAO Carbon Calculator, the development of the recent CO_2 Standard and the technical work supporting the proposal for a global market-based measure. ICSA's core belief is that it is essential that civil society is represented in these discussions, not only to provide an environmental and community perspective, but to demonstrate transparency, highlight the latest scientific evidence and the need for stretching targets. But ICSA has always aimed to do more than set out the challenges. Its members participate because they want to find the right solutions. Bringing experience of environmental policy and carbon markets, and offering a network of non-governmental organisations operating both internationally and nationally that is in touch with different regional perspectives, ICSA has always sought to engage with CAEP members and observers to identify effective measures.

Outside of CAEP, ICSA has been present at every Assembly since 2001 and has been invited regularly to give presentations at ICAO's environmental colloquiums. We are now aiming to build on our work at CAEP by engaging further on ICAO's environmental work programme at every level. To facilitate this, earlier this year ICSA took the step of appointing a permanent representative in Montreal, a new departure for an organisation that until now has been reliant entirely on the staff resources of its members. It is hoped that this will improve ICSA's wider visibility but that it will also send a strong signal that ICSA remains committed to helping ICAO set and meets environmental goals for both noise and emissions.

Looking to the future, ICAO has some important environmental challenges ahead as traffic growth continues to outpace technological and operational improvements: ensuring international civil aviation makes a fair contribution to the emissions pathway that will stabilise global temperature rises at 1.5 degrees, maintaining a focus on improved efficiency and in-sector reductions, reducing emissions that contribute to local air quality, and limiting noise at airports and under flightpaths are to name but a few. ICSA hopes to continue its role in helping to shape a timely global response.

CHAPTER 1

Laurent Box

He is an environmental assessment specialist at EUROCONTROL and an expert in Air Traffic Management validation. He is the co-manager of the development of the IMPACT environmental modelling web platform and as such is also deeply involved in ICAO MDG environmental assessments. Laurent is an engineer from the French École Nationale de l'Aviation Civile (ENAC).

Laurent Cavadini

He has been EUROCONTROL's principal aircraft noise and performance modelling expert since 2002. He is an active member of the ICAO and ECAC working groups that maintain environmental modelling standards for aviation. He leads the design and development of the web-based IMPACT environmental modelling platform. Laurent has an engineering degree with mechanics and acoustics specialities from the Université de Technologie de Compiègne.

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 the co-Rapporteur of CAEP's Modeling and Databases Group.

Ivan de Lépinay

He has been working in the field of aviation and environment since 2001. After ten years of consultancy for various European organisations, he joined EASA's Environment Department in 2011 where he is in charge of impact assessments. Ivan holds a degree in civil engineering and applied acoustics and a master's degree in sociology.

David Marsh

He joined the forecasting team at EUROCONTROL in 2001. He was soon running the forecast service, and has since added responsibility for data warehousing, all-causes delay analysis and network business intelligence. He steered the development of the Aircraft Assignment Tool, and at ICAO is involved in CAEP FESG, North Atlantic EFFG and the Aviation Data and Analysis Panel. David has a doctorate in pure mathematics, master's degree in applied statistics and is a Chartered Statistician.

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 master's 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 current Swiss CAEP member and is the co-Rapporteur of CAEP's Modelling and Databases Group.

CHAPTER 2

Peter Coen

Peter Coen is the manager for the Commercial Supersonic Technology Project in NASA's Aeronautics Research Mission. In this role he leads a team from four of NASA's Research Centers in the development of tools and technologies for a new generation of quiet and efficient supersonic civil transport aircraft. Peter has worked at NASA for more than 33 years. During his career he has studied technology integration in practical designs for many different types of aircraft and has made technical and management contributions to all of NASA's supersonics related programs over the past 25 years.

Dominique Collin

Dominique Collin is the Lead Noise Expert for the SAFRAN Group and the coordinator of the European aviation noise research network X-NOISE. Contributors to this article also include key participants to X-NOISE and associated research projects: Michael Bauer (Airbus) Dick Bergmans (NLR), Paul Brok (NLR), Harry Brouwer (NLR), Delia Dimitriu (Manchester Metropolitan University), Denis Gély (Onera), Nick Humphreys (Rolls-Royce), Eugene Kors (SAFRAN), Stéphane Lemaire (Dassault Aviation), Pierre Lempereur (Airbus), Uwe Mueller (DLR), Nico van Oosten (Anotec Engineering).

Charles Etter

Charles Etter is currently employed at Gulfstream Aerospace Company as a Staff Scientist, Environmental & Regulatory Affairs. Today, he is Gulfstream's lead engineering authorized representative (EAR) in Acoustics. Mr. Etter was recognized for his outstanding engineering achievements in 2012 when he was awarded the distinguished position of Technical Fellow at Gulfstream. He participates in CAEP's WG1 SSTG group, where the early phases of a new noise standard specific to civil supersonic aircraft are being developed. He also works with other industry representatives and regulators in the areas of renewable fuels and in the development of a new emissions standard recently approved at CAEP/10.

Shannon Gardiner

Shannon is currently an environmental analyst and student from the University of Waterloo. Shannon has taken a keen interest in land use planning and transportation during her undergraduate career including attending a 'Hands on Sustainable Mobility' workshop, in partnership with the Karlsruhe University of Applied Sciences in Karlsruhe, Germany. Shannon joined the Environmental Management branch at Transport Canada for her final co-op term in September 2015 . Previously, Shannon has completed co-op terms with GO Transit-A division of Metrolinx, Public Works and Government Services Canada and Teledyne DALSA.

Rainer Heger

He is Aeroacoustics Expert at Airbus Helicopters and holds a Master's degree in Aerospace Engineering from the Technical University of Munich. In the past decade, he was directly involved in the development and testing of the Blue Pulse active rotor and the Bluecopter demonstrator, as well as in major European research projects on helicopter noise abatement procedures and low noise design. Furthermore, he was responsible for the successful noise certification of the latest H135 and H145 models. He serves in the ICAO CAEP Noise Working Group and was appointed ICCAIA focal point for rotorcraft noise in 2014.

Eric Jacobs

Eric Jacobs has been working for Sikorsky Aircraft since 1985. He is a technical expert in rotorcraft acoustics and noise certification, having been responsible for conducting every helicopter noise certification executed by Sikorsky Aircraft since its first in 1989. He has been a member of ICAO Working Group 1 on Aircraft Noise since 1998, having served as the Rotorcraft Industry Focal Point.

Michael O. Kartyshev

As a Ph.D. candidate at the St. Petersburg State University of Civil Aviation, Michael has carried out many experiments on the propagation of noise from aircraft sources. He supervises the organization of a noise monitoring system at the Vnukovo Airport (Moscow). He also represents the interests of aviation organizations in dealings with local governments. In the CAEP/10 cycle, he presented AcousticLab, a software model for noise mapping, which was later approved by CAEP.

Oleg A. Kartyshev

He has been the Director of the Aviation Environment Science Institute (Moscow) since 1976. He is also the author of many domestic regulatory documents and methods related to the assessment of the impact of airports on the environment. He supervises relationships between aviation industry organizations, the Federal Air Transport Agency, the Society on Aviation Impact on the Environment. Oleg leads the project aiming to organize a noise monitoring system for the Moscow air hub. During the CAEP/9 and CAEP/10 cycles, he participated in the CAEP's Modelling and Databases Group.

Rick Norman

A Master's graduate in Environmental Science and Management from Brunel University Rick has worked in aviation since 1989. Over a long career at two of the world's busiest and environmentally sensitive airports his career has focused primarily on aircraft noise but has also included a range of wider environmental management roles and responsibilities. Apart from 5 years at Gatwick, Rick has been based at Heathrow. For the past 9 years he has been Head of Noise Strategy and responsible for driving forward the airports strategic approach to noise with accountabilities including the development and implementation of Heathrow's EU Environmental Noise Directive Noise Action Plan and long term strategic approach to noise management. He is currently Noise Rapporteur for the ACI Europe Noise Task Force.

Xavier Oh

He worked as a Senior Manager Environmental Protection at Airports Council International (ACI) until 2016, led the CAEP/10 Community Engagement task and was the ACI Observer on CAEP. As secretary of ACI's World Environment Standing Committee he was in charge of developing, coordinating and implementing policy and positions on issues relating to the environment and airports, as well as supporting environmental training for airports, sharing best practice between airports and working with aviation industry organizations. In 2016, he moved to London, UK, to become the Noise Strategy Manager at Heathrow Airport and will continue to work with community engagement.

Christian Roehrer

Christian Roehrer has been working as the Head of Environmental Management Department of Vienna Airport since March 2013 and has been involved in the environmental management activities of the airport since 1978, holding progressively more responsibilities. He has experience in noise measurements, noise zone calculation, flight track monitoring, air navigation, aircraft noise and emissions and regional communication. Christian also was a noise expert in Meditation Process from 2000 to 2005. He has been a member of the Dialogue Forum Vienna since its inception.

Sheila Sankey

Sheila Sankey is a Senior Environmental Advisor at Transport Canada, she has worked in the aviation environmental field for 19 years. Sheila provided secretariat support to the Task Group for the Airport Planning Manual Part 2 updated during CAEP/10.

Alec Simpson

Alec Simpson is the Senior Director, Environmental Management, and the Executive Director, Safety and Security 2020 Transformation for Transport Canada. He brings to the department over 30 years of experience in domestic and international aviation management. Alec has been a member of ICAO/CAEP Working Group 2 – Airports and Operations since 1996, and was its co-Rapporteur from 2001 – 2011. He is the Task Group co-leader with Xavier Oh for the Airport Planning Manual Part 2 – Land Use and Environmental Control.

Oleksandr Zaporozhets

DrSc, Professor, He is a Director at the Environmental Safety Institute of the National Aviation University (NAU) in Kiev, Ukraine, a Head of the Research Center of Environmental Issues of the Airports of the NAU and a member of the ICAO Council's Committee on Aviation Environmental Protection (CAEP), Oleksandr is also a consultant to Civil Aviation Authority (CAA) of Ukraine. For over 20 years, he has served as an scientific adviser on environmental impact assessments and environmental protection related subjects for the Department of Airports of the CAA, contributing to developing policies and regulations.

CHAPTER 3

Benjamin Brem

He is a Research Associate at the Laboratory for Advanced Analytical Technologies at the Swiss Federal Laboratories for Materials Science and Technology (Empa). His work focuses on instrumentation and analytical methods for the measurement of combustion generated particles. He has a Swiss precision mechanic certificate and a Ph.D. in Civil and Environmental Engineering from the University of Illinois.

Daniel Jacob

S. Daniel Jacob is a Physical Scientist and Program Manager at the U.S. Federal Aviation Administration Office of Environment and Energy. 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 on non-volatile particulate matter emissions testing, 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. He co-led the Particulate Matter Task Group of the CAEP WG3 during the CAEP/10 cycle.

Rick Miake Lye

Rick Miake Lye 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.

Theo Rindlisbacher

Theo Rindlisbacher serves as an advisor on environmental subjects and expert for aircraft environmental certification for the Swiss Federal Office of Civil Aviation (FOCA). 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 was co-leading the Particulate Matter Task Group of CAEP WG3 for the development of the first ICAO particulate matter standard.

Inger Seeberg Sturm

Inger Seeberg Sturm joined Copenhagen Airports in 2006 and has been responsible for Environmental Affairs since 2010. She is a member of the ACI Europe Environmental Strategy Committee and was nominated by ACI to represent the organization in the ICAO CAEP Working Group 3 during the CAEP/10 cycle. Among other representations, she is chairing NISA, Nordic Initiative for Sustainable Aviation. Inger has a master degree in law (LL.M.).

Kateryna Synylo

PhD, works at the National Aviation University of Kiev, Ukraine, and currently as an Assistant Professor of the Chair of Safety of Life Activities of the Institute of Environmental Safety. Kateryna is leading the Local Air Quality assessment and control in the Research Center of Environmental Issues of the Airports of the NAU, she is a member of CAEP Modelling and Database Group beginning from 2014. She has been involved in national and international studies and projects related to environment protection from civil aviation impact, focused on the assessment air pollution and organization of monitoring of aircraft engine emissions inside and around the airports.

CHAPTER 4

Steve Arrowsmith

Steve Arrowsmith is an Environmental Protection Officer at the European Aviation Safety Agency (EASA). He has 20 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 the aircraft engine NOx emissions standard at CAEP/8 and the aeroplane CO_2 standard during CAEP/9 ad CAEP/10.

Annie Benn

Annie Benn is a Senior Associate at Carbon War Room/Rocky Mountain Institute. She works with the Sustainable Aviation team to develop industry-led strategies for reducing the climate impact of aviation, and engages stakeholders in Carbon War Room's work. Ms. Benn holds a BA from Swarthmore College and a Master of Public Administration from New York University.

Arnaud Bonnet

He is the Engine Performance Consulting Engineer for Embraer, having worked for 26 years on propulsion systems performance related matters. He is a member of CAEP WG3 since 2012 and has participated to the CO_2 Standard definition activities within ICCAIA. He holds an Electronic Engineering Degree from ENSEEIHT (Toulouse, France) and a Master of Science in Propulsion from ENSAE (Toulouse, France).

David Brain

David previously worked as an en-route Air Traffic Controller in the UK and has over 20 years extensive experience in ATC, ATM and Project Management. David currently leads EUROCONTROL's operational efforts on reducing aviation's impact on the environment, chairs the European CCO/CDO Taskforce as well as leading several other European operational projects. David is a member of the CAEP Airport and Operations Working Group and Modelling and Databases Working Group and currently leads two tasks within CAEP; to estimate the global environmental benefits of ASBU Block 1; and a further task to estimate global inefficiency levels due to ATM. David has a private pilot's license, a degree in Geography and a Master's degree in Sustainable Aviation.

Robin Deransy

Robin Deransy leads the team responsible for EUROCONTROL's environmental impact modelling and research activities at the EUROCONTROL Experimental Centre. Robin was the project leader of the SESAR 1 Environment Coordination and Support function (Project 16.06.03). He is active in ICAO's Committee on Aviation Environmental Protection (CAEP), contributing to the work of its Airports & Operations and Modelling & Database Working Groups. In this context, Robin was leading the task group responsible for collecting examples of good practice environmental assessments during CAEP/10.

Moussa Halidou

Halidou Moussa currently works as Chief Delegate of ASECNA to ICAO and Representative of Niger to ICAO. He is also an Air Navigation Commissioner and Chairman of the Steering Committee of the ICAO Comprehensive Regional Implementation Plan for Aviation Safety in Africa (AFI Plan). Since 2008, Mr. Halidou has been an elected Member of the ICAO Air Navigation Commission (ANC) and has served as 2nd Vice President of the ANC in 2011, 2014 and 2015. He is an Internal Auditor of ASECNA in Integrated Management System (SMS-QMS) as well as an ICAO USOAP-CMA Auditor in the area of ANS. Mr. Halidou also holds an ICAO SMS Train the Trainers Certificate and qualification certificates in air traffic management from ASECNA. Mr. Halidou' extensive professional experience in civil aviation spans 34 years.

Rolf Hogan

As RSB's Executive Director, Rolf is supporting the expansion of the RSB's globally renowned standard and certification scheme from liquid biofuels to cover biomaterials such as bioplastics and other products derived from biomass. With an academic background in both natural and social sciences, Rolf has 20 years' experience with the non-profit sector and global environmental policy. He led a multi-country program on protected areas for WWF International and represented the organization at the Convention on Biological Diversity. He also worked for the International Union for the Conservation of Nature (IUCN) advising the UNESCO World Heritage Committee.

P.S.Jayan

With 15 year of experience as a Journalist, Mr.P.S.Jayan joined Cochin International airport in 2014. Now he works as Manager-Corporate Communications. He is a British Chevening Scholar and Editor of two books; Nations of the World, Insignia of a Dream.

Ian Jopson

Ian has over twenty years' experience in the sphere of environmental aviation issues in Europe and beyond, working for the Civil Aviation Authority and an independent consultancy. Ian is Head of Environmental and Community Affairs at NATS, which provides air traffic services to 2.2 million flights a year and to 13 airports in the UK. Ian is Chair of the UK Sustainable Aviation coalition and he advises the UK state member of ICAO's Committee on Aviation Environmental Protection. In Europe, he is part of the environmental research transversal programme in the Single European Sky ATM Research programme, SESAR.

Adam Klauber

As the Aviation Lead for Carbon War Room/Rocky Mountain Institute, Adam Klauber heads a program to activate market based solutions for the climate. In his last position, he led ICF International's Sustainable Aviation practice supporting airports, airlines and the National Academies of Science with cost effective energy and resiliency strategies. Mr. Klauber has advanced innovative aviation sustainability, including managing high performance building design for the FAA NextGen program and developing the first United States based carbon neutral airport project for the Massachusetts State Department of Transportation.

Petra Koselka

At Carbon War Room, Ms. Koselka focused on designing and delivering innovative business solutions in the Aviation space, driving significant reductions in CO_2. She previously held various positions at Shell, ranging from Finance and New Business Development to significant P&L roles including their aviation business. She recently joined AkzoNobel as the new Corporate Director of Strategy and M&A.

Merel Laroy

Merel Laroy is head of the marketing & sales department at SkyNRG. She focuses on the development of SkyNRG's Corporate Programmes and is in charge of boosting the marketing up to a higher level. Before joining SkyNRG in 2012, Merel studied European Studies at Amsterdam University and International Relations & Philosophy in Sydney, at the University of New South Wales in 2010. Previously, Merel worked for several charities such as Pink Ribbon Netherlands, a charity organization aimed to create a community to support breast cancer patients and KIKA, a Dutch charity foundation that brings in funding for research to childhood cancers.

Jarlath Molloy

Jarlath has worked on environment and aviation topics with NATS, ICAO, a European Commission aviation project, Aer Lingus and CDSB. As Environmental Affairs Manager, he is responsible for developing NATS' Corporate Social Responsibility policy and improving environmental performance, as well as expanding NATS' external CSR reporting and supporting projects to reach NATS' airspace environmental targets. He attends ICAO's Committee on Aviation Environmental Protection WG2 on behalf of the UK CAEP member. Jarlath gained a PhD from Imperial College London, where he focused on climate change and aviation, and he is a Chartered Physicist.

Gerard Ostheimer

Dr. Ostheimer serves as the Global Lead for the SE4ALL Sustainable Bioenergy High Impact Opportunity. Working with diverse partners he promotes the development and deployment of sustainable bioenergy solutions to help achieve SE4All's goals of increasing energy access and doubling the use of renewable energy. Previously, Dr. Ostheimer served as a Science Advisor for the Foreign Agriculture Service and was the U.S. government technical lead to the Global Bioenergy Partnership (GBEP) and contributed to finalizing the GBEP Indicators of Sustainable Bioenergy Production and Use.

Sebastien Remy

Sebastien Remy has been Head of AIRBUS GROUP INNOVATIONS since 2013. He leads the Airbus Group's network of research centres with a highly skilled workforce of more than 800 employees in over 10 countries. Together with his team, Sebastien REMY operates the laboratories that guarantee Airbus Group's technical innovation potential with a focus on the long-term. He graduated from the French engineering School "Ecole Nationale Supérieure de l'Aéronautique et de l'Espace" in 1984 and after joining Airbus in 1986 later became Head of Alternative Fuels Research Programmes, initiating the activities that led to the world premiere A380 flight with alternative fuel in 2008.

Célia Alves Rodrigues

Célia Alves Rodrigues is the Environment Officer and Release Outcome Manager at the SESAR Joint Undertaking based in Brussels, Belgium since March 2010. Célia works in the Development and Delivery Unit and is responsible for the monitoring and supporting the dissemination of the SESAR Releases results (SESAR Solutions). She is also the focal point for SESAR environmental aspects. In parallel she manages the on-going RPAS (Remotely Piloted Aircraft Systems) demonstration activities. In the past she was responsible for the programme management of the Atlantic Interoperability Initiative to Reduce Emissions (AIRE).

Thomas Roetger

Thomas Rötger joined IATA in 2008 as Assistant Director Environment Technology. His main activity is to implement IATA's strategy to reduce aviation's environmental impact through technological measures, in particular sustainable fuels. He is a member of ICAO CAEP WG3 (Emissions), Alternative Fuel Task Force and Impact Science Group; he is chairman of the end-users chamber in the Roundtable on Sustainable Biomaterials (RSB), and rapporteur of the Environment and Energy working group in the Advisory Council for Aviation Research and Innovation in Europe (ACARE). From 1988 to 2008 he worked at Airbus in Toulouse and Hamburg, with a focus on noise and emissions reduction. He studied physics and chemistry in Heidelberg, Hamburg and Grenoble and holds a doctoral degree in physics.

Donald J. Scata

Don is an aviation professional working in the United States Federal Aviation Administration (FAA) Office of Environment and Energy (AEE) as the Senior International Advisor. Don has been working at FAA since 2012. His work is focused on coordinating AEE's International Environmental Activities, including work in the International Civil Aviation Organization (ICAO) Committee on Aviation Environmental Protection (CAEP). In this role, he supports the Executive Director and the rest of AEE in their engagement on a number of ICAO/CAEP Technical Groups. In CAEP WG2 (airports and operations), Don co-led the analysis of the environmental benefits of global Aviation System Block Upgrade (ASBU) implementation. Don is also a National Environmental Policy Act (NEPA) expert, and co-led the update of FAA Order 1050.1E and creating a supporting Desk Reference.

Pedro Scorza

Pedro Rodrigo Scorza is a Line Captain at GOL Airlines and responsible for supporting C-level executives in long term projects like renewable fuel and sustainability. He also acted as Operations Control Director, Operations Director and Technical Operations Director. Since February 2015, he is also a Director of Renewables for Aviation at Ubrabio (União Brasileira de Biodiesel e Biokerosene). The executive began his professional career in 1989 and has been working at GOL since 2006.

Katie Sullivan

Katie serves as IETA's Director of The Americas and International Climate Finance. On behalf of IETA's global multi-sector business membership, Katie leads efforts to inform climate change policy and market design with government and non-government partners across The Americas. She also manages IETA's growing international work on innovative instruments and market mechanisms, capable of leveraging and scaling low-carbon private capital. Katie's a member of the University of Toronto's Environmental Finance Committee, Ontario Environment Commissioner's Climate Change Advisory Panel, and the Climate Advisory Group to Ontario's Minister of Environment & Climate Change.

Niclas Svenningsen

Niclas Svenningsen is the Manager for the Strategy and Relationship Management unit in the UNFCCC Secretariat. In this capacity he is responsible for developing and strengthening approaches and strategies for catalysing climate action under, and in addition to, activities mandated by UNFCCC, in particular through market based instruments such as the Clean Development Mechanism (CDM). He was previously working in the United Nations Environment Programme (UNEP) where he was in charge of the climate neutral strategy of the UN system, as well as for the implementation of UNEP's programmes for sustainable buildings, urban development, and sustainable procurement.

Laszlo Windhoffer

Laszlo Windhoffer is an aerospace engineer who works at the United States Federal Aviation Administration's (FAA) Office of Environment and Energy. Specializing in aircraft emissions, he has been involved in various research projects ranging from automatically optimizing en-route air traffic for minimal fuel consumption to assessing national aviation fuel efficiency metrics and goals. He also led the design of the FAA's state of the art environmental modeling lab. In recent years, he was the co-lead of a technical working group that designed the first global carbon emission standard for commercial aircraft. He is currently focused on implementing the international CO_2 standard within the United States regulatory framework.

CHAPTER 5

Alfredo Iglesias

He is the Head of the Environmental Service at the State Aviation Safety Agency (AESA) and works in the development and implementation of noise and emission measures which lead to achieve the sustainability of the aviation transport. He is an Aerospace Engineer, specialized in propulsion and he has worked in different areas such as aircraft/engine certification and environment. Nowadays he is the Spanish member of the CAEP and Co-rapporteur of the GMTF. From 1998 to 2004 he was member of the CAEP Noise Scenarios Group (NSG), prior to the CAEP 5.

Ramesh Lutchmedial

Mr. Ramesh Lutchmedial has been the Director General of Civil Aviation and the Chief Executive Officer of the Trinidad and Tobago Civil Aviation Authority for the past 15 years with an aviation career extending to over 45 years. He is a UK Certified Aircraft Engineer and holds a Master's in Business Administration. He pioneered the development of civil aviation in Trinidad and Tobago with the establishment of the TTCAA consisting of an ultra-modern civil aviation complex that includes a Control Tower and an Area Control Centre. Ramesh is a member on the Board of the Caribbean Air Navigation and Advisory Services Limited, Vice Chairman of the Caribbean Aviation Safety and Security Oversight System (CASSOS) of CARICOM.

Raúl Martín

In 2006 Raúl Martín joined SENASA, Spanish State Company linked to the Civil Aviation Authority. Since 2015 he leads the Spanish Observatory of Sustainability in Aviation (OBSA), a SENASA project that has become a reference on aviation and sustainability, facilitating policy-making in this field by interacting among the authorities and the stakeholders. Besides, the OBSA develops technical activities, training and consultancy in several areas such as Climate Change, Local Air Quality, Noise mitigation, etc. in relation with aviation.

Julia Municio

Julia Municio is an environmental expert and has worked in different companies related to environmental issues until she arrived at the Observatory of Sustainability in Aviation at SENASA in 2009. She has been involved in many projects related to the sustainability of the aviation sector such as the National Inventories of Emissions from Aviation, the annual publication of the Sustainability Report of the Aviation Sector in Spain, the EU-ETS, etc. and nowadays she gives support to the AESA in the development of the Spanish Action Plan for Emissions Reduction in Spain.

Giovanni Tobar

Mr. Tobar is an industrial engineering working for the Central American Corporation for Air Navigation Services (COCESNA) on the regional programme for climate change and environment protection. He studied strategic planning, political investigation, climate change science, sustainable development and he is a Ph.D. candidate in engineering and climate change at the University of Almería in Spain. After being vice-minister for environment and undersecretary for economic planning of Guatemala, Mr. Tobar is currently a representative of the academic sector in the Guatemalan National Council on Climate Change. Since he took up his position in COCESNA, Mr. Tobar has been appointed as a focal point to update the Central American plan to reduce international aviation emissions and implement environment and civil aviation mitigation measures decided by the Latin American Civil Aviation Commission (LACAC).

Salifou Zanga

Salifou Zanga is the head of the aircraft airworthiness Department of the National Civil Aviation Agency of Burkina Faso since March 2014. In 2013, he joined the National Civil Aviation Agency at the Department of aircraft operations. From 1995 to 2003, he worked as aircraft Engineer in Dakar (Senegal) Industrial Center, where he participated in major maintenance works on Airbus and Boeing aircraft, from A-check to D-check, as well as, in Abidjan and Bordeaux. He is currently the Coordinator of the CO_2 action plan team in Burkina Faso.

CHAPTER 6

Julien Dezombre

Julien Dezombre received a Master's degree in Chemical Engineering from École Supérieure de Chimie Organique et Minérale, Cergy-Pontoise (France) in 2003. He then joined Airbus and participated in the implementation of a management system under ISO14001 and towards an important end-of-life demonstration project. He joined Bombardier Aerospace in 2009 as Design for Environment engineering specialist. Mr. Dezombre successfully managed several initiatives relating to product-based environmental improvements for both new and legacy Bombardier aircraft, which involves collaboration with outside partners and suppliers on research and development projects.

Laura Dwulet

Laura Dwulet is General Manager of the Aircraft fleet Recycling Association (AFRA), which is the leading global organization for developing and promoting the safe and sustainable management of end-of-life aircraft and components. Established in 2006, AFRA is a membership-based global collaboration to elevate industry performance and increase commercial value for end-of-service aircraft. AFRA represents companies from across the globe and throughout the supply-chain – from manufacturers to materials recyclers. Through the collective experience of its members, AFRA's Best Management Practice (BMP) Guide has significantly improved the management of end-of-life aircraft in terms of environmental and sustainable performance.

Kahina Oudjehani

Kahina Oudjehani received a Master's degree (M.A.Sc.) in Chemical Engineering from École Polytechnique de Montréal (Canada) in 2001, and a Bachelor's degree in the same field in 1997. She has 17 years combined experience in different areas (Research, Soil Remediation, Telecommunication, Consulting and Aerospace). She joined Bombardier Aerospace in 2008 as an Environmental Specialist. In 2011, Ms Oudjehani was appointed of EcoDesign Lead for the entire Aerospace Group. She is responsible for integrating environmental concerns involving product design and also for producing environmental product declarations for new Bombardier aircraft. The EcoDesign team won two awards, in 2013 and 2014, for its leadership role in developing Bombardier's Corporate Social Responsibility and its innovative approach for Design for Environment.

CHAPTER 7

Rachel Burbidge

Rachel Burbidge joined EUROCONTROL in 2005. She has been leading EUROCONTROL's work on climate change adaptation since 2009. She is the Agency's policy officer for international aviation market-based measures for CO_2 reduction and a member of the ICAO Global Market Based Measures Technical Task Force, as well as being a member of the ICAO CAEP Impacts and Science Group and Airport and Operations Working Group. She also 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 Master's degree in Sustainable Development.

Kristin Fjellheim

Ms. Kristin Fjellheim has been an energy adviser in Avinor's infrastructure and ground services department since 2014 working with issues related to energy efficiency, emission reduction, renewable energies and climate adaptation in buildings. She has a master's degree in industrial ecology from the Norwegian University of Science and Technology with a thesis on using input-output methodology to model the environmental impact of world trade.

Olav Mosvold Larsen

Mr. Olav Mosvold Larsen has been a senior adviser in Avinor's Strategy department since 2007, with a special responsibility for issues related to climate change and the environment. Mr. Larsen is also chair of ACI Europe's Environmental Strategy Committee. He holds a degree in political science and has previously worked as a researcher at the University of Oslo, Centre for Development and the Environment.

Herbert Puempel

Herbert obtained a Ph.D. in Theoretical Meteorology at the University of Innsbruck in 1978. He has taken on leading roles in Expert Teams of the Commission for Aeronautical Meteorology of the World Meteorological Organization from 1990, and became Chief of the Aeronautical Met Division at the WMO Secretariat in 2006 until 2013. He has been involved in the work of CAEP since 1999, and currently is a member of its Implementation and Science Group. His focus is the study of the effects of climate change on aviation, and aspects of how this change will affect the need for improved cooperation between MET service providers, ATM and operators. Within Austrocontrol, he is currently in charge of Strategic Planning for MET and looks after a number of European SESAR and similar projects.

Karyn Rains

Karyn Rains is a Communications and Approvals Manager for the New Parallel Runway (NPR) Project at Brisbane Airport Corporation (BAC). She won the Grand Award for Best Water Management in the World at the International Water Association (IWA) Awards in 2008, In 2005, Karyn joined the NPR Project team as Assistant Project Manager. Her team obtained very quickly approvals for a new runway and won the Tourism and Transport Forum Corporate Leadership Award for Public Affairs Excellence. Since 2007 Karyn has held a senior management role. Her current focus within the NPR team is the airspace planning and implementation to the opening of the new runway.

Paul Williams

Dr Paul D. Williams is currently a Royal Society University Research Fellow in the Department of Meteorology at the University of Reading. He obtained his PhD in atmospheric, oceanic and planetary physics from the University of Oxford in 2003. His scientific research focuses on atmospheric waves and turbulence. He was the lead author of a recent study into the effects of climate change on aircraft turbulence.

CHAPTER 8

Ban Ki-Moon

Ban Ki-moon is the eighth Secretary-General of the United Nations. He has sought to be a bridge builder, to give voice to the world's poorest and most vulnerable people, and to make the Organization itself more transparent, effective and efficient. Mr. Ban took office on 1 January 2007, was unanimously re-elected by the General Assembly in 2011, and will serve until 31 December 2016. His priorities have been to mobilize world leaders to address global challenges ranging from poverty and climate change to violent conflict and intolerance. He pressed successfully for the creation of UN Women, and during his tenure the number of women in senior management positions reached the highest level in UN history. He has undertaken major efforts to strengthen UN peace efforts, promote accountability for violations of human rights, and improve humanitarian response, and has advocated for the rejuvenation of the disarmament agenda.

Christina Figueres

Christiana Figueres has been Executive Secretary of the UN Climate Change secretariat since 2010. She has worked extensively with governments, non-governmental organizations and the private sector on climate change and sustainability issues, including as a board member of the Clean Development Mechanism, Vice-President of the Climate Change Conference, as well as many non-governmental organizations. Ms Figueres has greatly contributed to literature on climate solutions and holds a Master's Degree in Anthropology from the London School of Economics, a certificate in Organizational Development from Georgetown University and honorary Doctorate degrees from the University of Massachusetts and the Georgetown University.

Angela Gittens

Angela Gittens began her tenure as Director General of Airports Council International (ACI World) in 2008. She was formerly airport CEO for Miami and Atlanta and Deputy at San Francisco International Airport. In previous roles, Angela served as Vice-President, Airport Business Services for HNTB Corporation. As Vice-President at TBI Airport Management, she oversaw the transition to private ownership of London Luton Airport. Angela has served on aviation industry boards and committees including the FAA Management Advisory Committee, the FAA Research, Engineering and Development Committee, the National Civil Aviation Review Commission, the Executive Committee of the Transportation Research Board, the Airport Cooperative Research Program Oversight Committee and the Board of Directors of JetBlue Airways.

Tim Johnson

Tim has worked with the Federation for over twenty years. He provides AEF's representation at ICAO as well as on the Department for Transport's External Advisory Group. On behalf of the environmental NGO coalition ICSA (the International Coalition for Sustainable Aviation), Tim plays an active role in ICAO's Committee on Aviation Environmental Protection where he chairs ICAO's carbon calculator task force and is co-lead on tasks related to the development of a global market-based measure. Tim won the 2014 Royal Aeronautical Society Green by Design award for his work to move the environmental aviation debate in a landscape of conflicting interests.

David Melcher

David F. Melcher is President and CEO of the Aerospace Industries Association. Following a 32-year career in the U.S. Army, Lieutenant General (Ret.) Melcher joined AIA from Exelis Inc., where he was CEO and President. As AIA President and CEO, Melcher chairs the International Coordinating Council of Aerospace Industries Associations, industry's representative to the International Civil Aviation Organization. Melcher was also sits on FAA's NextGen Advisory Committee, providing advice for the nation's aviation modernization efforts.

Jeff Poole

Director General of CANSO (Civil Air Navigation Services Organisation) was appointed on 1 December 2012. In addition to leading and managing CANSO, he represents its Members as the global voice of air traffic management. He is responsible for delivering the CANSO strategic plan for air traffic management, Vision 2020; further expanding CANSO's worldwide membership; and governing CANSO's relationship with its industry peers and stakeholders. Jeff previously served at the International Air Transport Association (IATA) 2004-2012. In one of his prior assignments, Jeff was responsible for the development of all business aspects of the Airbus A380 programme. His final position at Airbus was as Senior Vice President for Procurement Strategy and Services.

John Roome

As Senior Director for Climate Change at the World Bank Group, John Roome leads a team of climate finance and policy specialists and works across the institution to advance the mitigation, adaptation and resilience agenda.

Erik Solheim

Erik Solheim assumed leadership of the United Nations Environment Programme in June 2016, having served as Chair of the Development Assistance Committee of the Organization for Economic Cooperation and Development since 2013. Previously, Erik served as Norway's Minister of the Environment and International Development, as a peace negotiator in Sri Lanka, and contributed to the peace process of Sudan, Nepal, Myanmar and Burundi, as UNEP's Special Envoy for Environment, Conflict and Disaster, and as a Patron of Nature for the International Union for the Conservation of Nature.

Tony Tyler

Tony Tyler took on the role of Director General and CEO of the International Air Transport Association (IATA) in 2011. Tyler has championed IATA's commitment to addressing aviation's impact on the environment. His effort led governments to reach an agreement on a market-based measure (MBM) as a tool to manage aviation's carbon footprint and achieve the industry's carbon-neutral growth target. Tony carries with him a message that aviation delivers extensive social and economic benefits—supporting 57 million jobs and enabling over $2.2 trillion of business annually. He has also overseen a major internal restructuring of IATA to improve the association's organizational effectiveness in delivering greater value to its members.

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ICAO Annexes

- Annex 16 to the Convention on International Civil Aviation — Environmental Protection, Volume I — Aircraft Noise
- Annex 16 to the Convention on International Civil Aviation — Environmental Protection, Volume II — Aircraft Engine Emissions
- Annex 16 to the Convention on International Civil Aviation — Environmental Protection, Volume III — Aeroplane CO_2 Emissions

ICAO Guidance Documents

Noise

- Guidance on the Balanced Approach to Aircraft Noise Management (Doc 9829)
- 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, Vol I)
- Report to CAEP by the CAEP Noise Technology Independent Expert Panel. Aircraft Noise Technology Review and Medium and Long Term Noise Reduction Goals. Report (Doc 9943)
- Report by the Second CAEP Noise Technology Independent Expert Panel. Novel Aircraft-Noise Technology Review and Medium- and Long-Term Noise Reduction Goals (Doc 10017)

Local Air Quality Emissions

- Environmental Technical Manual Volume II – Procedures for the Emissions Certification of Aircraft Engines (Doc 9501, Vol II)
- Report of the Independent Experts on the Medium and Long Term Goals for Aviation Fuel Burn Reduction From Technology, 2010 (Doc 9963)
- Review and the Establishment of Medium and Long Term Technology Goals for NOx, 2010 (Doc 9953)
- Offsetting Emissions from the Aviation Sector, 2011 (Doc 9951)
- Scoping Study of Issues Related to Linking "Open" Emissions Trading Systems Involving International Aviation, 2011 (Doc 9949)
- Guidance on Aircraft Emission Charges Related to Local Air Quality (Doc 9884)
- Independent Experts NOx Review and the Establishment of Medium and Long Term Technology Goals for NOx (Doc 9887)
- Airport Air Quality Manual (Doc 9889)
- ICAO's Policies on Charges for Airports and Air Navigation Services (Doc 9082)

CO_2 Emissions

- Environmental Technical Manual, Volume III, Procedures for the CO2 Emissions Certification of Aeroplanes (Doc 9501, Vol III)
- Report on Voluntary Emissions Trading for Aviation (VETS Report), 2010 (Doc 9950)
- Scoping Study on the Application of Emissions Trading and Offsets for Local Air Quality in Aviation, First edition, 2011(Doc 9948)
- Guidance on the use of Emissions Trading for Aviation (Doc 9885)

Operations

- Guidance on Environmental Assessment of Proposed Air Traffic Management Operational Changes (Doc 10031)
- Operational Opportunities to Minimize Fuel Use and Reduce Emissions (Doc10013)
- Continuous Descent Operations (CDO) Manual (Doc 9931)
- Procedures for Air Navigation Services — Aircraft Operations (OPS) (Doc 8168)
- Global Air Navigation Plan for CNS/ATM Systems (Doc 9750)
- Environmental Management System (EMS) Practices in the Aviation Sector (Doc 9968)

ICAO Circulars

- Circular on the CO_2 Standard Certification Requirement (Circ. 337)

CAEP Reports

- Report of the Committee on Aviation Environmental Protection, Tenth Meeting Montréal, 1 – 12 February 2016 (Doc 10069, CAEP/10)
- Report of the Committee on Aviation Environmental Protection, Ninth Meeting Montréal, 4 – 15 February 2013 (Doc 10012, CAEP/9)
- Report of the Committee on Aviation Environmental Protection, Eighth Meeting Montréal, 1 – 12 February 2010 (Doc 9938, CAEP/8)
- Report of the Committee on Aviation Environmental Protection, Seventh Meeting Montréal, 5 – 16 February 2007 (Doc 9886, CAEP/7)
- Report of the Committee on Aviation Environmental Protection, Sixth Meeting Montréal, 2 – 12 February 2004 (Doc 9836, CAEP/6)

Related Material: ICAO Environmental Reports

- ICAO Environmental Report, 2013
- ICAO Environmental Report, 2010
- ICAO Environmental Report, 2007

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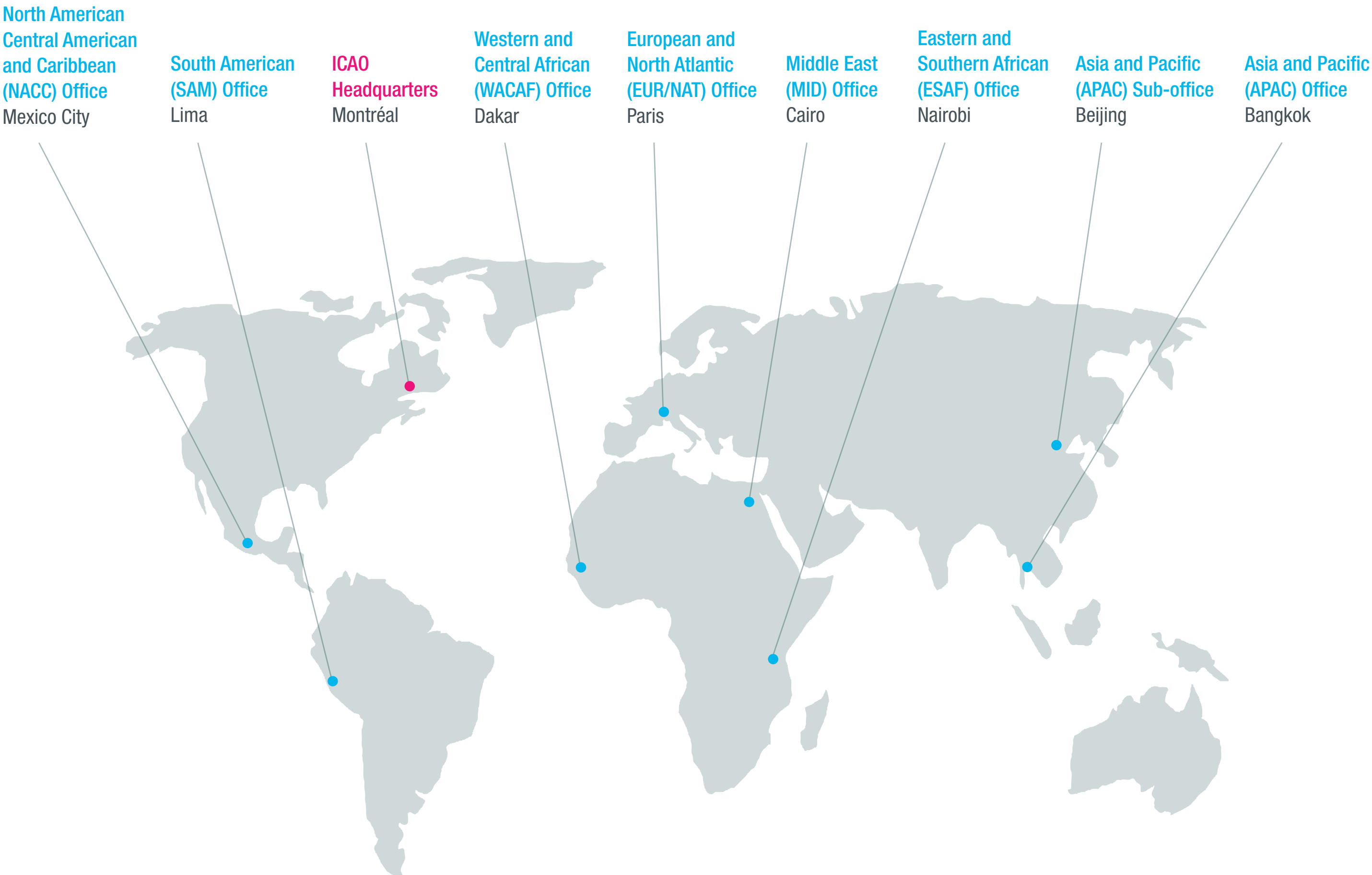

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