ICAO

2019 Environmental Report

AVIATION AND ENVIRONMENT

DESTINATION GREEN

The Next Chapter

Cover image

FRANCESCO CAMILLO GIORGINO

Francesco Camillo Giorgino (1979) better known for his project Millo, is an Italian street artist internationally recognized for his unique murals. He paints large-scale murals that feature friendly inhabitants exploring their urban setting. He uses simple black and white lines with dashes of color when necessary, and often incorporates elements of architecture into his multi-story paintings. He took part to several street art festival and NGO art event all around world. www.millo.biz

ICAO

ENVIRONMENT

2019 Environmental Report

Aviation and Environment

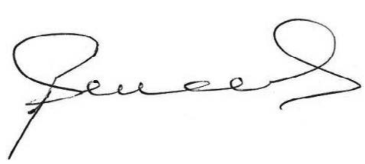
Message from the President of the International Civil Aviation Organization (ICAO) Council

In 2010, ICAO Member States gave a strong mandate and a roadmap to the Organization to act on climate change. International aviation became the first global sector to adopt global aspirational goals for CO_2 emissions – two per cent fuel efficiency improvement annually, and carbon neutral growth from 2020 - and a "basket of measures" to progress towards these goals. In 2013, during the following session of the ICAO Assembly, commitment towards this climate change strategy was reaffirmed and enabled ICAO to take the necessary actions to realize the ambition set, through incentivizing innovative aircraft technologies, implementing more efficient operations, facilitating the use of sustainable alternative fuels, and creating a global market-based measure, the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA).

These achievements have required the increased involvement of ICAO's traditional partners, and the cooperation with new governmental and non-governmental organizations, industry bodies and research institutes. True to its reputation as an innovative sector, international aviation, through ICAO, is creating new rules and new forms of engagement for the implementation of CORSIA that will set a precedent globally. Indeed, the discussions on the sustainability criteria for the production of sustainable aviation fuels and the capacity-building efforts leveraged by ACT CORSIA will durably seal ICAO's leadership role in limiting and reducing emissions from international civil aviation. As President of the ICAO Council, I express my sincere appreciation for the intense work conducted by ICAO and its Member States to enhance our collective preparedness for the entry into force of CORSIA requirements.

However, such ambition should not falter. As preparations for the 40th Session of the Assembly intensify, a series of landmark events are being held to remind us that international aviation has a key role to play in complementing the objectives set out in the Paris Agreement. Accordingly, ICAO's 193 Member States should consider how to further articulate the long-term aviation environmental journey. A number of seeds have been sown to make this journey greener, on a door-to-door basis, with green mobility concepts being developed for accessing the airports. Airports themselves are multiplying initiatives to reduce their environmental impacts and help others on the airport site contribute to this collective effort. Last but not least, a holistic approach to greener aircraft operations is emerging, on a life-cycle basis. All of these aspects are embedded in the 2019 edition of the ICAO Environmental Report.

This approach demonstrates the ability of international aviation, under the leadership of ICAO to think of a green future and put it in motion. Going forward, our success will rely heavily on ICAO's ability to evolve as an agile Organization and integrate in its work the major changes affecting international aviation. This will be essential for ICAO and its Member States to adopt the global Standards and Policies international aviation needs to grow sustainably and to support all ICAO Member States in achieving a long-term vision of sustainable development, to the wider benefit of society.



Dr. Olumuyiwa Benard Aliu

President of the Council

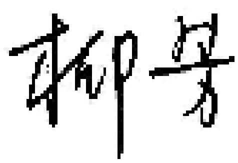
Message from the Secretary General of the International Civil Aviation Organization (ICAO)

This year, the International Civil Aviation Organization (ICAO) is celebrating the 75th anniversary of the Chicago Convention, setting forth the mission of the Organization, ensuring that "international civil aviation may be developed in a safe and orderly manner and that international air transport services may be established on the basis of equality of opportunity and operated soundly and economically". 75 years later, while we seize the opportunity of this landmark anniversary to applaud the progress accomplished thus far, we should also reflect upon the foundations of our collective success and prepare for the challenges lying ahead of us.

Over more than five decades, ICAO's work on environmental protection has undoubtedly formed a success story, acknowledged by all in the international aviation sector, and beyond. A series of historical decisions have been made, demonstrating the ability of the world's nations to come together and make meaningful decisions. The adoption by ICAO Member States of the first ever global sector market-based measures in 2016 will remain a long-standing illustration of ICAO's ability to adjust to new environmental challenges. Organizational leadership and tireless work are the two key ingredients to mobilize the resources needed to successfully implement a scheme such as the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA).

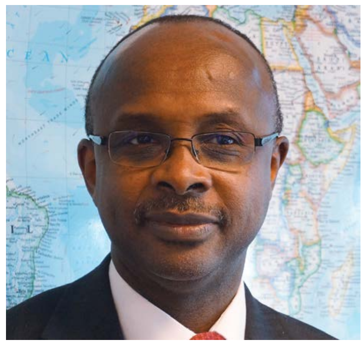
Along the years, ICAO has stepped-up to the expectations set by its Member States, demonstrating its capability to build-up the required expertise in all areas of environmental protection, from noise to local air quality and climate change.

This 2019 ICAO Environmental Report was developed to reflect the intensive work carried out by the international aviation stakeholders to mitigate the current challenges of the sector and stimulate collective thinking on the future challenges. Forging the right responses to address these challenges will require more engagement with all - long-standing partners of ICAO or non-traditional aviation stakeholders and may involve new forms of cooperation, so we can reach our *Destination Green: The Next Chapter*.



Dr. Fang Liu
Secretary General

Message from the Director of the Air Transport Bureau, International Civil Aviation Organization (ICAO)



With the adoption of the 2030 Agenda for Sustainable Development in 2015, the United Nations established a plan of action for people, planet and prosperity. As the United Nations specialized agency for international civil aviation, ICAO facilitates the delivery of socio-economic benefits at the global level and contributes to 15 out of 17 Sustainable Development Goals (SDG). ICAO's work on environmental protection contributes to 14 SDGs.

The 2019 Environmental Report of ICAO illustrates the vast array of work carried out by the Organization with the aim to support all international aviation stakeholders reduce their environmental footprint in the air and on the ground. From the adoption of a new Standard on non-volatile Particulate Matters (nvPM) for aircraft engines to guidance on green and resilient airports and the establishment of all building blocks for the implementation of CORSIA, ICAO holds a leadership role in providing States and their partners with the required Standards and Recommended Practices, as well as international policies to design and implement the most appropriate strategies at the national level.

This technical work is supported by a comprehensive capacity-building and assistance strategy to leave none of ICAO's 193 Member States behind.

Indeed, an environmentally-responsible air transport is an essential component of the sustainable growth of the sector and we are committed to ensure that each ICAO Member State has the opportunity to enjoy this growth now, and in the future.

Mr. Boubacar Djibo
Director, Air Transport Bureau

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The Triennium in Review: Paving the Way to a Green Future

By Ms. Jane Hupe, Deputy Director, Environment

Over the past three years, the progress and pace of change in international aviation environmental protection has been unprecedented, driven by key decisions from ICAO Member States, technological progress and societal expectations. The ICAO Environmental Report 2019 is the result of our efforts and consolidates the progress in a single reference publication, through various articles and case studies that can best inform the public of the work conducted by the ICAO Secretariat, ICAO Member States, aviation industry and the many other stakeholders involved in this fast evolving topic.

Major steps have been taken since the 39th Session of the ICAO Assembly in 2016, in order to support States in the implementation of key activities on international aviation environmental protection. In 2016, the world turned to ICAO and applauded the adoption of the first ever global market-based measure for an entire sector, the Carbon Offsetting and Reduction Scheme for International Aviation – CORSIA. With this decision, ICAO Member States demonstrated an unprecedented level of leadership on environmental protection and confirmed their commitment to progress collectively towards the aspirational goal of carbon neutral growth from 2020. At the Assembly, they also started the countdown to the implementation of CORSIA requirements on CO_2 monitoring, reporting and verification (MRV) from 1 January 2019.

Indeed, CORSIA represents a new area of work for a number of aviation stakeholders, and for ICAO Member States. Ensuring timely implementation of CORSIA has required one of the most ambitious capacity building initiatives amongst Member States, under the umbrella of ICAO. 15 States provided training to 98 States, and successfully enhanced their preparedness for the implementation of the newly developed ICAO Standards and Recommended Practices (SARPs) – Annex 16, Volume IV required for making CORSIA MRV fully operational across the world from 2019, and thus ensuring that *No Country is Left Behind*. Although the roadmap to CORSIA implementation was extremely challenging, we are pleased to report that CORSIA implementation is on track.

Under ICAO's policy for climate change, CORSIA is one element of the "basket of measures" agreed by Member States to meet our aspirational goals of a two per cent per annum fuel efficiency improvement, and carbon neutral growth from 2020 onwards. During the past three years, ICAO and its partners have made great strides in progressing further the implementation of the other elements of the "basket of measures", namely innovative technologies, more efficient operational procedures and sustainable aviation fuels.

The new ICAO SARP on CO_2 emission certification for aeroplanes was adopted in 2017, as reflected in Volume III of Annex 16. Its role is to ensure that the best technologies are included into aeroplane designs and will apply to new aeroplane type designs from 2020, and to aeroplane type designs already in-production as of 2023. It will prevent any backsliding of aircraft environmental performance and allow aircraft and engine manufacturers to continue exploring ground-breaking technologies to address CO_2 emissions.

The new CO_2 emissions standard is complemented by more efficient flight operations, and in this regard, ICAO Member States adopted a Global Air Navigation Plan in 2016, which outlines a performance improvement and technology roadmap towards shorter routes and less emissions-intensive takeoffs and landings, through performance-based navigation (PBN) and the ICAO Aviation System Block Upgrades (ASBUs). ICAO has been active in assessing the CO_2 emissions saved, as a result of the implementation of the ASBU concepts. Such work is critical to supporting States and operational stakeholders build the necessary business case prior to initiating such operational changes.

A positive business case remains a key trigger for the implementation of environmental measures by airlines and, in the last years, many important steps have been taken to make the more than 200,000 commercial flights using a mix of sustainable fuels a reality in our skies. ICAO has taken a number of initiatives aimed at removing the outstanding barriers to the large-scale commercial use of sustainable aviation fuels by airlines, and organized the Second Conference on Aviation Alternative Fuels (Mexico City, Mexico, 11-13 October 2017), adopting the "2050 Vision for Sustainable Fuels". In order to make progress on the quantification of the 2050 Vision, the First ICAO Stocktaking Seminar (Montréal, Canada, 30 April-1 May 2019) was held to further trigger actions, synergies and partnership for the development and deployment of sustainable aviation fuels. Both events have confirmed the commitment of the international aviation sector and sustainable aviation fuel producers to this element of the ICAO Basket of Measures. ICAO has also demonstrated its leadership role in facilitating discussions on the most relevant policy framework for the development of such fuels and on establishing a global framework for its use within CORSIA. In addition, on the technical side, many feasibility studies were developed in the context of ICAO's capacity building projects, which can be used as a blueprint to be replicated in other ICAO Member States.

One of ICAO's Environmental Protection Strategic Objectives involves limiting or reducing the impact of aircraft engine emissions on local air quality. Since the late 70's, ICAO established SARPs to certify aircraft engines for emissions that affect local air quality (NOx, HC, CO and Smoke Number). Since visible smoke has been eliminated from aircraft engine exhaust, ICAO has increased the NOx standards stringency many times as combustion technologies evolved, and recently, a new standard to limit the emissions of non-volatile Particulate Matter (nvPM) from aircraft engines was developed and recommended for consideration by the ICAO Council. This new ICAO standard will ensure that the best technologies are included in engine designs in order to limit nvPM, which in turn will minimize the potential environmental and health impacts of these pollutants. Its final adoption is expected by 2020.

Regarding noise, 2019 marks the celebration of 50 years since the adoption of the first global standards for aircraft noise certification. After half a century of existence, these standards led to aircraft that are 75% quieter than the first jets. Reduction of noise at source is the first pillar of the ICAO Balanced Approach to Aircraft Noise Management, which also comprises land-use planning, noise abatement procedures and operating restrictions as a last resort. Over the past years, ICAO has also intensified its work on an emerging, yet essential aspect of noise management, i.e. community engagement. A key challenge is to ensure that the guidance and best practices developed by ICAO, through the collaboration of hundreds of the world's best experts, find their way to implementation.

Indeed, capacity building and assistance remains a cornerstone of ICAO's activities on environmental protection. This triennium marked the implementation of two dedicated capacity building and assistance projects, one funded by the European Union (EU), and the other in partnership with the United Nations Development Programme (UNDP) with financing from the Global Environment Facility (GEF). Both projects have benefitted a total of fifteen ICAO Member States in Africa and in the Caribbean, but their environmental results have gone beyond these States. Indeed, the development of guidance material for the implementation of low carbon aviation measures, the implementation of solar-at-gate pilot projects, and the design of tools to assess the financial costs and environmental benefits of mitigation measures, provided opportunities for all States to concretely engage in the reduction of international aviation emissions.

With the implementation of all these activities, ICAO has consistently delivered on the ambition set by successive Assembly Resolutions on environmental protection, and is committed to maintaining its efforts by working together with Member States on the path towards a greener future.

Over the next triennium, ICAO and Member States, in collaboration with industry and other stakeholders, will move forward by continuing the implementation of measures to address aviation noise, and emissions that affect local air quality and the global climate; as well as undertaking work on new emerging technologies and forms of energy, such as all-electric and hybrid aircraft, supersonic aircraft, green and resilient airports, and adaptation to climate change, just to mention a few. Aviation is in essence a technology-driven sector that has fulfilled humankind's dreams of flying. The next chapter for aviation will be to fulfil the societal aspiration of an environmentally sustainable flying future. The fourth industrial revolution offers an enormous opportunity, and innovation is at the forefront of the breakthrough needed to deliver fully sustainable air transport.

The future of mobility is in the air, and "urban flying vehicles" are now a reality. With the unprecedented pace of technological development, this is an inspiring time for aviation and ICAO will continue to be gearing progress towards providing the next generation with access to sustainable travel, and facilitate their connection to people and cultures of this global village without affecting the environment. An exciting new era is starting and with it our collective challenge and incommensurable opportunity, for a brighter future where the sky is not the limit. I do hope you enjoy the report.

Ms. Jane Hupe
Deputy Director, Environment

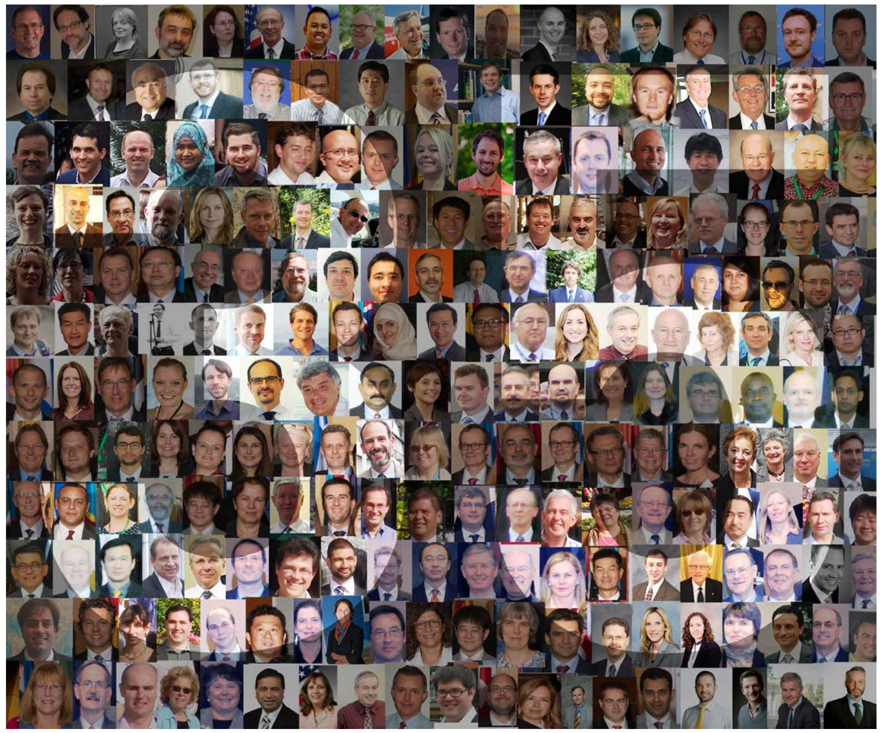
ICAO

CHAPTER ONE

Aviation and Environment Outlook

CAEP 35th Anniversary

By ICAO Secretariat



The ICAO Council established its technical Committee on Aviation Environmental Protection (CAEP) 35 years ago on 5 December 1983, superseding the Committee on Aircraft Noise (CAN) and the Committee on Aircraft Engine Emissions (CAEE). Over these 35 years, the role of CAEP has been crucial in assisting the ICAO Council in formulating new policies and adopting new international Standards and Recommended Practices (SARPs) relating to aircraft noise and emissions. CAEP consists of Members and Observers from States, intergovernmental and non-governmental organizations representing aviation industry and environmental interests. The successes achieved by CAEP are due to the commitment and technical prowess of the experts nominated by CAEP Members and Observers.

CAEP has completed eleven cycles which were full of significant achievements, major challenges and hard work to address the environmental aspects associated with international civil aviation. This has aimed to limit or reduce the number of people affected by significant aircraft noise; to limit or reduce the impact of aviation emissions on local air quality; and to limit or reduce the impact of aviation greenhouse gas emissions on the global climate.

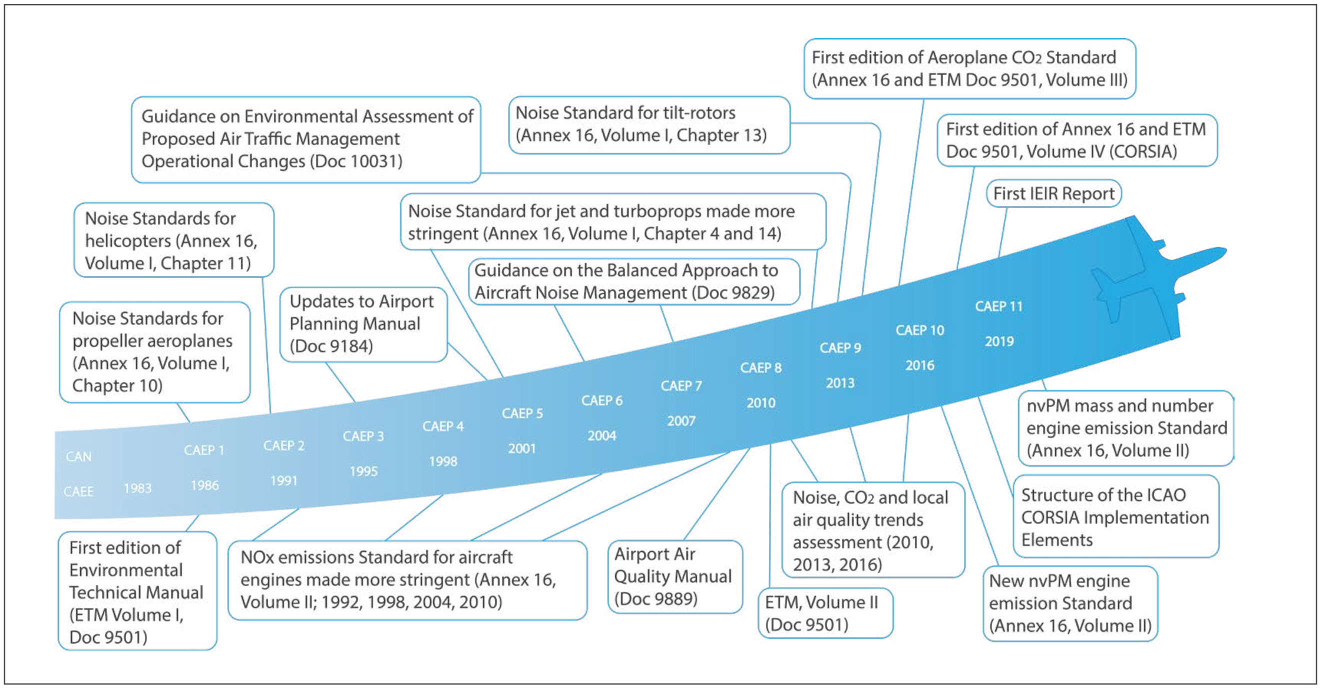
The most significant and demanding deliverables from CAEP are reflected in the International Standards and Recommended Practices (SARPs) contained in Annex 16 to the Convention on International Civil Aviation. These encompass: aircraft noise (Annex 16, Volume I), aircraft engine emissions (Annex 16, Volume II), aeroplane CO_2 emissions (Annex 16, Volume III), and, most recently, the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) contained in Annex 16, Volume IV. These SARPs were developed by means of a technically-driven and consensus based approach, with effective cooperation between ICAO Member States, industry, relevant aviation stakeholders and civil society. During the past 35 years, CAEP has worked diligently to develop and to keep ICAO environmental SARPs up-to-date, ensuring that the latest environmental technologies are incorporated into new aircraft designs, and the environmental impact of international civil aviation is limited and reduced.

CAEP also developed various guidance materials that support States' initiatives towards the environmental goals defined by the ICAO Assembly. The overarching ICAO Policy on aircraft noise management, the "balanced approach", is fully detailed in ICAO Doc 9829, *Guidance on the Balanced Approach to Aircraft Noise Management*. ICAO Policies on local air quality are addressed in the Airport Air Quality Manual (ICAO Doc 9889). CAEP's work has also resulted in the development of guidance to address the climate change impacts of civil aviation. ICAO Doc 9184 Part 2, *Airport Planning Manual* is a significant piece of guidance delivered by CAEP, as it provides a comprehensive analysis of international aviation environmental impacts and outlines strategies to reduce them from the design, planning and operations of airports. The global environmental trends developed by CAEP have also provided the fundamental basis for ICAO decision-making on environmental matters. Recently, in light of the challenges ahead of the sector, CAEP has expanded its scope of actuation by providing sound technical analysis on topics such as sustainable aviation fuels, climate change adaptation, community engagement, and aircraft end-of-life.

The most recent meeting of CAEP, the 11th CAEP Meeting (CAEP/11) took place in ICAO Headquarters in Montréal in February 2019. The meeting agreed, inter alia, on new non-volatile particulate matter (nvPM) mass, and number standards, new integrated noise, and emissions technology goals for the sector. The meeting also considered technical details associated with the consideration of CORSIA eligible fuels, a global synthesis on climate change adaptation and aircraft end-of-life and recycling. It also considered an eco-airports toolkit e-collection, community engagement for Performance Based Navigation (PBN), and the environmental analysis of the ICAO Aviation System Block Upgrades (ASBU), amongst many other items to address aircraft noise and emissions.

The new, quickly emerging aviation technologies and innovations demand an enhanced approach for the consideration and analysis of their impact on environment, with the subsequent delivery of relevant SARPs. In turn, this requires coordination with different stakeholders and the involvement of new specialists and expert groups. New electric and hybrid aircraft technologies, while

FIGURE 1: Timeline



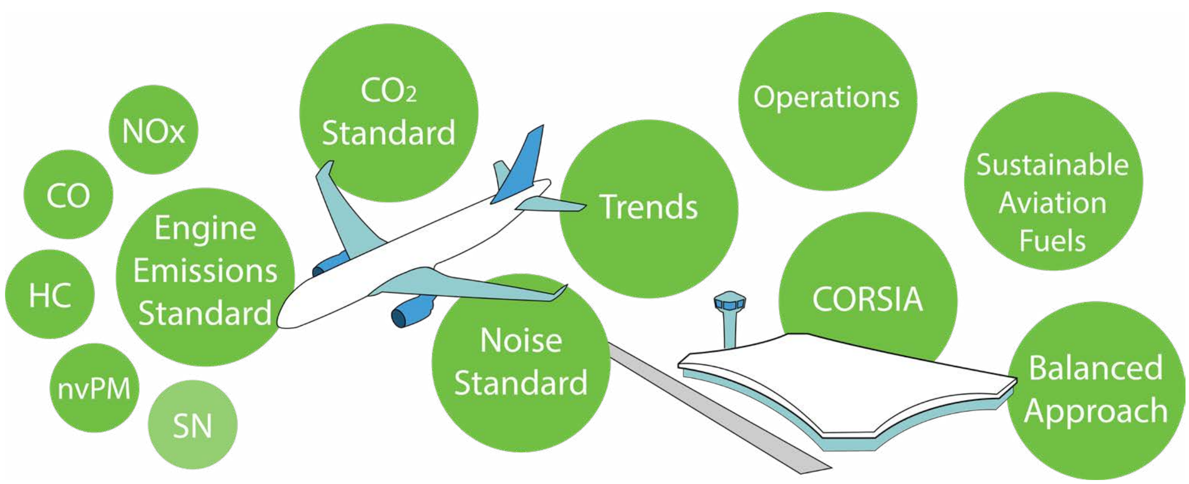
promising significant environmental benefits, require specific considerations on the use of batteries and possibly on non-traditional certification procedures. To keep the pace towards new, emerging fields and the fast speed in which new technologies arise, CAEP periodically reviews its structure and approach to the work and considers novel practices into its working process.

CAEP has experienced changes and evolved continuously through its 35 years, and as the Committee's work continues to be based on the commitment of people: the CAEP Members, Observers, and their technical advisors. Over 600 experts from 31 States and 10 international organizations contribute to the work of CAEP. Numerous meetings and hundreds of teleconferences are held during each 3-year CAEP work cycle. All these efforts result in ICAO policies and SARPs being aligned with the main principles of CAEP work which accounts for technological feasibility, economical reasonableness, environmental benefit and interdependency of measures.

Moving into the future, CAEP will continue to monitor the developments and new emerging issues in aviation environmental protection, in order to take necessary actions, and make well-considered recommendations to the ICAO Council, in a timely manner.

All of these developments demonstrate that CAEP continues to provide invaluable contributions that have enabled a sustainable path for international aviation, and will remain of paramount importance in continuing this path in the future, and in enabling the ICAO Council to address upcoming environmental challenges.

FIGURE 2: CAEP Deliverables



CAEP Publications

- Reports of the Committee on Aviation Environmental Protection (CAEP/10, Doc 10069; CAEP/9, Doc 10012; CAEP/8, Doc 9938; CAEP/7, Doc 9886; CAEP/6, Doc 9836; CAEP/5, Doc 9777);
  - Annex 16 to the Convention on International Civil Aviation — Environmental Protection: Volume I — Aircraft Noise
  - Volume II — Aircraft Engine Emissions
  - Volume III — Aeroplane CO_2 Emissions
  - Volume IV — Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)
- Environmental Technical Manual (Doc 9501, Volumes I, II, III, and IV)
- Guidance on the Balanced Approach to Aircraft Noise Management (Doc 9829)
- Offsetting Emissions from the Aviation Sector (Doc 9951)
- Report on Voluntary Emissions Trading for Aviation (VETS Report) (Doc 9950)
- Guidance on Aircraft Emission Charges Related to Local Air Quality (Doc 9884)
- Guidance on the Use of Emissions Trading for Aviation (Doc 9885)
- Airport Air Quality Manual (Doc 9889)
- Report of the Independent Experts on the Medium and Long Term Goals for Aviation Fuel Burn Reduction From Technology (Doc 9963)
- Airport Planning Manual, Part 2 — Land Use and Environmental Control, (Doc 9184)
- Noise Abatement Procedures: Review of Research, Development and Implementation Projects - Discussion of Survey Results (Doc 9888)
- Recommended Method for Computing Noise Contours around Airports (Doc 9911)
- Guidance on Environmental Assessment of Proposed Air Traffic Management Operational Changes (Doc 10031)
- Operational Opportunities to Minimize Fuel Use and Reduce Emissions (Doc 10013)

Other e-publications available on:

- https://www.icao.int/environmental-protection/Pages/environment-publications.aspx
- https://www.icao.int/environmental-protection/Pages/Ecoairports.aspx

Environmental Trends in Aviation to 2050

By Gregg G. Fleming (US DOT Volpe) and Ivan de Lépinay (EASA)

BACKGROUND

At the end of each three-year work cycle, the International Civil Aviation Organization (ICAO) Committee on Aviation Environmental Protection (CAEP) conducts an assessment of future environmental trends in aviation that includes:

- Aircraft engine Greenhouse Gas (GHG) emissions that affect the global climate,
- Aircraft noise, and
- Aircraft engine emissions that affect Local Air Quality (LAQ).

The environmental trends discussed in this section are based on the latest CAEP/11 air travel demand forecast data, using a base year of 2015. Forecast years were 2025, 2035, and 2045, and results were then extrapolated to 2050. The passenger and freighter forecasts were derived from ICAO's Long-Term Traffic Forecast, while the business jet forecast was developed by CAEP. Data presented for years earlier than 2015 are reproduced from prior CAEP trends assessments. Fuel burn and emissions results are for international aviation only, while noise trends include both domestic and international operations. In 2015, approximately 65 per cent of global aviation fuel consumption was from international aviation. This proportion is expected to remain relatively stable out to 2050.

The trends presented here were developed in the context of a longer-term view, and assume that there would be no airport infrastructure or airspace operational constraints. Such trends can be affected substantially by a wide range of factors such as fluctuations in fuel prices, and global economic conditions.

Three environmental models contributed results to the fuel burn and emissions 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). Three models contributed results to the noise trends assessment: US FAA's AEDT, EC / EASA / EUROCONTROL's SysTem for AirPort noise Exposure Studies (STAPES), and UK Civil Aviation Authority's (CAA) Aircraft Noise Contour Model (ANCON).

Key databases utilized in this assessment included: CAEP's Global Operations, Fleet, and Airports Databases.

TRENDS IN EMISSIONS THAT AFFECT GLOBAL CLIMATE

Table 1 below summarizes the aircraft technology and operational scenarios developed for the assessment of trends for fuel burn and aircraft emissions that affect the global climate.

TABLE 1: Fuel Burn and GHG Emissions - Technology and Operational Improvement Scenarios

Scenario	Aircraft Technology: per annum fuel burn improvements for fleet entering after base year	Aircraft Technology: Emissions Improvements against CAEP/7 IE NOx Goal	Additional Fleet-Wide OP Improvements by Route Group from CAEP/9 IE
Fuel 1 - Baseline	NA: use only base-year in-production fleet	NA	NA: maintain baseline meet-demand efficiency
Fuel 2 - Low Aircraft Technology and CAEP/9 IE Operational Improvements	Low: 0.96% to 2015 then 0.57% to 2050	NA	Apply added fleet-wide improvements
Fuel 3 - Moderate Aircraft Technology and CAEP/9 IE Operational Improvements	Moderate: 0.96% to 2050	NA	Apply added fleet-wide improvements
Fuel 4 - Advanced Aircraft Technology and CAEP/9 IE Operational Improvements	Advanced: 1.16% to 2050	NA	Apply added fleet-wide improvements
Fuel 5 - Optimistic Aircraft Technology and CAEP/9 IE Operational Improvements	Optimistic: 1.5% to 2050	NA	Apply added fleet-wide improvements
NOx 1 - Baseline	NA	NA	NA
NOx 2 - Moderate Aircraft Technology, CAEP/9 IE Operational, and 50% CAEP/7 IE Emissions Improvements	Moderate: 0.96% to 2050	50% by 2026 nothing thereafter	Apply added fleet-wide improvements
NOx 3 - Advanced Aircraft Technology, CAEP/9 IE Operational, and 100% CAEP/7 IE Emissions Improvements	Advanced: 1.16% to 2050	100% by 2026 nothing thereafter	Apply added fleet-wide improvements

Trends in Full-Flight Fuel Burn and CO_2 Emissions

Figure 1 shows results for global full-flight (i.e., from departure gate to arrival gate) fuel burn for international aviation from 2005 to 2045, 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% annual fuel efficiency aspirational goal were to be achieved.

Even under the most optimistic scenario, the projected long-term fuel efficiency of 1.37% per annum falls short of ICAO's aspirational goal of 2% per annum. The long-term forecast fuel burn from international aviation is lower by about 25% compared with prior CAEP trend projections. This decrease can be attributed to a combination of more fuel efficient aircraft entering the fleet, as well as a reduction in the forecast long-term traffic demand. The computed 1.37% per annum long-term fuel efficiency includes the combined improvements associated with both technology and operations. The individual contributions from technology and operations is .98% and .39%, respectively. The .98% is slightly lower than the 1.3% cited in the latest CAEP/11 Independent Experts (IE) Review for single aisle aircraft.

Figure 2 depicts these contributions in the context of the uncertainties associated with the forecast demand, which is notably larger than the range of potential contributions from technological and operational improvements. Despite these uncertainties, the CAEP/11 forecast traffic trends are broadly consistent with other published aviation forecasts. The forecast commercial market trend, which is for available tonne kilometres (ATK), shows a 20 year (2015-2035) compound average annual growth rate (CAGR) of 4.3%. By way of comparison, using revenue passenger kilometres (RPK) for all traffic as the forecast measurement, forecasts of Boeing, Airbus and Embraer for 2015 have 20-year (2015-2035) CAGRs of 4.8%, 4.5%, and 4.7%, respectively. The CAEP/11 RPK 20-year forecast (2015-2035) has a CAGR of 4.4%.

Figure 3 presents full-flight CO_2 emissions for international aviation from 2005 to 2045, 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

FIGURE 1: Fuel Burn from International Aviation, 2005 to 2050

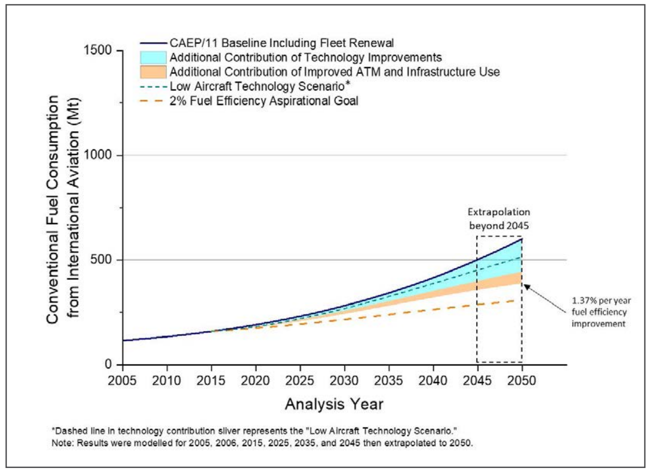


FIGURE 2: Range of Uncertainties Associated with Demand Forecast, 2005 to 2050

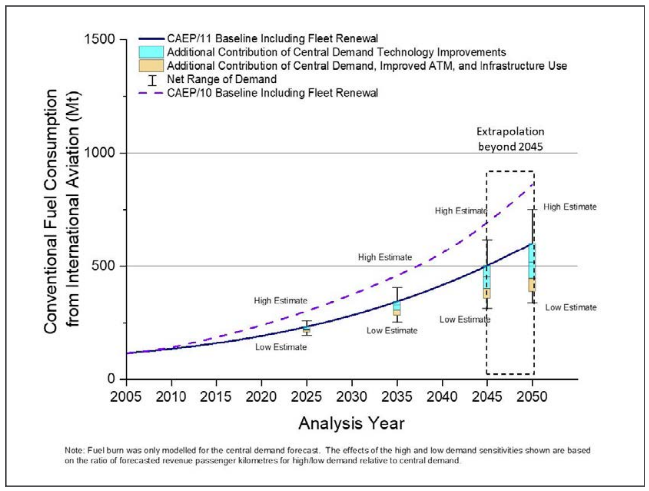
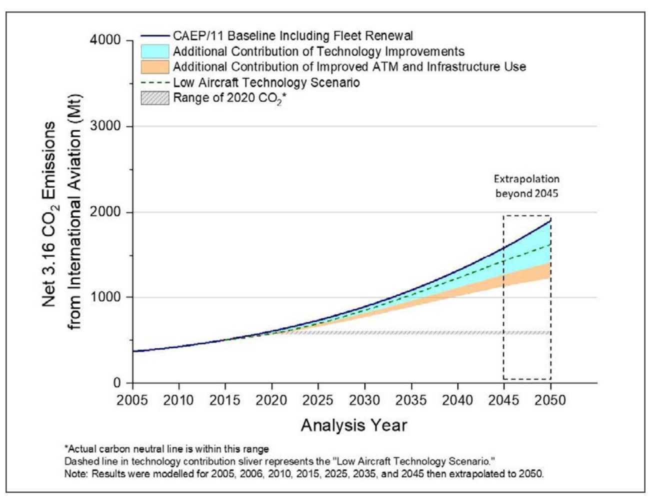


FIGURE 3: CO_2 Emissions from International Aviation, 2005 to 2050



fuel burned generates 3.16 kg of CO_2. As with the previous fuel burn analyses, 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 relative 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 3 has a similar effect on the CO_2 results. With reference to the fuel consumption scenarios in Table 1; the highest anticipated fuel consumption in 2020 (Scenario 1), and the lowest anticipated fuel consumption in 2045 (Scenario 5), a minimum CO_2 emission gap of 517 million metric tonnes (Mt, 1kg × 10^9) is projected for 2045. Extrapolating Scenario 5 to 2050, results in a minimum gap of 612 Mt.

Contribution of Alternative Fuels to Fuel Consumption and CO_2 Trends

CAEP's Alternative Fuels Task Force (AFTF) was charged with calculating estimates of sustainable aviation fuel (SAF) contributions to fuel replacement and life cycle GHG emissions reductions in conducting its trends assessment out to 2050. Analyses were performed for 2020 and 2050. The short-term scenarios for SAF availability were established from announcements made by fuel producers regarding their production plans from State-sponsored production plans. For the long-term scenarios, CAEP assessed future jet fuel availability in three ways: by estimating the primary bioenergy potential constrained by selected environmental and socio-economic factors, by estimating the proportion of bioenergy potential that could actually be achieved or produced, and by exploring the quantity of SAF that could be produced from the available bioenergy. SAF availability calculations included 9 different groups of feasible feedstocks: starchy crops, sugary crops, lignocellulosic crops, oily crops, agricultural residues, forestry residues, microalgae, municipal solid waste, and waste fats, oils and greases. The final values provided by AFTF to the Modelling and Databases Group (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 result in up to 2.6% petroleum-based fuel replacement and up to 1.2% GHG emissions reductions.

For 2050, CAEP calculated 60 production achievement scenarios and two GHG emissions scenarios, resulting in a total of 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 trend assessment figures for international aviation shown below include the range of CAEP results, and an "illustrative" scenario that achieves 19% 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, and Net CO_2 emissions results are shown in Figure 5. The amount of SAF, and the associated CO_2 emission reductions were allocated proportionally between international use and domestic use, based on projected fuel demand (65% and 35% in 2015, 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 the 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 Measures Task Group:

Total Emissions = 3.16 × (CJF + SAF*(LCA_SAF/LCA_CJF))

Where CJF = conventional jet fuel, SAF = sustainable aviation fuel, and LCA_X = life cycle CO_2 equivalent emissions of fuel X.[1]

1 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.

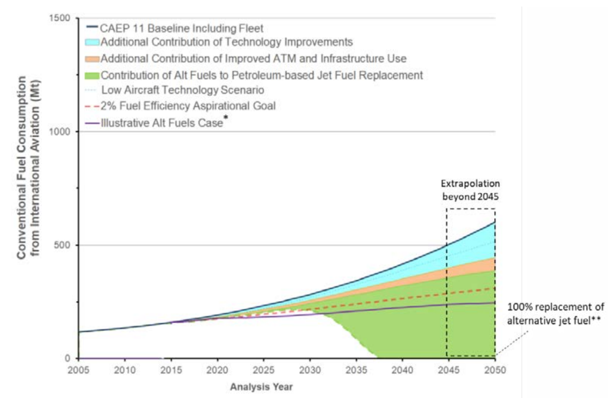
The green GHG reduction "wedge" was created by connecting the least contribution scenario values to each other and the greatest contribution values to each other. The 2020 "medium scenario without green diesel" was connected to the 2050 value for the illustrative scenario. CAEP elected to assume a linear growth for intermediate and high GHG reduction scenarios.[2]

Several of the 2050 scenarios that CAEP evaluated resulted in zero alternative jet fuel production and therefore no contribution to GHG emissions reduction.[3] The zero SAF results are equivalent to the line associated with Scenario 5 for technology and operational improvements as described above. The scenario with the largest 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 5.

If the alternative fuel industry growth were to follow an S-shaped curve, the highest growth rates would occur around 2035, in which 328 new large bio-refineries 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. If growth occurred linearly, complete replacement would require approximately 170 new large bio-refineries to be built every year from 2020 to 2050, at an approximate capital cost of US$15 billion to US$60 billion per year.

Achieving the most optimistic net CO_2 emissions scenario would require the highest levels of: agricultural productivity, availability of land for feedstock cultivation, residue removal rates, conversion efficiency improvements, and reductions in the GHG emissions of utilities. It would also require 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

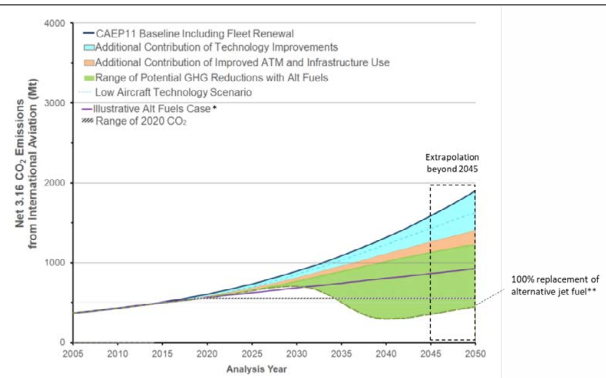
FIGURE 4: Conventional Fuel Consumption from International Aviation, 2005 to 2050, Including Potential Replacement by Alternative Fuels



*Illustrative case would require high availability of bioenergy feedstock, the production of which is significantly affected by price or other policy mechanisms;

**100% replacement of alternative jet fuel would require a complete shift in aviation consumption, from petroleum to biofuel based fuels, and a significant expansion of the agricultural sector, both of which would require substantial policy support.

FIGURE 5: Net CO_2 Emissions from International Aviation, 2005 to 2050, Including Alternative Fuels Life Cycle CO_2 Emissions Reductions (Based on 3.16 kg of CO_2 per 1 kg of fuel burn)



2 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 SAF 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 exists with which to calibrate the curve. Therefore, values for the intervening years, between 2020 and 2050, for the SAF scenarios should be considered illustrative only.

3 These scenarios reflect a lack of bioenergy availability in general or a prioritization of other bioenergy usages over aviation.

opposed to other uses. It should be noted that all the CO_2 emission scenarios evaluated considered rainfed energy crop production only on land available after satisfying predicted 2050 food and feed demand. Additionally, primary forests and protected areas were not considered for conversion to cultivated energy crop production.

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 and the implementation of aggressive technological and operational scenarios. The effort required to reach these SAF production volumes would have to significantly exceed historical precedent for other alternative fuels, such as ethanol and biodiesel for road transportation.

Interpretation

In 2015, international aviation consumed approximately 160 Mt of fuel, resulting in 506 Mt of CO_2 emissions. By 2045, fuel consumption is projected to have increased 2.2, or 3.1 times the 2015 value, while revenue tonne kilometres are expected to increase 3.3 times under the most recent forecasts. Extrapolating to 2050, fuel consumption is projected to increase 2.4 to 3.8 times the 2015 value, while revenue tonne kilometres are expected to increase 3.9 times.

Under the most optimistic Scenario 5, as defined in Table 1, international aviation fuel efficiency, expressed in terms of volume of fuel per RTK, is expected to improve at an average rate of 1.29% per annum to 2045, and at 1.37% per annum, if extrapolated to 2050. This indicates that ICAO's aspirational goal of 2% per annum fuel efficiency improvement is unlikely to be met by 2050. While in the near-term (2015 to 2025), efficiency improvements from technology and improved ATM and infrastructure use are expected to be moderate, they are projected to accelerate in the mid-term (2025 to 2035). During that 2025 to 2035 period, fuel efficiency is expected to improve at an average rate of 1.08% per annum under Scenario 5. This is about as expected, given the 1.5% per annum fuel technology improvement associated with Scenario 5, and the variability of the forecasted RTK.

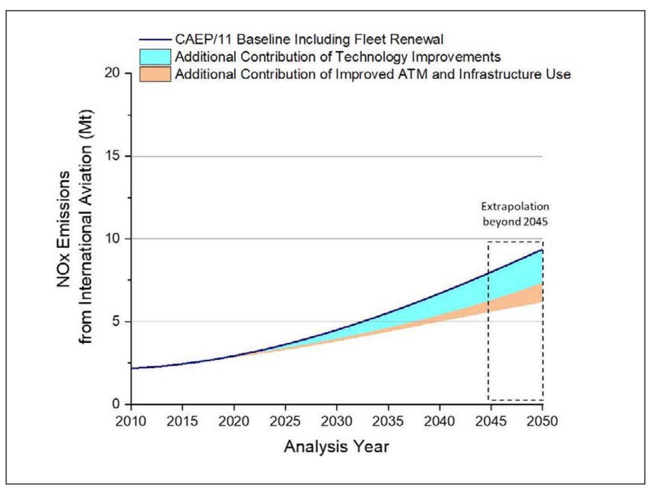
By 2025, it is expected that international aviation will require somewhere between 207 and 226 Mt of fuel, resulting in 655 to 713 Mt of CO_2 emissions. A number of near-term scenarios evaluated by CAEP indicate that up to 2.6% of fuel consumption needs by 2020 could be satisfied by SAF. This analysis also considered the long-term availability of sustainable alternative fuels, finding that it would be physically possible to meet 100% of demand by 2050 with SAF, corresponding to a 63% reduction in emissions. However, this level of fuel production could only be achieved with extremely large capital investments in sustainable alternative fuel production infrastructure, and substantial policy support.

Even under this scenario, achieving carbon neutral growth exclusively from the use of sustainable alternative fuels is unlikely to happen by 2020 or shortly thereafter as an initial ramp-up phase for the production of SAF is required before production can reach the levels mentioned above. Market-based measures are anticipated to help fill the gap to carbon neutral growth, although also later than 2020.

Trends in Full-Flight NOx Emissions

Trends in full-flight nitrogen oxides (NOx) emissions from international aviation are shown in Figure 6. The 2015 baseline NOx emissions were 2.50 Mt. In 2045, forecast NOx emissions range from 5.53 Mt under Scenario 3, to 8.16 Mt under Scenario 1. As with fuel burn, the long-term full-flight NOx from international aviation is lower by about 21% compared with the prior trends projections. This can be attributed to a combination of aircraft with lower NOx engines entering the fleet, as well as a reduction in forecasted long-term traffic demand.

FIGURE 6: Full-Flight NOx Emissions from International Aviation, 2010 to 2050



TRENDS IN AIRCRAFT NOISE

A range of scenarios was developed for the assessment of future noise trends. The noise indicators used are the total contour area and population inside the yearly average day-night level (DNL) 55 dB contours of 315 airports worldwide, representing approximately 80% of the global traffic.

Scenario 1 (CAEP/11 Baseline) assumes no further aircraft technology or operational improvements after 2015. Scenarios 2, 3, and 4 (low, moderate, advanced technology) assume that the noise levels of all new aircraft delivered after 2015 will reduce at a rate of 0.1, 0.2, and 0.3 EPNdB[4] per annum, respectively. For all scenarios, an additional 2% reduction is applied to the population counts inside the noise contours, to reflect a possible improvement of aircraft routing around airports.

Population counts for airports in the US, Europe, and Brazil rely on local census data. For all other airports, the NASA Gridded Population of the World, version 4 (GPW v4) was used.

Figure 7 shows the total 55 dB DNL noise contour area from 2010 to 2050. In 2015, this area was 14,400 square-kilometres, and the population inside that area was approximately 30 million people. By 2045, the area is expected to grow from 1.0 to 2.2 times, compared with 2015, depending on the technology scenario. Of note is that under the advanced aircraft technology scenario (Scenario 4), from about 2030 onwards, the total yearly average DNL contour area may no longer increase with an increase in traffic. The long-term total DNL 55 dB contour area is lower by about 10%, compared with the prior trends projections. This decrease can be attributed to a combination of quieter aircraft entering the fleet, as well as a reduction in the long-term traffic demand.

TRENDS IN EMISSIONS THAT AFFECT LOCAL AIR QUALITY

A range of scenarios have also been developed for the assessment of aircraft emissions that occur below 3,000 feet above ground level (AGL) and affect local air quality; namely NOx and total (volatile and non-volatile) particulate matter (PM). The NOx scenarios are the same as in Table 1. For assessing PM trends, there are two scenarios as follows: Scenario 1 (CAEP/11 Baseline) assumes no further aircraft technology or operational improvement after 2015. Scenario 2, represented by the bottom of the orange sliver, assumes that only operational improvements apply, with no aircraft technology improvements.

Figure 8 provides results for NOx emissions below 3,000 feet AGL from international aviation from 2010 to 2050. The 2015 NOx emissions were 0.18 Mt. In 2045, they are forecast to range from 0.44 Mt under Scenario 3, to 0.80 Mt under Scenario 1. The projections of NOx emissions below 3,000 feet are lower by about 2% compared with the prior

FIGURE 7: Total Aircraft Noise Contour Area Above 55 dB DNL for 315 Airports (km^2), 2010 to 2050

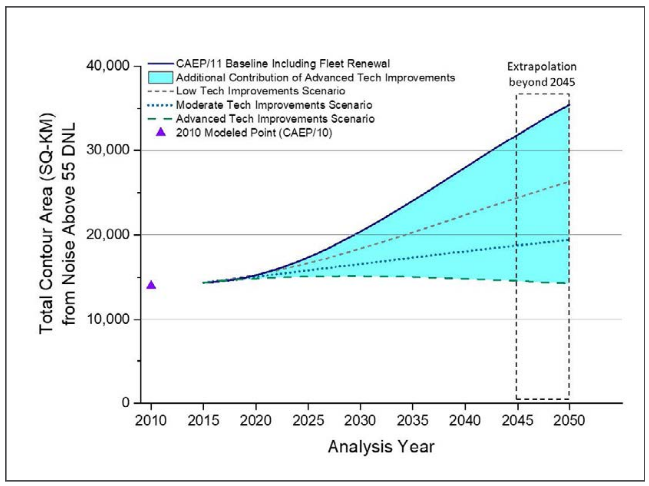
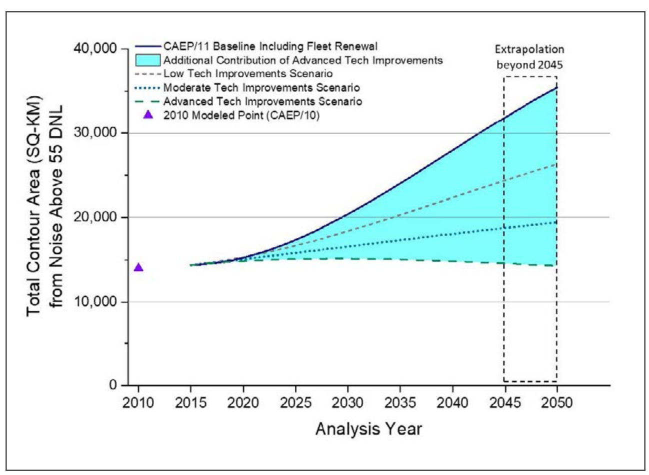


FIGURE 8: NOx Emissions below 3,000 Feet - International Aviation, 2010 to 2050.

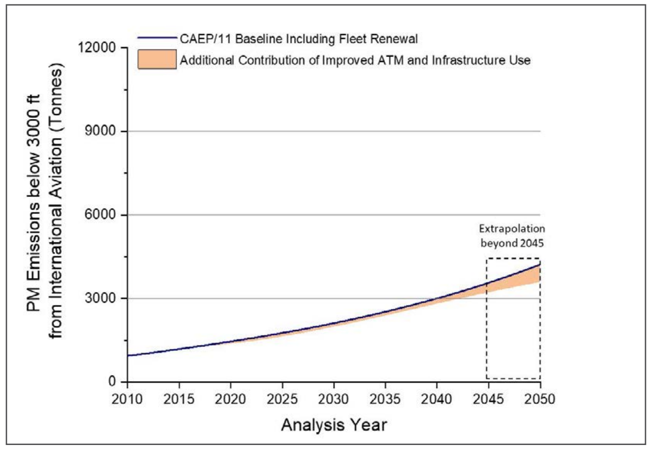


4 EPNdB is Effective Perceived Noise Level in Decibels.

trend projections. This will be due to three main factors: a combination of aircraft with lower NOx engines, a reduction in the long-term traffic demand, and a refinement to the method used for computing emissions below 3,000 feet.

The results for PM emissions from international aviation below 3,000 feet AGL follow similar trends as those for NOx, as shown in Figure 9. The 2015 PM emissions were 1,243 tonnes (t). In 2045, they are projected to range from 3,230 t under Scenario 2, and 3,572 t under Scenario 1.

FIGURE 9: PM Emissions Below 3,000 feet - International Aviation, 2010 to 2050.



CONCLUSION

Emissions from international aviation that affect the global climate and local air quality are expected to increase through 2050, by a factor ranging from approximately 2 to 4 times the 2015 levels, depending on the type of emissions (CO_2, NOx or PM), and the analysis Scenario used. Under an advanced aircraft technology scenario, the total area of day-night levels (DNL) noise contours around airports may stabilize after 2030. However, it should 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, however ICAO's aspirational goal of 2% per annum fuel efficiency improvement is unlikely to be met by then. The aspirational goal of carbon neutral growth after 2020 is also unlikely to be met. Sustainable alternative fuels have the potential to fill the gap to carbon neutral growth but not in the short term, and data is still lacking to confidently predict their availability over the long term. Market-based measures can help fill that gap as well, but also later than 2020.

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Aviation and the Environment: Outlook

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The authors would like to acknowledge the invaluable contribution of the Independent Expert Panel: Juan Alonso (ICSA), Fernando Catalano (Brazil), Nick Cumpsty (UK) Co-chair, Chris Eyers (EC), Marius Goutines (France), Tomas Grönstedt (Sweden), Jim Hileman (USA), Alain Joselzon (France), Iurii Khaletskii (Russia), Dimitri Mavris (USA) Co-chair, Frank Ogilvie (UK), Malcolm Ralph (UK), Jayant Sabnis (USA), Richard Wahls (USA), David Zingg (Canada).

BACKGROUND

Growth in air travel is having an increasing environmental impact. Concerns about climate change are also increasing, and aviation is expected to contain the growth of its carbon footprint in the context of the global efforts to reduce CO_2 emissions. Reactions to aircraft noise still exist around many world airports, and there is growing concern about local air quality with an increased emphasis on small particles from engine combustion, referred to here as non-volatile Particulate Matter (nvPM).

At the International Civil Aviation Organization's (ICAO) Committee on Aviation Environmental Protection (CAEP) 10th Meeting in Montreal, Canada, in February 2016, it was agreed that a process led by Independent Experts (IEs) would be used to conduct an integrated technology goals assessment and review. That review process is described below. It was agreed that this review would be conducted for subsonic aircraft at an engine level, providing assessment of engine technology, including both non-volatile Particulate Matter (nvPM) and oxides of nitrogen (NO_x), and at an aircraft level, providing an assessment of aircraft fuel efficiency and noise technologies. It was also agreed that this review would consider progress relative to current ICAO Standards and goals. This article describes the process of the Integrated Review, summarizes the evidence, and presents the goals and recommendations. Extensive evidence was taken from industry, relevant scientists and engineers, and published reports and papers.

The panel consisted of 15 Independent Experts nominated by seven CAEP Member States (i.e., Brazil, Canada, France, Russia, Sweden, United Kingdom and United States), and two CAEP Observers from International Organizations, specifically the European Commission and the International Coalition for Sustainable Aviation (ICSA)[1]. The full report is available through ICAO[2].

PRECEDING IE REVIEWS, STANDARDS AND GOALS

ICAO Standards have been set to follow the latest available technology in order to prevent backsliding. This has given rise to the need to have a separate set of technology goals, to guide subsequent regulations, and to which industry and ICAO may aspire. The goals defined by present Independent Experts need to be "challenging but achievable", which is the same definition as that adopted by previous groups of Independent Experts established by ICAO CAEP. This section provides an overview of the current standards for noise, emissions, and fuel burn.

1 The IE Panel consisted of the following, with their nominator in parenthesis: Juan Alonso (ICSA), Fernando Catalano (Brazil), Nick Cumpsty (UK) Co-chair, Chris Eyers (EC), Marius Goutines (France), Tomas Grönstedt (Sweden), Jim Hileman (USA), Alain Joselzon (France), Iurii Khaletskii (Russia), Dimitri Mavris (USA) Co-chair, Frank Ogilvie (UK), Malcolm Ralph (UK), Jayant Sabnis (USA), Richard Wahls (USA), David Zingg (Canada).

2 ICAO Doc 10127, Independent Expert Integrated Technology Goals Assessment and Review for Engines and Aircraft, ICAO, 2019.

Noise from large aircraft was the first environmental impact to be regulated at an international level by ICAO, with the adoption in 1971 of Annex 16 to the Convention on International Aviation (Chicago Convention). Since then, the regulation has been made more stringent in subsequent cycles, most recently as Chapter 14 in 2014. The two previous Independent Expert noise reviews, reporting in 2010 and 2014, set goals for 10 and 20 years forward from their respective dates.

The first ICAO certification standard for engine emissions was adopted in 1981, with requirements for fuel venting, smoke, unburned hydrocarbons (UHC), carbon monoxide (CO), and NO_x (oxides of nitrogen). The regulated level of NO_x emission emitted over the landing and take-off cycle is allowed to increase in proportion to the engine overall pressure ratio. The original ICAO standard has been followed by a gradual increase in stringency, principally for NO_x, and new levels were defined most recently in 2010 at CAEP/8. The two previous Independent Expert reviews of NO_x emissions, reporting in 2008 and 2010, set goals 10 and 20 years forward from their respective dates. The goals for NO_x produced in the landing and take-off cycle were expressed on the same principle as the regulations and retained the proportionality to overall pressure ratio. More recently in March 2017, the ICAO Council adopted its first ever nvPM engine emissions standard, which will apply to turbofan and turbojet engines.

The Independent Expert review of fuel burn reduction technology reported in 2011. At the time, there was no standard for fuel burn, but goals were established for the single aisle (SA) and twin aisle (TA) aircraft with three different technology scenarios: TS1 'continuation of current trend', TS2 'increased pressure', and TS3 'further increased pressure'. These goals were in terms of the fuel-burn metric (mass of fuel burned per payload-tonne-kilometre, kg/ATK). In March 2017, the ICAO Council adopted the ICAO Aeroplane CO_2 Standard that will apply primarily to new aircraft type designs from 2020, and to aircraft type designs already in-production as of 2023. There is no direct read-across from 2011 fuel-burn metric to the current CO_2 standard.

The second review of noise technology carried out by Independent Experts drew attention to the interdependency between noise and fuel burn. Since the advent of the jet engine, the steps to increase efficiency have generally led to a reduction in noise, mainly by reducing the jet velocity. The jet noise now is no longer dominant, so this linkage is no longer obviously present. This raises the question as to whether noise and fuel burn will both decrease in the future or could attempts to reduce one, for example fuel-burn, lead to an increase in noise? Additionally, it has been known for many years that increasing the overall pressure ratio (OPR) of the engine leads to an increase in the emissions of NO_x, such that the regulations have been formulated so that more NO_x may be emitted as OPR is increased. Increasing OPR has been associated with more efficient engines and a reduction in fuel burn. Could the increase in pressure to reduce fuel burn lead to increased NO_x? Or could the technology to limit NO_x lead to higher fuel burn than the minimum possible? The above important questions are the underlying basis for the current review.

INTRODUCTION

The Independent Expert panel was tasked with providing goals for fuel burn, noise, and emissions in the mid-term (2027) and the long-term (2037). The panel was also asked to consider the interdependencies among changes to fuel burn, noise, and emissions. During the IE modelling process, it was only possible to consider interdependency between fuel burn and noise. In considering and optimizing for fuel burn, the IEs used the fuel-burn metric (mass of fuel burned per payload-tonne-kilometre, kg/ATK), but for the final recommended goals, these were converted to be in terms of the CO_2 metric value. The optimization for noise used the cumulative noise (in EPNdB) of the three certification points (side-line, fly-over and approach).

The IEs considered four classes of aircraft: business jets (BJ), regional jets (RJ), single-aisle aircraft (SA) and twin-aisle (TA). To establish fuel burn, emissions, and noise baselines, reference aircraft were modelled which were chosen to represent the four major in-service categories. Originally, the plan was to use generic (i.e. hypothetical) Technology Reference Aircraft (TRA), which are representative of aircraft in service in 2017, so as to avoid competitive issues. However, to ensure the availability and consistency of input data, the most recently certified aircraft fitting as closely as possible into each class were used as notional references, and these aircraft are listed in Table 1. Attention was concentrated on the Single-aisle (SA) and the Twin-aisle (TA) aircraft, which overwhelmingly have the largest environmental impact.

It became apparent during the review that the division between RJ and SA aircraft was blurred. The Embraer E190-E2, used for this review, and the Airbus A220 (formerly Bombardier C-series) both carry more than 100 passengers although they are notionally classed as regional jets. Likewise, a large business jet (BJ), like the G650ER, is comparable in size to some smaller RJs, though it is very different in terms of mission.

TABLE 1: Technology Reference Aircraft Types and Related Operational Aircraft

Aircraft Class	Number of Seats	Notional Aircraft
Business Jet (BJ)	<20	Gulfstream G650ER
Regional Jet (RJ)	20-100	Embraer E190-E2
Single Aisle (SA)	101-210	Airbus A320neo
Twin Aisle (TA)	211-300	Airbus A350-900

The counter-rotating open-rotor (CROR) was discussed, but it was considered to have a low probability of being ready for service by 2037 and was not therefore modelled in this review.

AVIATION ENVIRONMENTAL IMPACT OVERVIEW

For climate change, the primary concerns are emissions of CO_2, NO_x and nvPM. Also of concern are persistent contrails which lead to cirrus clouds when the atmosphere is ice-supersaturated. A significant complication arises because the emissions (or their subsequent transformations) have quite different residence times in the atmosphere. They also have quite different values of radiative forcing, which is a measure of the associated heating or cooling effect. It is the combination of a number of factors which determine overall impact on global surface temperature over a given timescale. These factors are: quantities emitted, residence time, radiative forcing, and the temperature response profile of a particular pollutant. CO_2 is of particular concern because of its exceptionally long residence time (thousands of years). The radiative forcing value for aircraft NO_x per unit emission is now thought to be lower than the two previous Independent Expert NO_x reviews, but it remains of concern. Although nvPM is implicated in cloud formation, the processes are less well understood. Contrails, leading to cirrus clouds and aircraft induced cloudiness, have large RF impacts but are short lived (hours). There is high confidence in the estimates of global warming due to CO_2 whereas for all other emissions there is a significant level of uncertainty which needs to be reduced.

TECHNOLOGY REDUCTION POTENTIAL

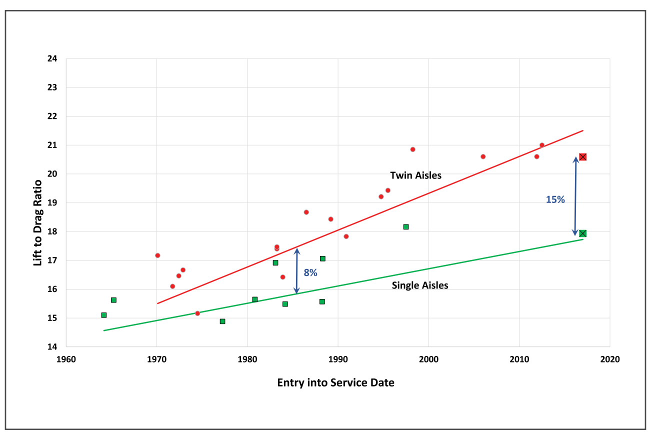
Fuel Burn Reductions

Fuel burn is considered here for the two aircraft classes that burn the largest proportion of fuel, the single-aisle and twin-aisle. The discussion is separated into airframe and engines, with the airframe section itself being divided into aerodynamics and mass (often referred to as weight).

Airframe

A useful measure of aerodynamic performance of an aircraft is the lift-drag ratio, L/D. Historical data for L/D is shown in Figure 1 where trend lines have been drawn through the values for the SA and TA. The L/D ratio is higher for long-range TA aircraft than for the shorter-range SA aircraft. In both cases, the L/D has increased with time, but the average rate of improvement for the TA is about twice that for the SA. An important piece of information relating to the difference between the two aircraft sizes comes from the mid-1980s, when both Airbus and Boeing were each

FIGURE 1: Historical Trend in Lift-to-Drag Ratio



building SA and TA aircraft; because this was going on at the same time the technology level of the two aircraft classes was broadly the same. At that time, L/D was about 8% higher for the TA, and this difference is believed to be mainly because of different design and missions for the SA and TA, each with the same level of technology.

The IEs had the technology reference aircraft listed in Table 1 for 2017. The L/D for the TA in this case is about 15% higher than the SA, implying a relative slippage of about 7%. As Figure 1 shows, the aerodynamic performance of the airframe (characterized by lift/drag ratio) for a SA aircraft, such as B737 and A320, has improved over the past four decades by approximately half as much as the larger TA aircraft. A significant part of this difference is believed to be because the B737 and A320 have their origins far in the past, with improvements in their airframe technology being incremental. Incremental change does not allow the gains possible for an all-new aircraft from a full basket of new technologies.

The aerodynamic performance can be improved by the use of laminar flow: natural laminar flow for smaller aircraft, which usually fly slower and have less sweep, and hybrid laminar flow (requiring suction) for the TA aircraft. The use of laminar flow technology on wings has primarily been held back due to manufacturing and operational considerations and challenges. Evidence provided by the International Coordinating Council of Aerospace Industries Associations (ICCAIA) suggests that reasonable goals for aircraft aerodynamics, adopting a basket of technologies, including laminar flow, are between 3% and 4% total draft reduction for SA and TA aircraft by 2027 and between 8% and 10% by 2037. Based on the slower rate of historical improvement for the SA, the IE review panel have assumed that a wholly new airframe for the SA size of aircraft will be able to improve the aircraft aerodynamic performance over and above the incremental improvements quoted by ICCAIA. In modelling the performance of the SA aircraft, it was therefore assumed that there would be all-new airframes for this class by 2037. Based on this evidence, the total drag for the SA aircraft was lowered by an additional 3% by 2027 and 7% by 2037, beyond the reduction from the new technologies presented by ICCAIA.

There is now some evidence that the values of L/D for the TA aircraft may be approaching an asymptote (the value depending on materials properties and cost, as well as aerodynamic design). To get further significant improvements in L/D for the TA aircraft may require a switch to a non-conventional configuration (i.e. other than tube and wing) or to exploit the benefits of composites to increase wing span requiring increase to airport gate widths.

Reducing aircraft empty mass is vital. Improved metals and metal construction is available, but the use of composites is generally favored for structural components for all new designs. From information provided by ICCAIA, potential overall mass savings with metal are in the range 5±2%. With advanced composites, possible savings of 8±2% for the SA and 4±2% for the TA aircraft. There are other mass reduction technologies under consideration that could yield savings around 2.5% for small aircraft and 4% for large. Overall, for the purpose of setting fuel burn goals, the empty mass savings are in the range 2-4% for 2027 and 8-10% for 2037.

Engines

For engines, the overall efficiency is conveniently separated into propulsive efficiency, which depends only on the fan pressure ratio (FPR), and the thermal efficiency, which depends on the overall pressure ratio (OPR) and the turbine entry temperature. In addition, there is a strong dependence of overall engine efficiency on the component efficiencies of the fan, compression system, and turbines. OPR itself is limited by compressor delivery temperature at take-off and is unlikely to exceed 60. Turbine entry temperature is limited by available materials and airfoil cooling technology but is unlikely to increase significantly from the best current values since increased cooling air requirements reduce efficiency. Further improvements in thermal efficiency will require a combined approach, including incremental increases in OPR and turbine entry temperature, coupled with a continued increase in compressor and turbine efficiencies. Increasing, or even maintaining, compressor and turbine efficiencies becomes more important, but also more difficult, as OPR rises because of the reduction in core size.

Fan pressure ratio has been reduced in recent years to yield significant reductions in fuel burn and noise. As FPR is reduced, the diameter of the fan must increase to produce the same thrust. With the increase in diameter comes an increase in power plant mass and drag, as well as growing issues with power plant-airframe integration. The larger diameter fan rotates more slowly and therefore makes the design of the low-pressure turbine (LPT) more difficult. Some amelioration of the integration issues comes with the insertion of a gearbox between the fan and the LP turbine. The selection of optimum FPR therefore requires the integration issues to be taken into account, particularly the increased drag and mass.

For 2027, the potential fuel burn reductions attributable to the new propulsion technologies have been preliminarily estimated to be about 5% for SA and about 6% for TA aircraft. For 2037, an extra 5% fuel burn reduction might be obtained. These numbers include gains in thermo-propulsive efficiency, and mass and drag, derived from all new propulsion technologies). These estimates exclude benefits from possible new nacelle technologies and improved propulsion system/airframe integration for which no information was available.

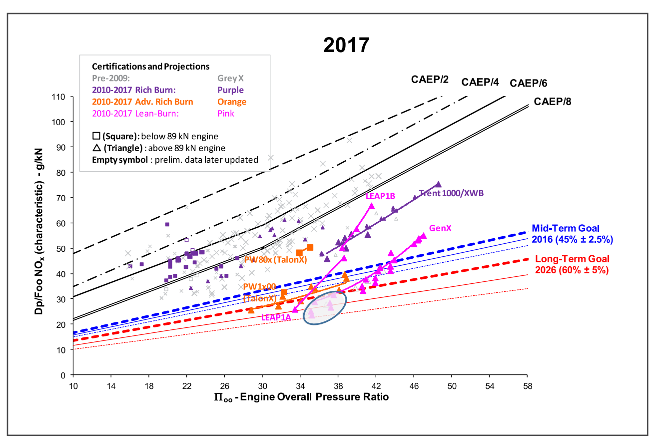
Engine Emissions: Status and Reduction

Emissions from combustion of aviation fuel affect human health and welfare through degraded air quality as well as through climate change. Under all reasonable scenarios of technology change and aviation growth, total fleet fuel burn and the mass of NO_x emissions are expected to continue to rise. Aircraft are unique in that they emit emissions that change air quality, both while on or near the ground and during cruise. At cruise altitudes, the emissions undergo chemical and physical transformations. The climate impact of NO_x emissions is still thought to be significant relative to CO_2, though less than in previous IE reviews. Some studies note that there is also the potential for aircraft emissions emitted at cruise altitudes to reduce surface air quality and affect human health. Historically, the focus has been on the landing and take-off (LTO) cycle, when aircraft are at their closest to populations around airports, with concentrations falling off rapidly with increasing distance from the airport.

Nitrogen dioxide (NO_2) from NO_x emissions, and its photochemical derivative, ozone (O_3), are identified as harmful to human health, though quantification of this is unreliable. More recently, attention has been directed at non-volatile particulate matter (nvPM), and of particular concern are ultrafine particles, less than 100 nano-metres, which is the particle size produced by aircraft combustors. Previously 'smoke' was a major concern, and standards are based on opacity measurements. In addition, NO_x and oxides of sulfur (SO_x) are precursors of secondary volatile PM formation, which takes place over considerable distances away from the source. The contributions to local concentrations of pollutants from LTO operations are higher than the contributions from cruise, but the numbers of people affected are relatively small. For emissions from higher altitudes, the increase in concentration at the surface is much smaller than for LTO but much larger numbers of people are potentially affected.

The LTO levels of NO_x plotted in the conventional way against engine OPR is depicted in Figure 2. Lines are shown for the certification levels and for the goals set by an earlier Independent Expert review. The current LTO-based NO_x goals set by Independent Experts for 2016 (mid-term) and 2026 (long-term) have both already been met. However, the engines which meet the goals are de-rated versions within an engine family. It should be noted that an engine operating at de-rated condition has poor fuel consumption and large weight in relation to thrust and would be uncompetitive. In most cases, higher-power versions in the same family perform relatively poorly for emissions against the same LTO goals. A major cause is the increase in allowable turbine entry temperature used to promote higher engine efficiency and lower CO_2 emission. The turbine entry temperatures are now reaching levels at which NO_x formation becomes unavoidable and significant. At sufficiently high temperature, the NO_x formation process is essentially independent of the

FIGURE 2: LTO NOx Levels as a Function of OPR. Points Refer to Engine Certification Levels



technology to control the main combustion process itself, and is not dependent solely upon the OPR on which the current LTO goals and regulation for NO_x are based. This results in a wide variation in performance of similar technology engines against the current LTO NO_x metric. A new way to characterize NO_x emissions needs to be found which accounts for the turbine entry temperature effect. This is of particular importance given the concern regarding NO_x emitted at altitude.

Looking at future NO_x technology, the IEs believe that as a result of the turbine entry temperature increases, the NO_x emissions from combustors with the best technology appear to be approaching an asymptotic value, with no step change envisaged during the goals timescale. In terms of goal setting, significant improvements in the best NO_x levels set against the current LTO metric are not anticipated, although there are expected to be improvements in the general NO_x levels across the range of engines.

The IEs noted that full-flight NO_x emissions per available seat kilometer across the fleet are not reducing significantly. The steps to reduce fuel burn, such as increasing OPR, have generally led to higher emissions of NO_x which still meet the current LTO NO_x standards and goals. The IEs propose the setting of a 2027 mid-term LTO-based NO_x goal at the level of 54% below CAEP/8, which is 6% below the current 2026 goal-meeting level, with tightened criteria to be defined when the goal is met. The goal applies to all aircraft classes.

The IEs recommend that CAEP consider carrying out urgent work to study two emission-related issues in particular. One is an assessment whether there is evidence of health impacts from aircraft-produced NO_x both near the airport and at cruise. The other is the development of a method to allow a future review to set full-flight based NO_x goals. On this basis, a goal for 2037 may be considered having in mind the interdependency with CO_2 emissions and cost.

The IEs were aware of the concerns regarding health impacts of nvPM, with increasing evidence of the harmfulness of ultrafine particles (smaller than 100 nm). It also appears that the particles emitted by aircraft engines are ultrafine, with the number of particles peaking at about 60 nm. Regulation is being considered for the much larger $nvPM_{2.5}$ particles (2.5 mm which is 2500 nm). Fortunately, the new technologies directed at reducing NO_x, which are currently entering service appear, initially, to offer an order of magnitude reduction in nvPM mass and number compared to most in-service engines. However, industry experts advise that early difficulties in service (making the combustors work stably and with adequate longevity) are likely to result in trade-offs between nvPM and NO_x emissions at higher OPRs and turbine entry temperature. As a result, development issues with lean-burn and advanced rich-burn may not result in the full order of magnitude reduction in nvPM being achieved, though reductions are still expected to be substantial. Given the lack of data, the lack of technologies to reduce nvPM directly, and the prospective step reduction in nvPM emissions from recent combustors designed to reduce NO_x, the IEs considered that the setting of nvPM goals at this time appears neither practical nor appropriate. Once technical data becomes available and climate and air quality impacts are better understood, there may be merit in setting goals for nvPM.

Aircraft Noise: Status and Reduction

Aircraft noise has a unique impact, as no other noise sources fly over where people live. The findings of the CAEP/10 ISG study[3] on the effects of aircraft noise were reviewed. The CAEP/10 trends assessment showed tens of millions of people affected by aircraft noise at the 55 dB day-night level (DNL), with these figures expected to rise significantly, even under the most optimistic technology scenarios. The studies covered community annoyance, children's learning, sleep disturbance, and health effects. The number of people affected may also rise because, historically, noise reductions have come as a result of technology principally aimed at reducing fuel burn by reducing jet velocity. Because jet noise is no longer the major source for larger aircraft, the historical trend is thought to no longer apply. The reverse situation where significant fuel burn potential might possibly be sacrificed in the pursuit of lower noise is unlikely, given the concerns over CO_2 and to a lesser extent NO_x.

Compared with the past, noise from recent new aircraft is characterized today by a significant change in the relative

3 https://www.icao.int/environmental-protection/Documents/ICAO%20Environmental%20Report%202016.pdf, pages 30 to 37

FIGURE 3: Noise Source Breakdown for a Modern Twin-Aisle Aircraft

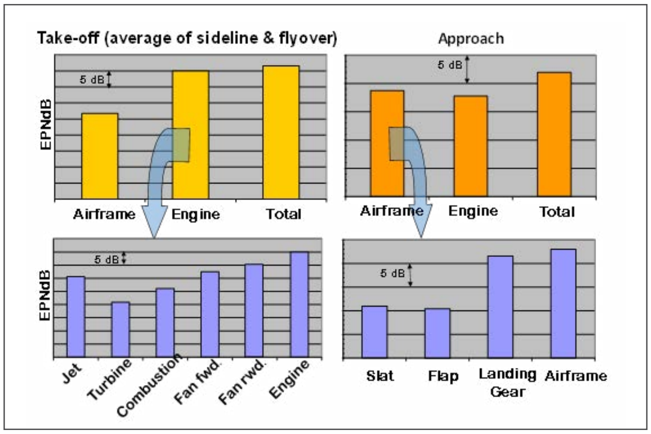
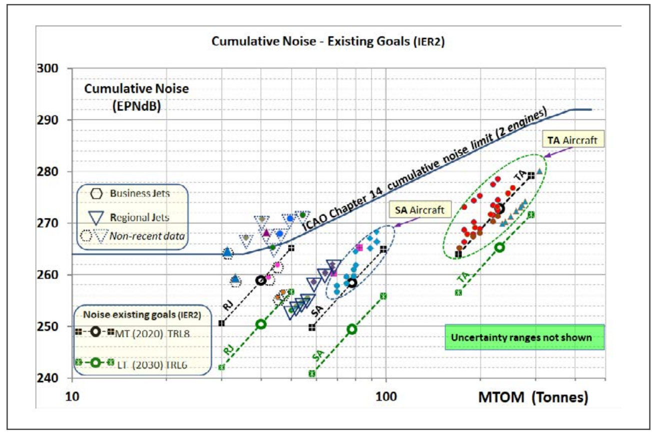


FIGURE 4: Prior IER2 Technology Goals and Recently Certified Noise Levels



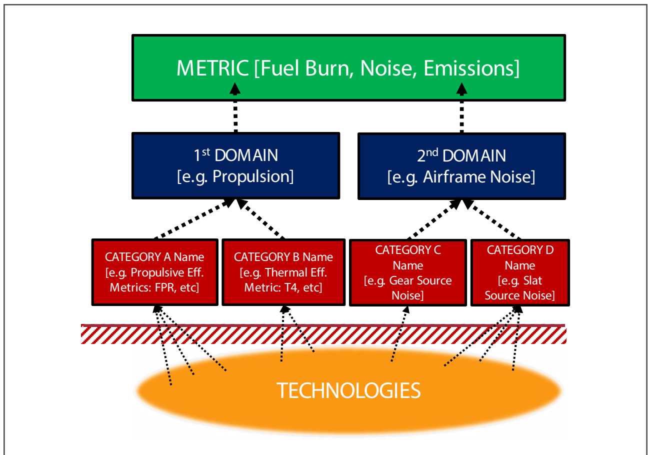
importance of engine and airframe noise sources. Figure 3 shows the current noise breakdown for a modern TA aircraft. For take-off, the engine is the largest contributor to noise, with the fan being the major component and jet noise some 5dB lower. For approach, the airframe noise dominates with the landing gear making the largest contribution. The jet noise is low because the fan pressure ratio has been reduced, thereby reducing jet velocity and increasing propulsive efficiency. The lower fan pressure ratio means that the engines have a larger diameter and specific features of design, including engine integration, aerodynamics, mass, and interaction effects become more important, leading to an increase in the level of interdependence. Furthermore, because jet noise is no longer dominant, basing noise levels on parameters such as bypass ratio, as in previous IE reviews, is no longer appropriate.

Today's new aircraft are meeting the existing mid-term noise goals with some margins. Figure 4 compares recently certificated cumulative aircraft noise with current 2020 and 2030 noise goals established by CAEP/9 (early 2013), following recommendations of the second Independent Expert Noise Review (IER2). The certification cumulative noise in EPNdB is shown versus maximum take-off mass for the four categories of aircraft considered (i.e., business jets-BJ, regional jets-RJ, single-aisle-SA, and twin-aisle-TA). In all cases, the recent noise levels are well below the ICAO Chapter 14 noise regulatory level. Because there is significant scatter within these classes, and there is no recent BJ data, older data is also shown for these types. Some of these do not meet ICAO Chapter 14 noise limits, and by some margin they do not meet the RJ goals set by IER2. The scope and potential remaining for further technology-based reductions in noise within conventional aircraft configurations are limited; although reduced speeds, particularly fan speed, will lead to some reductions. To achieve these, attention should focus particularly on acoustic wall liners in the power plant, noise from the fan, and airframe noise. In addition, consideration should be given to potential noise reduction from novel configurations of aircraft, as opposed to the existing "tube and wing" design.

MODELLING APPROACH AND RESULTS

The plan for the IE review was to perform modelling and from this, determine goals and interdependencies for fuel burn, noise, and emissions. The modelling used for the study is the Environmental Design Space (EDS), a modelling and simulation environment developed in Aerospace Systems Design Laboratory (ASDL) at the Georgia Institute of Technology. EDS has been widely used on conventional aircraft-engine vehicles and also used to assess unconventional aircraft and propulsion systems in support of the NASA and FAA advanced aeronautics programs. The majority of the EDS analysis components are NASA developed programs. The foundations for the EDS systems analysis capability are advanced methods developed at ASDL, coupled with integrated aircraft modelling and simulation. While EDS is capable of predicting the fuel burn, NO_x emissions and noise metrics, it became apparent that the model for emissions of NO_x in EDS is

FIGURE 5: IE Integrated Review Taxonomy.



heavily dependent on available NOx correlation equations. In order to predict NO_x for advanced combustors under consideration, specific NOx correlation is needed, which is not available for the study. The model in EDS was therefore unable to allow goals or interdependencies in NO_x to be determined, and only the goals and the interdependencies for fuel burn and noise were obtained from the EDS model.

Because of time constraints and because detailed technology information is proprietary, the interdependencies, which would be explored, were limited to those associated with design parameters with a fixed set of projected technology basket impacts defined at the base of a technology taxonomy. The taxonomy that was adopted for describing the process and the findings of the modelling are illustrated in Figure 5. The technology baskets were defined as three point estimates based on the technology categories: high (80%) confidence, nominal (50%) confidence and low (20%) confidence. The confidence levels applied to the categories, such as an improvement in thermal efficiency. This was done for the mid- and long-term, based on the category levels. Examples of categories are: reductions in component mass, drag, and component noise sources. For baskets with technologies of a given confidence level, the design parameter interdependencies were explored; examples of this are wing loading, aspect ratio, and fan pressure ratio.

Information on the potential new technologies was provided by International Coordinating Council of Aerospace Industries (ICCAIA), research organizations, the IEs, and others. Technologies were provided with Technology Readiness Level (TRL) values with TRL8 achieved when an aircraft is flight qualified ready to enter service. The aircraft and its technologies for the goals covered in this review were required to be at TRL8 in 2027 for mid-term (MT) and at 2037 for the long-term (LT). On the basis of past experience, it is assumed in this review that there will normally be a seven-years gap between TRL 6 and 8. Therefore, to achieve TRL8 on the goal dates, the technology should be at least TRL6 by 2020 and 2030, respectively. Likewise, the technologies on the current Technology Reference Aircraft (TRA), listed previously in Table 1, were assumed to have been at, or close to, TRL 5 or 6 around 2010. For each technology, a benefit was assigned; for example, the wing mass might be reduced by 2% using a new technology at TRL6 in 2020. Although this suggests that it *could* be brought into service by 2027, it does not mean that it *will* be. Consequently, likelihood bands were established by industry to indicate their assessment of the chances of it being used, and the fraction of the potential benefit being achieved and these estimates were adopted by the IEs.

The EDS model was run for the four classes of aircraft, though only the SA and TA aircraft are discussed here. The mission was computed at the R1 range (maximum range at maximum payload) to optimize performance. The input data consisted of various input parameters such as wing loading and fan pressure ratio; and technology parameters, like drag, empty weight, and compressor efficiency. The technologies were quoted for 2027 and 2037 at the three confidence levels of: high (80%), nominal (50%), and low (20%). The starting point for the modelling of new design parameters and new technologies was the technology reference aircraft (TRA) in 2017 for each class. Optimization was performed for a weighting factor of noise (cumulative EPNdB) and fuel-burn metric in steps of 10%, from all-noise to all-fuel burn.

Figure 6 shows the Pareto plots[4] for the SA aircraft and Figure 7 presents the Pareto plots for the TA aircraft, with the ordinate being the cumulative EPNdB, and the abscissa is the fuel-burn metric (kg-fuel per available tonne-kilometer). The fronts are for the high, nominal and low confidence in 2027 and 2037. For each front, the

4 https://en.wikipedia.org/wiki/Pareto_efficiency

FIGURE 6: Single Aisle Pareto Fronts

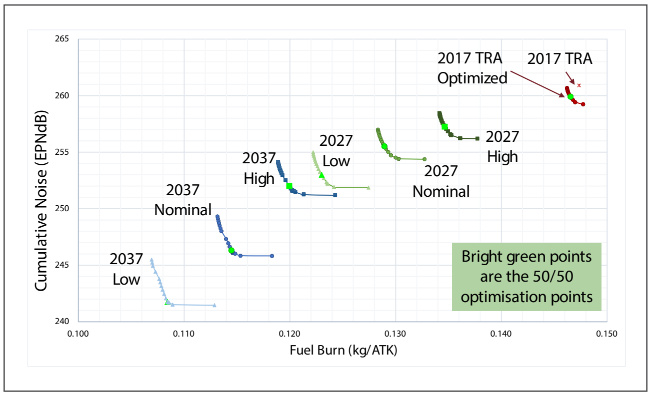
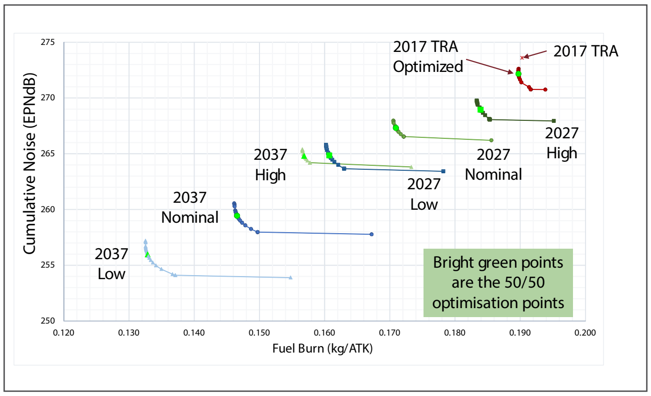


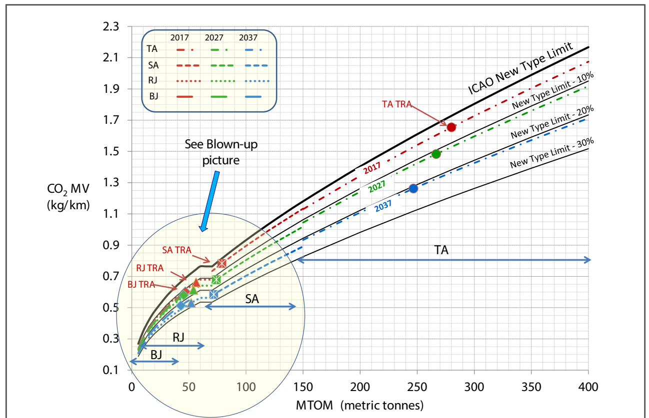
FIGURE 7: Twin Aisle Pareto Fronts



points correspond to different weightings for noise and for fuel-burn in the optimization; so the point on each front furthest to the right corresponds to an optimization for lowest noise whilst the highest point on each front corresponds to an optimization for lowest fuel-burn. The points along the front correspond to changes in the balance of optimization and the green dots correspond to equal weight in the optimization for noise and fuel-burn. It is apparent that this 50% noise/50% fuel-burn optimization gives a reasonable balance of benefits for noise and for fuel-burn and this optimization is used to form the goals.

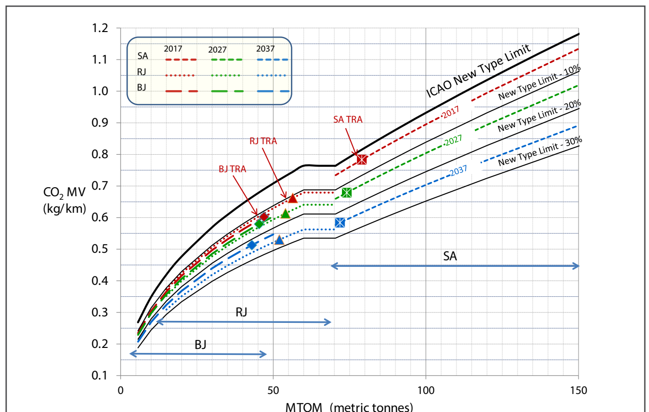
To allow improvements attributable to the use of new design parameters and technologies in 2027 and 2037 to be expressed in a consistent manner, the same EDS optimization method was applied to the technology reference aircraft of 2017, varying design parameters but holding technology constant. These 2017 TRA optimized Pareto fronts are shown in the top right corner as red curve of each figure and is closest to result for the TRA (with the given parameters and technologies).

FIGURE 8: CO_2MV versus MTOM and Percentage Reductions from the "New Types" Level



Points show Optimization for Nominal Confidence at the 50% fuel-burn/50% noise weighting, Performed at R_1 for 2017 TRA.

FIGURE 9: CO_2MV versus MTOM and Percentage Reductions from the "New Types" Level



Points show Optimization for Nominal Confidence at the 50% fuel-burn/50% noise weighting, Performed at R_1 for 2017 TRA.

The goals have been created on the basis of nominal confidence, highlighted as the bright green points in each figure. Based on the selection of the 50% noise/50% fuel-burn weighting, the fuel burn metric was obtained. The fuel burn metric was then translated to the current ICAO CO_2 Standard for the goal setting and these are shown in Figure 8 as the CO_2 metric versus aircraft maximum take-off mass, MTOM. The heavy black line is the recently adopted ICAO CAEP/10 regulatory level for new types and the lighter black lines give notional reductions in the CO_2 metric of 10, 20 and 30%. The red points correspond to the 2017 TRA, whilst the green are the 2027 goals and the blue the 2037 goals. Figure 9 is a zoomed-in part of Figure 8 for lower MTOM and shows the BJ, RJ and SA aircraft classes. The dashed lines represent the final goal recommendations by the IEs.

The cumulative noise from the optimization process (50% noise/50% fuel-burn weighting) are shown as solid symbols in Figure 10: red shows the 2017 TRA, blue the 2027 goals and green the 2037 goals. Also shown, as open symbols, are projected goals derived from goals of the second IE noise review, IER2. In general, the agreement between the projections and the model are good. In all cases there is a large margin to the Chapter 14 regulatory line.

RESULTS AND GOALS

Aviation Environmental Impact Overview

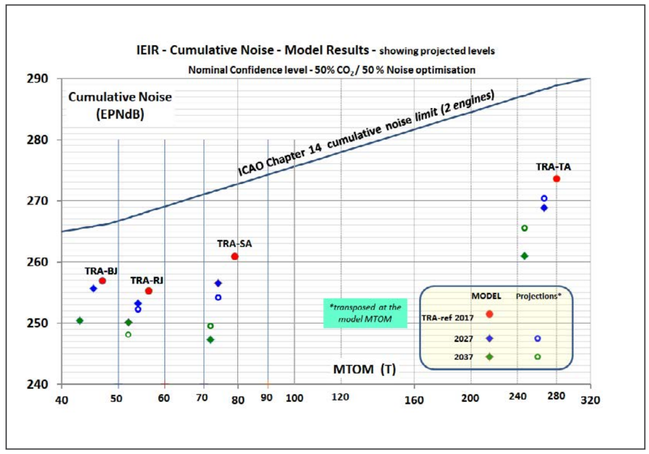
Air quality and health impacts

1. Better understanding of the effects, if any, of low-concentration NO_x engine emissions on human health is required; during both LTO and cruise phases of flight.
2. The nature of the particulates emitted by engines in terms of size, number, and composition, under different conditions while near the ground needs to be understood and quantified, as does their impact on human health.
3. Further evidence is needed about the effects of NO_x and sulfur oxides at altitude in creating particulates at ground level; this needs to include the process of formation, the regions of geographical concentration, and the health impacts.

Emissions and climate change

1. A new and robust consensus is needed on the climate change impacts, both present and future, of all aircraft emissions, both in absolute terms, and in relative terms, compared with other sources. For rational decisions to be made, the impacts are required over longer time spans than those presented to-date.
2. Contrails and the formation of related cloudiness make a large potential contribution to aviation radiative forcing but are still subject to large uncertainty with respect to their behavior and their radiative forcing. The potential to mitigate the effect of contrails by small alterations in aircraft flight paths or altitudes should be further investigated.

FIGURE 10: Noise Projections and Modelled Results versus Take-off Mass



Aircraft Fuel Burn and CO_2 Reduction

1. Because fuel burn is a key industry competitive parameter, any review tends to be hampered by limited publicly available information. For this review, the IEs had to construct proxy Technology Reference Aircraft. With the future availability of certification values using the CO_2 metric system, a future review looking at actual fuel burn estimates can be conducted with a more solid foundation.
2. The evidence presented to the IE Panel convinced members that one reason that the single-aisle aircraft lift/drag ratio had improved more slowly than for the twin-aisle aircraft was that the airframes of the former were substantially older and had not had the benefit of the all-new configuration of the TA aircraft. The penalty for this was estimated to be 7% in 2027. The IEs believe that an all-new SA airframe is needed to obtain the full potential fuel-burn improvement by 2037.
3. The goals for fuel-burn reduction proposed by the IEs represent their view of challenging, but achievable, technology for new aircraft. The highest rate is about 1.3% per annum. Compared with the ICAO aspirational goal of 2% global annual average fuel efficiency improvement, these results confirm that technology alone will not be able to meet ICAO aspirational goals. In order for the technology goals for fuel burn to be achieved, a substantial increase in investment in aircraft technology is urgently required.

4. Although not part of the goal setting, the IE review showed the impact of operating range and aircraft type on the fuel-burn metric. The fuel-burn metric reflects environmental cost, in terms of fuel burned, in the numerator and the benefit (mass of payload times distance flown) as the denominator. Table 2 shows the modelling results computed for the TRA (i.e., at the 2017 standard) for two ranges: these are the R1 range (maximum range at maximum payload) and the design range which is larger. These two ranges are listed in the footnote.[5]

TABLE 2: Fuel Burn Metric (FB/ATK) at Two Ranges for the Four TRAs in 2017.

	BJ	RJ	SA	TA
Design range	0.632	0.158	0.147	0.190
R_1 Range	0.343	0.146	0.125	0.126

A number of important observations emerge from Table 2. First, the fuel-burn metric is very high for the business jet compared with the other classes of aircraft. This is a consequence of small payload and long range of the BJ. The other striking observation is steep rise in fuel-burn metric as range is increased from R1 to design range. For the TA aircraft this longer ranges increases fuel-burn metric by about 34%, which is to some extent attributable to the sacrifice of payload to allow extra fuel to be carried. For the business jet, the effect is even more striking, with the fuel-burn metric rising by over 45% when range is increased from R1 to design range. To put this in context, the goals for fuel-burn improvement from the model show that 20 years of intense application of new technology could reduce fuel burn of the TA aircraft by around 23%.

Lastly, it should be noted from Table 2 that the fuel-burn metric for the SA at R1 range is marginally lower than that for the TA, notwithstanding the markedly higher L/D for the TA. This reflects the potential for major fuel-burn improvements by designing for shorter range, a point noted in the IE Fuel Burn Reduction Technologies in 2010. None of these features are revealed with the CO_2 metric, which does not include the effect of range or payload.

Emissions from Engines: Status and Opportunities

NO_x

1. The current LTO-based NO_x goals set by Independent Experts for 2016 (mid-term) and 2026 (long-term) have both already been met, but only with de-rated versions within an engine family, not intended to have significant market share. It is therefore recommended that in a future requirement, including this one, the engine be in substantial serial production for the goal to be accepted as being met.
2. The evidence shows a dependence on combustor exit temperature as well as OPR and any further consideration of LTO NO_x goals must be based on a methodology which reflects this. A new, low-order model is needed to predict NO_x emissions including the effect of OPR, turbine entry temperature, and design style and geometry. Such a low-order model would allow adequate optimization against fuel burn.
3. To reflect the potentially increasing importance of altitude NO_x relative to LTO NO_x levels, consideration should be given to the development of a cruise-based NO_x goal.
4. Setting a cruise-based NO_x goal level should take full account of the interdependencies, in particular, the technical trade-offs with fuel burn, especially as a result of higher turbine entry temperatures. Any cruise-based goal should also embrace the emerging understanding of health and environmental impacts on humans due to nvPM and NO_x emissions.

5 Design and R1 Range in Nautical Miles for the Four TRAs in 2017

	BJ	RJ	SA	TA
Design range (nm)	7,500	2,850	3,500	8,100
R_1 Range (nm)	6,450	1,750	2,450	5,900

nvPM

1. The particles emitted by combustion in aircraft engines are mainly ultrafine particles (i.e., smaller than 100 nm) and these are believed to be most harmful to human health.
2. It is noted that combustors entering service which are designed for low NO_x also appear to offer a substantial reduction in nvPM mass and number compared with most in-service engines. There is great uncertainty about the details of processes that lead to the formation of nvPM.
3. Setting goals for nvPM at this time appears neither practicable nor appropriate. Once technical data becomes available and climate and air quality impacts are better understood, there may be merit in setting goals for nvPM.

Noise: Status and Opportunities

1. The IEs regard the opportunities to be limited for new technologies to reduce noise further, short of major aircraft configuration changes, but noise generation will be reduced because of reduced speed (most notably of the fan). Better propulsion system integration with the aircraft is needed to encompass aerodynamic performance, noise, engine efficiency, and aircraft fuel burn.
2. More work is needed to improve the sound absorbing performance of thin acoustic liners and to increase the area of coverage. Liners suitable for the hot jet pipe are also needed for turbine noise and potentially for attenuating combustor noise.
3. Steps to reduce airframe noise, including landing gear and high-lift systems for low noise are required. A goal must be to find suitable geometries with practical parametric characterization of noise, aerodynamic performance, and mass, which can be used in the aircraft optimization process.

SUMMARY OF GOALS RECOMMENDED BY THE INDEPENDENT EXPERTS

Fuel Burn and Noise Goals

The goals for fuel burn and noise should be taken together, both following from the combined optimization process with the optimization weighting equal for both.

The fuel burn goals, expressed in terms of the CO_2 certification metric system as percentage margins relative to the CAEP/10 New Type Regulatory Level are presented below in Table 3. The results for the SA include the 3% and 7% increase in L/D attributable to the all-new aircraft.

TABLE 3: Fuel Burn Goals Expressed as Margin to CO_2 Metric Level

EIS Date	BJ	RJ	SA	TA
*2017 TRA**	-13	-11	-4	-4
2027	-15	-16	-14	-12
2037	-23	-26	-24	-21

*The 2017 numbers are not goals, but are shown for comparison purposes only.

Earlier Independent Expert goals for fuel-burn reductions were expressed in terms of fuel-burn metric (kg-fuel/ATK) and these are compared with the current review in Table 4 on an annualized basis beginning from 2000 for the 2010 IE review and from 2017 for the current review. It should be noted that for the 2010 review, the STA corresponds to the TA of the current review. As explained earlier, the present expectation of achievable reductions are significantly lower than was in 2010.

TABLE 4: Current Fuel Burn Goals Compared to Prior Goals

Goals from 2010 IE Review

Year	SA	STA
2020	1.70%	1.43%
2030	1.38%	1.43%

Goals from Current Review

Year	BJ	RJ	SA	TA
2027	0.42%	0.77%	1.26%	1.04%
2037	0.71%	1.03%	1.22%	1.28%

The complementary noise goals expressed as EPNdB cumulative below Chapter 14 Noise Limit are presented in Table 5.

TABLE 5: Noise Goals Expressed as EPNdB below Chapter 14 levels

EIS Date	BJ	RJ	SA	TA
*2017 TRA**	9	13	12	15
2027	10.0	14.5	15.5	19.5
2037	15.0	17.0	24.0	26.5

*The 2017 numbers are not goals, but are shown for comparison purposes only.

Interdependency of Fuel-Burn and Noise Goals

The interdependency of noise and fuel burn can be determined from the Pareto plots presented earlier. Interdependency of fuel burn and noise for the SA and TA were explored by varying the weighting of the optimization in the EDS method. Results are shown for the SA aircraft type (with the extra L/D to allow for all-new airframe) in Table 6 and for the TA aircraft in Table 7.

For the SA, the worsening of fuel burn between 100% and 50% fuel burn optimization is small, whereas the fuel burn is substantially greater for 100% noise optimization. The noise benefit of weighting the optimization to noise is barely more than 1 dB than the 50/50 optimization. For the TA aircraft type, Table 7, the optimization at 50% fuel burn again gives most of the benefits in fuel burn with less than 1dB noise penalty. Optimizing 100% for noise, however, causes large fuel-burn penalties for less than 2dB noise benefit.

TABLE 6: Variation with Optimization of FB/ATK and Cumulative EPNdB for SA

Year	Optimization weighting	% FB/ATK	Δ EPNdB
2017	100% FB	-0.23%	0.78
	50/50	0.00%	0.00
	100% Noise	0.81%	-0.67
2027	100% FB	-0.48%	1.49
	50/50	0.00%	0.00
	100% Noise	2.94%	-1.13
2037	100% FB	-1.15%	3.01
	50/50	0.00%	0.00
	100% Noise	3.36%	-0.50

Model Optimization for Nominal Confidence at the 50% fuel burn/50% noise Weighting, Performed at R_1 for 2017 TRA.

TABLE 7: Variation with Optimization of FB/ATK and Cumulative EPNdB for TA

Year	Optimization weighting	% FB/ATK	Δ EPNdB
2017	100% FB	0.00%	0.53
	50/50	0.00%	0.00
	100% Noise	2.16%	-1.33
2027	100% FB	-0.23%	0.66
	50/50	0.00%	0.00
	100% Noise	8.56%	-1.11
2037	100% FB	-0.30%	1.11
	50/50	0.00%	0.00
	100% Noise	14.08%	-1.66

Model Optimization for Nominal Confidence at the 50% fuel burn/50% noise weighting, Performed at R_1 for 2017 TRA.

Goals for Emissions

Based on the evidence available to them, the IEs recommend that a new 2027 goal for NO_x should be set at 54% below CAEP/8 at OPR=30, covering the entire OPR range, using the equation 5.75 + 0.577*OPR. There are no goal bands.

To avoid low-thrust versions of engines with small production possibilities being taken to achieve the goals, it is recommended that the goal be met only when the 50th goal-compliant engine model enters into service.

The IEs declined to set NO_x goals for 2037, pending the development of a methodology which will reflect the dependence on combustor exit temperature, and more evidence on the need in terms of harm to health and deleterious impact on climate.

The setting of nvPM goals at this time appears neither practicable nor appropriate.

APPENDIX

Remit of the Independent Expert review taken from CAEP Memo 102, Attachment A, (4th July 2017):

> "Based on the material reviewed by the IE panel, the final report should provide a balanced view of the current state of noise and emissions reduction technologies, in a manner suitable for broad understanding and it should summarize the expected new technological advances that could be brought to market in approximately 10 years from the date of review ("mid-term"), as well as the approximately 20-year ("long-term") prospects suggested by research progress, without disclosing commercially sensitive information. The report will include:
>
> - A scientific overview of aviation environmental effects related to the aircraft and engine at source;
> - For each technology, assess the possibility of noise reduction and fuel efficiency improvement, with specific focus on the interdependencies and trade-offs between fuel efficiency and noise;
> - An assessment of the technological possibilities for NO_x and non-volatile Particulate Matter (nvPM) emissions control with specific focus on the interdependencies and trade-offs between fuel efficiency and/or noise;
> - An assessment of the likelihood of successful adoption or implementation of the identified technologies and trends for the future, based on experience from past research and development programmes;
> - Details on progress, which should be stated with reference to the existing CAEP Standards and goals. It should be noted that:
>   - CAEP/10 established a new technology-based standard for aeroplane CO_2 emissions and so the IEs will need to make recommendations to reconcile past fuel burn goals with the new CO_2 metric system as appropriate;
>   - There are no existing baselines or goals for nvPM and ICAO-CAEP is currently in the process of developing Landing Take-Off (LTO) mass and number-based standards for nvPM, in which context related data is still being collected. At a minimum, the IEs are requested to give at least a qualitative assessment of the prospects of improvements in nvPM mitigation technologies in the foreseeable future."

ICAO

CHAPTER TWO

Aircraft Noise

50 years of Annex 16 – the Special Meeting on Aircraft Noise in the Vicinity of Airports

By ICAO Secretariat

INTRODUCTION

In 1968, the 16th ICAO Assembly instructed the ICAO Council to establish international specifications and associated guidance material relating to aircraft noise; and to include, in appropriate existing Annexes and other relevant ICAO documents, and possibly in a separate Annex on aircraft noise, such material as the description and methods of measurement of aircraft noise and suitable limitations on the noise caused by aircraft that was of concern to communities in the vicinity of airports.

In the three years that followed, technical specifications were defined and a "Special Meeting on Aircraft Noise in the Vicinity of Aerodromes", was convened (Montréal from 25 November to 17 September 1969[1]). This new technical work led to the ICAO Council, in August 1971, adopting the first edition of Annex 16 – Aircraft Noise, the first environmental Standard to be applicable to new aeroplane designs.

This article describes the seminal importance of this Special Meeting to ICAO's work on environmental aspects associated with international civil aviation, as well as major accomplishments during the past 50 years.

HISTORY OF THE SPECIAL MEETING ON AIRCRAFT NOISE IN THE VICINITY OF AERODROMES

The Special Meeting was attended by 161 representatives of 28 ICAO Contracting States, one non-contracting State and nine international organizations. The meeting considered the question of whether the Standards relating to the noise certification scheme should appear in a new and separate Annex to the Chicago Convention. After considering the applicability and limitations of the various existing Annexes, in particular Annexes 6 (Operation of Aircraft) and Annex 8 (Airworthiness of Aircraft), the meeting agreed that the noise certification Standards "should be issued in a new and separate Annex, which should deal exclusively with aircraft noise and which should therefore also include, to the extent practicable, related noise specifications and, as necessary, supplementary guidance dealing with other aspects of noise". This agreement was captured under Recommendation 3/1 of the Special Meeting, which recommended the issuance of the new "Annex X" dealing exclusively with Aircraft Noise. This was the original recommendation underlying the establishment of Annex 16.

1 The report of the meeting can be found in ICAO Doc 8857.

ANNEX 16 AND THE SPECIAL MEETING RECOMMENDATIONS

Nine Recommendations from the Special Meeting referred to proposals for Standards and Recommended Practices. After review by the Air Navigation Commission and the Council, these proposals were structured to form the complete text of Annex 16, as follows:

- Part I - Definitions,
- Part II - Standards adopted as applicable to all subsonic jet aeroplanes of over 5 700 kg weight, except aeroplanes with short take-off and landing (STOL) capabilities,
- Parts III, IV and V - Recommended Practices and Guidance Material for use by States with a view to promoting uniformity in: measurement of noise for monitoring purposes; use of an international noise exposure reference unit for land-use planning, and establishment of noise abatement operating procedures,
- Appendixes 1, 2 and 3 - technical information, grouped separately for convenience,
- Attachments A, B and C - supplementary material and guidance.

The relationship between these sections of Annex 16 (1st Edition) and the Special Meeting Recommendations are provided in Table 1.

NOISE CERTIFICATION METRIC

One important issue that the Special Meeting considered was the noise metric to be used in aeroplane noise certification. There are three main factors that influence the human perception of a noisy event (such as an aeroplane overflight): the amplitude (or volume), the frequency content (high/low pitch), and the duration of the event. Therefore, the challenge faced by the Special Meeting was to define a metric that would capture these variables and represent appropriately the human response to the noise

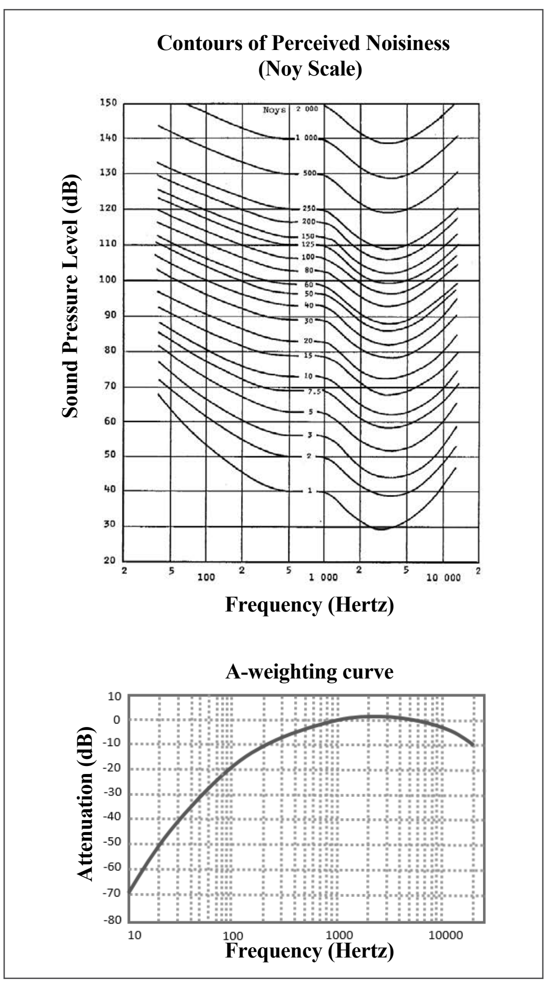
TABLE 1: Annex 16 and the Special Meeting Recommendations

First Edition of Annex 16	Special Meeting Recommendations
Part I - Definitions	3/7 - Definitions
Part II – Aircraft Noise Certification	3/2 – Administrative Part of Annex "X" 3/6 – Technical part of Annex "X"
Part III – Noise Measurement for Monitoring Purposes	1/2 – Noise Measurement for Monitoring Purposes
Part IV – International. Noise Exposure Reference Unit for Land-Use Planning	1/4 – Adoption of an International Noise Exposure Reference Unit
Part V – Aircraft Noise Abatement Operating Procedures	4/1 – Guidance material Relating to Safety considerations in the Establishment of Aircraft Noise Abatement Operating Procedures
Appendix 1 - Noise Evaluation Method for Aeroplane Noise Certification	3/6 – Technical part of Annex "X" 1/1 Noise Measurement for Aircraft Design Purposes
Appendix 2 - Monitoring Aircraft Noise on and in the Vicinity of Aerodromes	1/2 – Noise Measurement for Monitoring Purposes
Appendix 3 - Total Noise Exposure Level (TNEL) Produced by a Succession of Aircraft	1/4 – Adoption of an International Noise Exposure Reference Unit
Attachment A - Approximate Methods For Determining Effective Perceived Noise Level (EPNL)	5/1 – Guidance Material for Approximating EPNL from measurements
Attachment B – Suggested Methods for Weighting Total Noise Exposure Levels for Daily and Seasonal Factors (referenced in Appendix 3)	2/2 – Weighting Factors for Use with the International Noise Exposure Reference Unit
Attachment C - Guidance Material Relating to Safety Considerations in the Establishment of Aircraft Noise Abatement Operating Procedures	4/1 – Guidance material Relating to Safety considerations in the Establishment of Aircraft Noise Abatement Operating Procedures

from one aeroplane overflight. Since the main objective of the certification Standards is to compare technology levels of different designs, the Special Meeting agreed that the noise metric to be used should have maximum accuracy and validity in representing the human response to noise.

The Special Meeting considered the use of existing noise metrics at the time, however it was agreed that traditional noise metrics lacked the precision required for aeroplane noise certification. As a consequence, a new noise metric was proposed, the EPNL (Effective Perceived Noise Level), which takes into account all the physical variables associated with human perception of aeroplane noise: the different response to sounds of different frequencies and intensities, the presence of predominant irregularities in the frequency spectrum ("pure tones"), and the duration of the event.

FIGURE 1: Noy Scale and A-weighting curve (sources: Annex 16 First edition / IEC 61672)



Traditional noise metrics such as the A-weighted noise level (dB(A)) are based on the addition of an attenuation factor to the measured sound pressure levels, in an attempt to represent the variable sensitivity of the human ear to sounds of different frequencies. However, the dB(A) representation of the human ear includes some simplifications to facilitate its electronic implementation in sound metering devices. On the other hand, the EPNL correlates sound pressure levels with perceived noisiness by means of the Noy Scale, which provides a more accurate representation of the human sensitivity to noise. Figure 1 below illustrates how the dB(A) and the Noy scale represents the variability of human ear sensitivity to frequency. It can be seen that the Noy Scale (on the top) presents a much more refined representation of the human ear response.

LAND USE PLANNING AND OPERATING PROCEDURES

In Parts III, IV and V, the first edition of Annex 16 already included Recommendations on land use planning and operating procedures for the mitigation of aircraft noise impacts. Many years later, in 2001 the ICAO Assembly included these elements as two of the pillars of the "ICAO Balanced Approach to Aircraft Noise Management"; the main overarching ICAO policy on aircraft noise, which contains details on all the elements that can be employed to achieve noise reductions. The Balanced Approach is described in detail in ICAO Doc 9829.

OTHER OUTCOMES FROM THE SPECIAL MEETING

The Special Meeting recommended the establishment of an appropriate body to examine additional aspects that could not be fully dealt with during the Meeting, such as development of noise certification Standards for other classes of aircraft such as supersonics and light aircraft. As a response to this recommendation, the Council agreed to establish the Committee on Aircraft Noise (CAN) to work on these tasks.

Several years later, the same concept was used by the ICAO Council with the creation of the Committee on Aircraft Engine Emissions (CAEE), which developed the first edition of Annex 16, Volume II – Aircraft Engine Emissions, resulting in an expanded scope of environmental impacts addressed by Annex 16.

As many measures taken to mitigate aircraft noise could have implications on engine emissions, the interdependencies between noise and emissions needed to be properly considered. As a consequence, in 1983 the Council agreed to merge CAN and CAEE into a single committee, the Committee on Aviation Environmental Protection (CAEP), which to date is the main technical body assisting the Council in formulating new policies and adopting new Standards and Recommended Practices (SARPs) related to aviation environmental impacts.

Some elements of the Terms of Reference adopted for CAEP can also be traced back to the Special Meeting conclusions: when discussing the noise limits to be included as part of Annex 16 Standards, the Special Meeting agreed that the prescribed maximum noise levels would be limited by what is “technically feasible and economic reasonable”. In line with that, the CAEP Terms of Reference state that the CAEP work shall take into account the “effectiveness and reliability of certification schemes from the viewpoint of technical feasibility, economic reasonableness and environmental benefit to be achieved”, as well as the interdependencies between measures. This conclusion of the Special Meeting had therefore a paramount importance, laying down the basis of ICAO action on environmental matters for the next 50 years.

EVOLUTION OF ANNEX 16

In these five decades, Annex 16 has been subject to several changes and SARPs have been incorporated that are associated with other environmental impacts associated with aviation, such as local air quality and climate change.

Specifically on noise, the scope of Annex 16 was expanded to encompass helicopters, light aeroplanes, supersonics (with Type Certification submitted before 1 January 1975) and tiltrotors. Regarding Emissions, Annex 16, Volume II now addresses the various pollutants emitted by aircraft engines, such as NO_x, HC, CO, and non-volatile particulate matters (nvPM). On climate change, Annex 16, Volume III was adopted to cover aeroplane CO_2 emissions, and the more recent Annex 16, Volume IV is dedicated to the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA).

A brief overview of this evolution is provided in Table 2.

CONCLUSIONS

ICAO has been successfully addressing the environmental impacts associated with international civil aviation, with the important contribution of the environmental Standards laid out in Annex 16 to the Chicago Convention. In this regard, the importance cannot be understated of the “Special Meeting on Aircraft Noise in the Vicinity of Airports”, which was convened 50 years ago, in setting the initial direction for ICAO work on environmental matters. Nor can the crucial work that has taken place since then in developing the completed suite of ICAO environmental SARPs on aircraft noise and emissions.

Moving into the future, new innovative technologies and energy sources for aviation are under development at a fast pace, and much work by ICAO will be required to keep pace with the timely environmental certification of such new technologies, as appropriate. Therefore, Annex 16 SARPs will continue to be of fundamental importance to consolidate ICAO Policies on environment for many more years to come.

TABLE 2: Evolution of Annex 16

Meeting	Year	Key recommendation on Annex 16 SARPs
Special Meeting on Aircraft Noise in the vicinity of airports	**1969**	**First Edition of Annex 16 – Aircraft Noise**
CAN2	1972	Noise Standards for light aeroplanes
CAN6	1980	Noise Standards for helicopters and supersonics with Type Certification submitted before 1 January 1975
CAEE2	1981	**First Edition of Annex 16, Volume II - Aircraft Engine Emissions**
CAEP1	1986	Noise Standards for light propellers
CAEP2	1991	Noise Standards for light helicopters
CAEP2	1991	Increase in Stringency of NO_x Emissions
CAEP4	1998	Increase in Stringency of NO_x Emissions
CAEP5	2001	Increase in stringency for turbojet and heavy-propeller noise Standards (Chapter 4)
CAEP6	2004	Increase in Stringency of NO_x Emissions
CAEP8	2010	Increase in Stringency of NO_x Emissions
CAEP9	2013	Increase in stringency for turbojet and heavy-propeller noise Standards (Chapter 14) Noise Standards for Tiltrotors (Chapter 13)
CAEP10	2016	nvPM engine emissions Standard
CAEP10	2016	**First Edition of Annex 16, Volume III - Aeroplane CO_2 Emissions**
CAEP Steering Group	2017	**First Edition of Annex 16, Volume IV (CORSIA)**
CAEP11	2019	nvPM mass and number emission Standard

Legend:

Noise	Local Air Quality	Climate Change

Aviation Noise Impacts White Paper

State of the Science 2019: Aviation Noise Impacts

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

SUMMARY

This paper provides an overview of the state of the science regarding aviation noise impacts as of early 2019. It contains information on impacts including community noise annoyance, sleep disturbance, health impacts, children's learning, helicopter noise, supersonic aircraft, urban air mobility and unmanned aerial systems. The paper also considers the economic costs of aviation noise. This information was collected during an ICAO/CAEP Aviation Noise Impacts Workshop in November 2017 and in subsequent follow-on discussions.

1. INTRODUCTION

The purpose of this document is to provide an overview of the state of the science in the area of aviation noise impacts. As part of its work programme, CAEP's Impacts and Science Group (ISG) was tasked with providing an updated white paper on the topic of aviation noise impacts. A white paper on aviation noise impacts was provided at the CAEP/10 meeting, and was later published in 2017 as an open access journal article[1], but it did not address some emerging areas in aviation. So instead of merely providing an update, the course taken was to extend the review to the above mentioned topics. An Aviation Noise Impacts Workshop was held for invited scientists and other observers and guests in Montreal, Canada November 1-3, 2017. The purpose of this workshop was to lay the foundation for this white paper, and over 50 attendees participated. One specific topic requested by the CAEP was for ISG to address the non-technical environmental aspects of the public acceptability for supersonic aircraft noise, and ISG began to explore this topic. In addition, the authors found much material on supersonics that had not previously been summarized for CAEP, and these details are provided in a separate document[1]. Subsequent follow-up discussions led to additions to this white paper beyond those discussed at the workshop, and this includes urban air mobility (UAM) and unmanned aerial systems (UAS) noise. The basic of metrics for aircraft noise were defined in a Glossary which can be freely accessed at the ICAO public website[2] and those will not be repeated here.

2. COMMUNITY NOISE ANNOYANCE

2.1 Definition

Community noise annoyance refers to the average evaluation of the annoying aspects of a noise situation by a "community" or group of people. Annoyance, in this context, comprises a response that reflects negative experiences or feelings such as dissatisfaction, anger, disappointment, etc. due to interference with activities (e.g., communication or sleep) or simply an expression of being bothered by the noise.

To facilitate inter-study comparisons standardized annoyance questions and response scales have been introduced by the International Commission on Biological Effects of Noise, ICBEN.[2] These recommendations have been adopted by the International Standards Organization[3], ISO TS 15666, and translated into a number of new languages, following a standard protocol.[4]

2.2 Exposure-response relationships

Over the years, many attempts have been made to relate the percentage of respondents highly annoyed by a specific noise source to the day-night average noise exposure level, L_{dn}, or a similar indicator, e.g., day-evening-night average noise exposure level, L_{den}.[5,6] The standard ISO 1996: 2016 has tables with % HA as a function of L_{dn} and L_{den} for various transportation noise sources.[7] A review by Gelderblom et al.[8] confirms these data for aircraft noise. Another review suggests different relationships, particularly for aircraft noise annoyance.[9]

2.3 Generalized versus local exposure-response relationships

While exposure-response relationships have been recommended for assessing the expected annoyance response in a certain noise situation, they are not applicable to assess the effects of a change in the noise climate. Existing survey results reveal a higher annoyance response in situations with a high rate of change, for instance, where a new runway is opened.[10,11,12] Such heightened annoyance response seems to prevail.

Since airports and communities may differ greatly with respect to acoustic and non-acoustic variables, local exposure–response relationships, if available, may be preferred for predicting annoyance and describing the noise situation with desired accuracy. Still, generalized exposure–response relationships are desirable to allow assessment across communities and to establish recommended limit values for levels of aircraft noise.

2.4 Moderating variables

Analyses show that the common noise exposure variables *per se* explain about one third of the variance of individual annoyance responses. The annoyance response is moderated by a series of other factors, both acoustic and non-acoustic. Acoustic factors can be maximum levels, number of flights, fleet composition, and their respective distribution over time. Non-acoustic factors are for instance, personal noise sensitivity and attitude towards the noise source. In the aviation industry all "non- L_{dn} factors" are commonly referred to as "non-acoustic".

Two old meta-analyses on the influence of non-acoustic factors on annoyance[13,14] showed the factors of fear of

1 www.icao.int/environmental-protection/Noise/Documents/ICAO_Noise_White_Paper_2019-Appendix.pdf
2 www.icao.int/environmental-protection/Noise/Documents/NoiseGlossary2019.pdf

danger of aircraft operations, followed by noise sensitivity and age, had the largest effects. More recent results indicate that fear is no longer a dominating modifying factor. Other important modifying factors may be distrust in authorities and expectations of property devaluation.[15] Guski et al. suggested[9] that the rate of change at an airport with respect to noise and operational procedures could be an important moderating factor. They defined two types: LRC and HRC, low/high rate of change airport. Gelderblom et al. have shown that the average difference in the annoyance response between these two types of airports, LRC and HRC, corresponds to a 9-dB-difference (9 dB ± 4 dB) in the noise exposure.[17] Guski et al. reported a similar, but smaller difference, about 6 dB.[9] The difference between the two studies is likely due to different selections and weighting of survey samples.

An important non-acoustic factor seems to be the attitude towards the noise source and/or its owner. Contrary to common beliefs, people that benefit from the air traffic are not more tolerant to aircraft noise.[18] A lack of trust in the authorities, misfeasance, and a feeling of not being fairly treated will increase the annoyance.[15] People may adapt different coping strategies, i.e. to master, minimize or tolerate the noise situation. Noise sensitive people have more difficulties coping with noise than others.[19]

If the respondents in a survey are selected according to proper random procedures, and the number of respondents is large enough to be an accurate representation of the population, individual factors will have the same effect in all surveys. However, other factors are location specific, for instance number of aircraft movements, prevalence of night time operations, LRC/HRC categorization, etc. The survey results from different airports will therefore vary unless these location specific factors are the same, or that they are accounted for statistically. Hence the search for a common exposure-response function, a "one curve fits all" solution, may not be applicable for all purposes.

2.5 Temporal trends in aircraft noise annoyance

Systematic surveys on aircraft noise annoyance have been conducted regularly over a good half century. Analyses by some researchers indicate that there has been an increase in aircraft noise annoyance over the past decades.[20,21] These authors state that at equal noise exposure levels, people today seem to be more annoyed by aircraft noise than they were 30-40 years ago.

Other researchers, however, claim that they can observe no change provided that the comparisons comprise similar and comparable noise situations.[17] Gelderblom et al. point out that the trend observations made by others can be explained by variations in non-acoustic factors, such as the fact that the prevalence of HRC airports are higher among recent surveys than among older ones. When LRC and HRC airports are analyzed separately they claim that there has been no change in the annoyance response over the past 50 years. Guski et al. on the other hand, claim that even at LRC airports the prevalence of highly annoyed people is higher for all exposure levels compared to older studies.[9]

Survey results from different airports show a large variation in the annoyance response. The result of a trend analysis based on a limited sample of surveys is therefore highly dependent on the selection criteria.

2.6 Noise mitigation strategies

Annoyance due to aircraft noise has been recognized by authorities and policy makers as a harmful effect that should be reduced or prevented. Priority is given to noise reduction at the source (e.g., engine noise, aerodynamic noise) and reducing noise impact by adjusting operational procedures and take-off and landing trajectories. Attempts to modify the noise spectrum to produce a more agreeable "sound" were made in the EU-funded COSMA project.[22] Such changes gave little or no effect. Sound insulation of dwellings is often applied, but such measures have no consequences for the outdoor experience of aircraft noise. The observed influence on annoyance of personal non-acoustic factors such as perceived control, and trust in authorities suggests that communication strategies addressing these issues could contribute to the reduction of annoyance, alongside or even in the absence of a noise reduction.

2.7 Conclusions

There is substantial evidence that there is an increase in annoyance as a function of noise level, e.g., L_{dn} or L_{den}. The noise level alone, however, accounts for only a part of the annoyance. Location and/or situation specific acoustic and non-acoustic factors play a significant role and must be taken into account.

There is conflicting evidence that there has been a change in the annoyance response in recent years. Under equal conditions, people today are not more annoyed at a given noise level than they were 30-40 years ago. However, due to changes in both acoustic and non-acoustic factors (more HRC airports, higher number of aircraft movements, etc.), the average prevalence of highly annoyed people at a given noise level (L_{dn} or L_{den}) seems to be increasing. Existing exposure-response functions should be updated and diversified to account for various acoustic and non-acoustic factors. The difference between a high rate change and a low rate change situation seems to be particularly important.

3. SLEEP DISTURBANCE

3.1 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.23,24 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 one of the most important non-auditory effects of environmental noise exposure.

3.2 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.[25] At the same sound pressure level (SPL), meaningful or potentially harmful noise events are more likely to cause arousals from sleep than less meaningful events. As aircraft noise is intermittent 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[26]) and individual (e.g., noise sensitivity) moderators.[25]

Sensitivity to nocturnal noise exposure varies considerably between individuals. The elderly, children, shift-workers, and those in ill health are considered at risk for noise-induced sleep disturbance.[24] Children are in a sensitive developmental stage and often sleep during the shoulder hours of the day with high air traffic volumes. Likewise, shift-workers often sleep during the day when their circadian rhythm is promoting wakefulness and when traffic volume is high. Sleep depth decreases with age, which is why the elderly are often more easily aroused from sleep by noise than younger subjects.

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.[26,27] 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.28 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.[29,30] However, noise-induced arousals are not part of the physiologic sleep process, and may therefore be more consequential for sleep recuperation.132 Short-term effects of noise-induced sleep disturbance include impaired mood, subjectively and objectively increased daytime sleepiness, and impaired cognitive performance.[31,32] 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 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.[16,33]

3.3 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.[34,35] 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).[34] 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.[27,36] At the same time, the per cent highly sleep disturbed assessed via self-reports is typically higher for aircraft noise compared to road and rail traffic noise at the same L_{night} level.[37]

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 intermittent 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 economic and societal benefits of air traffic. Accordingly, night-time noise legislation differs between Contracting States.

3.4 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 near 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 night-time. 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. It is important to line up the curfew period with the (internationally varying) sleep patterns of the population.

3.5 Recent evidence review

For sleep disturbance, a systematic evidence review based on studies published in or after the year 2000 was recently published.[37] According to GRADE[38] criteria, the quality of the evidence was found to be moderate for cortical awakenings and self-reported sleep disturbance (for questions that referred to noise) induced by aircraft noise, low for motility measures of aircraft noise induced sleep disturbance, and very low for all other investigated sleep outcomes. Significant exposure-response functions were found for aircraft noise for (a) sleep stage changes to wake or superficial stage S1 (unadjusted OR 1.35, 95% CI 1.22-1.50 per 10 dB increase in $L_{AS,max}$; based on N=61 subjects of a single study) and (b) per cent highly sleep disturbed for questions mentioning the noise source (OR 1.94, 95% CI 1.61-2.33 for a 10 dBA increase in L_{night}; based on N=6 studies including > 6,000 respondents). For percent highly sleep disturbed, heterogeneity between studies was found to be high (I^2=84%).

4. HEALTH IMPACTS

4.1 Introduction

There is good biological plausibility for health impacts of environmental noise, with potential mechanisms involving sleep disturbance, 'fight and flight' physiological response and annoyance.[39,40] The number of epidemiological studies investigating impacts of environmental noise on disease risk and risk factors has increased greatly since the previous ICAO white paper[1] and these have been used to define exposure-response relationships. Some variability is expected between epidemiological studies due to differences in populations, methodology, exposures and study design. Therefore, a combined estimate from a meta-analysis of studies with a low risk of bias is used to provide a state of the art estimate of the exposure-response relationship.

This section highlights main findings from the systematic literature reviews and meta-analyses published in 2017-2018. These reviews reference the noise and health literature up to August 2015 for cardiovascular outcomes[41] and December 2016 for birth outcomes.[42] This section also considers new publications up to end July 2018, including from the NORAH (http://www.laermstudie.de/en/norah-study/) and SIRENE (http://www.sirene-studie.ch/) studies in Germany and Switzerland respectively. Almost all studies available were conducted in European and North American populations.

In the following paragraphs it is important for the reader to be mindful of scientists' use of the terms association, correlation, and causation. The statistical finding of an association means that two variables are related. It needs additional clarification to say if it is statistically significant. For research investigating links between noise and impacts, linear correlation is usually too strong of a term to use, so the preferred term is association. Hence, associations do not necessarily mean causation. Determining causality requires a combination of evidence including biological plausibility, consistency across studies, and if available from experimental or natural experiment studies.

4.2 Aircraft noise and cardiovascular impacts

The systematic review on cardiovascular and metabolic effects of environmental noise was performed by van Kempen et al.[41] and described in detail in an RIVM (Dutch National Institute for Public Health and the Environment) report.[46] The authors reviewed studies on the association between environmental noise (different source types) and hypertension in adults (none were identified focusing on children), ischaemic heart disease, stroke and obesity published up to August 2015. Findings for aircraft noise were reported to be consistent with findings for road traffic noise, where there are more studies available.

For hypertension: the van Kempen et al.[41] meta-analysis included nine cross-sectional studies and provided an estimated increased risk of 5% (95% confidence intervals -5% to +17%) per 10 dB (L_{den}) aircraft noise (comprising 60,121 residents, including 9487 cases of hypertension). The one cohort study identified[50] (4721 residents and 1346 cases in Sweden published in 2010) did not show an overall association with hypertension incidence, but there were significant associations in subgroup analyses of males and of those annoyed by aircraft noise. The authors of the review ranked the quality of the evidence for noise from air traffic as "low" using the GRADE ranking system, meaning that further research is considered very likely to have both an important impact on confidence in the estimate of effect and to change the size of the estimate. Subsequent to the systematic review, a large case-control study (137,577 cases and 355,591 controls) from the NORAH study[51] found no associations overall for aircraft noise with hypertension, but an increased risk for the subgroup of those who went on to develop hypertension-related heart disease, i.e. more severe cases. A subsequent publication from a small cohort (N=420) with up to 9 years follow-up in Athens who formed part of the original HYENA (Hypertension and Exposure to Noise Near Airports) study found a 2.6-fold increased risk of hypertension in association with a 10 dB increase in night-time aircraft noise.[52]

Hypertension shows a positive but non-statistically significant association overall reflecting inconsistency between studies. This can be a difficult outcome to define precisely – the PURE multi-country study published in 2013 found nearly half of all cases of hypertension were unrecognised.[198] There are various issues about defining hypertension by medication use, and recognised issues about measuring blood pressure in individuals. Also, hypertension may not be the only or most important mechanism contributing to potential impacts of noise on the heart – inflammation, small blood vessel function and sleep disturbance also need to be considered.[196,197]

For ischaemic heart disease (IHD) and heart failure, findings were more consistent than for hypertension: the van Kempen et al. systematic review[41] reported a statistically significant increased risk of new cases of ischaemic heart disease of +9% (95% confidence intervals +4% to +15%) per 10 dB L_{den}, derived from a meta-analysis of two very large registry-based studies of 9.6 million participants and 158,977 cases. Taking into account evidence relating to existing as well as new cases and to mortality, the authors of the systematic review concluded "Overall, we rate the quality of the evidence supporting an association between air traffic noise and IHD as 'low'" [using the GRADE ranking system] "indicating that further research is very likely to have an important impact on our confidence in the estimate of effect and is likely to change the estimate". Subsequent published analyses from the SIRENE project using data from the Swiss National Cohort covering 4.4 million people[53], reported associations between aircraft noise and myocardial infarction mortality with increased risk of +2.6% (95% confidence intervals +0.4% to +4.8%) per 10 dB L_{den}. Highest associations between noise and IHD were seen with intermittent night-time exposures.[54] A large case-control study in Germany (19,632 cases and 834,734 controls) forming part of the NORAH study found associations of aircraft noise with diagnosis of myocardial infarction at higher noise levels (>55 dB) in the early morning hours, although not for 24 hour average noise levels. A further large NORAH study analysis[55] found a statistically significant linear exposure-response relationship with aircraft noise for heart failure or hypertensive heart disease of +1.6% per 10 dB increase in 24 hour continuous noise level (analysis based on 104,145 cases and 654,172 controls).

For stroke: the van Kempen et al. systematic review[41] considered seven studies of different designs including one cohort study (the Swiss National Cohort). Findings were mixed but the meta-analysis did not show statistically significant associations of aircraft noise with stroke outcomes. This result is consistent with subsequently published SIRENE study findings on stroke mortality also using the Swiss National Cohort but with improved noise exposure estimates.[53]

Comparisons with findings for road traffic noise: findings for aircraft noise and the cardiovascular disease outcomes presented above are consistent with those for road traffic noise as reported in the van Kempen et al systematic review.[41] In particular, for ischaemic heart disease, the systematic review rated the quality of the evidence supporting an association between road traffic noise and new cases of ischaemic heart disease to be high, providing an increased risk of +8% (+1% to +15%) per 10 dB L_{den} road traffic noise (as compared with findings for aircraft noise for this outcome of +9% (+4% to +15%) as noted above). Analogy with road traffic noise is meaningful, because, as well as impacts on annoyance, noise also functions as a non-specific stressor with non-auditory impacts on the autonomic nervous system and endocrine system. These stressor effects are seen with noise from different sources and result in adverse effects on oxidative stress and vascular function in experimental studies.[196,197]

4.3 Aircraft noise and metabolic effects (diabetes, obesity, waist circumference, metabolic biomarkers)

The van Kempen et al. systematic review[41] identified one Swedish cohort study considering aircraft noise,[56] which found a significant association between aircraft noise exposure and increased waist circumference over 8-10 years follow-up, but not for Body Mass Index (BMI) or type 2 diabetes. The authors of the systematic review concluded that further research would be likely to have an important impact on both size and statistical confidence in the estimate of effect. Three more recent publications also report some associations of aircraft noise with metabolic disturbance.[57-59] A 2017 Swiss cohort study analysis forming part of the SIRENE project suggested an approximate doubling of diabetes incidence per 12 dB L_{den} increase in aircraft noise exposure[57] and positive although non-significant associations of aircraft noise exposure with glycosylated haemoglobin, a measure of glucose control over the past three months and a predictor of diabetes.[58] A 2017 study in Korea of 18,165 pregnant women identified through health insurance records,[59] found an association between night-time but not daytime aircraft noise exposure during the first trimester of pregnancy and risk of gestational diabetes mellitus.

Findings are consistent with a hypothesis that noise exposure is related to stress-hormone-mediated deposition of fat centrally and other impacts on metabolic functioning and/or adverse effects of disturbed sleep on metabolic and endocrine function, also with results from a small number of studies considering road traffic noise that also found associations with diabetes, but more studies are needed to strengthen the evidence base for this outcome.

4.4 Aircraft noise and birth outcomes

A systematic review by Nieuwenhuijsen, et al.[42] published in 2017 considered literature published up to December 2016. Six aircraft noise studies were included, but there were too few studies to conduct a meta-analysis. Four studies (published 1973-2001) considered birth weight and all studies found associations with aircraft noise exposure, but noise exposure levels in these studies were high (> 75 dB, various metrics). A further two studies conducted in the 1970s considered birth defects, of which one found significant associations – again, noise levels considered were high. Evidence was considered such that any estimate of effect is very uncertain. The authors commented that "there may be some suggestive evidence for an association between environmental noise exposure and birth outcomes" with some support for this from studies of occupational noise exposure (which were higher than most current environmental aircraft noise exposures), but that further and high quality studies were needed. No further studies relating birth outcomes to aircraft noise have been published to date.

4.5 Aircraft noise and mental health

There remain very few studies of aircraft noise exposure in relation to wellbeing, quality of life, and psychological ill-health. Since the previous ICAO paper and publication[1] in 2017, there has been one major German analysis[60] published from the NORAH study, which found a significant association with depression as recorded in health insurance claims. Risk estimates increased with increasing noise levels to a maximum Odds Ratio (OR) of 1.23 (95% CI=1.19-1.28) at 50-55 dB (24 hour average), but decreased at higher exposure categories. The reason for this is unclear but it may potentially be due to uncertainties related to very small numbers of exposed and cases at higher noise levels. A cohort study following 1185 German school children[61] from age 5-6 to 9-10 years did not find associations of aircraft noise exposure with mental health problems (such as emotional symptoms, hyperactivity and conduct problems), but as the study used parental noise annoyance at place of residence as the measure of exposure as opposed to objectively assessed (modelled or measured) quantitative exposure levels, it is difficult to draw firm conclusions.

4.6 Conclusions

There has been a large increase in studies in recent years examining associations of noise exposure with health outcomes. The best epidemiological evidence relates to cardiovascular disease, which includes analyses from population-based studies covering millions of individuals, in particular for new cases of ischaemic heart disease. Findings for aircraft noise are consistent with those for road traffic noise (for which more studies have been conducted and where the quality of evidence is rated as high). Results from epidemiological studies are also supported by evidence from human and animal field and laboratory experimental studie[45-49] showing biological effects of noise on mechanistic pathways relating to risk factors for cardiovascular disease. This experimental evidence, together with consistency with findings for road traffic noise, supports the likelihood that associations for aircraft noise with heart disease observed in epidemiological studies are causal. However, the exact magnitude of the exposure-response estimate for heart disease varies between studies and best estimates (obtained by combining results from good quality studies in a systematic review) are likely to change as further studies add to the evidence base.

There are important gaps in the evidence base for other outcomes. Perhaps surprisingly, few studies have been conducted in relation to impact of aircraft noise on mental health. There are also few studies relating to maternal health and birth outcomes including birth weight.

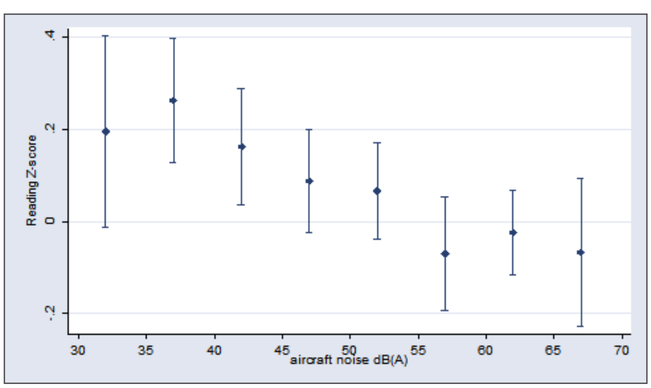
Generally, health studies to date have used L_{den}, L_{day} and L_{night} metrics, most likely as these were available and had been extensively validated in annoyance studies. There is a need to examine other noise metrics that may be more relevant to health endpoints – some of the more recent studies are starting to include other metrics, including intermittency ratio,[43] maximum noise level and to examine specific time periods,[44] especially for night-time exposures. These new metrics should be additional, but not replace the standard equivalent metrics (L_{Aeq}, L_{den}) to allow for comparability of results, at least at present while the evidence base is being compiled.

5. CHILDREN'S LEARNING

5.1 Chronic aircraft noise exposure and children's learning

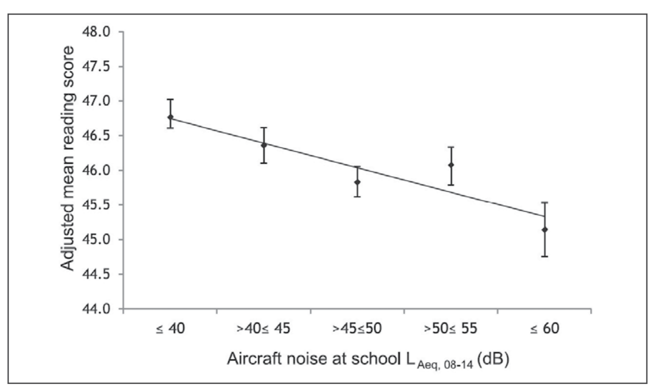
Several studies have found effects of aircraft noise exposure at school or at home on children's reading comprehension or memory skills[62] or standardized test scores.[63,64] The RANCH study (Road traffic and Aircraft Noise and children's Cognition & Health) of 2844 9-10 year old children from 89 schools 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 exposure, into account.[65] A 5 dB increase in aircraft noise exposure was associated with a two month delay in reading age in the UK, and a one month delay in the Netherlands.[66] These associations were not explained by co-occurring air pollution.[67] 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.[68] The recent NORAH study of 1242 children aged 8 years from 29 primary schools around Frankfurt airport in Germany found that a 10 dB (L_{Aeq} 08.00am-14.00pm) increase in aircraft noise was associated with a one-month delay in terms of reading age. The RANCH and NORAH studies examine the effect of aircraft noise on children's reading comprehension starting from a very low level of exposure. This enables the studies to adequately assess where effects of aircraft begin (i.e. identify thresholds): we should not be concerned by the inclusion of the examination of such low levels of aircraft noise exposure as both the RANCH and the NORAH study adjust the results for other noise exposures (e.g., road noise in RANCH and road and rail noise in NORAH) making the assessment meaningful in terms of considering other noise exposures and ambient noise exposure per se. Effects of aircraft noise on children's learning have been demonstrated across a range of aircraft noise metrics including L_{Aeq}, L_{max}, number of events above a threshold, and time above a threshold. [64]

FIGURE 1: Exposure-effect relationship between aircraft noise exposure at school and reading comprehension in the RANCH study. The vertical axis shows the adjusted mean reading z scores and 95% confidence intervals for 5-dB(A) bands of aircraft noise at school (adjusted for age, gender, and country)[66]



Data from the RANCH study and the NORAH study enable the exposure-effect association between aircraft noise exposure and children's reading comprehension to be estimated[69,70] (see Figures 1 and 2). Both studies suggest that the relationship between aircraft noise and reading comprehension is linear, so reducing exposure at any level should lead to improvements in reading comprehension. In the RANCH study, reading comprehension began to

FIGURE 2: Exposure-response function between aircraft noise exposure at school and reading comprehension in the NORAH study [70]



fall below average at exposures greater than 55 dB L_{Aeq} 16 hour at school.

It is possible that children may be exposed to aircraft noise for many of their childhood years, but few studies have assessed the consequences of long-term noise exposure at school on learning or cognitive outcomes. Whilst it is plausible that aircraft noise exposure across a child's education may be detrimental for learning, evidence to support this position is lacking. A six-year follow-up of the UK sample of the RANCH study, when the children were aged 15-16 years of age, failed to find a statistically significant association but did suggest a trend between higher aircraft noise exposure at primary school and poorer reading comprehension at follow-up,[71] as well as a trend between higher aircraft noise exposure at secondary school and poorer reading comprehension at secondary school. This study was limited by its small sample size, which may be why it detects trends rather than significant associations. There remains an urgent need to evaluate the impact of aircraft noise exposure throughout a child's education on cognitive skills, academic outcomes and life chances.

5.2 How might chronic aircraft noise exposure cause learning deficits?

Aircraft noise may directly affect the development of cognitive skills relevant for learning such as reading and memory. A range of other plausible pathways and mechanisms for the effects have also been proposed. Communication difficulties might also account for the effects: teacher behavior is influenced by fluctuations in external noise, with a recent observational study finding associations between aircraft noise events and teacher voice-masking (when the teacher's voice is distorted or drowned out by noise) and teacher's raising their voice).[72] Effects might also be accounted for by 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.[73,74] 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.

5.3 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 Munich Airport study[75] 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 first two-year period following the opening of the new airport. A recent 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.[64] In a sub-sample of 119 schools, they found that the effect of aircraft noise on children's learning disappeared once the school had sound insulation installed. These studies evidence the effectiveness of the insulation of schools that may be exposed to high levels of aircraft noise.

Sound-field systems, which ensure even distributions of sound from the teacher across the classroom, could provide a solution to improving children's learning in situations of aircraft noise. However, an evaluation of these systems in schools in the UK, which were not exposed to aircraft noise, found that whilst the systems improved children's performance on tests of understanding of spoken language they did not influence academic attainment in terms of test of numeracy, reading or spelling.[76] Whether such systems may be an effective intervention for children attending schools with high levels of aircraft noise exposure remains to be evaluated.

5.4 Conclusions

There is robust evidence for an 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. Whilst a range of plausible mechanisms have been proposed to account for aircraft noise effects on children's learning, future research needs to test these pathways, to further inform decision-making concerning the design of physical, educational and psychological interventions for children exposed to high levels of aircraft noise. Further knowledge about exposure-effect relationships in different contexts, using either individually collected cognitive performance data or standardized school test data, would also further inform decision-making. It would also be productive 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 lifecourse studies of aircraft noise exposure at school and cognitive skills, educational outcomes and life chances.

6. HELICOPTER NOISE

6.1 Exposure-response relationships

Exposure-response relationships derived for annoyance by aircraft noise were viewed as not necessarily valid for specific sources such as helicopters, low-flying military aircraft or aircraft ground noise.[6] Although relatively little is known on annoyance induced by helicopter noise, some surveys performed in the past have shown that helicopter noise is more often reported as annoying than fixed-wing aircraft noise, at similar or even lower A-weighted outdoor noise levels.[78-82] This was found for heavy military helicopters as well as for lighter civilian helicopters. A more recent survey[83] was done in three residential areas under or adjacent to helicopter corridors that were used by light civilian helicopters. The study was limited to only three surveys, but it was clear that for light civilian aircraft there was not a pronounced difference between response to fixed wing and rotary wing aircraft. The study did show that there was a residual annoyance associated with helicopter operations that was not associated with noise exposure level.

6.2 Role of non-acoustic factors

Some field studies[81,84] have shown that helicopter noise annoyance is heightened by certain non-acoustic factors, in particular fear of a crash, lack of information on the reason of the flights, and low perceived necessity of the helicopter flights themselves (such as when the helicopter is viewed as 'rich person's toy') or of the noise that is produced by them (for instance when it is felt that the pilot or operator could reduce the disturbance by choosing a different flight pattern).

A more recent study[83] also found that for three surveys completed under or near light civil helicopter routes there was 'residual annoyance,' not a function of noise exposure level, an annoyance that was constant for all noise exposures with no evident tendency to approach zero at even very low noise levels. This lack of correlation between noise exposure level; and annoyance was associated with the strong influence of non-acoustic factors. These and earlier findings suggest that observed differences in annoyance between helicopters and fixed-wing aircraft may heavily depend on non-acoustic factors.

6.3 Role of impulse noise

Several laboratory studies have explored whether the degree of impulsiveness of the helicopter noise may contribute to annoyance.[85-89] No consistent differences in annoyance were found between helicopter and aircraft noise, again suggesting that observed differences in the field were partly due to non-acoustic factors, nor did annoyance depend on the degree of impulsiveness. Therefore, the overall consensus is that there is no evidence to justify the application of an impulse correction to the noise level of helicopters with impulsive characteristics.[90-91]

6.4 Role of rattle noise and vibrations

There is evidence that helicopter noise characterized by large low frequency components may impact the building and produce rattle (i.e. sounds of rattling objects or windows within the dwelling) or vibration (the perception of vibrating building elements or furniture), which in turn may lead to increased annoyance by the helicopter noise.[92] While rattle noise and vibration may also be induced by the low-frequency components of ground noise during aircraft landing and take-off,[93,94] it is only sporadically induced by overflying fixed-wing aircraft.[95] In a large field study in the United States[96] it was found that noise from helicopters flying over was rated by subjects (seated in a wooden frame building) as more annoying than a control stimulus, but only when the helicopter induced rattle noise or vibration within the building. The results suggest a decibel offset of at least 10 dB to account for the extra annoyance when rattle or vibration were induced by the helicopter noise (i.e. the control stimulus had to be at least 10 dB higher to induce equal annoyance). An extension of this study suggested similar offset values of 10 and 8 dB for two helicopter types inducing rattle and vibration.[80] A recent study in the Netherlands suggests a lower offset, around 5-6 dB, for helicopter noise in combination with rattle noise induced within the building.[97] This conclusion is not supported for light civil helicopter surveys[83] where survey respondents did not report vibration or rattle as a source of annoyance. The relatively small degree of low frequency energy associated with light civil helicopters as compared to heavy lift helicopters is not expected to produce rattle noise, which is the most plausible explanation for the difference.

7. EN-ROUTE NOISE FROM SUPERSONIC AIRCRAFT

7.1 Introduction

Sonic booms are the unique sounds produced by supersonic aircraft. This section summarizes many of the properties and impacts of sonic booms, as we know them today.

Conventional sonic booms are widely considered to be loud, and this forms the basis of current regulations in many countries that prohibit supersonic overland flight. However, new research has enabled aeronautical engineers the tools to develop quiet “low-boom” aircraft designs that may be available in 5 to 10 years. Hence, sonic boom research needs to clearly distinguish whether the sonic booms are the conventional N-wave sounds, so called because of their letter N pressure versus time shape, or the new low-booms which are considerably smoothed. The low-booms, or “sonic thumps”, can be as much as 35 dB quieter than conventional booms.

7.2 Human response studies

Studies have shown that sonic booms can be reproduced quite accurately in the laboratory, and this makes it possible to perform subjective experiments under controlled conditions. Although no supersonic aircraft has produced a low-boom signature yet, a similar surrogate sound can be created using a special aircraft dive manoeuver. This makes it possible to conduct tests with real aircraft outdoors for either N-waves or low-booms, complementing the laboratory tests.

A number of subjective tests have been conducted. One trend seen in studies from both the U.S. and Japan is that annoyance to sonic boom noise is greater indoors compared to outdoors. The findings show that indoor annoyance can be estimated based on the outdoor sonic boom exposure. There has been recent work to establish that both rattle and vibration contribute to indoor annoyance of sonic booms. One interesting point is that although conventional N-waves can be accompanied by a startle response, it turns out that low-booms are of low enough amplitude that they don’t induce a consistent physiological startle response.

There has been substantial work in recent years to establish metrics to assess sonic boom noise. Out of a list of 70 possible metrics, a group of 6 metrics has been identified for the purposes of use in certification standards and in developing dose-response curves for future community response studies. Clearly the low-booms are much quieter than the conventional N-wave booms, but additional community studies with a low-boom aircraft need to be conducted to assess public response.

7.3 Non-technical aspects of public acceptability for sonic boom

An additional aspect that should be considered for sonic booms includes the non-technical aspects of acceptability. The CAEP Steering Group specifically requested that ISG look into this topic. A preliminary discussion has revealed a strong resemblance to the non-acoustical factors of subsonic aircraft noise, previously mentioned in Section 2 “Community Noise Annoyance” of this white paper. There are currently no peer-reviewed studies on the topic of non-acoustical factors for sonic boom noise, but it seems plausible that the knowledge of subsonic aircraft non-acoustical factors could be extended for application to sonic boom noise non-technical aspects.

7.4 Impacts of sonic boom on animals

Recently there has been renewed interest regarding the impacts of sonic boom noise on animals. Fortunately there is an extensive literature extending from before the days of Concorde to recent years, mostly for conventional N-wave aircraft.

There have been substantial studies for both livestock and other domesticated animals, and detailed studies of some wildlife species. For conventional sonic booms the animals usually show no reactions or minimal reactions, although occasionally they may startle just as humans do. There are no reported problems of developing fish eggs or of avian eggs due to sonic boom exposures. NASA conducted a number of studies in the late 1990s and early 2000s to assess the impact of overwater sonic booms on marine mammals. There is a good bit of knowledge as to how much sonic boom noise transitions from air into water, and fortunately, very little of the sound gets into the water. For the California sea lion, elephant seals, and harbor seals, careful lab experiments showed no temporary hearing shifts in those species.

In 1997 and 1998 a study of a colony of seals exposed to Concorde booms on a regular basis showed that the booms didn't substantially affect the breeding behavior of gray or harbor seals. It instead seems that these animals substantially habituated to hearing these N-wave sonic booms on a routine basis.

Most of what is known about noise impacts on animals comes from the literature of the effects of subsonic aircraft and other anthropogenic noise sources, not sonic booms, on animals. It is well known that human activities can interfere with animal communication, for example.

There have not been many specific studies on the effects of sonic boom noise on animals in recent years. Some species with good low-frequency hearing, such as elephants, have never been evaluated regarding sonic boom noise. But it makes sense that if the already tested animals were not negatively affected by sonic boom noise from conventional N-waves, that they will likely not be affected by the proposed lowbooms of the future. Long-term effects of sonic boom exposure on animals seem unlikely.

7.5 Conclusions

Much progress has been made to model and mitigate the effect of sonic booms from supersonic flight. Ongoing research to assess the impact on the public indicate that new supersonic aircraft designs will create quieter sonic thumps that are much less annoying than conventional sonic booms. Upcoming community tests with a low-boom demonstrator aircraft will collect the data needed on noise exposure and resulting public reactions.

8. UAM/UAS NOISE

8.1 Current status

New aircraft technologies for increased mobility are likely to lead to new sources of community noise. Urban Air Mobility (UAM) refers to a range of vehicle concepts and missions operating in a community, from small Unmanned Aerial Systems (sUAS) to vehicles large enough for several passengers. The sUAS are envisioned for package delivery, surveillance, agriculture, surveying, and other similar applications that can benefit from use of a small and agile autonomous system, while the larger vehicles are envisioned for on-demand urban passenger transportation.[165] Electric propulsion is seen as a key technology that could enable these kinds of systems, across the range of vehicle types and sizes.[165]

UAM vehicles have the potential to alter the community soundscape due to their noise characteristics that are qualitatively different from traditional aircraft.[166-168] In addition, similar to sonic booms from supersonic aircraft en route, the noise may not be concentrated around traditional airports. There is very little scientific research on the human impacts of noise from UAM aircraft, although there have been increased efforts to measure and model the noise generated by them and their components.[167,169-172] Two psychoacoustic studies are briefly described here.

A study[166] was conducted by NASA to evaluate human annoyance to sUAS noise, including the effect of variation in operational factors and a comparison of annoyance to noise from road vehicles. The noise from four commercially available sUAS and four road vehicles, ranging in size from a passenger car to a step van, were recorded and presented to test subjects in a specialized simulation facility. For this limited set of noise sources, a systematic offset was found that indicates the noise of sUAS is more annoying than noise from road vehicles when presented at the same loudness.

Another NASA psychoacoustic study[168] concentrated on annoyance to noise from a simulated distributed electric propulsion (DEP) aircraft. Using auralizations from noise predictions of spatially-distributed, isolated propeller noise sources, the subjective study in a specialized psychoacoustic facility found that the number of propellers and inclusion of time-varying effects were significant factors in annoyance, while variation of the relative revolutions-per-minute (RPM) between propellers was not significant. The study also developed an annoyance model based on loudness, roughness, and tonality for predicting annoyance to these DEP sounds. Despite the limitations in prediction methods and simplifications, the study identified the relevant parameters and metrics that should be studied further.

8.2 Conclusions

Growing interest in UAM aircraft has been observed from different sectors, such as hobbyists, commercial entities, the military, government agencies, and scientists.[165] There is preliminary evidence that the public may be concerned with these new noise sources intended for transportation and package delivery.[173] Although there is only a very limited amount of research on subjective reaction to noise from these new aircraft types, indications that the noise characteristics differ from traditional aircraft warrant further research to understand and predict human perception of these sounds.

9. ECONOMIC COST OF AVIATION NOISE / MONETIZATION

9.1 Introduction

Sleep disturbance, myocardial infarction, annoyance, stroke, dementia, and other health effects are increasingly recognized as economic costs of noise.[174] Recent studies estimating annual noise costs around specific major world airports are useful in considering the scale of the challenge and include: Taipei Songshan Airport €33 million[175] and Heathrow £80.3 million.[176] An unpublished student thesis by Kish (2008) suggests annual costs for aviation noise at 181 airports worldwide in excess of $1 billion, which is not out of line with the individual airport estimates.[177] It is clear that noise can be a key factor when airport expansion is considered. Values of disturbance from aircraft noise are used in analysis and planning decisions affecting airport development and operations. Their main application is in estimating the costs or benefits arising from changes in noise levels and/or exposure. It is therefore important to look at the evidence that underpins these value estimates. There are three main approaches for monetizing noise costs, two of which value the nuisance according to individual preferences: revealed preference, usually hedonic pricing, and stated preference methods, which include contingent valuation and stated choice. The third type of approach, the impact pathway, links health effects of noise nuisance to monetary values from reducing morbidity risks that are typically derived from elsewhere. These are discussed in turn below.

9.2 Hedonic Pricing (HP)

The main method using revealed preference is hedonic pricing whereby the market for an existing good or service, in this case housing, is used to derive the value for components of that good, in this case the noise environment. House price in HP is modelled as a function of property characteristics that should include all social, spatial, and environmental factors. HP then provides the percentage change in house prices resulting from a 1 dB change in noise levels.[178,179] The method has been extensively applied to the problem of aircraft noise, especially in North America. Individual studies yield a wide range of price changes from 0% to 2.3% per dB.[180] Thus a key challenge is to derive values that are applicable or transferable in different contexts.

Meta-analyses have sought to estimate consensus values based on pooled evidence from individual studies.[181-183] These meta-analyses are based on a reasonably small number of, US dominated studies, observations of 30, 29 and 53 respectively. Nelson (2004) and Wadud (2013) converge on 0.5 to 0.6% house price fall in response to a

1 dB increase in aviation noise, with caveats concerning the broad range of estimates and a dearth of studies in less developed countries. Using data on income, Kish (2008) carried out a meta-analysis on US based HP evidence, estimating a model with a low but reasonable fit, which he found did not transfer well to UK data. He et al. (2014) built on this work[184] but their model fit was poor. The evidence from these studies also suggests that values in Canada are higher[182,183] or more generically that values outside the US are higher.[184] Interestingly, Kopsch (2016) reports a meta-analysis including air and road noise, finding that aviation noise increases the NDI by 0.4 to 0.6% relative to road.[185] To conclude, the best available evidence from the HP is that house prices fall by 0.5 to 0.6%, on average, per 1 dBA increase in aircraft noise, and there is also some support for country specific effects.[182,183]

9.3 Stated Preference (SP)

Stated preference approaches have been increasingly applied to value noise nuisance especially in Europe. These involve either direct questioning on value, contingent valuation, or trade-off approaches, stated choice or ranking. As with HP, individual studies exhibit a wide range in values per unit of noise. A data set of 258 values of transportation noise derived from SP studies, adjusted to 2009 prices, yielded an average value per decibel change per household per annum of $141.59, 95% Confidence Interval (CI) +/- $30.24 with a range from $0 to $3,407.67. However the aviation noise values within this data, 69, exhibit less variation with a mean of $292.24 and a CI of +/- $23.10 and smaller range of $15.05 to $1097.83. Such variation in values may reflect genuine variations in preferences, the impact of contextual variables, variations in approach, systematic study or country effects, and changing preferences over time or some combination of these effects.[186] Again, meta-analysis can assist in explaining some of this variation. Only one meta-analysis has been conducted on studies of transportation noise, utilising 258 values derived from 49 studies across 23 countries conducted over a 40-year period.[186] As might be expected, the value of noise reduction or the cost of noise increases were found to be dependent on level of annoyance and income. The income elasticity was close to one, suggesting that the value placed on reduced noise increases broadly in line with income; this is higher than estimates from cross sectional studies. There were no country effects found in this meta-analysis, suggesting that the model and values derived from it are transferable. Additionally, aviation noise was found to have a higher cost per dBA than road and rail noise. A result that is consistent both with studies of annoyance,[6] and HP meta-analysis.[185] Furthermore, comparison with the then HP-based approach applied by the UK Department for Transport at the time (2014) indicated that the values from the SP meta-analysis and the HP-based approach were broadly comparable. [186] This is also supported by the primary research of Thanos *et al.* (2015), applying SP and HP in the same context.[195]

9.4 Impact pathway

The third approach is rather different by exploring the impact pathway (IP) for noise effects on human health, and expressing those endpoints in terms of Disability Adjusted Life Years (DALYs) or Quality Adjusted Life Years QALYs) to quantify healthy life years lost. The World Health Organization adopted this approach[174] and identified disability weights (DW) for cardiovascular disease, sleep disturbance, tinnitus and annoyance resulting from environmental noise. The evidence on the health impacts in all areas has been growing over the years. However, the evidence base underpinning the DWs for sleep disturbance and annoyance is extremely sparse, with a high degree of uncertainty.[180] This is reflected in the WHO (2011, p: 93) weight on annoyance where "a tentative DW of 0.02 is proposed with a relatively large uncertainty interval (0.01-0.12)". This DW is only applicable those who are "highly annoyed", so any individuals experiencing annoyance who are not highly annoyed are assigned a value of zero.

There is uncertainty around the value of a healthy life year lost, which is combined with the DW weights to derive monetary values. In practice, value of life has been derived from stated preference studies of traffic fatalities in the UK,[188] or reduced mortality risk based on stated preference studies in Europe.[189] As these values do not stem from analysing the health risks of noise nuisance, there is an added element of uncertainty regarding transferability of values from diverse contexts. Furthermore, the impact pathway approach has many steps each with potential to add error and uncertainty to the value/cost estimates. As Freeman et al., (2014, p: 441) put it, "significant work is needed to improve and update the values of reducing risks that lead to morbidity and/or mortality."[190] Nevertheless, the method has been adopted into policy analysis by the UK Department of Transport[191] in assessing transport schemes and by the European Commission in evaluating the environmental noise directive.[192]

9.5 The abatement and mitigation costs of dealing with noise

The costs imposed by noise lead to efforts to measure, manage and mitigate. Airports can bear substantial costs, for example at the high end of the scale, Amsterdam Schiphol spent approximately €644.6m largely on insulation between 1984 and 2005.[193] Nevertheless this only amounted to €0.58 per passenger. Whilst manufacturers have produced quieter aircraft, there is a trade-off between achieving energy efficiency and quieter design and operation. The benefits of any mitigation activity should outweigh the costs. The costs of mitigation are relatively straightforward to estimate, as they have a market price of implementation and maintenance, in the case of noise insulation or barriers, or of estimating forgone benefits, for instance, of noise curfews. It is also rational to compare the costs of different routes to achieving a noise reduction target, for example through regulation or market incentives. Once both the costs of noise and any additional costs of mitigation are established; cost benefit analysis (CBA) can be used to guide towards solutions with the highest net benefits.

9.6 Conclusions

Economic valuation of noise nuisance and health effects is necessary and robust values are available. Most importantly, these values are applied and used in decision making. Meta-analysis of both hedonic pricing and stated preference studies suggests that these approaches, when properly applied, deliver robust values of noise nuisance. These preference-based approaches do not capture the health effects of noise that are not perceived by the exposed population. The impact pathway approach provides nonmarket values for these health effects. However, IP does not value annoyance at levels less than "highly annoyed", has a less well developed evidence base than HP and SP, and requires more steps that have the potential to introduce more error. Furthermore, HP and SP meta-analyses have improved the transferability of values providing confidence intervals for their variation, whereas there is no robust evidence on value transferability for the IP approach. This approach should be viewed with caution in the absence of a well-developed evidence base, and especially in the case of annoyance effects perceived by the exposed populations, for which robust values of noise nuisance can be delivered by tested methods.

10. OVERALL CONCLUSIONS AND FUTURE WORK

This paper has provided an overview of the many different aircraft noise impacts. There is substantial evidence that increases in noise levels lead to increases in community annoyance, but there are other nonacoustical contributors to annoyance. In future work, existing exposure-response functions should be updated and diversified to account for various acoustic and non-acoustic factors. The difference between a high rate change and a low rate change situation seems to be particularly important.

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 exposureresponse 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.

Epidemiological evidence from a systematic review published in 2018 covering studies up to 2016 and subsequent published studies involving several million participants show associations of aircraft noise with ischaemic heart disease. This is consistent with the evidence for road traffic noise, with larger numbers of studies. There is biological plausibility for impacts of noise on health and experimental evidence of effects of noise on the mechanistic pathways relating to cardiovascular disease, supporting the likelihood that associations are causal. Associations between aircraft noise and hypertension or stroke are less consistent across epidemiological studies, but other biological mechanisms than hypertension are available to explain associations with heart disease. However, the evidence base for aircraft noise remains limited and further research may result in changes to exposure-response relationships with cardiovascular disease, such as those derived from the systematic review of studies published in 2018. The evidence base is limited for non-cardiovascular outcomes; further research is particularly needed on diabetes and obesity, mental health, and pregnancy and birth outcomes. Further research is also needed using additional noise metrics, including those that better characterise air traffic events than average sound level (e.g., number of events above a certain noise threshold) and that consider time period (e.g., late evening and early morning).

There is robust evidence for an effect of aircraft noise exposure on children's cognitive skills such as reading and memory, as well as on standardized academic test scores. Future research needs to test the different mechanisms and to inform key individuals who can intervene on the behalf of exposed children. Longitudinal studies over the lifecourse need to be conducted.

While some surveys suggest a higher response to helicopter noise than to noise from fixed-wing aircraft, any observed differences in annoyance seem to heavily depend on non-acoustic factors. Overall, there is no evidence for a pronounced difference between response to fixed-wing and to rotary wing aircraft at equal noise levels that would justify a stricter evaluation of helicopter noise. Only when the helicopter noise is characterized by a large degree of low-frequency energy, which may produce rattle noise or vibration in buildings, there is evidence that annoyance is markedly increased. Further research should consider the consequences of rattle noise to the evaluation of helicopter noise, as well as the important role of non-acoustic factors.

Using laboratory simulators and testing in the field with special aircraft manoeuvers, progress has been made on understanding and predicting human response to sonic boom noise from overflight of new proposed quiet supersonic aircraft. To confirm these results and extend the applicability of derived models, a new low boom flight demonstrator aircraft is being built to conduct sonic boom community response studies. Plans are underway for designing these experiments to develop exposure-response models for this new kind of quiet supersonic aircraft. Several aspects of human response to low-boom supersonic flight still remain to be researched. Subjective studies have not fully investigated perception of focus booms, booms from other parts of the trajectory outside the cruise portion, noise in the shadow zone beyond lateral cut-off, Mach cut-off booms, and secondary booms. In addition, sleep disturbance relating to low-boom supersonic cruise flight or any of these other conditions has not been studied. Finally, community studies are needed using quiet supersonic aircraft in areas where people are not accustomed to hearing sonic booms, in order to develop a dose-response relationship for this new sector of commercial transportation. Regarding the non-technical aspects of public acceptability for supersonic aircraft noise, there is nothing in the literature that directly applies. However, it may be possible in the future to draw from the existing literature on the topic of non-acoustical factors for subsonic aircraft noise. We are fortunate that there already have been many studies on how animals react to conventional sonic booms, and current thinking is that the new low-boom aircraft would even have less of an impact. It is still unknown if large animals with good low-frequency hearing such as elephants will respond any differently compared to the medium and small sized animals that have already been studied.

There is preliminary evidence that the public may be concerned with the new UAM noise sources intended for transportation and package delivery. Although there is only a very limited amount of research on subjective reaction to noise from these new aircraft types, indications that the noise characteristics differ from traditional aircraft warrant further research to understand and predict human perception of these sounds.

Evidence from hedonic pricing and stated preference studies suggests that these approaches, when properly applied, deliver robust monetary values of noise nuisance. Although the impact pathway approach additionally provides non-market values for health effects, it should be viewed with caution especially in the absence of a well-developed evidence base and evidence on value transferability. There remains a need for further research to improve the robustness of the impact pathway approach and comparisons with other approaches. A further issue is that of evidence for lower income countries which is very sparse.

Comparisons between aircraft noise impacts and other noise source impacts, such as rail, road, and industrial noise, are beyond the scope of this current white paper. Others have already pointed out some of the similarities and differences in impacts between different types of noise sources, so much of that information is currently available.[194]

11. ACKNOWLEDGMENTS

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https://www.icao.int/environmental-protection/Documents/Noise/ICAO_Noise_White_Paper_2019-References.pdf

Recommended Method for Computing Noise Contours Around Airports – Recent Updates to ICAO Doc 9911

By Darren Rhodes (UK CAA) and Eric R. Boeker (US DOT)

INTRODUCTION

In 2018, the second edition of ICAO Doc 9911 "Recommended Method for Computing Noise Contours around Airports" was published[1]. Doc 9911 provides guidance and methodologies for modelling noise that emanates from aircraft in the vicinity of airports, as well as providing guidance on the aircraft performance needed to appropriately model that noise. It provides guidance for full Doc 9911 harmonization and implementation in computer models used to undertake ICAO policy assessments and in models used in ICAO contracting States for environmental analyses.

This article presents background on the efforts leading up to the publication of the second edition of Doc 9911, the technical updates included in that document, and some potential upcoming updates to the guidance document.

GUIDANCE DOCUMENTS LEADING UP TO DOC 9911

The second edition of ICAO Doc 9911 "Recommended Method for Computing Noise Contours around Airports" was completed at the end of CAEP/10 and published in 2018. This marked the end of a multi-year effort to update the first edition of Doc 9911, published in 2008[2], which in turn was an update to ICAO Circular 205 ("Recommended Method for Computing Noise Contours Around Airports"), published in 1988[3].

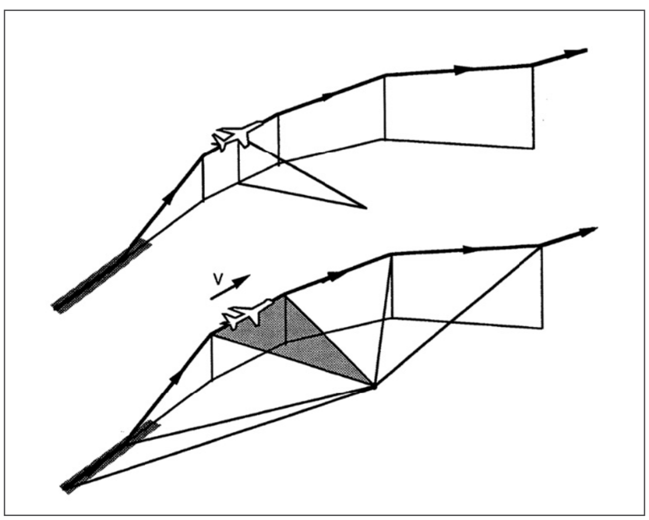
The international guidance that led up to the creation Doc 9911 can be traced back to the document, "Procedure for the Calculation of Airplane Noise in the Vicinity of Airports" (SAE-AIR-1845), which was first published by SAE International in 1986[4]. This represented the first internationally agreed text on a common method for the calculation of aircraft noise in the vicinity of civil airports.

Much has changed since that time. In the mid-1980s, most States where aircraft noise was a serious problem, had developed their own national noise calculation methods, usually linked to nationally developed noise indicators. There were no international standard calculation methods, and there was no common method for the provision of supporting data collected from aircraft manufacturers. Without high quality standardized reference data, harmonized calculation methods had obviously limited application.

The original foundation document SAE-AIR-1845 was, by modern standards, a simple method. It was known as a 'closest point of approach' method, and it solely related noise level at a single point on the ground to the state of the aircraft at the closest point of approach to that point. The first edition of Doc 9911 comprehensively enhanced this aspect so that the method took into account all flight path segments and thus fully reflected situations where the maximum noise level may be associated with a segment other than the segment nearest to the observer point on the ground (See Figure 1). This can occur, when the noise emission is higher for flight path segments that are more distant from the observer. In such cases, the higher noise emission offsets the additional attenuation associated with the flight path segment which is further from the observer than the closest segments.

A secondary advance in Doc 9911 over the SAE-AIR-1845 method is improved modelling of the lateral effects of sound. Lateral attenuation is the process by which sound is attenuated or reduced to the side of the aircraft relative to directly beneath it. Previously, lateral attenuation was calculated as a function of lateral distance and elevation angle only. This was derived empirically from a large pool of data based on 1980's vintage aircraft, predominantly with tail-mounted engines such the Boeing 727 and Douglas DC-9. This lateral attenuation model remains reliable for aircraft with tail-mounted engines in non-turning flight but the latest SAE-AIR-5662[5] method now recognizes that part of this 'attenuation' is in fact a lateral directionality associated with engine installation effects. This is described in an aircraft frame of reference so that aircraft banking during turns - previously irrelevant - now has to be taken into account. Although lateral directivity might be sensitive to various features of engine installation, at present only two lateral directivity functions are employed: for aircraft with tail-mounted and wing-mounted engines respectively.

FIGURE 1: Change from closest point of approach to a segmentation method



ICAO AIRCRAFT NOISE AND PERFORMANCE (ANP) DATABASE

The first edition of Doc 9911 was written around a common data specification which describes the fundamental aircraft performance and noise characteristics of an aircraft. Unlike ground-based transportation noise sources, aircraft noise is highly dependent on the performance of the aircraft since this, along with how an aircraft is operated, dictates the height and position of an aircraft, which are so strongly related to the noise level calculated (or measured) on the ground.

The data specification has led to the development of a harmonized data request form that is provided to aircraft manufacturers. In 2000, data for some of the most common aircraft types operating had not been provided to the international noise modelling community. By 2010, most of the major data gaps had been addressed. The ICAO endorsed ANP database is hosted by EUROCONTROL[6] and maintained in collaboration with the US DOT and European Union Aviation Safety Agency (EASA) providing independent access to the data.

IMPROVEMENTS IN DOC 9911 SECOND EDITION

This latest version of Doc 9911 represents the current state of the science for environmental analyses of aircraft noise in the vicinity of civil airports. Its methodologies and guidance have been leveraged by multiple entities for the development of aircraft noise and performance models. The second edition of Doc 9911 reflects a number of technical updates to the noise and performance modelling methodology developed since the release of the first edition in 2008, as well as editorial updates and additional clarification identified during code development efforts to implement Doc 9911 in computer software. The majority of the guidance found in Doc 9911 second edition is harmonized with similar guidance found in European Civil Aviation Conference (ECAC) Doc 29 "Report on Standard Method of Computing Noise Contours around Civil Airports" fourth edition.[7]

Several technical amendments went into the second edition of Doc 9911, in order to improve or expand its methodology. First, an aircraft substitution method and guidance based on similar guidance found in ECAC Doc 29 third edition Vol. 1[8] was added and expanded, which allows for a standardized method for modelling aircraft not directly represented in the ICAO Aircraft Noise and Performance (ANP) Database.

Second, a change in the aircraft source height in the methodology was made. Previously a source height of 0.0 m (0.0 ft.) was assumed in the guidance. While this may have been acceptable for modelling when the aircraft is in flight, it is somewhat unrealistic when the aircraft is on the ground during takeoff and landing. Therefore, a recommended minimum height for modelling an aircraft noise source is 1.0 m (3.3 ft.) above the aerodrome level or local topography was added to the guidance.

Third, in an effort to improve aircraft performance modelling guidance, updates were made to the aircraft flight segmentation methodology, including the method for sub-segmenting flight tracks with arcs, initial climb segments, final approach segments, and ground roll tracks. Additional supplemental guidance for determining power and velocity across a segment was also provided, along with supplemental guidance for determining equivalent flight path geometry for the lateral attenuation adjustment.

During the development of the second edition of Doc 9911, SAE published "Application of Pure-Tone Atmospheric Absorption Losses to One-Third Octave-Band Data" (SAE-ARP-5534)[9]. This guidance document was intended as a replacement for "Standard Values of Atmospheric Absorption as a Function of Temperature and Humidity" (SAE-ARP-866A)[10]. Since several guidance documents and regulations continue to reference SAE-ARP-866A, Doc 9911 was updated to include both SAE-ARP-866A and SAE-ARP-5534 methods for modelling the atmospheric absorption of sound for non-standard atmospheric conditions, as well as the corresponding example calculation in the document's appendices.

Several Doc 9911 compliant models utilize an acoustic impedance adjustment, to correct the reference-day noise data for off-reference, non-sea level conditions. The acoustic impedance adjustment takes into account temperature, atmospheric pressure, and altitude, indirectly through this adjustment to the noise levels. Therefore, Doc 9911 was supplemented with this acoustic impedance adjustment.

Also during the development of the second edition of Doc 9911, SAE published "Method to Calculate Behind Start of Takeoff Roll Noise Level Adjustments" (SAE-AIR-6297)[11], which includes two methods to calculate noise level adjustments at various angles behind an airplane (directivity) at the start of takeoff roll (SOTR); one for modern commercial jet aircraft and another for modern turboprop aircraft. These directivity curves were based on empirical data (collected in 2004), and replaced the method described in SAE-AIR-1845A, which used empirical data from a much older fleet (circa 1980). This adjustment was included in the second edition of Doc 9911 along with updates to the finite segment correction for ground roll and guidance on their implementation.

Two ANP data submittal forms were included in the Doc 9911 update: "ANP Database Submittal Form" and "ANP Database Submittal Form for Propeller-Driven, Fixed-Wing Aircraft". These forms promote and standardize the submission of new data for inclusion in the ICAO ANP database to be used as aircraft source inputs for by Doc 9911 compliant models.

Finally, several example studies were added to the second edition of Doc 9911. These case studies provide input and output results for verification of software implementation and confirmation of the Doc 9911 methods.

FUTURE DEVELOPMENTS

During the development of the second edition of Doc 9911, several potential updates to the guidance and methodology were identified in order to: expand the capabilities, improve accuracy, and provide clearer guidance for software implementation. From that list, the following potential updates are being considered for a third edition of Doc 9911 to be developed during the CAEP/12 cycle (through 2021). Those potential updates could include (and are not limited to):

- Adding a helicopter noise calculation methodology.
- Adding a line-of-sight blockage calculation methodology to account for terrain features shielding the propagation path between source and receiver.
- Guidance on modelling population growth for forecasting noise.
- Modelling the effects on noise level of variable aircraft configurations and speeds which may become increasingly important as airframe noise becomes a greater component of total aircraft noise.
- Developing a ranking/rating method for accounting for the effects of certain modelling aspects on the results.
- Reviewing and updating the Doc 9911 performance modelling methodology (Doc 9911 Second Edition, Appendix C), in order to improve and/or include: departure and approach aircraft performance modelling, reduced power takeoff modelling, calculation of bank-angle on flight path geometry, guidance for modelling airports that have intersecting runways, and guidance on the level of detail required to better define arrival and departure flight profiles.

Future updates beyond the third edition of Doc 9911could include expanded source noise models. These models could cover: low frequency noise, improved propeller driven aircraft source models, taxi and reverse thrust noise, and on-route aircraft noise sources. The third edition could also cover new aircraft types (i.e., supersonic, commercial space vehicles, and unmanned aerial vehicles), as well as additional environmental effects (i.e., variable ground impedance).

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Using Flight Data Recorder Data to Determine Aircraft Noise Levels in the Vicinity of Airports

By Mikhail O. Kartyshev

INTRODUCTION

Airport operators, especially those operating airports located close to residential areas, need to evaluate noise levels of individual aircraft in the vicinity of the airport. This information can feed community engagement activities, as well as assess aircraft adherence to noise abatement procedures, such as NADP1 and NADP2.

Land use planning policies and their associated restrictions on the construction of new residential dwellings in the most significantly noise exposed areas around airports are often questioned due to changes in flight intensity, composition of used air fleet and conditions for modeling the noise area for a specific airport. Updating results of calculated analysis and field measurements is a resource intensive activity, which airports must carry out on a regular basis.

Because of this, it is suggested that a simple approach to this would involve the use of flight data recorder (FDR) data to determine aircraft noise levels for individual aircraft at specific points around the aerodrome along the takeoff and landing trajectory. This is done by synchronizing mandatory FDR parameters with aircraft noise levels measured in the field at various reference points around the airport, including during certification testing[1].

This can be achieved by building a database of source data for each type of aircraft operated that would include aircraft noise levels measured at specific flight phases and synchronized with FDR data during the aircraft's flight period. This would include actual engine operating parameters as well as other registered parametric information.

FDR DATA APPLICATION PRACTICE

On-board flight data recorders record specific aircraft performance parameters to enable precise determination of such variables as flight path, speed, attitude, engine thrust, and others.

ICAO documents (Amendment 17 to Annex 6 to the Convention on International Civil Aviation, "International Standards and Recommended Practices"[2]) include recommended lists of between 15 and 32 recorded parameters for various aircraft types.

Aircraft operating parameters recorded second-by-second can be decoded and presented in matrix or graphic form. The matrix view supports automatic processing and precise analysis of all recorded data for each second of the flight. The graphic data view allows one to visually compare changes of certain aircraft parameters over the specified time period.

To find a correlation between measured noise levels around the airport and the aircraft's flight performance characteristics, one has to identify the parameters influencing the area with the specified noise level at its borders and evaluate the contribution of each of them based on instrumental measurement data matched to FDR data. This problem was solved for some aircraft by conducting experimental research that yielded enough unbiased data to establish dependency between noise level at a point on the ground and the aircraft's flight performance characteristics.

There are generally available published environmental studies that use flight data recorder information to examine only certain environmental aspects such as: evaluation of pollutant emissions[3], and validating models of aircraft noise distribution over residential areas[4].

CONDUCTING EXPERIMENTAL RESEARCH

Specialists working at the Civil Aviation Environmental Safety Center in CITY, carried out tens of thousands of noise level measurements for all aircraft types operated in Russia for various scientific studies, upon requests of airports, inhabitants, municipal authorities of populated areas near airports and for various design works. These were conducted without regard for the information obtained from aircraft noise continuous monitoring systems.

To achieve this task, several experimental studies under various operating conditions were prepared and carried out with the assistance of airlines and aircraft operators. Circular circuit test flights were performed using various aircraft types including: Tu-154, Il-76, Sukhoi Superjet, Irkut MS-21, A319, A320, A321, B737.

Using simultaneous noise measurements at various specific points on the ground (from 8 to 24), including data from automated aircraft noise monitoring system sensors, and subsequently gathered FDR data, the aircraft maintenance center was able to build a database of noise observations synchronized with aircraft attitude parameters[5].

Comparison of FDR data and automated aircraft noise monitoring system data showed that the FDR data provided more detailed aircraft information and reduced ambiguity errors inherent to the automated aircraft noise monitoring system. This was mostly due to: limited amount of information transmitted over the radio channel, transmission delay, and frequent loss of accuracy. Additionally, the number of microphones used to collect data for the acoustic noise database was significantly larger than the number of microphones used by the aircraft noise continuous monitoring system.

The completed studies identified dependencies between noise levels and aircraft performance characteristics during aircraft maneuvering, along specified flight paths, and during circular circuit flights.

Research Method

Noise measurements on the ground were conducted using well-known standardized methods, while ensuring the required ambient conditions, and clear visibility of the aircraft's flight path.

Microphones were placed on the ground perpendicular to the takeoff path projection, starting 3 km from the executive start, and then spaced every 1 kilometer to a distance of 8.5 km. For evaluating noise levels during the landing phase, microphones were also placed perpendicular to the landing path projection starting 2 km away from the closest runway end, and every 1.5 km to a distance of 6.5 km.

An aircraft's spatial location was determined using triangulation theodolites during takeoff at the point located on the 6.5km perpendicular and during landing at the point located on the 2.0 km perpendicular, combined with FDR data, and supported by similar data obtained from the air traffic radar control system. Parameters such as acoustic noise measurement, aircraft location, and weather data provided by the automated airport weather station and mobile weather station (e.g., Vaisala WXT520) were synchronized using information about the spatial location of objects including: noise level measurement points, aircraft location on the flight path, as well as the time parameter. Aircraft parametric data were entered into the database at 1-second intervals.

The speed, vector of the wind and crosswind component, temperature, and relative humidity were all monitored for each aerodrome during the entire measurement period.

Experimental Data Analysis

Aircraft noise level measurements on the ground were taken and analyzed at four Russian aerodromes and involved 112 aircraft takeoffs and 78 aircraft landings. This was done during 24 circuit circular test flights of different noise category aircraft, and a linear dependency was established between FDR parametric data and measured noise levels for each aircraft type and flight phase. In total, more than 2,000 noise level values were recorded for various points on the ground.

Out of FDR data array for each flight, various characteristics of a specific aircraftat the moment of measurement were selected including: altitude, speed, engine thrust, aircraft weight, angle of attack, flaps configurations, landing gear position, etc. The following parameters were examined to approximate discrete data:

X, Y – aircraft coordinates,
h - aircraft altitude (m),
V - aircraft speed (m/s),
P - compressor revolutions (% of maximum),
m – aircraft weight (t).

No relevant dependencies were found between: aircraft noise and the angle of attack, flaps configuration, and landing gear position. Because the sample is quite limited, these parameters cannot be declared to have no influence at all, however, at the current stage of research using them was considered to be unreasonable.

As an example, Table 1 shows FDR data for each flight and the measured highest noise level at a point on the ground located X=8.5 km away from the line-up at the Pulkovo aerodrome along the takeoff path projected on the ground and Y=0.8 km sideways of the specified path. The highest noise measurement levels are rounded to integers.

Analysis of the data in Table 1 shows that aircraft with similar parameters of aircraft weight, engine power and close enough values of speed have similar noise levels (VQ-BAU, BQ-BIU, VQ-BAQ). With comparable speed, thrust and takeoff weight, but different flight altitude at the examined plane a 2 dBA difference was discovered (EI-EZD, VQ-BAQ). With two parameters being significantly

TABLE 1: Experimental data observations – Pulkovo Aerodrome

No.	ID	Aircraft type	Noise level L_A, dBA	Aircraft geometric altitude h, m	Aircraft speed V, m/s	Aircraft engine power P, %	Aircraft weight m, t
1	1408	A319 EI-EZD	75	784	103	94.4	57.252
2	1427	A319 EI-ETO	75	532	91	93.1	57.335
3	1458	A319 VQ-BAS	80	611	108	95.3	67.066
4	1514	A319 EI-ETP	75	561	95	93.8	61.000
5	1515	A319 VQ-BAT	75	636	106	94.7	62.676
6	1535	A319 EI-EYM	71	930	99	93.5	53.279
7	1555	A319 VP-BIT	74	589	96	93.0	56.29
8	1620	A319 VQ-BAV	75	530	94	94.5	64.762
9	1621	A319 VQ-BDV	74	505	98	96.1	70.543
10	1637	A319 VQ-BAU	73	633	104	93.8	58.612
11	1647	A319 VP-BIU	73	720	99	94.0	57.843
12	1649	A319 VQ-BAQ	73	624	95	92.9	57.462
13	1717	A319 EI-ETN	75	585	93	93.0	56.327
14	1725	A319 VP-BIQ	74	766	103	93.9	55.039

different – takeoff weight (+14t) and flight altitude (-319m) – a 9 dBA difference in measured acoustic noise was discovered (VQ-BAS, EI-EYM).

The research revealed that when parameters such as aircraft type, aerodrome location, and other external factors are the same; differences in aircraft operational parameters such as aircraft speed and aircraft altitude which may differ twice can have significant impacts on perceived noise levels on the ground.

Figures 1, 2, and 3 show graphical representation of FDR data recorded for the examined aircraft. Observations show that during the research most aircraft failed to follow the stepped departure climb according to NADP 1 or NADP 2 procedure for noise reduction and speed requirements for each climb phase. These are required for estimating equal-loudness contours in the vicinity of an aerodrome, which, basically, allows one to conclude that in this case, that the perceived noise levels did not match the noise contours obtained by calculation.

During training and circular circuit test flights with simulated approach, engine thrust and flight altitude had especially significant influence on the noise level at measurement points. During circular circuit test flights without simulated approach, the decoded FDR data showed that the flight altitude during the initial and final stages of the flight was a significant noise contributor.

Approximation methods were used to process the obtained experimental data in order to identify linear dependencies that give as close as possible representations of operating parameters for each monitored aircraft.

Based on the entire array of sound measurements and parametric data for various flight modes, the noise level expected at the point on the ground within 1 km from the borders of the monitored area was determined with a tolerance equal or less than ΔL_{Amax}= 3 dBA for 88% of measurements.

FIGURE 1: 1 Changes in engine operating mode of monitored aircraft during takeoff

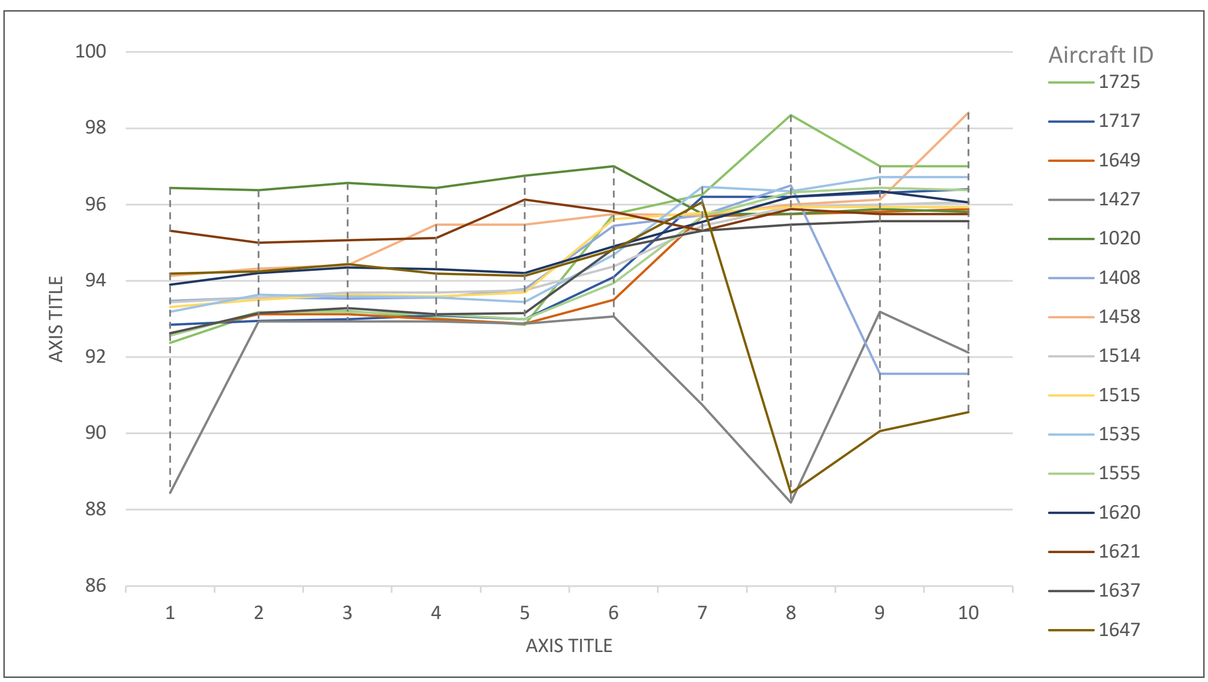


FIGURE 2: Changes in flight speed of monitored aircraft during takeoff

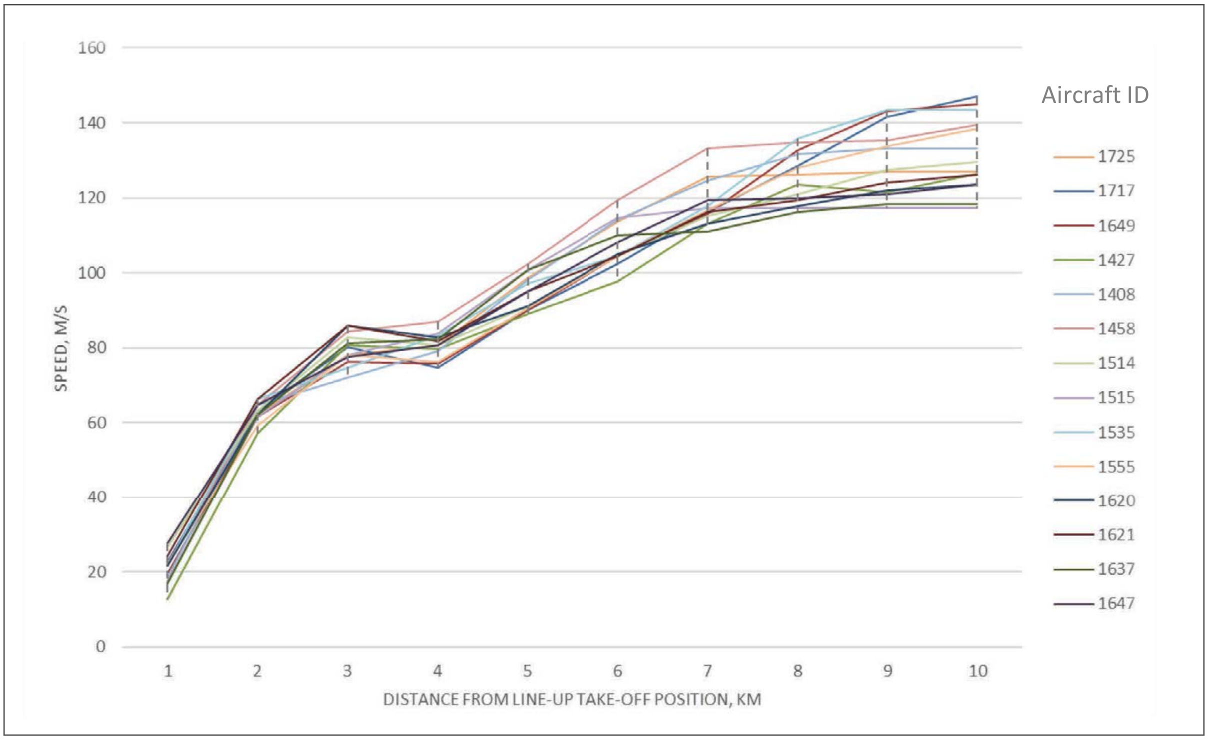
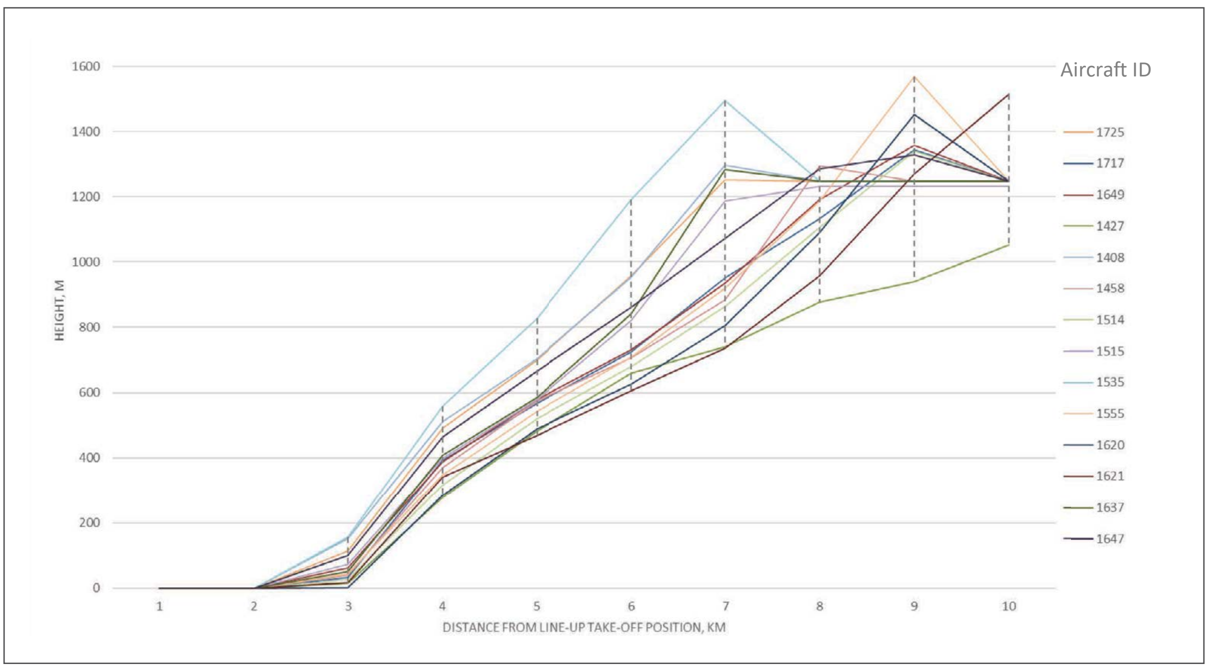


FIGURE 3: Changes in flight altitude of monitored aircraft during takeoff



CONCLUSION

Further applications of the approach described above could include creating a database of initial experimental data for each operated aircraft type by organizing and conducting comprehensive aircraft noise measurements to be subsequently synchronized with FDR data for an active airport. This would allow the ongoing monitoring of the acoustic environment in the vicinity of the aerodrome and could assess the degree of aircrew compliance with the requirements for low-noise flight modes during the landing and takeoff cycle.

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Status of Noise Research Aimed at Subsonic Transport Technology Solutions

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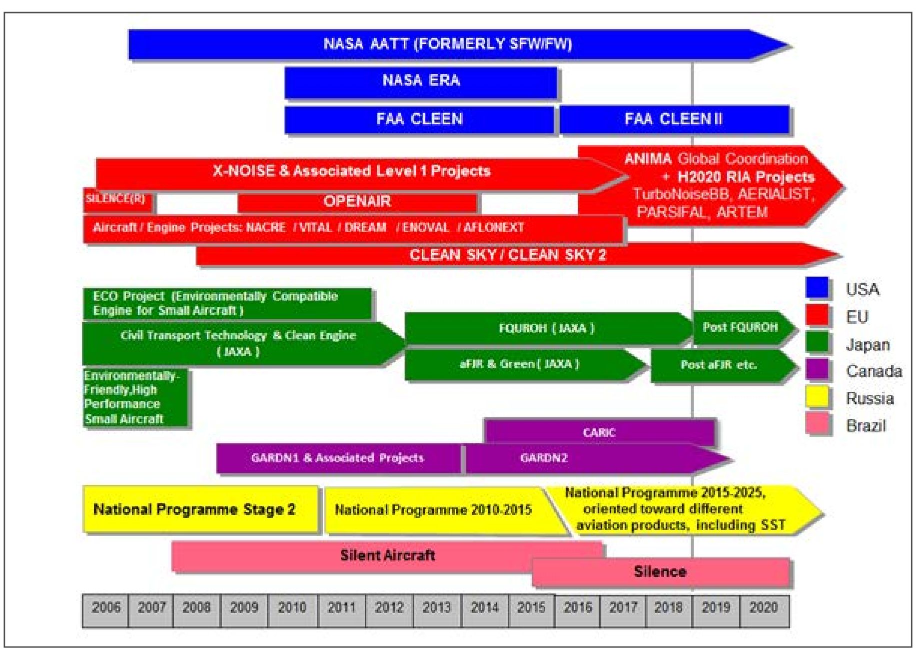
INTRODUCTION

The task of monitoring noise technology research programs has been underway since the CAEP/6 cycle (2006). This has provided an opportunity to develop a broader view of the status of joint Government / Industry efforts in implementing research initiatives. As such, this article provides an overview of the ongoing research projects on noise technology worldwide.

The global situation of noise technology research initiatives as of December 2018, is summarized in Figure 1. It covers a 15-year period (2006-2020), and provides an evolutionary perspective, indicative of the worldwide commitment to continuously support the technology side of ICAO's Balanced Approach.

Summaries of each research initiative represented in Figure 1 are provided in the following sections of this chapter.

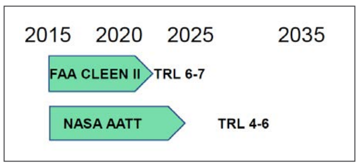
FIGURE 1: Committed major national / regional initiatives as of end 2018



US NOISE TECHNOLOGY RESEARCH PROGRAMS

Aircraft noise research efforts in the United States have two major funding sources: the National Aeronautics and Space Administration (NASA), and the Federal Aviation Administration (FAA). For both entities, noise reduction concepts must meet multidisciplinary criteria and should have minimal impact on aircraft weight and performance.

FIGURE 2: Timeline for US aircraft noise reduction research



NASA's Advanced Air Transport Technology (AATT) project has numerous technical challenges related to noise reduction. Its objective is to demonstrate Technological Readiness Level (TLR) 4-6, looking toward mature technology solutions in the 2035 – 2045 timeframe. The noise reduction technical objectives target 22-32dB (below Stage 4) in the near-term (2015-2025), 32-42dB in the mid-term (2025-2035) and 42-52dB in the far term beyond 2035. Of the $90M of funding in 2018, $11.7M was focused on noise reduction and involved 37 researchers. For 2019, $11.2M in funding and 35 researchers were allocated for noise research. Solicitations for NASA Research Opportunities in Aeronautics continue on an annual basis.

TABLE 1: NASA AATT technology objectives

TECHNOLOGY BENEFITS	TECHNOLOGY GENERATIONS (Technology Readiness Level = 5-6)		
	Near Term 2015-2025	Mid Term 2025-2035	Far Term beyond 2035
Noise (cum below Stage 4)	22 - 32 dB	32 - 42 dB	42 - 52 dB
LTO NOx Emissions (below CAEP 6)	70 - 75%	80%	> 80%
Cruise NOx Emissions (rel. to 2005 best in class)	65 - 70%	80%	> 80%
Aircraft Fuel/Energy Consumption (rel. to 2005 best in class)	40 - 50%	50 - 60%	60 - 80%

Technologies currently being researched under AATT are: low-noise high-lift devices to reduce airframe noise on approach, multi-degree-of-freedom low-drag liners on purpose-built research turbofan engines (DART) including full-scale flight tests, novel fan case-liners for short intakes, and system studies on novel aircraft designs.

The FAA CLEEN II program looks at more mature noise reduction technologies to demonstrate TRL 6-7. The objectives of CLEEN II include demonstrating certifiable technologies to meet the environmental targets of 32dB below Stage 4 by 2020. While CLEEN II will be ending in 2020, CLEEN III plans to pick up with new projects solicitations expected in 2019. CLEEN II funded $18.9M for research in 2018, and $6.7M is planned in 2019. Key participants for noise reduction studies were Boeing/Aurora, GE, and Collins (formerly UTAS).

TABLE 2: FAA CLEEN technology objectives

Goal Area	CLEEN I Goals (2010-2015)	CLEEN II Goals (2015-2020)
Noise (cumulative below Stage 4)	-32 decibels (dB)	-32 decibels (dB)
LTO NO_X Emissions (Below CAEP/6)	-60 percent	-75 percent (-70 percent re: CAEP/8)
Aircraft Fuel Burn	-33 percent	-40 percent

In July and August of 2018, Boeing completed the Quiet Technology Demonstrator 3 (QTD3) flight test under the NASA AATT program to demonstrate and increase the TRL of the low-drag Multi-Degree Of Freedom (MDOF) acoustic lining in the inlet. Introduction of the low-drag lining technology led to a 3.4 EPNdB cumulative benefit on measured inlet noise when compared with a standard production liner (see Figures 3 and 4, and Table 3).

FIGURE 3: Low-Drag Lining technology progression

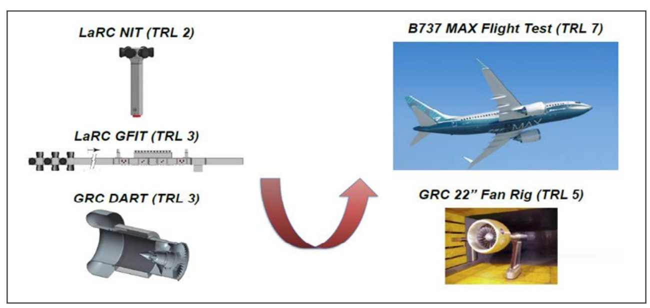


FIGURE 4: Hardware tested and noise measurements taken

TABLE 3: Inlet measured component noise reduction

Condition	Approach	Cutback	Takeoff	Cumulative
Benefit (re Production Liner)	0.6 EPNdB	1.5 EPNdB	1.3 EPNdB	**3.4 EPNdB**

Under FAA's CLEEN I, GE Aviation completed open rotor wind tunnel tests which demonstrated 15 EPNdB cumulative reduction relative to Chapter 4 and a 26 per cent fuel burn reduction relative to engines with BPR of ~5-6. Under FAA's CLEEN II, GEis developing two noise technologies:

- Liners employing new manufacturing and analytical techniques to provide 2 EPNdB cumulative noise reduction relative to single degree of freedom liners. Another objective of this technology is not to impact fuel burn.
- Three-dimensional aero-acoustic design of fan-OGV to reduce fan-OGV interaction noise to provide ~1 EPNdB cumulative noise reduction. GE plans to test such designs in a sub-scale rig.

Under CLEEN I, Pratt & Whitney developed and demonstrated an ultra-high bypass ratio Geared TurbofanTM (GTF) engine, and associated advanced technologies.

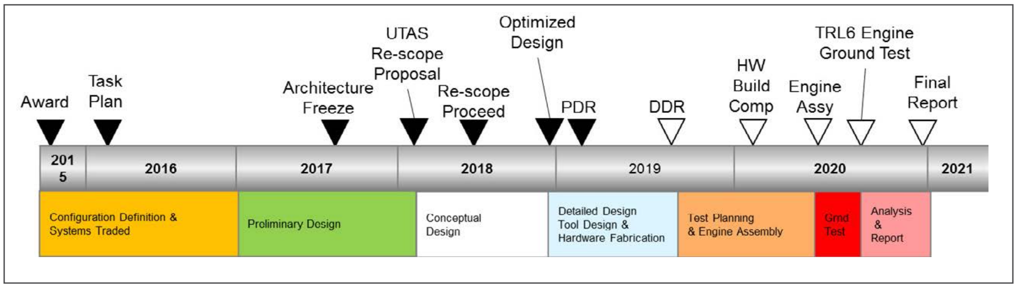
In 2017, Pratt & Whitney completed an ultra-high bypass engine test campaign, demonstrating aerodynamic performance, mechanical, and acoustic characteristics of advanced fan system technologies. GTF engine technologies contributed to a 20 dB aircraft noise reduction and a 20 per cent fuel burn reduction because of increased engine efficiency. This advancement builds on the completion of 275 hours of fan rig testing of the technology in 2014 and 2015. A key element in the technology maturation is the development and application of highly-integrated Computational Fluid Dynamics (CFD) tools developed by United Technologies, which provide accurate predictions and design guidance.

Under NASA funding, United Technologies Research Center (UTRC) is developing a first-of-its-kind database of detailed unsteady measurements characterizing noise sources of advanced (N+3) low-emissions aero-combustors. This data enables improvements to reduced-order models for use in system level noise assessments. In the longer term, it will address the validation needs of high fidelity prediction methods suited for detailed multi-disciplinary acoustics and emissions combustor design.

Under CLEEN II, the efforts of Collins Aerospace are aimed at maximizing efficiency of 2025 high-bypass ratio propulsion systems, by conducting a nacelle technology demonstrator that incorporates an aerodynamically and acoustically optimized fan duct architecture (Figure 5). The ground demonstrator, which will be tested on a Pratt & Whitney engine, simulates a clean fan duct with maximized acoustic area, low drag surfaces, and zoned acoustic liners. The overall package targets 2.0 EPNdB community noise benefit. Manufacturing efforts are currently underway to support a full-scale acoustic test in 2020. The overall project schedule is summarized in Figure 6.

FIGURE 5: Collins Aerospace CLEEN II technologies

FIGURE 6: Collins Aerospace CLEEN II schedule



EU NOISE TECHNOLOGY RESEARCH PROGRAMS

A full assessment of the situation relative to the ACARE 2020 noise target (-10 dB/ operation relative to 2000) was performed in 2015. Conclusions were that the European aircraft noise research effort was to be considered on-track to meet its objective, albeit requiring maintaining significant support in the few years remaining before 2020. In parallel, the 2012 ACARE Strategic Research and Innovation Agenda (SRIA) had already established noise targets for the longer term, and laid out key directions for post-2025 technology solutions.

A number of projects have then addressed both aspects, involving major manufacturers (Airbus, Rolls-Royce, Safran, MTU, GKN, Leonardo) and leading research establishments (DLR, Onera, NLR, CIRA) among others. The whole effort is further described below and summarized in Figure 7.

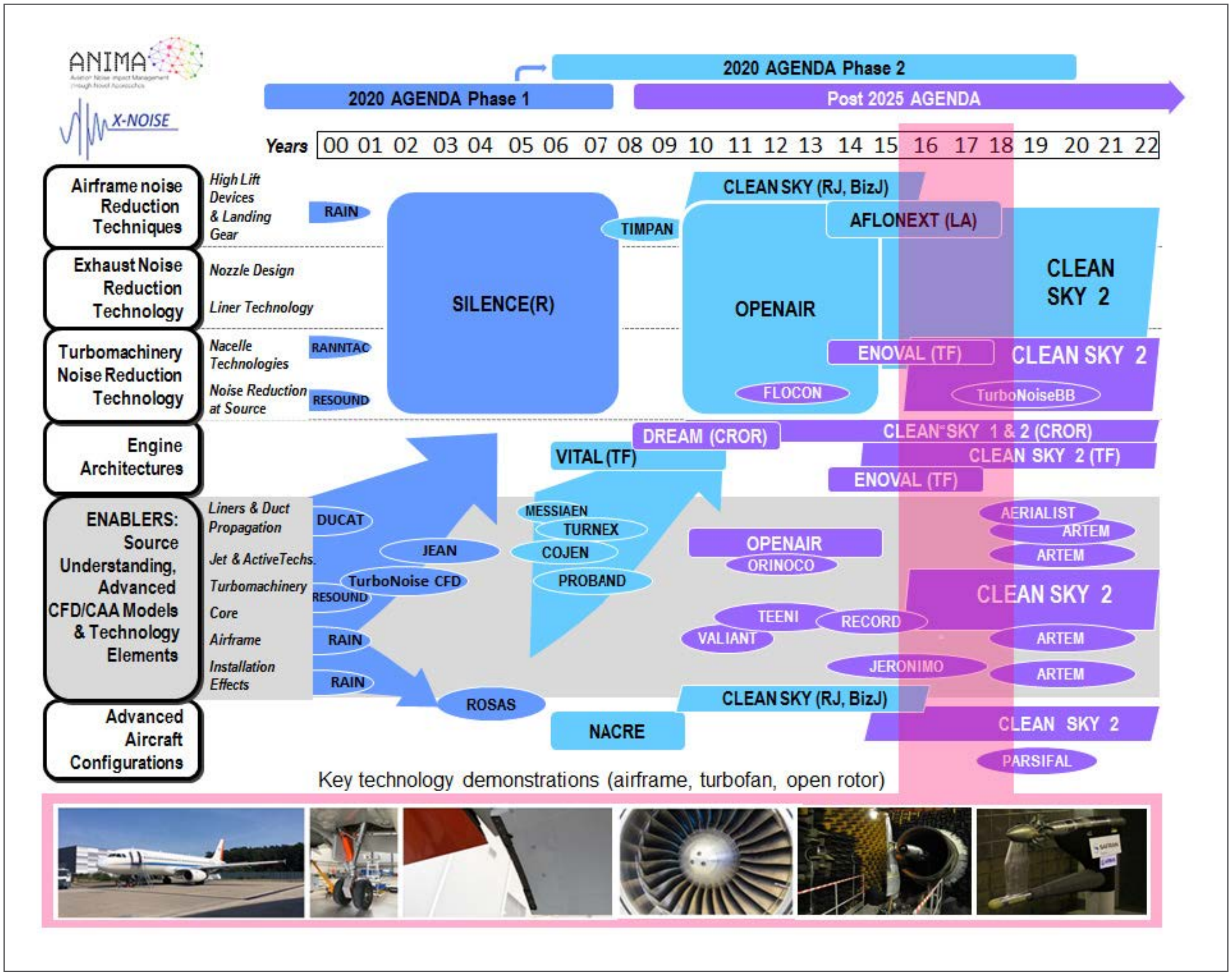
On the aircraft side, the project AFLONEXT (Active Flow, Loads & Noise control on next generation wing) successfully advanced maturation of airframe noise reduction technologies through flight testing a series of flap and main landing gear solutions in 2018. On the engine side, JERONIMO (Jet noise of high bypass ratio engine: Installation, advanced modelling and mitigation) completed its experimental assessment of “under the wing” installation effects on jet noise generated by UHBR engines. ENOVAL (Engine Module Validators) addressed similar engine designs from the fan noise perspective, supporting low noise rotor and stator configurations, associated with advances on active liner concepts. In this area, TurboNoiseBB (Validation of improved Turbomachinery Noise prediction models and development of novel design methods for fan stages with reduced BroadBand noise) has now taken over, supporting the validation of improved turbomachinery noise prediction models and the utilization of novel design methods for fan stages with reduced broadband noise, while CLEAN SKY 2 is involved in further maturation of engine acoustic liners.

With regard to the longer term agenda, while a general novel aircraft architectures effort is further supported in CLEAN SKY 2 and PARSIFAL (Prandtlplane Architecture for the Sustainable Improvement of Future Airplanes), the project ARTEM (Aircraft Noise Reduction Technologies and related Environmental Impact) has initiated a wide approach investigating new “generation 3” noise reduction technologies and installation effects relevant to the use of UHBR turbofans and distributed propulsion configurations (DEP) on such aircraft concepts. This effort is complemented by AERIALIST (AdvancEd aicRaft-noIse-AlLeviation devIceS using meTamaterials), a project specifically addressing the use of meta-materials applied to the reduction of engine and airframe noise emission.

Concerning Open Rotors engine designs, further wind tunnel experiments carried out under CLEAN SKY 2 have helped to consolidate the assessment of noise levels expressed in the previous report, while a full-scale engine demonstrator ran to confirm the high interest in such a propulsion concept. When placed in perspective with the best expectations resulting from the original 1987 flight-test assessments conducted on such a concept, this represents a typical 20dB noise reduction on a cumulative margin basis, a spectacular achievement for the European research effort that was initiated in 2008.

At last, in response to the expressed need for a strongly coordinated and integrated approach, taking over the legacy of the X-NOISE coordination action, the ANIMA (Aviation Noise

FIGURE 7: European noise projects roadmap and key technology demonstrations



Impact Management through novel Approaches) project team has now been tasked to: support the global coordination of EU research activities, establish a common strategic research roadmap for aviation noise reduction through the involvement of a pan-European network of experts and project leaders, and address international collaboration opportunities.

JAPANESE NOISE TECHNOLOGY RESEARCH PROGRAMS

A couple of projects in Japan have addressed both aircraft and engine noise reduction. Both JAXA's FQUROH (Flight Demonstration of Quiet Technology to Reduce Noise from High-lift Configurations), aFJR and Green projects are discussed below.

JAXA's FQUROH project is aimed at establishing technologies for airframe noise reduction. Noise reduction concepts for flap side – edges and main landing gear were applied to JAXA's experimental aircraft "Hisho" which is a modified version of a Cessna Citation Sovereign. The project name "FQUROH" is derived from the word for "owl" in Japanese. The 2nd flight test campaign was conducted in 2017 to validate the CFD/CAA-based noise reduction designs, and successfully showed flap and MLG noise reductions of 3 to 4 dB[A].

JAXA's aFJR (advanced Fan Jet Research) project is aimed at developing a light-weight acoustic liner panel made from resin. The aFJR project was a collaboration between JAXA and IHI. A fan rig test in an acoustic facility confirmed noise reduction similar to what was achieved with a conventional

Al-based liner panel in 2017.The Green engine program involved noise reduction technologies including a "notched nozzle". JAXA and IHI have demonstrated acoustic and aerodynamic performances of the notched nozzle. A microjet nozzle was also studied through international cooperation.

The FQUROH project is going to finish in 2019, and the FQUROH+ project will be continued. The aFJR project and Green programs completed in 2018, however new research programs are to be continued. For example, demonstration of aFJR acoustic panel with a full-scale engine has been planned, also acoustic R&D nacelle, nozzle, etc., with rig and subscale engine has been started.

FIGURE 8: Overall views of research outcomes from the FQUROH project

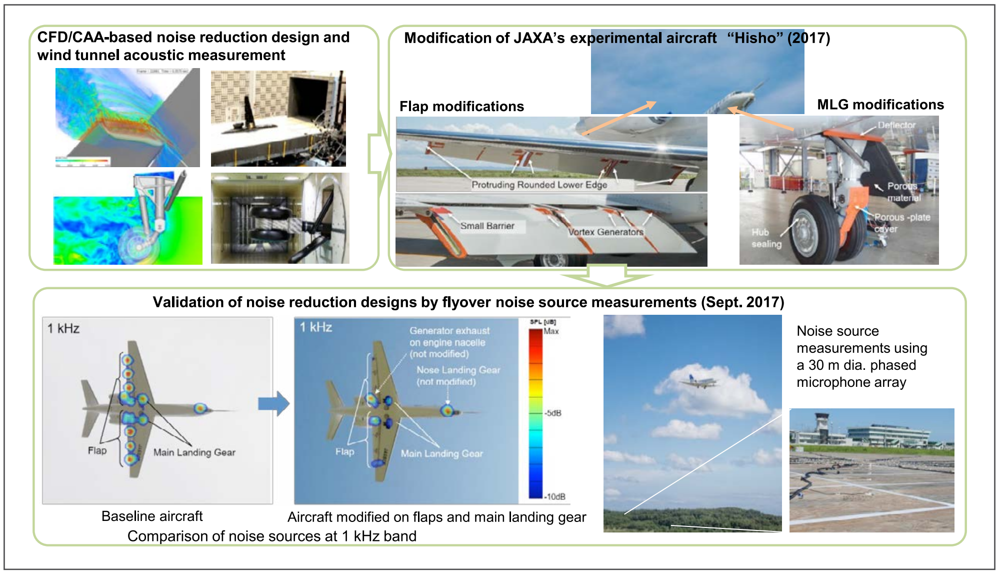
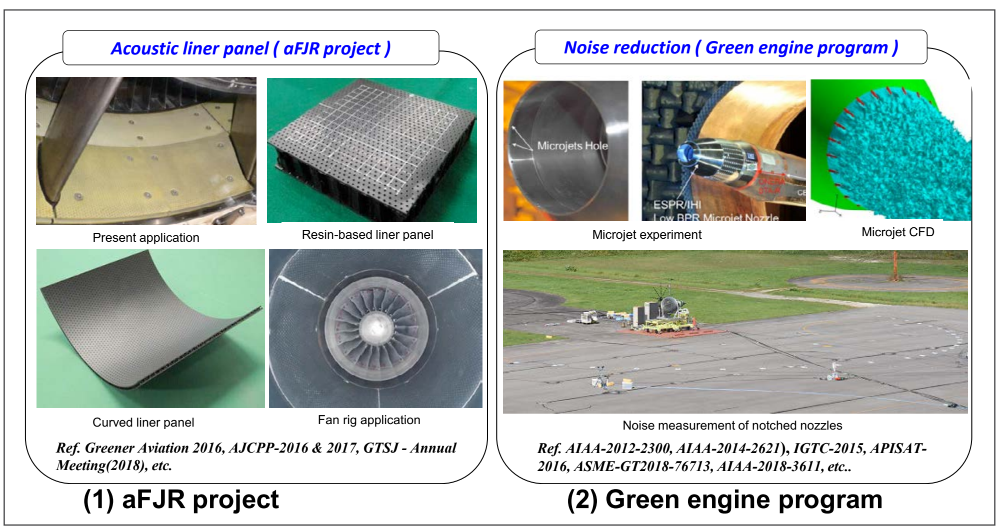


FIGURE 9: Overall views of research outcomes from aFJR project and Green engine program



CANADIAN NOISE TECHNOLOGY RESEARCH PROGRAMS

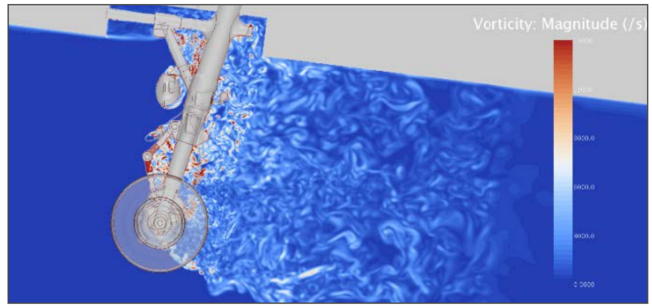
The Canadian Green Aviation Research and Development Network (GARDN) has funded three noise source reduction projects since 2014.

Airframe Noise Reduction for Business and Commercial Aircraft

This project sought to improve noise modeling and to develop noise reduction techniques to reduce exterior noise of new aircraft designs. Partners included: Bombardier, Héroux-Devtek, University of Toronto, and the National Research Council of Canada (NRC).

- Phase array technology: Advanced algorithms to enhance sound source localization, particularly low frequency methods.
- Airframe noise prediction and reduction: Improved computational methods to predict noise from high-lift devices as well as nose and main landing gears. Numerical predictions were validated by high-quality on-surface and far-field measurements.

FIGURE 10: Landing Gear noise: Numerical Prediction

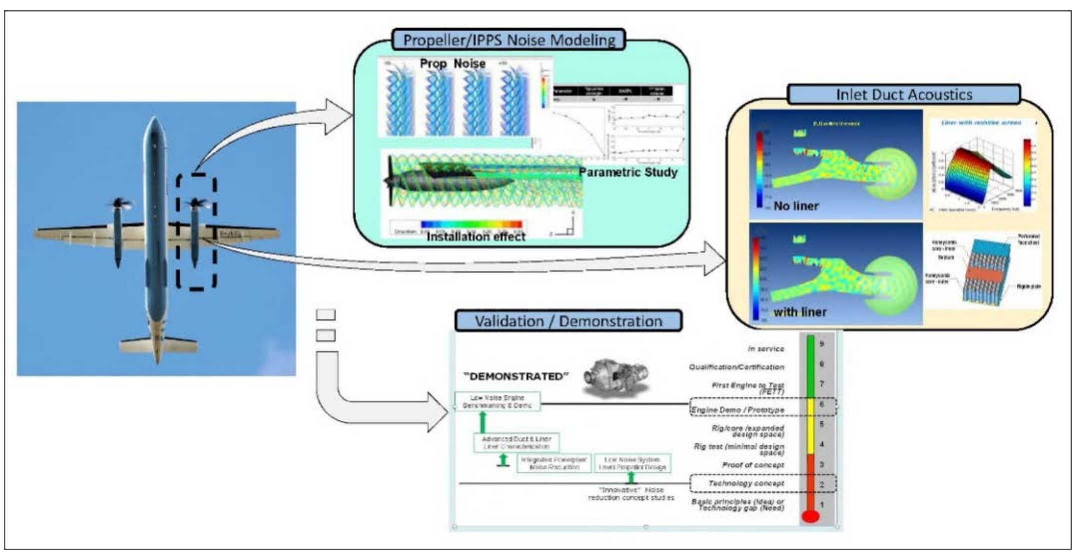


- Semi-empirical methods: The phased-array and computational aeroacoustic results were used to enhance traditional semi-empirical methods for the prediction of airframe noise.

Noise Reduction for Next Generation Regional Turboprop

The objective of this project is to leverage new technologies, to develop new design methodologies, and to enhance concepts in support of the development of low-noise large regional turboprop aircraft. Partners included Pratt & Whitney Canada, Mecanum Inc., Carleton University, and Université de Sherbrooke.

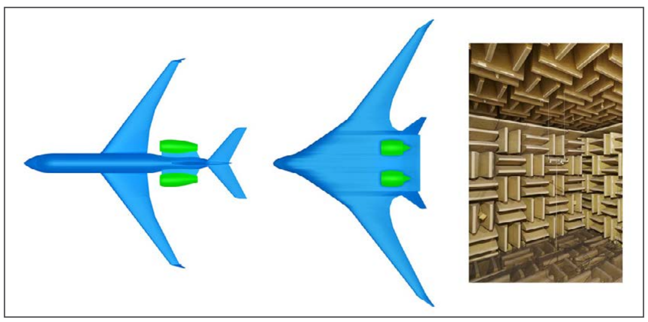
FIGURE 11: Noise measurements of innovative, environmentally friendly aircraft configuration



Noise Measurements of Innovative, Environmentally Friendly Aircraft Configuration

Bombardier, the NRC, and Mecanum Inc. conducted acoustic measurements using NRC's anechoic acoustic chamber facility and a point source developed by the Université de Sherbrooke. The project partners measured sound using a conventional aircraft model for experiment validation and tool calibration then conducted measurements using a novel aircraft configuration model. It is apparent that the novel configuration may have an advantage over the conventional configuration by using the wing, body, and tail to shield the engine noise from propagating to the ground.

FIGURE 12: Novel aircraft (centre) modeled by Bombardier using data found in: Bonet, J.T., "Boeing ERA N+2 Advanced Vehicle Concept Results", 50th AIAA Aerospace Sciences Meeting, 2012-01-11



RUSSIAN NOISE TECHNOLOGY RESEARCH PROGRAMS

The research on aviation noise in Russia addresses such topics as airframe noise, engine noise (including fan and jet noise), and interaction noise (primarily, jet-wing interaction noise).

Research on airframe noise includes: developing methods of noise reduction for landing gears based on small-scale experiment, large-scale tests of wing noise sources (slat, flap-side edges etc) and methods of their mitigation, and airframe noise localization of MS-21 in flight tests.

Engine noise research comprises acoustical tests of single-rotor and counter-rotating fan models in CIAM C-3A test facility, and confirmation of their required mechanical and aerodynamic parameters in full-scale engine tests. Small-scale and large-scale acoustic liners with different geometrical parameters were manufactured and studied. Methods of impedance eduction were elaborated together with Onera and DLR (EU project ASPIRE, IFAR cooperation). Measurements of azimuthal acoustic modes in small-scale and full-scale engine inlets were carried out in three different configurations: in the model air inlet with incoming flow in AC-2 TsAGI, in the large-scale inlet without flow in the anechoic chamber of PNRPU in Perm, and at the open test rig OS-5 of "ODK-Aviadvigatel".

For jet noise reduction, active methods such as plasma actuators were studied. To enhance the physical understanding of jet noise sources, theoretical research and dedicated experiments were performed. Theoretical studies addressed large-scale sources, such as instability waves and vortex rings, and small-scale turbulence described by the correlation model. The vortex ring results were validated in large-scale experiments with vortex rings at Lavrentiev Institute of Hydrodynamics in Novosibirsk. For the first time, the azimuthal modes of a turbulent jet of an aviation engine were measured at OS-5 of "ODK-Aviadvigatel" and showed a significant agreement with the azimuthal mode measurements for small-scale jets in anechoic chamber AC-2 TsAGI.

Theoretical models of jet noise sources provided the input data for modelling jet noise shielding by the wing/fuselage, as well as jet-wing interaction. Jet noise shielding effects studied in AC-2 TsAGI for dual-stream nozzles with and without geometrical modifications (chevrons, corrugations, etc). Methods for reduction of jet-wing interaction noise were considered including different nozzle geometries and active methods such as plasma actuators.

BRAZILIAN NOISE TECHNOLOGY RESEARCH PROGRAMS

Brazilian Silent Aircraft Initiative – Aeronave Silenciosa (Fase I and Fase II - 2007 to 2015)

The objective of this initiative was to study and develop methodologies that will permit the estimate of aircraft noise generation and propagation through three main approaches: numerical simulation (CAA), analytical and semi-empirical models, and wind tunnel and flight tests.

Another objective was to bring together Brazilian specialists working on aerodynamics and acoustics, to start working cooperatively on aeroacoustics and community noise.

The main goals were to develop methodologies for prediction and measurements of jet noise, fan noise and airframe noise using wind tunnel and flight tests methodologies and tools for noise source identification.

The following Brazilian organizations were involved in this project: FINEP - Brazilian Innovation Agency, FAPESP - São Paulo Research Foundation, Embraer, USP–University of Sao Paulo, UFSC - Federal University of Santa Catarina, IAE - Brazilian Institute of Aeronautics and Space, UnB - University of Brasilia, and UFU - Federal University of Uberlandia.

SILENCE Project = Solutions for Integrating Low External Noise ConcEpts (2015 to 2018)

This initiative was designed to study and develop concepts and solutions for low external noise generation through: airframe wind tunnel testing, fan and jet rig tests, and numerical studies. A secondary objective was to improve the capabilities of Brazilian universities in providing accurate research on aeroacoustics through the use of state of the art experimental and computational techniques.

The main goals were to: develop airframe noise improvements through small scale wind tunnel tests, develop prediction and experimental methods for fan liner effects, and improve experimental and numerical capabilities on engine-airframe interaction and integration.

The following Brazilian organizations were involved in this project: FINEP - Brazilian Innovation Agency, Embraer, USP–University of Sao Paulo, UFSC - Federal University of Santa Catarina and ITA – Aeronautical Technological Institute.

FINAL REMARKS

The information presented in the foregoing article provides a useful perspective of the strong government and industry commitment that exists in numerous countries to address the technology aspects of ICAO's Balanced Approach.

In this context, the general trend for large research initiatives has been to address a global environmental agenda, with tradeoffs and interdependency aspects being considered in scientific and technical work programs. It is interesting to note that innovative approaches are investigating how an improved understanding of annoyance factors related to noise can influence noise technology development efforts. A number of such initiatives have recently emerged, broadening the scope of technology related research even further.

Finally, it should be noted that, beyond research goals, anticipated progress trends will remain dependent on several success factors such as the capability to ensure viable industrial applications for promising technology breakthroughs, as well as the commitment by governments and industry groups to maintain a steady funding support over a significant period of time.

Aviation's Next Advance: Sustainable High-Speed Flight

By Aerospace Industries Association (AIA)

In the 100 years since the Aerospace Industries Association (AIA) was founded to represent America's fledging aviation sector, our industry has transformed the way humanity lives, works, and thinks about the Earth. When far-off places are within our reach, we become more connected to the rest of the world around us. Today, anyone can get on an airplane and travel thousands of miles in a matter of hours – trips that simply would be too arduous and impractical by any other form of transport.

However, what we now take for granted is a result of the continuous advances our industry has made over the past century. In the 1930s, a business trip across the Pacific – now a regular occurrence – was far from an easy experience. Traveling from San Francisco to Hong Kong on Pan Am's *China Clipper* took 6 days. By the mid-1940s, a journey from Miami to Buenos Aires still took 71 hours. At these slow speeds, aviation – and long-distance travel more generally – would never become part of most people's lives. With the dawn of the commercial jet age in the late 1950s, everything changed. Travelers could fly across the Pacific in half a day.

While aviation has continued to develop in almost every other way, the speed at which we fly has remained largely the same since the 1960s. However, we are close to achieving the next great breakthrough in civil aviation that will shrink our world even further: environmentally responsible supersonic flight.

U.S. manufacturers have announced projects that will offer the possibility of traveling faster than the speed of sound, at speeds ranging from Mach 1.4 to Mach 2.2. At Mach 1.4, the voyage from Miami to Buenos Aires takes less than 6 hours. A transpacific flight from San Francisco to Hong Kong shrinks from 14 subsonic hours to 5.5 hours at Mach 2.2. And this could become a reality in just the next five to ten years.

The idea of supersonic air travel is not a new one, but the first generation of supersonic aircraft introduced in the 1970s were not environmentally friendly. Concorde and the Tupolev Tu-144 faced international challenges due to environmental concerns – in particular the sonic boom they generated limited the number of viable routes.

While these concerns were warranted, aviation technology has advanced considerably since then and its environmental impacts have been drastically reduced. These improvements from manufacturers are due in no small part to the work that takes place at the International Civil Aviation Organization (ICAO), where governments, aviation stakeholders, and the NGO community all work constructively and collectively. The standards and policies set through ICAO require manufacturers to continually improve environmental performance through technologically feasible and economically reasonable means, bringing broad benefits.

Modern airplanes are now 85% more fuel efficient than the first airliners and a flight today emits 50% less CO_2 than a comparable flight did as recently as the 1990s. Similarly, in the United States, aircraft noise affects a fraction of the population that it did in the 1970s, despite the number of daily flights more than quadrupling.

Advances in propulsion technologies, materials, and aerodynamic design capabilities mean the next generation of civil supersonic airplanes will be far more environmentally responsible than their predecessors.

Sonic booms are widely regarded as the least acceptable aspect of supersonic airplanes. Industry is undertaking extensive research and development to reduce or eliminate this problem, but until these solutions can be matured, supersonic aircraft are being designed to only operate at supersonic speeds over water – to avoid any unacceptable impacts over people. State-of-the-art aerospace technologies, when paired with advanced operational procedures, will also minimize noise impacts during the landing and takeoff phase of supersonic flight.

Airplane noise is only the most noticeable environmental impact; we also need to take our climate responsibilities seriously. AIA was part of the Air Transport Action Group's 2008 agreement that made aviation the first industrial sector to set goals to reduce its climate impact – including a long-term goal to deliver a 50% reduction in net CO_2 emissions by 2050 relative to 2005 levels. U.S. manufacturers remain fully committed to this goal and supersonic airplanes and engines will be designed with fuel efficiency as a key consideration for both economic as well as environmental reasons.

New technologies will allow stricter requirements to be set for supersonic aircraft in the longer term, but these aircraft also will be able to leverage other measures to reduce their environmental impact. Many American manufacturers, including those with an interest in supersonic aircraft, are taking active steps to help spur growth of the nascent sustainable aviation fuels industry. Supersonic engines are being designed to accommodate drop-in sustainable fuels as readily as subsonic engines. In addition, market-based measures such as ICAO's Carbon Offsetting and Reduction Scheme for International Aviation and optimized operational procedures also will play their part to ensure aviation meets its climate commitments.

AIA MEMBER ACTIVITY

Two U.S.-based manufacturers have announced plans for civil supersonic aircraft projects. Working through the International Coordinating Council of Aerospace Industries Associations and the International Business Aviation Council, these manufacturers are contributing technical expertise, modeling resources, and data to ICAO's Committee on Aviation Environmental Protection to inform future environmental standards for supersonic aircraft.

Aerion AS2

Aerion Supersonic is developing the AS2 supersonic business jet, which is expected to take flight in 2023. In 2018, Aerion and GE Aviation announced the first civil supersonic engine program in 55 years, called the Affinity, which will power the AS2. The AS2 is being designed to be able to fly on 100% sustainable aviation fuels, and Aerion is dedicating one flight test airframe with the intention of performing its test campaign with 100% sustainable fuels. The AS2 will cruise at a top speed of Mach 1.4 and operate at "Mach cut-off" speeds over populated areas, taking advantage of atmospheric conditions to cruise at up to Mach 1.2 without generating a sonic boom that reaches the ground.

FIGURE 1: Aerion AS2

The AS2 is expected enter service in 2025, shaving hours from itineraries like New York to Cape Town and London to São Paulo. In February 2019, Aerion announced a partnership with Boeing, through which Boeing will lend engineering, manufacturing, and flight test resources to support the AS2 development program. For decades, Boeing has made significant contributions to supersonic technology. In recent years, Boeing has collaborated with the Japanese government and industry on wind tunnel testing and participated in a study on the use of a revolutionary new material called Shape Memory Alloy.

Boom Overture

Boom Supersonic is focused on making the planet dramatically more accessible through supersonic flight. The company's first commercial product will be a 55-seat,

FIGURE 2: Boom Overture

Mach-2.2 airliner called Overture, designed with operating costs similar to today's subsonic commercial business-class aircraft. Overture will enter service in the mid-2020s and could dramatically shorten flight times on hundreds of global routes by cruising at supersonic speeds over water. Boom is currently building XB-1, a two-seat demonstrator that will begin flight testing within the next year. XB-1 is the world's first independently-developed supersonic jet and will be the fastest civil aircraft in history when it reaches its Mach-2.2 design cruise speed.

Other U.S. manufacturer activity

FIGURE 3: NASA/Lockheed Martin X-59

In 2018, the National Aeronautics and Space Administration (NASA) awarded Lockheed Martin the contract to design, build, and complete initial flight testing of the X-59, which is scheduled to fly in early 2021. Producing shaped sonic boom signatures with a perceived level of noise between 70–80 decibels (PLdB), the X-59 is intended to inform the design of future commercial supersonic airplanes with sonic boom characteristics allowing for quiet overland supersonic flight. NASA is developing community response testing plans using X-59 to investigate public acceptance of quieter, shaped sonic booms. The efforts of Lockheed Martin and NASA will support future rulemaking on acceptable supersonic on-route noise levels.

Collins Aerospace is supporting Lockheed Martin's and NASA's work on the X-59 by working with them to develop avionics solutions allowing pilots to navigate without a forward-looking window – which is impractical on the long airframe necessary for low-boom flight. Collins Aerospace is also working with NASA on other areas of supersonic technology, including avionics displays that provide pilots with a prediction of how their sonic boom will propagate, enabling them to mitigate or avoid noise impacts.

Gulfstream is also a leader in supersonic airplane research, having invested in low- and high-speed aerodynamics, engine design and integration, field performance, and both landing and takeoff and sonic boom noise research. Since 2014, Gulfstream has contributed to NASA programs, validating sonic boom prediction models and developing flight research plans for NASA's low-boom flight demonstrator.

NATIONAL RESEARCH ORGANIZATIONS

U.S. manufacturers also support the work being done by NASA, other research agencies, and national aviation authorities to further state-of-the-art research in supersonic flight. Around the world, these organizations are making valuable contributions to sustainable supersonic travel.

NASA

NASA has undertaken a number of projects in different areas of supersonic airplane research. Among its collaborations with other national research agencies are partnerships with The French Aerospace Lab and the Japan Aerospace Exploration Agency on sonic boom prediction research. As mentioned above, NASA is developing the X-59 Quiet Supersonic Technology research X-plane in partnership with Lockheed Martin, which is intended to create a sonic "thump" to approximate sounds that may be produced by future large, quiet supersonic aircraft. Community response testing with the X-59 is expected to begin in 2022. NASA also has undertaken modelling of supersonic transport-category airplane environmental performance with contributions from manufacturers including Aerion, Boeing, Boom, GE, Gulfstream, and Rolls Royce.

Japan Aerospace Exploration Agency

Since 2016, the Japan Aerospace Exploration Agency has conducted research and development into future economically-viable and environmentally-friendly supersonic airliners through the System integration of Silent SuperSonic program. The associated project airplane is a 50-seat, Chapter 14-compliant airliner with more than 3,500 nautical miles of range and a perceived sonic boom signature of less than 85 decibels. The agency has also developed sophisticated sonic boom modelling capabilities as part of its low-boom concept demonstration “Drop test for Simplified Evaluation of Non-symmetrically Distributed sonic boom,” and created a sonic boom prediction code called “Xnoise,” validated with measurement data from the demonstration.

RUMBLE

RUMBLE (RegUlation and norM for low sonic Boom LEvels) is a three-year program sponsored by the European Commission and the Russian Federation. RUMBLE is coordinated by Airbus and involves 19 European and Russian partners, including advisory input from the European Union Aviation Safety Agency and Directorate General for Civil Aviation. The project seeks to address both technical and regulatory aspects of sonic booms. Ultimately, RUMBLE seeks to produce the scientific evidence necessary for governments and ICAO to develop an on-route supersonic noise standard, and the project will make recommendations for this sonic boom standard.

TsAGI and CIAM

The Russian research centers called TsAGI and CIAM, subsidiaries of the National Research Center -Zhukovsky Institute, conduct research on community noise produced by supersonic civil aircraft. Some results on noise reduction from takeoff thrust management and jet speed effect on supersonic transport-category airplane community noise were submitted at the Committee on Aviation Environmental Protection 11 meeting.

ICAO

As work continues on civil supersonic development programs and research initiatives, ICAO has a significant role in developing global environmental standards appropriate for future supersonic airplanes and engines. U.S. manufacturers are supporting ICAO’s efforts to develop a regulatory framework appropriate for civil supersonic airplanes. A set of exploratory studies was recently assigned to ICAO to develop understanding on supersonic aviation noise, emissions, and environmental modelling, with input from technical expert working groups. This work program is designed to assess environmental performance and demand scenarios for future supersonic airplanes and will afford a better understanding of the impacts of potential supersonic operations.

CONCLUSION

Despite fundamental technical differences between supersonic and subsonic airplanes, and the comparative lack of maturity in civil supersonic technology, U.S. manufacturers are fully committed to producing environmentally responsible supersonic aircraft and minimizing their environmental footprint. Reducing fuel burn, supporting the development of sustainable aviation fuels and mitigating or eliminating sonic booms are just some of the many activities and research projects being undertaken to improve performance and speed connections around the world. In light of civil aviation’s undeniably beneficial influence on modern society, and urgent needs to address the long-term impacts of climate change, this research is even more important. Current efforts by industry and research being performed by other organizations are the first steps towards making environmentally-friendly supersonic flight a reality.

Operational Opportunities to Reduce Aircraft Noise

By Kevin Morris (ADS/ICCAIA)

Learning from others is an efficient way of ensuring progress, and international aviation stakeholders often look for guidance on best practices in the area of environmental protection to help them identify and reduce their environmental impacts. ICAO has a robust track record of providing guidance documents to benefit its Member States as well as the entire aviation community. One example is the ICAO Document – *Operational Opportunities to Reduce Fuel Burn and Emissions* (Doc 10013), which has proven so successful that a decision was made to develop a similar document aimed at reducing noise from aircraft operations. The purpose of this latter document is to build on the willingness of all parties in the aviation sector to learn from each other in order to help them advance their performance, and ensure that good practices for minimizing aircraft operational noise are implemented globally.

INTRODUCTION

ICAO's Balanced Approach on aircraft noise management around airports (Doc 9829) is the only globally recognized policy for managing noise impacts around airports, and is implemented world-wide. It is based on four pillars consisting of: reduction of noise at source, effective land-use planning, operational procedures, and the use of operating restrictions, as a last resort.

In this context, the ICAO Guidance Document "*Operational Opportunities to Reduce Aircraft Noise*" would complement the work carried out for one aspect of the implementation of the Balanced Approach on aircraft noise, by providing comprehensive information about operational techniques to help reduce aviation noise, where practicable, and operationally safe to do so.

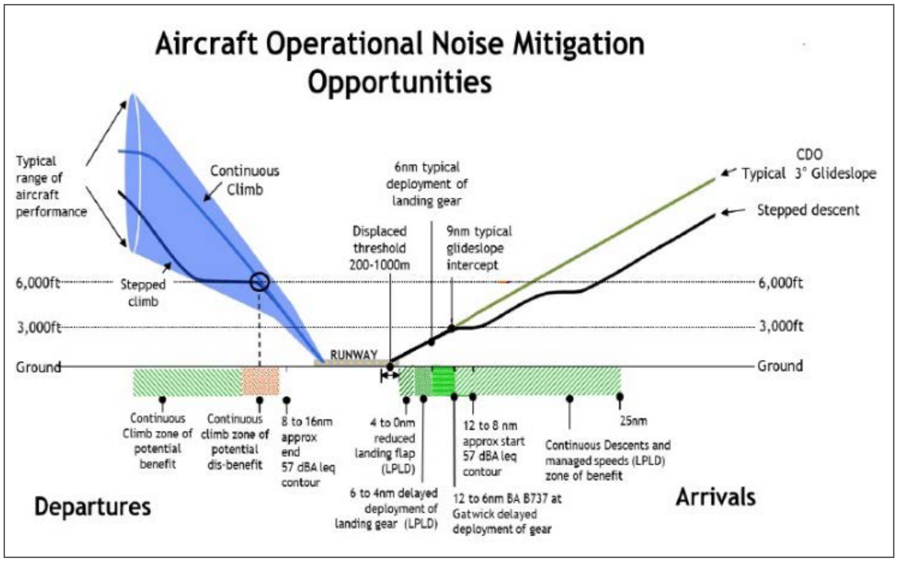
This work is being performed by a task group as part of ICAO's Committee on Aviation Environmental Protection (CAEP), for an expected delivery in 2022.

THE DOCUMENT – OPERATIONAL OPPORTUNITIES TO REDUCE AIRCRAFT NOISE

The manual is being developed to provide a reference to airlines, airport operators, air traffic management and air traffic control service providers, airworthiness authorities, and environmental agencies, as well as other government bodies and interested parties. Its objectives are to:

- Document industry experience and the benefits, in terms of operational noise exposure resulting from optimizing the use of current aircraft and infrastructure, and the related benefits of technology and infrastructure improvements.
- Identify opportunities that could result in measurable noise impact reductions.
- Highlight emerging technology that, when used, could result in reductions in operational noise impacts.
- Demonstrate that a more efficient use of infrastructure is an effective means of reducing civil aviation noise impacts and therefore promote enhanced use of the capabilities inherent in existing aircraft, ground service equipment and infrastructure including airspace management.
- Highlight the importance of stakeholder collaboration to address operational changes that impact community noise exposure.

FIGURE 1: Example of noise mitigation opportunities during aircraft operations.[1]



It is important to note that it may not be possible to realize the benefits from every opportunity at every airport; and for this reason, the document is not prescriptive and is not intended to be the basis for regulatory action. The choice of the operational procedures presented depends upon many factors other than noise benefits, as highlighted by the interdependencies section, and it may not be appropriate for certain of them to be implemented everywhere. For this reason, local issues need to be addressed locally, and this document is aimed at helping inform that process.

CONTENT

The document will be a reflection of the actual experience collected from aviation practitioners and will cover the following elements.

Collaborative aspects

Collaboration with local communities is of paramount importance when new operational procedures are considered; as is pointed out in ICAO Circular 351 *Community Engagement for Aviation Environmental Management*. Collaboration among industry and regulator stakeholders is also an important factor to be able to share good practices and identify potential unintended consequences of not thoroughly evaluating all environmental impacts.

Departure (take-off and climb) operations

Continuous Climb Operations are described, as well as the construction and protection of Noise Preferential Routes to avoid unnecessary exposure to aircraft noise. It is interesting to note that in addition to the differences in noise contours incurred by Noise Abatement Departure Procedures, there may be noise benefits above 3,000 feet to be considered as well. Aviation stakeholders have already flagged the importance of considering the use of noise preferential runways, as well as the possibility to alternate their use to give respite to local communities. It is also clear that the use of newer Performance Based Navigation (PBN) and aircraft-based systems Multi-Criteria Departure Procedures (MCDP) could be part of the operational toolkit to be considered in the context of the implementation of noise abatement operational procedures.

1 https://www.sustainableaviation.co.uk/goals/noise/

Arrival (approach and landing) operations

Approach operations cannot deliver equivalent reductions in noise, as those resulting from improved aircraft climb performance, as aircraft are required to follow the same track within 5-10 miles of the airport at the same altitude, according to stabilized approach criteria. A few procedures can be considered, based on the principles of Standard Arrival Routes and Continuous Descent Operations, Preferential runway use, and the optimal use of PBN or the Low Power Low Drag (LPLD) procedures. Potential changes to the airport infrastructure using displaced thresholds, and possibly small increases in glideslope angle could also deliver additional noise reduction.

Airport ground operations

It is recognized that ground noise is a lesser issue than airborne noise from take-off and landing but can impact sensitive areas around the airport, especially where local communities are close to the airport boundary. A range of options can be explored to mitigate noise from ground operations, including minimizing: APU use, aircraft taxiing operations, ground running of aircraft engines, use of Ground Service and Ancillary Equipment, and noise optimized airport design (ICAO Doc 9184 *Airport Planning Manual Part 2, Land-use and Environmental Management* refers).

Helicopter operations

Some ICAO Member States and international aviation stakeholders are carrying out significant work programs to identify low noise procedures for helicopters. Similar to other types of aircraft, the operational noise of helicopters can be managed based on appropriate guidance on departure, on-route, and in arrivals phases of flight, as well as hovering operations.

Maintenance for reduced operational noise

Under specific circumstances, targeted maintenance practices are expected to help reduce the noise generated by aircraft. In this respect, the main focus areas are on: maintaining the airframe and engine gas-path ‘cleanliness’, minimizing and managing weight, reducing and removing acceptable defects (ADDs) affecting noise performance, and the timely incorporation of any product improvement and software packages that may help improve the aircraft’s noise performance.

Potential future developments

Aircraft technology is fast-evolving and new on-board systems may pave the way to more effective noise abatement procedures. A look at what some aspects of the future may bring, will help identify potential opportunities that may result from emerging technologies. This involves considering what advances may become available in the near future from initiatives that the aerospace manufacturing industry and airspace service providers are developing. An example of this would be the possible benefits that might be gained from optimizing lateral flightpaths using concepts innovatively, such as PBN, followed by vertical flightpath optimization during both departure and arrival operations. For the latter, it may be feasible to perform novel approaches in the future such as those with two-segments. A developing issue with new aircraft designs may mean that a shallower - rather than steeper – descent angle prior to transitioning onto the normal glideslope may provide a greater noise reduction benefit with these aircraft, thus complicating the whole process. When implemented, the impact of, new operational procedures on overall traffic flow optimization, development, and implementation should be assessed and managed.

Interdependencies and trade-offs

Any decision on environmental management should result from a careful evaluation of all the possible environmental impacts. This means identifying interdependencies and trade-off among environmental impacts (e.g., noise and greenhouse gas emissions), or between environment and other strategic areas of aviation operations, such as capacity, safety, and economics. Sound guidance has been developed and documented by ICAO's CAEP group on this matter[2]. The issue of noise displacement is also highlighted, where minimizing noise impacts in one area may lead to increases in others, and why flying at a higher altitude may not necessarily mean that the noise impacts from an aircraft operation, will be less.

Finally, it is important to recognize that all aviation stakeholders have worked hard to achieve an enviable level of safety within the sector. In this respect, safety must always be the overriding consideration in all civil aviation operations; and the operator, in conjunction with the operating crew, must remain the ultimate judge of what can be done to minimize operational noise impacts while maintaining the necessary safety margins. This is an important factor in the Collaborative aspects section of the manual, and it is inherent that by working together, the optimum outcome may be achieved while at the same time, maintaining safe operations.

THE NEXT 3 YEARS AND BEYOND…

The document is intended to be a 'living' document, updated with new information as additional good practices are identified. In particular, the impact of new technologies and the potential of newer aircraft-based systems could contribute to a further enhancement of the noise situation around airports, and these should be followed and implemented as they become readily available. ICAO's work will take this technological component into consideration with the simple understanding that all parts of the aviation sector can learn from one another to help the advancement of operational noise performance. The consequence of this will benefit all areas and communities impacted by aircraft noise by recognizing and implementing better practices where practicable and operationally safe to do so.

2 https://www.icao.int/environmental-protection/Pages/CAEP-Operational-InterdependencyTask.aspx

Aircraft Noise Annoyance

By Truls Gjestland

RECENT DEVELOPMENTS

Researchers have tried for half a century to identify predictive statistical relationships between transportation noise exposure levels and human annoyance levels. A number of curves have been developed to illustrate this relationship since the Schultz' initial general dose-response curve in 1978[1]. Although most researchers agree that the annoyance of aircraft noise is only partially determined by noise exposure levels, many still believe that a single "correct" dosage-response relationship can be used to predict annoyance in all airport communities.

Researchers continue to feed the ever-growing database of social survey results into correlational software which yields regression functions that only statisticians understand, and which lack causal interpretability. Noise-induced annoyance depends on a variety of survey-specific, non-acoustic factors that move dose-response curves back and forth, or up or down[2]. For each new survey, claims are then made that a new and more "correct" dose-response relationship has been established.

However, a scatter plot of the results from 63 different surveys of aircraft noise annoyance conducted between 1961 and 2017, comprising 653 paired responses from more than 100,000 individuals (see Figure 1) is convincing documentation that a dose-response curve derived from these data points using conventional regression techniques is a very poor predictor of the prevalence of highly annoyed persons at most airports. At a noise level of L_{dn} = 55 dB, the prevalence of highly annoyed varies between 0 % and 90 %. Conversely, a 10 % prevalence rate of "highly annoyed" has been observed at exposure levels between 35 dB ≤ L_{dn} ≤ 70 dB[3].

After more than fifty years of meager success in predicting community reaction to transportation noise, it is time for a new approach. The first step in developing a more sophisticated understanding of community response to transportation noise is to formally acknowledge that responses to questions such as, "How annoyed are you by aircraft noise?", are determined not only by the noise exposure itself, but also by a variety of non-acoustic (or more specifically, "non-DNL") factors. These factors can be personal such as noise sensitivity, fear of accidents, mistrust towards the airport authorities, feelings of misfeasance, and so on, or more physical ones like maximum noise levels, changes in the exposure pattern and the rate at which these changes occur, duration of silent periods between noise events, *inter alia*. As Basner *et al*. have noted[4], noise exposure alone accounts for only about a third of the variance of individual responses. Since the aggregate influence of these non-acoustic factors varies from one airport community to the next, it may be irrelevant to seek a single function that accurately describes the relationship between noise exposure and prevalence of annoyance in all airport communities. In fact, such attempts ignore the effect of non-acoustic factors and effectively prevent us from finding out how they affect the annoyance response[5].

THE COMMUNITY TOLERANCE LEVEL

As a further development of observations made by Schultz in his original synthesis, Fidell *et al*. launched the Community Tolerance Level ("CTL") analysis[6]. They observed that the growth of annoyance with noise exposure seemed to follow the effective loudness function, but the onset of the annoyance, *i.e.* the location of the "starting point" on the abscissa of the response curve varied and was determined by a community-specific annoyance decision criterion. In other words, the shape of the dose-response curve is the same for all aircraft noise situations, but the position of the curve relative to the noise axis depends on the non-acoustic factors. The position is defined by the CTL-value.

Any arbitrary point on the dose-response curve ("the effective loudness function") could be selected to anchor it to the noise axis. Since the choice is arbitrary, the midpoint of the function—the point corresponding to a 50 % high annoyance prevalence rate, and the point with the steepest growth —was selected as a convenient anchor point. This choice of anchor point has mistakenly led some researchers to believe that the CTL method only considers annoyance at very high levels (50 % HA "highly annoyed"). On the contrary, a single CTL value is associated with a complete dose-response curve from 0 % HA to 100 % HA, and the corresponding noise levels at which these responses can be observed.

So, instead of finding an arbitrary mathematical function to fit a set of empirical field measurements that lacks any physiological, psychological or other interpretability (as in standard regression analysis), the CTL method seeks to fit an *a priori* function (*i.e.*, a duration-adjusted loudness function) to the survey data. This method is further explained in the International standard ISO 1996-1.

Each community is treated separately in the CTL analysis and characterized by a single CTL value. The results from different surveys can be combined simply by calculating means and standard deviations of individual CTL values. Each CTL value is associated with a unique dose-response function. Thus, the complete noise situation with respect to annoyance can be described by a single quantity, and differences between communities and situations can be quantified by comparing their respective CTL values.

An example of CTL analysis is shown in Figure 2. Two datasets from Figure 1, with somewhat extreme responses, have been identified. In one of the surveys (triangular markers), the prevalence of "highly annoyed" is very low, whereas in the other survey (square markers), the annoyance response is much higher. The two dashed dose-response functions are identical functions but their position relative to the x-axis varies. The CTL values are 83.6 dB and 63.8 dB, respectively. In other words, people at one airport (triangles) "tolerate" 20 dB higher noise levels in order to express a certain degree of annoyance than the residents at the other airport (squares). The limit for 10 % prevalence of highly annoyed residents at this first airport is L_{dn} 66 dB, whereas this limit is reached already at a noise level L_{dn} 46 dB at the other one.

PRACTICAL USE OF CTL

The dose-response curves developed by Miedema & Vos have been widely accepted as a standard for annoyance from transportation noise[7]. Their aircraft noise curve is based on the results from 20 different surveys. A closer look at the Miedema & Vos curve for aircraft noise annoyance shows that this curve is very similar to a curve corresponding to L_{CT} 73.5 dB. The average value for all 63 surveys presented in Figure 1 is L_{CT} 74.5 dB. This is very similar to the Miedema & Vos curve, but there is a very wide spread in the survey results, 63.0 dB < L_{CT} < 87.6 dB. The community tolerance level shifts by almost 25 dB between the two extremes, a shift that is caused by non-acoustic factors. A community with a CTL value of about L_{CT} 75 dB displays an average response to noise. Communities with higher CTL values are less annoyed, and lower CTL values indicate annoyance higher than average.

Most airports are in a constant change-mode. These changes may be gradual, or they can happen abruptly. Janssen and Guski have proposed a classification of airports for survey purposes that groups them according to their rate of change. High-rate-change airports (HRC) have experienced large operational changes (but not necessarily changes in the noise exposure) within 3 years prior to the survey. An airport is also characterized as HRC if plans have been launched to alter the current operations within 3 years after the survey, and/or if the airport has received controversial public attention. Low-rate-change (LRC) is the default characterization.

The 63 surveys analyzed above have been characterized as HRC or LRC according to the definition presented by Janssen & Guski. The mean CTL value for the two types were 67.5 dB (HRC) and 76.4 dB (LRC), making the difference in the annoyance response between the two types of airports to be about 9 dB. Remembering that a shift of 10 dB represents a doubling of the subjective loudness, one may say in popular terms that residents at an LRC airport "tolerate almost twice as much noise" as those living near an HRC airport. The rate-of-change is thus an important non-acoustic factor.

Other factors that may modify the annoyance response have also been studied. The traffic volume characterized by the number of aircraft movements can play a role for the annoyance assessment. At equal noise levels, the annoyance has been observed to increase with an increasing number of movements. A doubling of movements is equivalent to a shift of 1.8 dB in the CTL value. But this shift can only be observed at LRC airports. At HRC airports the annoyance response seems to be independent of the number of aircraft movements[8]. One explanation may be that few (but louder) noise events leave longer quiet inter-event intervals than many events at lower levels. Quiet periods may be desirable, and the noise situation is therefore considered less annoying. The effect is not very strong. At HRC airports, however, the factor that causes a shift in the CTL value of 9 dB is probably so dominating that the number-of-movement-effect is masked or "overruled".

ARE PEOPLE BEING MORE ANNOYED BY AIRCRAFT NOISE?

Some researchers claim that there has been a shift in the annoyance response over the years; they claim that people today are more annoyed by aircraft noise than they were 25-50 years ago. This conclusion may primarily be based on different selections of surveys. More surveys have been conducted at HRC airports in recent years, so naturally the average CTL value for a selection of new surveys will be lower due to a high percentage of HRC airports. However, if the two types of airports are analyzed separately, there is no indication of a change. A selection of post-2000 surveys yield the following CTL values: 76.9 dB (LRC) and 67.8 dB dB (HRC)[9]. These CTL values are almost identical to those found for the whole set of 63 surveys dating back from 1961 indicating that people today are equally annoyed as they were 25 or 50 years ago, and people at an LRC airport still seem to "tolerate about twice as much noise" as those living near an HRC airport in order to express a certain degree of annoyance.

The World Health Organization (WHO) has recently published new environmental noise guidelines for Europe[10] that state that the annoyance has increased, and it therefore recommends a limit of L_{den} 45 dB for aircraft noise in order to prevent adverse health effects. WHO's newly identified noise exposure levels are an order of magnitude lower than those identified by WHO in 2000[11].

However, this recommendation has been based on a selection of non-representative and non-standardized surveys with results that cannot be applied to a general airport population. The recommendation is therefore unwarranted and unsupported by the reported evidence[5]. As pointed out above, detailed analyses of all available survey results reveal no change over time. WHO's previous recommendation from 2000 leaves about 8 % of the population highly annoyed.

FIGURE 1: Results from more than 50 years of aircraft noise surveys

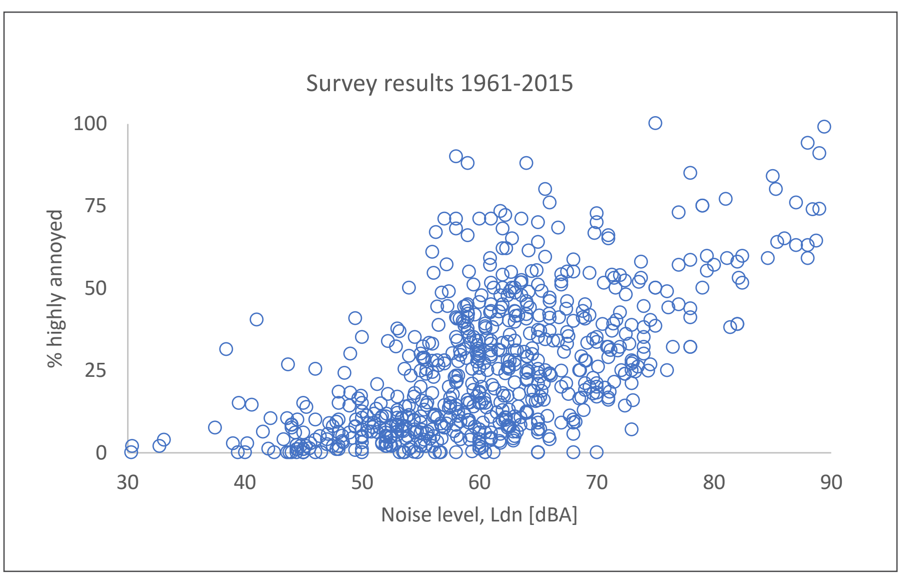
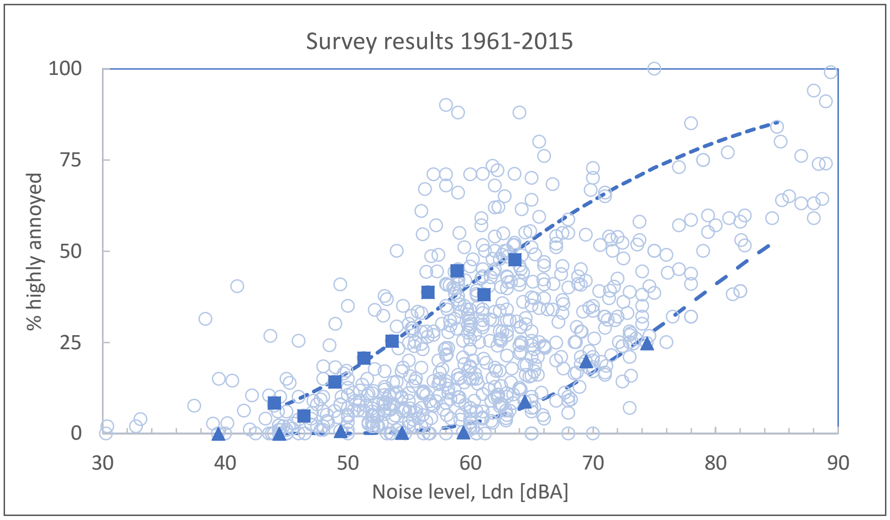


FIGURE 2: Separate dose-response curves for two airports



CONCLUSIONS

There has been no change in people's response to aircraft noise over the past half century. People today are equally annoyed as they were 25 or 50 years ago. However, there is a big spread in the annoyance response. This is due to the influence of various non-acoustic factors.

The Community Tolerance Level method provides a single number characteristic, a CTL value, of the noise annoyance situation around an airport, which represents a quantification of all non-acoustic factors that govern the annoyance response. A study of the CTL values for different airports may yield important information on how to manage the annoyance within the constraint of a given noise situation.

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Stakeholder Engagement and Performance-Based Navigation as a Noise Mitigation Platform

By Jonathan Bagg and Blake Cushnie (NAV CANADA)

Spurred by growing levels of aviation activity, regional and global environmental commitments, technology advancement, and industry economics, airspace modernization is no longer optional. This is the context in which Air Navigation Service Providers (ANSP) are compelled to drive forward providing safety, efficiency, and environmental gains in order to deliver value to a varied set of stakeholders. Finding common ground between industry and communities and their elected representatives can be challenging. Expectations from stakeholders have increased and, as a result, the need for effective community and stakeholder engagement is now the path to airspace change success.

EMPLOYING A STAKEHOLDER-CENTRIC APPROACH

A key component of successful airspace deployment for NAV CANADA is one that place with stakeholders at the heart of the process, going from the ground up. Deployment teams are formed, comprised of airspace designers, air traffic control staff at the facilities in question, operations project managers, and members of the stakeholder relations team to proceed with airspace development. They work together towards a common goal of reducing airspace complexity, improving safety and accessibility, delivering efficiencies, and generating environmental gains. Airline customer representatives also participate in early concept of operations meetings so that the project team understands operational requirements, cockpit/workload processes and factors, flight management system characteristics, and aircraft performance limitations. This helps ensure operational feasibility and efficiency while anticipating future pilot awareness and training needs.

The design process is informed by design criteria and operational constraints, but goes a step further by considering community impacts from the outset. In this manner, airspace design is not just considered against a controller's situational display, but also by the relative location of neighboring communities. This is done by plotting potential procedures against satellite imagery and seeking opportunities to place tracks over commercial, industrial, and other non-residential use land. In addition, noise modeling is used to understand how many people are affected by a proposal with an objective of developing a concept of operations that reduces noise impacts. The result is a draft proposal that is cognizant of community impacts while meeting operational objectives and constraints. The cross-functional nature of the airspace project teams has resulted in increased flexibility in stakeholder and community engagement, with technical staff having a better understanding of how to approach public events. It also gives stakeholder relations/public affairs staff knowledge about technical matters so that they are better positioned to tell the airspace change story in a factual and relatable manner.

With a draft concept of operations, the project team will meet with airport operations and community affairs representatives to discuss impacts and potential further enhancements given the airport's front-line knowledge of noise sensitive areas. Further adjustments are made to designs and the associated noise modeling, prior to community engagement planning which is developed in lockstep with the concerned airport authority. The active participation of airports in the design process can result in better design outcomes because it allows them to contribute their on-site knowledge regarding current noise exposure, identification of noise sensitive areas, and other community concerns.

FOUNDATION FOR EFFECTIVE ENGAGEMENT: AIRSPACE CHANGE PROTOCOL

In Canada, airspace community engagement methodologies are guided by the industry's Airspace Change Communications and Consultation Protocol. The voluntary protocol was developed in 2015, and co-signed by NAV CANADA and the Canadian Airports Council, and endorsed by the Canadian Minister of Transportation. The protocol outlines when and how consultation should occur, with a consultation methodology that is largely informed by community impacts. The Airspace Change Protocol sets thresholds that help determine if consultation or communications processes should occur. This includes quantifiable thresholds related to the number of aircraft movements at the airport, the altitude at which flight path changes are anticipated (lower altitude flight have the potential for greater impacts), and anticipated increases in procedure utilization with considerations for nighttime operations. While many of the projects that are guided by the protocol are related to airspace design, it also seeks to guide major airport projects that can impact runway utilization or drive changes in air traffic flows.

Regardless of whether consultation is required or not, the protocol promotes proactive notification efforts and the availability of comprehensive information on the proponent's website and is distributed through the airport's various communication channels. Another fundamental tenet of the protocol is the importance of air navigation service (ANS), airport, and airline participation and collaboration in shaping and conducting airspace change. In this manner, it is not unusual for representatives of the ANS, airports, and airlines to participate at community events to ensure a more holistic understanding of the various facets of operations.

COLLABORATING ON ENGAGEMENT

NAV CANADA works directly with airport authorities to define public consultation and engagement processes that are sensitive to the community and socio-political environment at any given location. The project team will propose an engagement format that may include events such as public open houses, notice processes, earned media considerations, and informative web content. The format is discussed with the airport authority and events will be added, promotion activities will be adjusted, and messaging considerations will be shaped according to the airport authority's feedback. This ensures that both parties are aware of how communications will occur and that it happens in a coordinated fashion, the details of which are elaborated in an Engagement Plan. At this phase, the project team will involve a key stakeholder – the airport's noise management committee – to brief them on the proposed airspace changes and seek the committee's input on potential improvements and possible community engagement mechanisms.

CASE IN POINT: TORONTO PEARSON AND THE "6 IDEAS"

In the spring of 2018, NAV CANADA and the Greater Toronto Airports Authority (GTAA) consulted on a series of 6 ideas with communities surrounding Toronto Pearson, the busiest airport in the country. The ideas sought to deliver potential mitigations both close to and further away from the airport. NAV CANADA proposals included: new nighttime RNAV procedures, new nighttime departure procedures, and updates to Standard Terminal Arrivals. In parallel, the GTAA proposed a Summer Weekend Runway Alternation trial and enhancements to the nighttime preferential runway system. Noise modeling demonstrated that as many as 220,000 fewer people would be impacted by the new nighttime procedures at noise levels above 60 dBA when compared with the current, typical flight profile. The joint consultation represented a significant collaboration between the two stakeholder groups by bringing a package of mitigations that could work in concert and proposed in partnership, shoulder to shoulder.

A significant promotion effort was brought forward by the airport authority and executed in partnership with NAV CANADA, including: newspaper notices, paid and organic social media promotions, automated telephone notifications, and a comprehensive web package. These actions surpassed requirements of the protocol and ensured that communities were aware of their opportunity to participate in the process. A series of 19 public open house style consultation events were held across the Greater Toronto Area, two of which had a livestream capability for those who could not attend one of the in-person sessions. A key feature of the events was that the provision of information went beyond information boards and staff, to include address lookup stations. These allowed residents to provide their address or postal code and receive an interpretive briefing as to what they can observe currently and what they can expect under the proposal. This was done using Google Earth with flight track data and noise modeling to illustrate operations and impacts over very specific locations.

Overall, hundreds of residents participated and provided feedback, either in person or through an online feedback tool. Subsequent to the consultation, a report was produced that: showed that communities broadly supported implementation, responded to feedback where appropriate, and provided an overview of implementation plans. Since the completion of the consultation process, all of NAV CANADA's proposed procedures have been phased in, including new night procedures that were implemented in November 2018, and new STAR profiles that enable increased Continuous Descent Operations were implemented in February 2019. Utilization rates of the new nighttime procedures have been high to date, while results for the new STAR profile are as anticipated and expected to increase over time.

PERFORMANCE BASED NAVIGATION (PBN) AS A DRIVER OF POSITIVE CHANGE

As shown in the example above, the industry needs to work together to turn the corner on negative perceptions towards PBN. This can be achieved by utilizing PBN and hybridization to achieve airspace objectives while delivering benefits to residential communities. When design teams actively consider how CDO, route placement, and the combination of PBN and vectoring can be leveraged, outcomes are improved. When that process is combined with effective education, consultation, and engagement, PBN-based navigation is no longer the source of uncertain opposition but the potential for positive change for communities and industry stakeholders alike.

Over the past four years, NAV CANADA has been leading this positive change throughout its airspace projects. It has employed Required Navigation Performance-Authorization Required (RNP-AR) to reduce the number of people impacted by noise by targeting non-residential areas at several Canadian airports. In some cases, vectors off the ground have been used to connect up with an Area Navigation (RNAV) Standard Instrument Departure (SID), to deliver the operational benefits of PBN, while minimizing impacts at lower altitudes. More recently, after significant work with partners at ICAO, NAV CANADA has improved traffic integration at Calgary International Airport by being among the first to leverage the Established on RNP-AR standard. Close to 3,000 aircraft are approaching on continuous descent per month, reducing low level altitude flying over communities by 140 hours per month, and reducing greenhouse gas emissions by 1,000s of metric tons. On an annual basis, 36,000 RNP-AR approaches at Calgary International will result in a reduction of 4.1 million kilograms of CO_2 emissions from reduced fuel burn, and will reduce use of low altitude levelling over residential areas by more than 1,500 hours.

These are just a few ways that PBN is being used as a source for noise mitigation, combined with transparent engagement, to deliver on NAV CANADA's mandate and generate value for stakeholders.

CHAPTER THREE

Local Air Quality

Introduction to LAQ

By ICAO Secretariat

ICAO STANDARDS AND RECOMMENDED PRACTICES (SARPS), ANNEX 16, VOLUME II

One of ICAO's environmental goals is to limit or reduce the impact of aviation emissions on local air quality (LAQ). Starting the late 1970s, ICAO has been developing measures to address emissions from aircraft engines in the vicinity of the airport and from relevant airport sources. The Volume II of Annex 16 to the Convention on International Civil Aviation contains Standards for aircraft engine emissions and is accompanied by the related guidance material and technical documentation. Following the latest successful adoption of the CAEP/10 nvPM Standard based on visibility criterion, CAEP/11 agreed on nvPM mass and number Standard, moving it towards consideration for adoption by the ICAO Council in the next year. ICAO provisions on LAQ also address liquid fuel venting, smoke (which is expected to be superseded by the nvPM Standard), and the main gaseous exhaust emissions from jet engines, namely: hydrocarbons (HC), oxides of nitrogen (NOx), carbon monoxide (CO).

ENGINE CERTIFICATION PROCEDURE

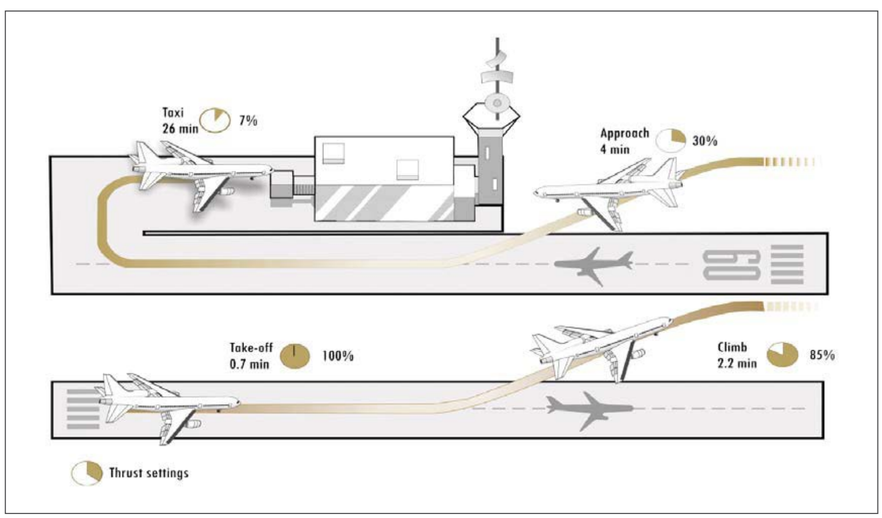
The engine certification process is based on the Landing and Take-off (LTO) cycle. This LTO cycle representing pollutant emissions in the vicinity of airports consists of four operating modes, which involve a thrust setting and a time-in-mode shown in Figure 1.

The engine certification process is performed on a test bed. For each thrust setting and corresponding fuel flow, the pollutant emissions are measured in accordance with the relevant SARPs. The submission of this data to the certificating authority is mandated as part of the engine emissions certification. This certification data is collected and stored in the publically available ICAO emissions databank[1].

Over the past three years, the ICAO Committee on Aviation Environmental Protection (CAEP) has conducted work to ensure the validity and consistency 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 non-volatile Particulate Matter (nvPM) mass and number Standards; an industry led combustion technology reviews, the update to ICAO SARPs to ensure their completeness; and an overview of the current state of the science regarding LAQ.

The recent approval by (CAEP/11) of non-volatile Particulate Matter (nvPM) mass and number Standards is a ground breaking achievement. The adoption of this new Standard by the ICAO Council will mark the completion of the final

FIGURE 1: Illustration of ICAO emissions certification procedure representing the LTO cycle



1 https://www.easa.europa.eu/easa-and-you/environment/icao-aircraft-engine-emissions-databank

component of aircraft environmental certification, closing the full circle on noise, local air quality and CO_2 Standards for subsonic aeroplanes. This new Standard would lead to nvPM emissions reductions from international aviation in the coming years.

NEW NVPM MASS AND NUMBER STANDARDS

During the combustion of hydrocarbon-based fuels, aircraft engines generate gaseous and particulate matter (PM) emissions. At the engine exhaust, particulate emissions consist mainly of ultrafine soot or black carbon emissions. These particles, referred to as "non-volatile" PM (nvPM), are present at high temperatures, in the engine exhaust. Compared to conventional diesel engines, gas turbine engines emit non-volatile particles of smaller mean diameter. Their characteristic size ranges roughly from 15 to 60 nanometres (nm; 1nm = 1/100,000 of a millimetre). These particles are invisible to the human eye and are ultrafine.

The CAEP/11 meeting recommended new nvPM mass and number Standard for aircraft engines and this will be considered by the ICAO Council for adoption in the early part of 2020. The new Standard will apply to new type and in-production engines with rated thrust greater than 26.7kN from 1 January 2023. The limit lines for nvPM mass and number provide some alleviation for engines with rated thrusts below 150kN. This Standard is less stringent for in-production engines and a supplementary "no-backsliding" measure was introduced.

The recommendation on the nvPM emissions Standard was supported by a significant data driven process and the cost-effectiveness modelling analysis of several different stringency options for mass and number. In addition, CAEP agreed on an end date for the Smoke Number Standard, of 1 January 2023, as the new nvPM emissions Standards preserve ICAO smoke visibility limit.

With this new Standard, ICAO will have completed the main environmental Standards for the certification of aircraft and engines, namely for noise, local air quality (NOx, HC, CO, nvPM) and climate change (CO_2), making the aviation industry the only sector with mandatory environmental certification requirements at the global level for the operation of its equipment. Once applicable, all new aircraft will need to be certified to these ICAO Standards before operating.

ADVANCEMENTS IN COMBUSTOR TECHNOLOGIES AND NOX GOALS

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 implementation of the latest technologies in engine design. 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).

Following several independent expert technology reviews on NOx, fuel burn and noise, a first of its kind, integrated independent expert technology goals assessment and review for engines and aircraft was performed, and presented to the CAEP/11 meeting. This review provided, inter alia, an assessment of advances in engine combustor design technologies for subsonic aircraft and the degree to which these technologies could influence gaseous emissions, and fuel flow reduction, including the potential interdependencies and trade-offs with 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 technology goals.

CAEP delivered new technology goals for the international aviation sector. For instance, for single-aisle aircraft, the mid-term NOx emission goal (by 2027) is 54 per cent lower relative to the latest ICAO NOx SARPs; and fuel efficiency gains up to 1.3 per cent per annum can be expected for new aircraft entering production. An article on the integrated independent expert technology goals assessment and review for engines and aircraft in provided in the Outlook section of this report.

UPDATES TO ICAO DOC 9889

ICAO has updated its Doc 9889, *Airport Air Quality Manual,* for consistency with the new nvPM Standards, in particular with respect to providing information on aircraft mass and number PM emissions. Doc 9889 contains both actual sample engine data, and the recommended calculation methodology, for aircraft main engines and auxiliary power units.

FUTURE WORK

The future work on LAQ related issues embraces a vast majority of topics and directions. ICAO continues to develop measures aimed at mitigating the impact of aviation on LAQ in the vicinity of airports. To this end, ICAO continues to develop Standards, guidance material, and technical documents, as appropriate, for the needs of the international community. This includes the maintenance of Annex 16, all volumes of ICAO Doc 9501, *Environmental Technical Manual*, and the ICAO emissions databank.

Based on the recommendation of the nvPM mass and number Standards, the work of CAEP will now involve further exploratory study and monitoring of various pollutants and CO_2 during the CAEP/12 cycle. The ICAO Standards-development process is driven by technological feasibility, environmental benefits and economic reasonableness while considering interdependencies between noise, pollutants and greenhouse gas emissions.

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 PM in the future. Additionally, in order to assess consequences for all regulated emissions, ICAO monitors various trends in aviation fuels, including fuel composition and sustainable aviation fuels.

The recommendation on the new nvPM mass and number Standard was accompanied by an agreement by CAEP to conduct an early review of the relevant regulatory levels. This will involve the collation and analysis of the certified and certification-like nvPM mass and number emissions data that will become available for all in-production engines during the period 2019 to 2022. The margins to the agreed CAEP/11 nvPM SARPs will be reviewed to assess possible technological advancements to reduce nvPM emissions.

During the CAEP/12 cycle it is also planned to conduct a scoping study for NOx for in-production engines to investigate the feasibility for further NOx stringency analysis. ICAO continues to monitor developments in aeroplane and engine applications, and concepts to develop methodologies for emissions certification. In addition, advancements in supersonic technologies are being monitored to assess possible consequences for aeroplane and engine based emissions and an exploratory study to provide a better understanding of airport noise impacts resulting from the introduction of supersonic aircraft is ongoing.

The Landing and Take-Off Particulate Matter Standards for Aircraft Gas Turbine Engines

By S. Daniel Jacob and Theo Rindlisbacher

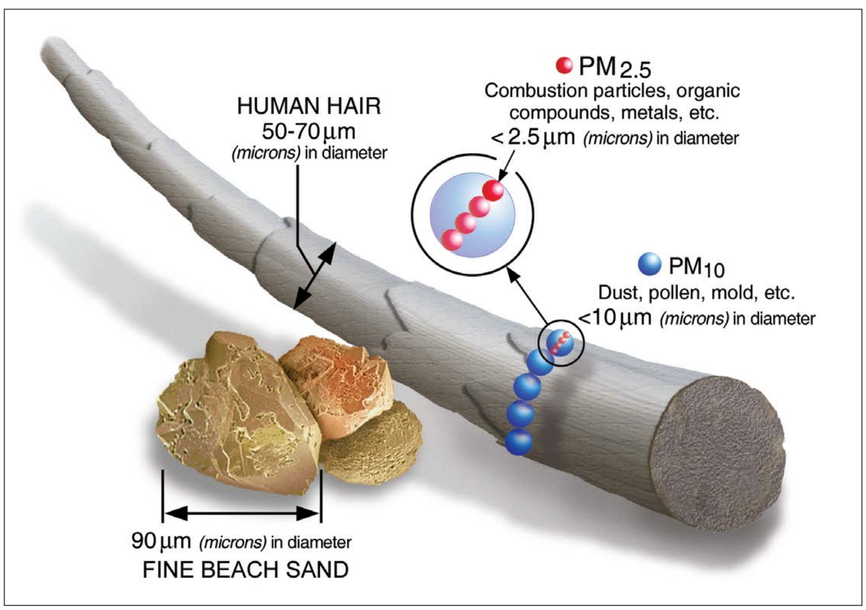
INTRODUCTION

Particulate matter emissions from aircraft gas turbine engines contribute to adverse health and climate impacts. The CAEP/11 recommended particulate matter standards for aircraft gas turbine engines are an important development that will lead to an overall reduction in particulate matter emissions and associated impacts. These new Standards and Recommended Practices (SARPs), which will be considered for adoption by the ICAO Council in March 2020, are the culmination of six years of effort and are a critical milestone contributing to ICAO's strategic objective of minimizing adverse environmental effects of civil aviation activities.

At the engine exhaust, particulate emissions mainly consist of ultrafine soot or black carbon emissions. Such particles are called "non-volatile" (nvPM). They are present at the high temperatures at the engine exhaust and they do not change in mass or number as they mix and dilute in the exhaust plume near the aircraft. The geometric mean diameter of these particles is much smaller than PM2.5 (geometric mean diameter of 2.5 Microns) and ranges roughly from 15nm to 60nm (0.06 Microns)[1]. These are classified as ultrafine particles (UFP). Mass and Number of nvPM emissions primarily depend on the engine technology and the LTO nvPM mass and number standards seek to reduce these emissions in the future with the introduction of cleaner combustor technologies. Synthetic fuels with low aromatics content can also help to reduce nvPM mass and number emissions at low thrust conditions.

Additionally, gaseous emissions from engines can also condense to produce new particles (i.e. volatile particulate matter – vPM), or coat the emitted soot particles. Gaseous emissions species react chemically with ambient chemical constituents in the atmosphere to produce the so called

FIGURE 1: Comparison of particle sizes from different sources (from US EPA)



1 10nm = 1 / 100000 of a millimetre

secondary particulate matter. Volatile particulate matter is dependent on these gaseous precursor emissions. While these precursors are controlled by gaseous emission certification and the fuel composition (e.g., sulfur content) for aircraft gas turbine engines, the volatile particulate matter is also dependent on the ambient air background composition.

The new ICAO standard is a measure to control the ultrafine non-volatile particulate matter emissions emitted at the engine exit, directly related to the combustion technology and fuel burn.

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). This plan was implemented during CAEP/9 and the newly formed WG3 Particulate Matter Task Group (PMTG) was tasked with the development of an nvPM standard first for turbofan engines of rated thrust greater than 26.7 kN. ICAO, through CAEP, also requested the SAE International E-31 Committee to develop a standardized nvPM measurement methodology. Test programmes were developed in North America and Europe through ICAO Member States and through Observers including the industry. These stakeholders also provided most of the man power and funding needed for this development.

Following this request, the SAE AIR6241 documented the specifications of the standardized nvPM sampling and measurement system. These specifications resulted from the establishment of a unique testing opportunity and the construction of a measurement prototype by the Swiss Federal Office of Civil Aviation, followed by a number of unique engine emissions tests performed in Switzerland in international cooperation. Subsequent tests in the USA and the UK 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 formed the backbone of the CAEP/10 nvPM certification requirement and standard as specified in Appendix 7 of the ICAO Annex 16, Volume II, Amendment 9.

THE CAEP/10 NVPM STANDARD

The inaugural engine nvPM emissions standard was agreed to by CAEP/10 in 2016. Any new regulation needs to be informed by the emissions levels of current technologies before future regulatory limits can be established. An important purpose of the CAEP/10 nvPM standard is therefore the mandatory reporting of health and climate relevant nvPM emissions, acquired through a certification process for the in-production engines. Noting that the nvPM mass concentration measurement performed with the new much more sensitive measurement method could be related to the smoke number standard to control non-visibility of exhaust plumes, the CAEP/10 standard was introduced with a maximum nvPM mass concentration limit. This maximum nvPM mass concentration was developed based on a statistical relationship between nvPM mass concentration and the smoke number (SN). Because of this, if an engine passes the current SN standard, by design of the regulatory level, it should also pass the mass concentration limit. As explained above, the CAEP/10 nvPM standard also mandates reporting of health and climate relevant emissions performance: a) the fuel flow at each thrust setting of the certification landing and take-off cycle (LTO); b) nvPM mass and number emission indices (EIs) for the four LTO thrust settings; c) maximum nvPM EI mass; d) maximum nvPM EI number; and e) the maximum nvPM mass concentration. In summary, the new standard is applied 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 LTO nvPM emissions. Furthermore, the maximum nvPM mass concentration obtained from the nvPM certification measurement was expected to help in maintaining the non-visibility criteria of the exhaust and to provide a pathway for ending the applicability of the SN standard for engines of rated thrust greater than 26.7 kN. A graphical representation of the CAEP/10 nvPM mass concentration standard is shown in Figure 2[2]. The CAEP/10 nvPM mass concentration standard and associated reporting were included in the ICAO Annex 16, Volume II, Amendment 9.

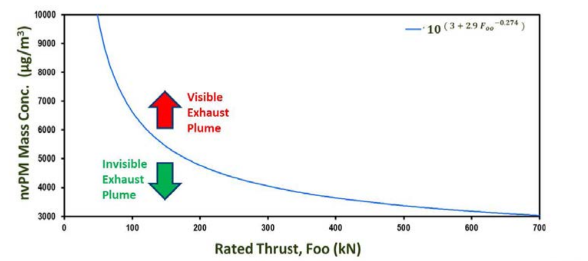
DEVELOPMENT OF THE CAEP/11 LTO NVPM MASS AND NUMBER STANDARDS

Following the development of the CAEP/10 nvPM mass concentration standard, ICAO CAEP continued the development of the LTO nvPM Mass and Number standards. About 25 engines that represented the range of in production engine combustor technologies and a full range of engine sizes were tested to characterize nvPM mass and number emissions. These tests were supported by various Member States, EU and the engine manufacturers. Using these datasets, metric systems for LTO nvPM mass and number emissions were developed. Metric values of nvPM mass and number provide an effective way to characterize and reduce real-world LTO nvPM emissions.

As noted earlier, the nvPM mass and number emissions are affected by aromatics in the fuel. The certification fuel has a small range of total aromatics including naphthalenes. Based on nvPM emissions data from dedicated tests supported by Swiss Federal Office of Civil Aviation (FOCA) where the fuel specifications were very carefully controlled and data from a few other tests, a reference fuel hydrogen content of 13.8% by mass was chosen to be the reference parameter to normalize the nvPM emissions. In addition to the fuel specification, ambient conditions on the test day also affect the measured nvPM emissions and it is desirable to normalize the measured data to International Standard Atmospheric (ISA) conditions at the surface. However, the methodology developed to normalize nvPM emissions to ISA conditions from a dedicated test funded by US Federal Aviation Administration (FAA) did not lead to satisfactory results. Therefore, the lack of ambient conditions corrections was included in the overall uncertainty of the metric value.

Emissions data from the dedicated tests of 25 engines of the same type funded by US FAA along with data from selected repeat engine tests, characteristic factors

FIGURE 2: Graphical presentation of the CAEP/10 nvPM Mass Concentration Standard



$$Regulatory\ limit\ concentration\ of\ nvPM_{mass} = 10^{(3+2.9\,F_{oo}^{-0.274})}$$

FIGURE 3A: The CAEP/11 LTO nvPM mass regulatory limits for in-production and new type engines of rated thrust greater than 26.7 kN

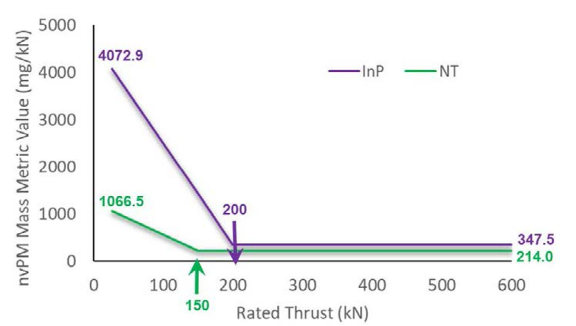
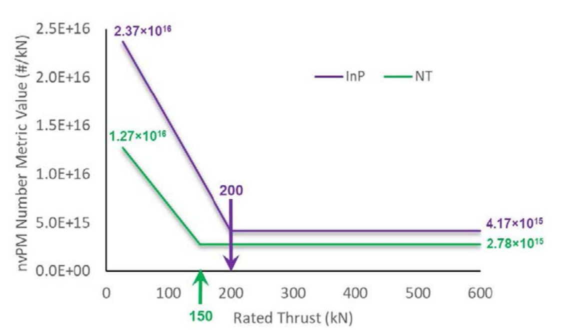
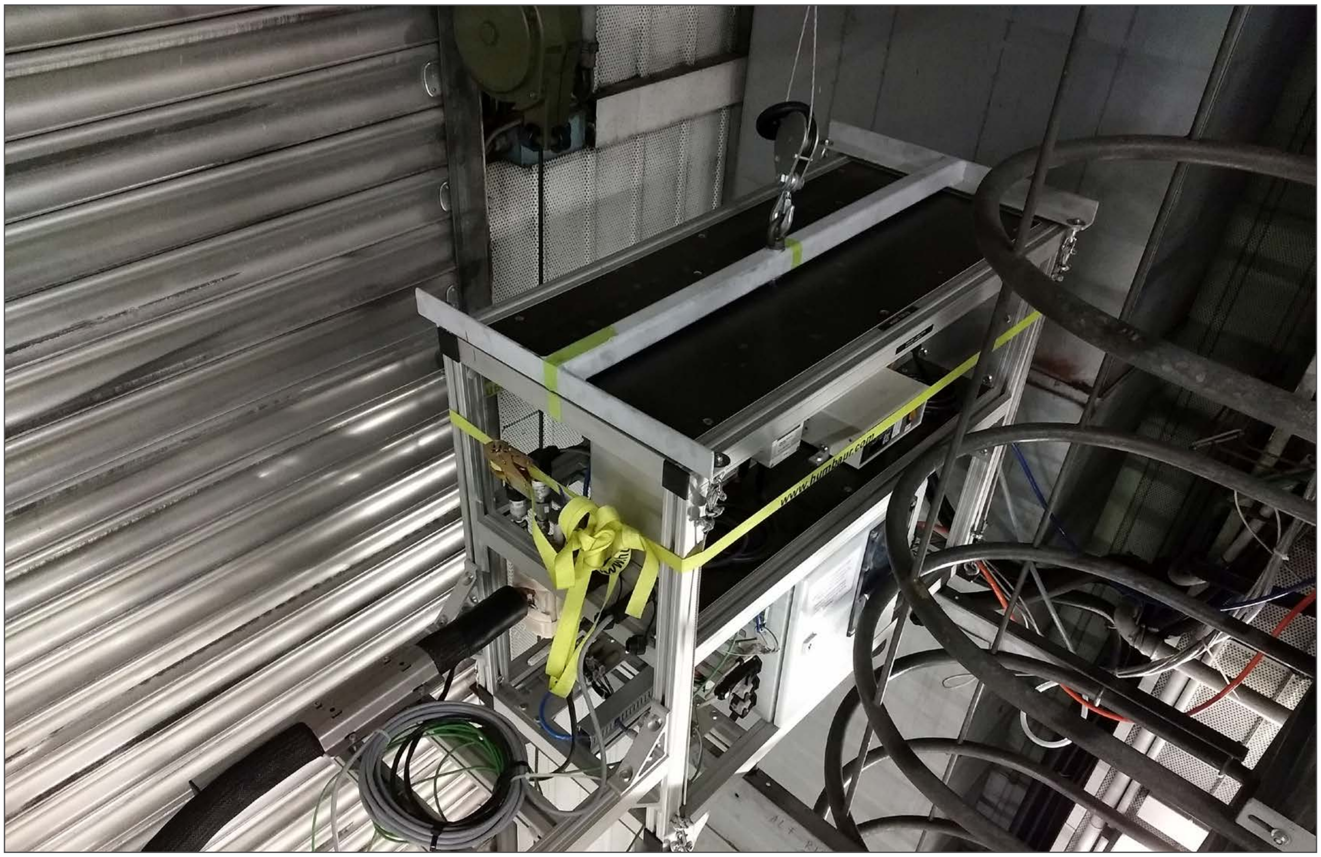


FIGURE 3B: The CAEP/11 LTO nvPM number regulatory limits for in-production and new type engines of rated thrust greater than 26.7 kN



for complying with the regulatory limits were developed. Similar to the factors for gaseous emissions and smoke, these characteristic factors are for adjusting the measured nvPM metric value of an engine type from a small number

2 Please see ICAO Environmental Report 2016 for more details

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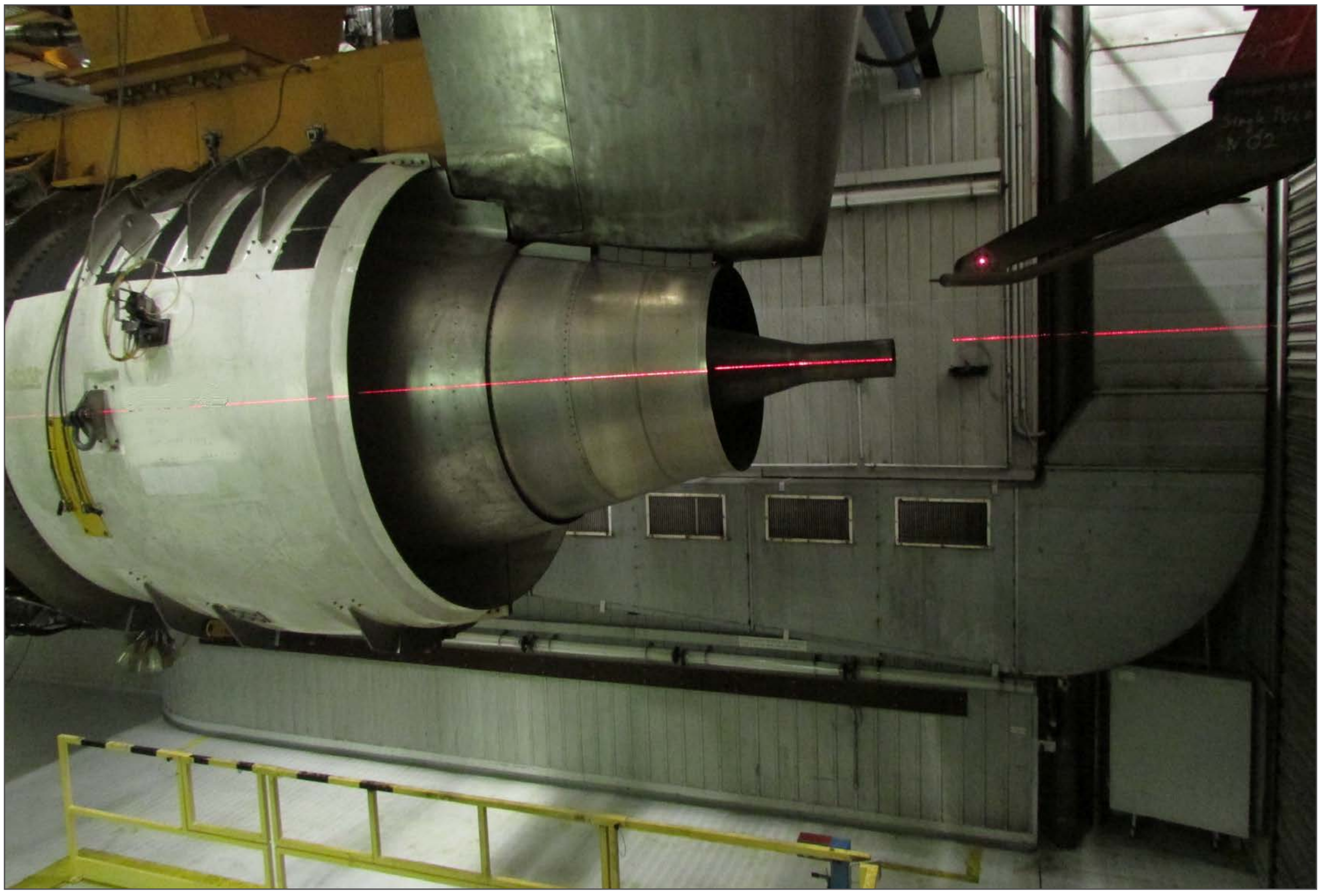
Thermo
Thermo



of engines tested (i.e. in most cases only one engine of the type will be tested) to guarantee compliance of the population of that engine type within a certain confidence limit.

Based on the metric values of the representative set of engines, five stringency options for nvPM mass and three stringency options for nvPM number were developed. Using the results of the cost effectiveness analysis and other factors such as technology readiness levels, CAEP/11 recommended the LTO nvPM mass and number regulatory levels for in-production and new engines, which will be considered for adoption by the ICAO Council in March 2020. These regulatory levels are shown in Figure 3.

END OF SMOKE NUMBER APPLICABILITY

With more than 50 years of advancement in our understanding of nvPM properties, extensive calculations were performed by a team from Massachusetts Institute of Technology to ensure that the non-visibility criteria of the SN limit will be maintained by the CAEP/10 nvPM mass concentration standard. It was established that for modern engines with high by-pass ratios, the CAEP/10 limit will indeed provide the necessary limit for light transmission. Because of this, CAEP/11 recommended the end date to the applicability of the smoke number standard for engines of rated thrust greater than 26.7 kN, which will be considered for adoption by the ICAO Council in March 2020. Given that the nvPM standards are not applicable to engines of rated thrust less or equal to 26.7 kN, these smaller engines will still need to comply with the SN standard.

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. The standardized methodology to estimate such system losses described in the Appendix 8 to the ICAO Annex 16 Vol II was updated during the CAEP/11 cycle. This update simplifies the calculation methodology and will allow all engine manufacturers to report loss correction factors using the same procedure. While the ICAO Annex 16, Volume II, Amendment 9 recommends reporting of the system loss correction factors, reporting of these factors is made mandatory through the CAEP/11 update to ICAO Annex 16, Volume II, Part IV. This will enable the engine manufacturers report the system loss correction factors together with the nvPM emissions data as soon as engine data are certified and will lead to more accurate estimates of nvPM emissions inventories.

EFFECT OF THE NEW STANDARDS

So far, aircraft gas turbine engine designs have not been designed for low nvPM emissions. With the implementation of CAEP/11 LTO nvPM mass and number standards, future engine designs will need to consider the full interdependencies between all pollutant emissions and fuel-burn. While there may be trade-offs and constraints, these engine emissions standards will encourage cleaner technologies to be included in engine designs in the future. Significant reductions in nvPM mass and number in addition to NOx are already seen with lean-burn staged and advanced rich-burn combustors. The new nvPM SARPs will result in the implementation of such technologies across the industry and this will lead to significant reductions in emissions from aircraft engines. These new nvPM standards mean that the full complement of ICAO environmental SARPs is now in place that will limit and reduce the impact of international civil aviation in terms of local air quality, noise and CO_2 emissions.

Update of ICAO's Airport Air Quality Manual (Doc 9889)

By Bethan Owen and Ralph Iovinelli

INTRODUCTION

ICAO's Airport Air Quality Manual (Doc 9889)[1], provides guidance for the determination of aviation-related local air quality emissions and pollutant concentrations within the vicinity of an airport (including aircraft, up to approximately 3,000ft above ground).

The document is published free of charge on the ICAO website and provides technical guidance and practical information to assist ICAO Member States in implementing best practices with respect to quantifying the incremental contribution of aviation-related emissions to ambient air quality. The document contains information related to: State requirements, emissions from airport sources, emission inventories, and emission allocations.

During the CAEP/11 cycle, Doc 9889 was updated to reflect recent advances in industry best practices, specifically with respect to emissions of particulate matter (PM) and especially emissions of non-volatile PM (nvPM) discharged by aircraft engines.

The update was done using new information on aircraft particulate matter emissions (mass and number) with recommended calculation methodologies that use new engine measurement data. Information has been updated on aircraft main engines and on auxiliary power units (APU) when the information was available.

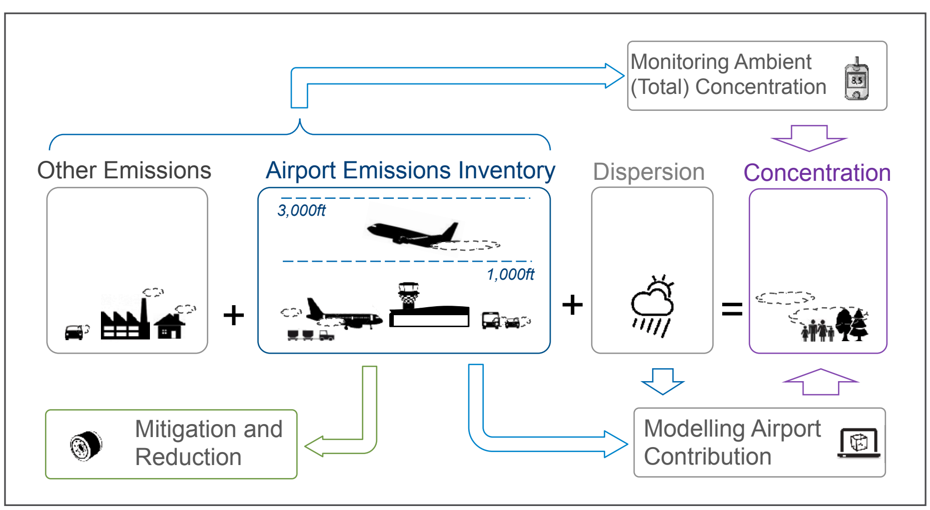
DOC 9889

As shown in Figure 1, the two main areas of an airport air quality assessment are:

- emissions inventories
- dispersion modelling of pollution concentrations

The opening chapters of Doc 9889 provide introductory material and information on the local air quality and emissions regulatory framework. Guidance is provided in Chapter 3 on a number of key subjects including: emission inventory construction, emissions parameters and species, airport-related sources, local and regional sources, forecasting, and quality assurance procedures. The Document then provides information on the temporal and spatial distribution of emissions, and guidance on dispersion modelling, including application and interpretation of results. Guidance and advice on ambient air quality measurements for airports is also provided on: designing a measurement

FIGURE 1: Local air quality elements and their interactions (figure courtesy of E. Fleuti, Zurich Airport)



1 ICAO's Airport Air Quality Manual (Doc 9889). https://www.icao.int/publications/Documents/9889_cons_en.pdf

plan, analysis of data, measurement quality assurance, and quality control. Finally, the concluding chapters of Doc 9889 provide guidance on mitigation options and the interrelationships associated with methods for mitigating environmental impacts.

Chapter 3 on constructing emission inventories and the associated appendices are thus the focus of this update article regarding PM emissions.

WHY UNDERTAKE THE UPDATES?

The technical emissions work undertaken by ICAO CAEP in support of the standard setting process involves state-of-the-art data analyses and the development of emissions quantification methodologies. This technical work enables ICAO CAEP to conduct global assessments of the incremental effects of aviation-related emissions. In addition, ICAO CAEP recognizes that Member States would also benefit from the use of already developed emissions methodologies to quantify aviation-related emissions for their domestic regulatory and planning purposes. ICAO Doc 9889 is the guidance document that allows ICAO CAEP to provide Member States with state-of-the-art emissions quantification methodologies to assess air quality in the vicinity of airports. To this end, it makes sense for ICAO CAEP to continue to update Doc 9889 periodically to reflect the evolutionary nature of technology in the civil aviation industry.

Driven by potential adverse health effects of ultrafine particulate matter concentrations in the ambient air, there is increasing environmental pressure to estimate the incremental particle mass and number emissions from aviation activities, as part of the broader set of PM emissions sources. In general, airports have a reasonable understanding of NOx emissions from airport related sources and their impacts on local and regional concentrations, and based on this understanding, they have developed and implemented mitigation plans that have successfully yielded benefits to local air quality. A developing consensus of understanding about the possible health effects of aircraft emitted pollutants, other than NOx, is driving airport operators' needs for a better quantitative and qualitative understanding of aircraft engine emissions of the mass and number of ultrafine particles (nvPM).

Improved quantification of the emissions of nvPM number and mass from aircraft sources will aid the better understanding of how pollutants evolve and disperse in the local and regional environment and will help put aviation emissions into context with other emission sources. Improving the quantification of the relative contribution of engine emissions and other airport sources in the context of wider transport sources will help to understand the potential reductions necessary. Ultimately, these methodologies may also be used to quantify the impacts of policy measures aimed at reducing PM emissions.

This latest update of Doc 9889 will bridge the gap until certified particle emissions data are publicly available. The methods covered in Doc 9889 also provide a way to estimate PM emissions contributions from older engine designs, where certified particle emissions data will not be available in the future.

Doc 9889 provides worldwide harmonization of methods which allows proper comparison between airport inventories and other sources.

WHAT UPDATES ARE INCLUDED?

While it is understood that local air quality and ambient pollutant concentrations in the vicinity of an airport include other non-airport sources of emissions, Doc 9889 focuses on the estimation of emissions from airport operations, concentrating specifically on aircraft combustion engines, including both propulsion engines and auxiliary power units (APUs). Airport emissions are also affected by emissions from other sources such as ground service vehicles, airside ground transportation and evaporative emissions of non-volatile organic compounds from de-icing and re-fueling operations, which are covered in Doc 9889 under the term aircraft handling emissions. 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. This update to Doc 9889 includes nvPM emission estimation improvements for aircraft engines, APUs and aircraft handling operations. The volatile PM emissions remain unchanged at this point, but work is planned in this area in the coming years.

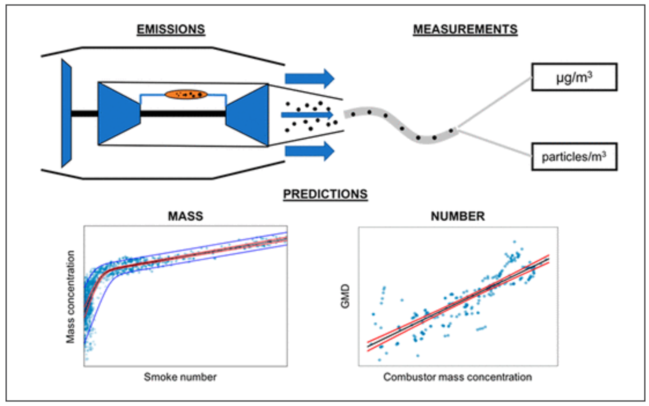
Aircraft engines with turbofans > 26.7 kN rated thrust are regulated for their emissions, which include: oxides of nitrogen (NOx), unburned hydrocarbons (HC), carbon monoxide (CO), and smoke. Smoke emissions are mainly carbonaceous particles emitted as a product of incomplete combustion, and these particles are now the subject of new standards that regulate the number and mass of non-volatile particles (nvPM).

The implementation of new regulatory standards means that emissions from new aircraft engines certified over the next few years will be specifically included in a publicly available database of nvPM mass and number measurements. This will allow airport operators to more accurately represent the nvPM emissions, using comparable methods as for NOx emission estimations, for example. However, in the meantime the data collected as part of the standard-setting process has been used to develop improved methods of nvPM mass emission estimation based on the certified smoke number (SN) measure and a new method has been developed to estimate the nvPM number for the first time. These methods can also be used in the longer term for engines where nvPM measurement data will not be available through certification, such as engines that are no longer in production but still in operation.

As work to develop the new nvPM standards has progressed in ICAO over the past six years, the data collected has lead to a better understanding of nvPM emissions from aircraft engines. As part of the standard-setting work, an engine nvPM values database, consisting of confidential proprietary measurement data for 24 current aircraft engine models, was built up using standardized measurement techniques (SAE, 2013) for both nvPM mass and nvPM number emissions, as well as the traditional SN measurements.

The database allowed a correlation to be derived between the traditional SN measurements and the new nvPM measurements, as illustrated in Figure 2. The correlation methods can then be used to estimate nvPM mass and number emissions from the SN measure and this method forms the nvPM part of the newly formulated 4th version of the First Order Approximation methodology (FOA4), as detailed in Doc 9889.

FIGURE 2: Illustration of the relationship between a visibility-based Smoke Number with both mass and number of non-volatile particulate matter. (Speth et al, 2019)[2]



In summary, the updated version of Doc9889 includes the following updates:

- Particulate matter emissions estimation method for aircraft main engines, auxiliary power units (APU), and for aircraft handling.
- Improvement of existing estimation method for non-volatile PM mass, using more robust measured data obtained during the development of the CAEP/11 nvPM standards.
- First time inclusion of an estimation method for non-volatile PM number.
- Total PM mass and non-volatile PM number methodology summarized as the First Order Approximation FOA 4.0 (Speth et al, 2019).
- Several new aircraft types have been added with their emissions from the LTO-cycle.

THE NEXT THREE YEARS

Doc 9889 will be continually updated as civil aviation technology evolves. As certification data for the CAEP/11 nvPM mass and number standards starts to become available in the coming years, the nvPM engine emissions database will be populated and the data will become publically available. The engine emissions certification data will then be used for the majority of the modern

2 Speth et al., "SCOPE11 Method for Estimating Aircraft Black Carbon Mass and Particle Number Emissions," Environmental Science and Technology, January 2019.

engines in the global commercial fleet to determine nvPM emissions from airport operations.

Further work planned on the Doc 9889 includes a review and assessment of the current volatile PM (vPM) estimation method (part of the FOA4), and a review of the dispersion modelling aspects of the document.

ICAO

CHAPTER FOUR

Climate Change Mitigation: Technology and Operations

Introduction to the ICAO Basket of Measures to Mitigate Climate Change

By ICAO Secretariat

INTRODUCTION TO GLOBAL EMISSIONS

In support of a data-driven decision making process, ICAO, in addition to the evolution of technological developments, is monitoring the evolution of scientific knowledge related to the impacts of aviation on the global climate. Aviation affects the global climate through both CO_2 and non-CO_2 induced effects. The aviation sector accounts for approximately 2% of global anthropogenic CO_2 emissions, including international and domestic aviation. International aviation alone accounts for 1.3% of global anthropogenic CO_2 emissions[1]. While the percentage of CO_2 emissions from global aviation has not significantly changed since 1992, the volume of CO_2 emissions has increased along with the increase in global CO_2 emissions across other sectors.

Other non-CO_2 factors such as ozone, methane, water vapor, or aerosols also affect global warming. Aircraft emit nitrogen oxides (NOx), which form ozone when emitted at cruise altitudes. Aircraft also trigger the formation of condensation trails, or contrails, which are suspected of enhancing the formation of cirrus clouds, which add to the overall global warming effect. These effects are estimated to be about two to four times greater than those of aviation's CO_2 alone[1].

While CO_2 impacts on the climate are well understood, there are important uncertainties regarding some of the non-CO_2 impacts and the underlying physical processes. That is why, since 1997, ICAO has requested scientific bodies to further investigate these impacts in order to develop appropriate measures to address such impacts. This resulted in the publication of the "IPCC Aviation and the Global Atmosphere report" in 1999, which provided the scientific basis for impacts of aviation on the global climate and highlights the state of understanding of the relevant science, aviation technology and socio-economic issues associated with aviation. Twenty years after the publication of this report, these estimates of aviation climate forcing could be enhanced by a new international scientific assessment. In the absence of such a report, in order to update and strengthen the scientific base, the information contained in the IPCC 1999 report is being supplemented by the work carried out by ICAO and the Committee for Aviation Environmental Protection (CAEP).

ICAO'S ASPIRATIONAL GOALS & BASKET OF MEASURES

With a view to minimize the adverse effects of international civil aviation on the global climate, ICAO formulates policies, develops and updates Standards and Recommended Practices (SARPs) on aircraft emissions, and conducts outreach activities. These activities are conducted by the Secretariat and the Committee on Aviation and Environmental Protection (CAEP). In pursuing its activities, ICAO also cooperates with other United Nations bodies and international organizations.

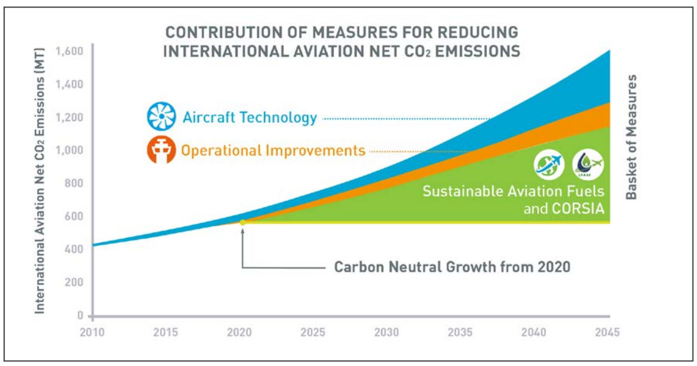
The ICAO Assembly at its 39th Session in 2016 adopted Resolution A39-2: *Consolidated statement of continuing ICAO policies and practices related to environmental protection — Climate change*. It reiterated the two global

1 IPCC 4th Assessment Report, 2007

aspirational goals for the international aviation sector of 2% annual fuel efficiency improvement through 2050 and carbon neutral growth from 2020 onwards, as established at the 37th Assembly in 2010.

To achieve the global aspirational goals and to promote sustainable growth of international aviation, ICAO is pursuing a basket of measures including aircraft technology improvements, operational improvements, sustainable aviation fuels, and market-based measures (CORSIA). ICAO is also exploring long-term global aspirational goals for international aviation, as reiterated by the 39th Session of the ICAO Assembly.

FIGURE 1: ICAO Global Environmental Trends on CO_2 Emissions and Contribution of Measures for Reducing International Aviation Net CO_2 Emissions



AIRCRAFT TECHNOLOGY AND STANDARDS

Advancement in aircraft technology is of great importance to reducing aviation emissions and significant progress has been made over the past 50 years. Today's aircraft are approximately 80 per cent more efficient in use of fuel per passenger kilometre than that in the 1960s. ICAO develops Standards, policies and guidance to ensure that the latest technology is incorporated to new type and in-production aircraft.

Adopted in 2017, the ICAO Aeroplane CO_2 Emissions Standard plays an important role in reducing the sectors fuel burn by ensuring that the latest fuel efficiency technologies are being implemented into the latest aeroplane designs. This Standard will apply to new aircraft type designs from 2020 and to aircraft that are already in production as of 2023.

ICAO recently conducted an Independent Expert Integrated Review of aircraft and engine technologies. This was the first review done in an integrated manner, considering the interdependencies between noise, fuel burn and emissions technologies. Based on this work, new integrated technology goals for engines and aircraft, including noise, emissions and fuel efficiency, were endorsed by ICAO's Committee on Aviation Environmental Protection (CAEP) and approved by the ICAO Council in 2019. More information on this review is provided in Chapter 1.

The progress on fuel efficiency improvement is the result of airframe, aero-engine, and aircraft systems manufacturers' continuous drive to develop new and innovative technologies. The utilization of higher By Pass Ratio (BPR) engines, as well as lighter and high temperature materials contribute to increased propulsive efficiency and lower fuel consumption. Reduction in aircraft weight is a key factor in reducing fuel burn. The combination of lighter weight materials and innovative structural technologies result in lower weight airframes. More recent technological developments continue to result in increased use of composite materials in the latest aircraft designs. New aircraft types also incorporate an increasing level of electrical systems and controls that contribute to a low operating weight and help further enhance the operating efficiency of the aircraft. Best practices on aircraft end-of-life such as through aircraft recycling are being developed.

The recent advance in electric or hybrid-electric aircraft technology has generated strong interest in aviation, due to its potential economic and environmental benefits. A number of ongoing projects have been identified globally, ranging from general aviation or recreational aircraft, business and regional aircraft, large commercial aircraft, motor gliders, unmanned aerial vehicles and vertical take-off and landing (VTOL) aircraft (also called electric urban air-taxis). Most of them target an entry-in-service date between 2020 and 2030, and some are already commercially available. ICAO is closely following-up innovative environmentally driven technologies that may impact the environment, including new energy sources for aviation. This will include assessing the consequences for noise and emissions, and maintaining and developing relevant ICAO environmental Standards and guidance. More details on electric aircraft can be found later in this chapter.

AIR TRAFFIC MANAGEMENT AND OPERATIONS

Optimization of air traffic management and operational procedures is a key element to avoid greenhouse gas emissions from aviation. The Global Air Navigation Plan (GANP) and the Aviation System Block Upgrades (ASBUs) are major initiatives developed by ICAO to that end. The GANP is a strategy to achieve a global interoperable air navigation system, for all users during all phases of flight that meets agreed levels of safety, provides for optimum economic operations, is environmentally sustainable and meets national security requirements. The ASBUs provide a roadmap to assist air navigation service providers in the development of their individual strategic plans and investment decisions. The Committee on Aviation Environmental Protection (CAEP) has estimated that current and planned implementation of ASBU Block 0 and 1 modules by 2025 are likely to provide a total annual global fuel saving in 2025 of between 167 to 307 kg per flight, which corresponds to a reduction of 26.2 to 48.2 Mt of CO_2.

ICAO develops and updates the necessary tools and guidance to assess the environmental benefits associated with air traffic management improvements. Environmental assessment tools such as the ICAO Fuel Savings Estimation Tool (IFSET) have allowed States to successfully assess the environmental benefit of implementing various operational measures. Airports are key stakeholders to improve practices on the ground. Better airport traffic sequencing, allowed by the growing implementation of innovative e-tools, such as Airport Collaborative Decision Making tools, help to improve the overall efficiency of airport operations, especially turn-around and pre-departure sequencing, thus avoiding unnecessary greenhouse gas emissions. Furthermore, ICAO fosters the exchange of information on best practices for Green Airports, covering such subjects as smart buildings, renewable energy, green mobility, climate change resilience, resource and biodiversity protection, community engagement and sustainability reporting, with the aim of sharing and harmonizing best practices amongst airports. Guidance material and tools such as the Eco-Airport Toolkit e-collection are being developed by ICAO to that end.

SUSTAINABLE AVIATION FUELS

Sustainable Aviation Fuels (SAF) have an important role to play in reducing CO_2 emissions from aviation. They are an important element of ICAO's basket of measures to mitigate climate change. Although time will be needed to deploy such fuels at scale, it is encouraging that the technologies for SAF production already exist today: the challenge is to accelerate SAF deployment, reduce its cost, and ensure the environmental integrity of the SAF production.

The growing societal concern with sustainability requires appropriate tools to inform decision making and ICAO is working to ensure that SAF deliver savings in CO_2 emissions. To achieve that, ICAO developed a unified methodology to assess SAF life cycle emissions environmental benefits, based on a life-cycle analysis that takes into account both direct and indirect land use change effects. ICAO also agreed on a set of sustainability criteria for SAF consideration under CORSIA, which require that SAF should achieve a 10% minimum GHG reduction, and that SAF should not be made from biomass obtained from land with high carbon stock (primary forests, wetlands, and peat lands). The ICAO Assembly requested States to recognize existing approaches to assess the sustainability of alternative fuels that should contribute to local social and economic development while avoiding competition with food and water. In that regard, work is ongoing to expand these sustainability criteria which will be subject to ICAO Council approval by the completion of the CORSIA Pilot Phase (end of 2023). More details on the consideration of SAF under CORSIA are provided in Chapter 6.

Since ICAO's first Conference on Aviation and Alternative Fuels (CAAF/1) held in 2009, significant progress has been achieved in the use of SAF. As of May 2019, more than 180,000 commercial flights used a blend of alternative fuel, six conversion processes have been certified for use in aviation, six airports are regularly distributing blended alternative fuel, and a number of sustainable aviation fuel initiatives and projects are ongoing or underway worldwide.

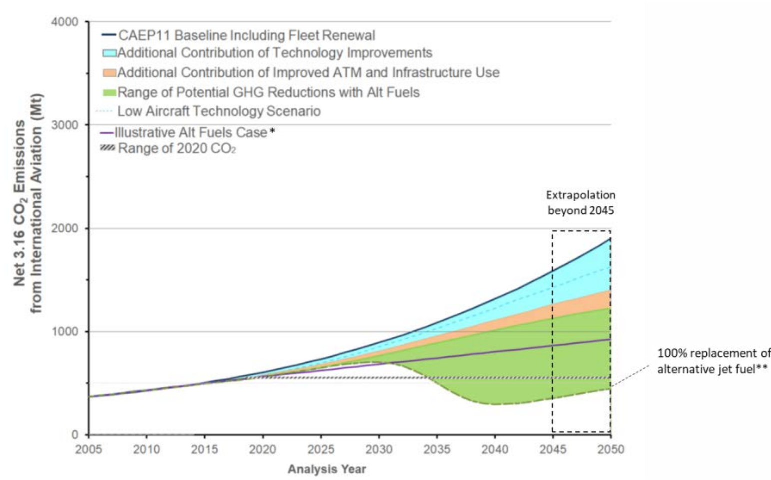
Significant uncertainties exist in predicting the contribution of sustainable aviation fuels in the future. However, a number of near-term scenarios evaluated by ICAO indicate that up to 2% of fuel consumption could potentially consist of SAF by 2025. This level of fuel production could only be achieved with large capital investments in sustainable aviation fuel production infrastructure, and substantial policy support. The effort required to reach these production volumes would have to significantly exceed historical precedent for other alternative fuels, such as ethanol and biodiesel for road transportation. The effect of such an expansion in the use of sustainable aviation fuels on CO_2 emissions from international aviation, without taking into account land use changes, has been assessed for the first time by ICAO (Figure 2 below).

ICAO supports States and stakeholders in their efforts to develop and deploy SAF by: establishing policies and measures that can hasten the use of sustainable aviation fuels; developing robust sustainability criteria and life cycle methodologies; sharing information and best practices including through ICAO's Global Framework for Aviation Alternative Fuels (GFAAF); assisting in the development of SAF feasibility studies; and organizing events for information-sharing and outreach. More details on these initiatives are provided in Chapter 5.

GFAAF

The use of sustainable aviation fuels could be crucial in achieving the carbon neutral growth goal from 2020 for international aviation.

FIGURE 2: Net 3.16 CO_2 Emissions from International Aviation, 2005 to 2050, including Sustainable Aviation Fuels Life Cycle CO_2 Emissions Reductions



Note: Reductions in atmospheric carbon from sustainable aviation fuel use occur from feedstock production and fuel conversion and not from fuel combustion.

However, the amount of current production is relatively small. To promote and regulate its use, incentives are needed through policies and regulatory frameworks, financial support to the production and certification of SAF, and technical and financial assistance at the State level. ICAO is actively working to that end, in collaboration with all relevant stakeholders.

CORSIA

At the 39th Session of the ICAO Assembly, ICAO Member States decided to implement the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), the first global market-based measures scheme in any sector, to address the increase in total CO_2 emissions from international aviation above the 2020 levels (Assembly Resolution A39-3). CORSIA represents a cooperative approach that moves away from a “patchwork” of regulatory initiatives through the implementation of a global scheme that has been developed through global consensus amongst governments, industry and international organizations. It offers a harmonized way to reduce emissions from international aviation thereby ensuring that there is no market distortion, while respecting the specific circumstances of all ICAO States. CORSIA complements the other components in the basket of measures by offsetting the amount of CO_2 emissions that cannot be reduced through the use of technological and operational improvements, and sustainable aviation fuels through the use of high quality emissions units from the global carbon market. It is estimated that between 2021 and 2035, the international aviation sector would have to offset about 2.5 billion tonnes of CO_2 emissions to achieve carbon neutral growth. More information on CORSIA can be found in Chapter 6 of this report.

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ICAO Environmental Protection webpage, https://www.icao.int/environmental-protection/Pages/default.aspx

Advancing Technology Opportunities To Further Reduce CO_2 Emissions

By International Coordinating Council of Aerospace Industries Associations (ICCAIA)

INTRODUCTION

Improvements in aerodynamic, propulsion and structures technologies have a direct link to aircraft emissions reduction. Improvements in systems design and manufacturing technology are also key to achieving future aircraft CO_2-reduction goals.

In the past 5 years, additional advanced long-range twin-aisle airplanes with significant improvements in each of these technology areas have entered operational service (the Boeing 787-9 and -10, the Airbus A350-900 and -1000), while the new Boeing B777-9 aircraft with a completely new composite wing is being prepared for certification testing. Moreover, several recently introduced new single-aisle aircraft (such as the Airbus A220-100 and -300) and several derivative aircraft with major propulsion and airframe technology upgrades (such as the Airbus A320neo and A330neo, the Boeing B737MAX family, and the Embraer E-Jets E2), have entered operational airline service and provide substantial reductions in fuel burn.

Large-scale national and international research programs with cooperation between industry, government and academia continue to be key enablers to advance and mature the state of art in breakthrough technologies that can lead to further reduction in aviation's environmental footprint.

Flight demonstrators offer important technical and integration data to progress technologies such as laminar flow, advanced structural designs as well as more electric systems and propulsion.

Integration and certification challenges associated with advanced technologies are significant and affect the time frame needed to mature and adopt viable new technologies into production (on the order of 10-20 years). Maturation and adoption of key technologies summarized in this Chapter would provide significant additional opportunities to reduce aeronautical emissions.

AERODYNAMICS

Skin-friction drag and lift-dependent drag are the largest contributors to aerodynamic efficiency of commercial aircraft. Advances in materials, structures and aerodynamics are enabling significantly reduced lift-dependent drag by increasing effective wing span. Wing-tip devices typically increase the effective span, and to further increase wing span in flight some airplanes may include a folding wing-tip mechanism (Figure 1) for use on the ground to mitigate span constraints of existing airport infrastructure.

FIGURE 1: On-ground folding wing tip to maximize in-flight wing span (Boeing B777-9) (Image courtesy Boeing)

Progress is being made in development and testing of practical aerodynamic and manufacturing technologies enabling reduced skin friction through *laminar* and/or conditioned *turbulent* boundary-layer flow on portions of wings, nacelles, tails, and fuselages.

Methods to apply robust micro-scale 'riblet' geometries for *turbulent-flow* skin-friction reduction continue to be developed and tested to progress maturation to practicality. Estimates suggest opportunities on order of 1 - 2% fuel-burn reduction on new and existing aircraft with significant areas covered by practical 'riblets' (Ref. 1). More significant reduction in skin-friction drag is possible by maintaining *laminar* flow on forward areas of engine nacelles, wings and tails. Surfaces intended for Natural Laminar Flow *(NLF)* are already present on some in-production commercial and business-jet aircraft (e.g., nacelle-inlet lip and winglets on some larger aircraft, and portions of wing and fuselage on some business jets). Achieving laminar flow on aircraft requires well-balanced aerodynamics and structural designs together with aligned manufacturing methods to meet necessary surface quality.

Research and developmental flight testing of integrated wing structures that offer substantial laminar flow as well as allow high-rate production are critical for technology maturation. Within the European Clean-Sky 2 Program (Ref. 2), the *BLADE* (*B*reakthrough *L*aminar *A*ircraft *D*emonstrator in *E*urope) project has delivered important data on such wing *NLF* design concepts. Flight tests conducted on an Airbus A340-300 (with modified outer wings that are built to enable *NLF*) explored limits of robust laminar flow at various flight conditions (Figure 2).

FIGURE 2: Integrated wing NLF (Natural Laminar Flow) integration concepts installed on modified outboard wings of A340-300 (Clean-Sky 2 flight demonstrator BLADE) (Ref. 3)

On wings of very large aircraft and on geometries with significant sweep such as a vertical fin, laminar flow can only be realized using suitable surface suction (Hybrid Laminar Flow Control*, HLFC*). Recent flight testing of a vertical-fin *HLFC* configuration on a single-aisle aircraft under the European *AFloNext* (Active Flow, Loads & Noise control on Next generation wing) program (Figure 3) complements first *HLFC* application on the Boeing B787 tail. Overall, practical and robust achievement of significant laminar flow on wings and other surfaces could reduce aircraft fuel burn on order of 5%. The magnitude of potential benefit depends on the fraction of airplane surfaces manufactured to achieve laminar flow.

FIGURE 3: AFLoNext HLFC empennage flight test on DLR's A320 test aircraft (Image courtesy DLR)

Lastly, opportunities for Active Flow Control *(AFC)* using localized blowing to keep flow attached over deflected flaps or over the nacelle-pylon/wing junction have also been investigated. Such *AFC* systems if demonstrated practical may facilitate integration of larger turbofan engines on wings of future aircraft.

PROPULSION

Three technology paths can reduce propulsion-system fuel consumption: increase thermal efficiency by increasing the compressor Overall Pressure Ratio (with consequent increase in core engine operating temperatures); increase propulsive efficiency by increasing the engine Bypass Ratio (*BPR*) and consequently fan diameter; and, reduce installed engine weight and drag.

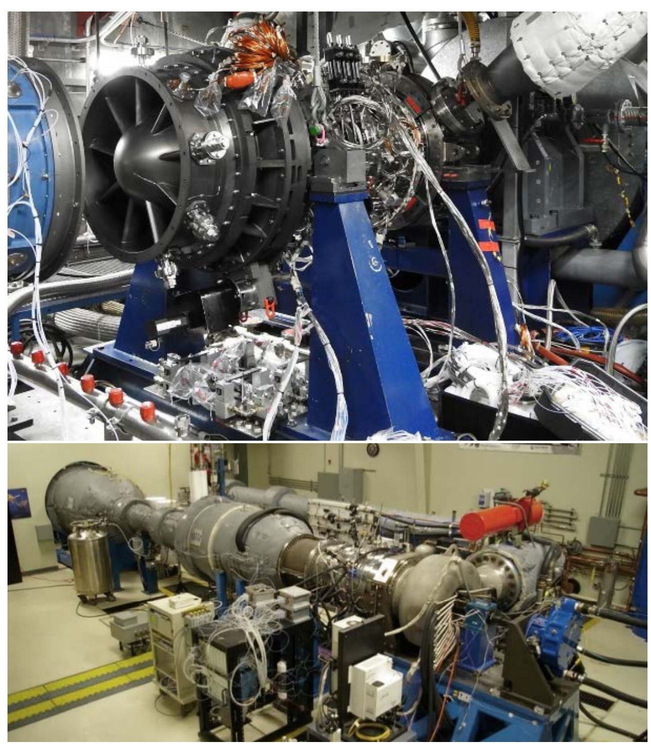
Over the last decade, newly introduced aircraft and major derivatives with new engines have followed these paths as diameters of engines have increased while aircraft manufacturers have maintained acceptable installation and integration penalties. Between 2016 and 2023, advanced technology engines have entered or will enter service on new and re-engined aircraft. New technology engines at *BPR*'s 9 to 12 for regional jets and single-aisle aircraft (such as the E2, A220, A320neo, B737MAX, MRJ, MC-21, and C919) provide a significant 15% reduction in fuel burn relative to earlier *BPR*~5 engines. Latest generation engines for new production twin-aisle aircraft (A330neo and B777-9) can deliver 10% fuel-burn reduction relative to 2014 in-service reference.

Major research programs continue to provide important contributions to develop, mature and demonstrate promising propulsion technologies along the three technology paths:

- Within the US, NASA's *ERA (Environmentally Responsible Aviation)* program (Ref. 4) significantly contributed towards development and demonstration of advanced propulsion (Figure 4). The US national research program *CLEEN (Continuous Lower Energy, Emissions, and Noise*) (Ref. 5) is an FAA-led public-private partnership effort to accelerate development and deployment of promising certifiable technologies towards reducing fuel burn by up to 40% compared to a 2005 baseline. *CLEEN Phase-I* benefits have demonstrated potential for 1% fuel-burn reduction with a Ceramic Matrix Composite engine exhaust nozzle (demonstrated on a Boeing 787); 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. *Recent CLEEN Phase-II* contributions are demonstrating the potential for up to 1% fuel-burn reduction (each) through compressor and turbine efficiency gains (PW); 3% with electric aircraft systems (GE's *MESTANG - More Electric Systems and Technologies for Aircraft in the Next Generation*), 1% through advanced turbine seals (Honeywell), and 1%

FIGURE 4: NASA ERA Wind-Tunnel Test (Top), FAA CLEEN Phase-I High BPR, Short Inlet Fan Rig and Engine Demonstrator Program (Bottom)

FIGURE 5: FAA CLEEN Phase-II Compressor (Top) and Turbine Core Technology Rigs (Bottom)



through new technology combustor impact on turbine temperature capability (RR) – see Figure 5.

- Europe's *Clean-Sky 2* Joint Technology Initiative aims to develop and demonstrate breakthrough technologies for civil aircraft that could reduce CO_2 emissions by 20% (2025) to 30% (2035) at aircraft level compared to current state-of-the-art aircraft (Ref. 4). In the propulsion arena, research builds on the success of previous *Clean-Sky 1* Sustainable and Green Engines (*SAGE*) program to validate more radical engine architectures, including:
  - Exploitation of Contra Rotative Open Rotor (*CROR*) demonstrator results from the successful Safran campaign in 2017 (Figure 6);
  - Design, development and ground test of a propulsion system demonstrator to validate selected low pressure modules and nacelle technologies for short/medium-range aircraft;
  - A short-range regional turboprop demonstrator (1800-2000 shp class) and small aero-engine demonstration projects for fixed-wing piston/ diesel and small turboprop engines;
  - Full scale ground-test in 2017 (Figure 6) and flight-testing planned for 2023 of Advanced Geared and Very High Bypass Ratio large turbofan engine configurations for large and middle-of-market type aircraft.
- European collaborative projects completed in 2017-2018, such as *ENOVAL* (ENgine mOdule VALidators - led by MTU Aero Engines), *LEMCOTEC* (Low Emissions Core-Engine Technologies - led by Rolls-Royce Deutschland) and *E-BREAK* (Engine Breakthrough Components and Subsystems - led by Safran Helicopter Engines) established propulsive efficiency improvements, higher thermal efficiency, and technological enablers for higher Overall Pressure-Ratio engines, respectively.

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

FIGURE 6: Ground and Flight Demonstrators in Clean-Sky 2 Program (Ref. 4).

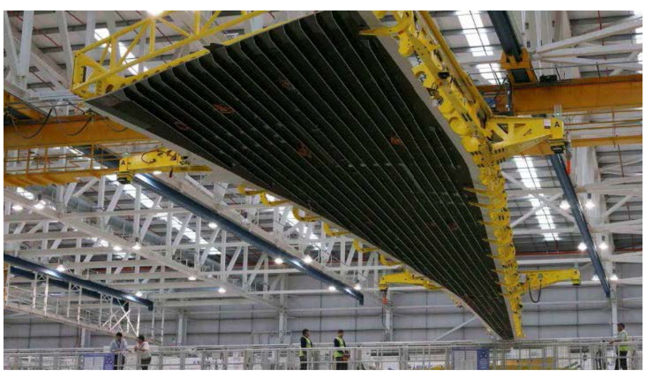
STRUCTURAL DESIGN AND MATERIALS

A key opportunity to reduce fuel burn and CO_2 emissions is further minimization of aircraft structural weight. Reduction in empty weight while maintaining structural requirements (strength, stiffness and safety) may be done with several levers:

- Further optimization of established structural technologies and/or materials;
- Introduction of new materials and/or structural technologies; and
- Alternate aircraft architectures.

Composite materials and structures technology have been developed and introduced in several new small and large aircraft (Figure 7). There is still progress anticipated in allowable margins linked to existing materials and in new designs targeting improved assembly process (such as bonding, stitching and welding). Aircraft manufacturers recognize the individual advantages of composites and advanced metallic alloys - and aim for optimum balance of both materials. For metallic materials, new alloys have been developed to be competitive with composites for thin parts applications (such as fuselages).

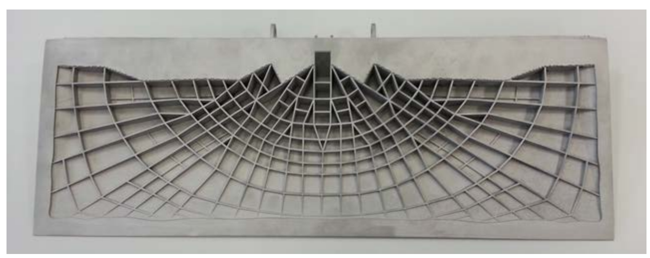
FIGURE 7: Composite upper wing skin with composite stiffeners for Twin-Aisle aircraft (Ref. 7)



Materials and structural design and optimization is now more efficient thanks to greatly improved computational simulation methods. This improved capability can be coupled with new design and manufacturing technologies like *ALM* (Additive Layer Manufacturing) to further reduce structural weight while optimizing load-carrying performance (Figs. 8 and 9). Multi-functionality is another axis of improvement by using the structure to fulfill additional roles. Structural multi-functionality can be reached by modifying the material (e.g., via nanotechnology) or via designs that can provide selected systems' functionality and/or geometry adaptivity.

FIGURE 8: Additive manufacturing of optimized part for reduced component weight (courtesy Airbus)

FIGURE 9: ALM wing spoiler component with "bionic" type structural optimization (Ref. 8)



Advanced load alleviation is an example of favorable interaction between aerodynamics and wing structural design. Further wing-span increase without significant concomitant weight increase is facilitated by introduction of reliable load-alleviation systems. The principle is to provide aerodynamic means to alleviate critical wing loads via active or passive systems when wing loading exceeds defined limits (Figure 10). Suitable design of composite structure can contribute to passive load alleviation via optimized fiber lay-up (Refs. 9 and 10).

Overall, future weight-reduction opportunities derived from combination of described technologies is estimated to be as much as 8% relative to current state-of-the-art structural configurations.

FIGURE 10: Wing span-load alleviation system to reduce root bending moment (schematic)

Finally, alternate aircraft architecture concepts (e.g., blended wing or truss-braced wing) may enable further structural opportunities, allowing larger wing spans and advanced material technologies for additional fuel-burn reduction. Maturation of aircraft configurations that are dramatically different from currently operational architectures will require significant development and demonstration to ensure that the same level of safety and integrated optimization is achieved.

SUMMARY

Several new as well as derivative airplanes with significant further reduction in fuel-burn are entering the global aviation system today - and are expected to continue to do so in the coming years. Airframe and engine manufacturers are working with governmental, regulatory and academic research agencies to continue progress and maturation of promising technologies in the areas of aerodynamics, propulsion and structural designs that can be safely, economically, and practically integrated in existing and new highly optimized aircraft. Further advances in computational simulation within each discipline and at the integrated aircraft level can enhance multi-disciplinary optimization of advanced technologies, while satisfying manufacturing requirements.

Continued research and development programs are key to progress technology and aircraft integration concepts from laboratory and computational research stages to full-scale demonstration and validation towards operational and certification readiness. Manufacturing, operational and economic considerations need to be considered in technology maturation assessment.

Opportunities in aerodynamic drag reduction, propulsive technology, manufacturing, structural design, as well as in aircraft configuration integration are expected to result in continued reductions in aircraft emissions. Due to integration complexity, some of the mentioned technologies may require incorporation in a new airplane (versus retrofitting existing aircraft), or a new aircraft configuration architecture altogether.

This article was written in collaboration by the following ICCAIA members: Jean-Pierre Cabanac, Gerd Heller and Rudiger Thomas (all Airbus); Krisha Nobrega (Embraer); Simon Smith (Rolls-Royce); Andrew Murphy (Pratt & Whitney); Olivier Penanhoat (Safran); Greg Steinmetz (GE); and Daniel Allyn and Paul Vijgen (all Boeing).

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10. https://www.nasa.gov/centers/armstrong/features/highly_flexible_wings_tested.html

Demonstrating New Technologies to Advance the Sustainable Growth of Air Transport

By Boeing

The Boeing Company ecoDemonstrator program which began in 2011, accelerates development of promising new technologies that have the potential to enhance the safety, design, evaluation, production, maintenance, in-service performance, comfort, environmental efficiency, and economics of commercial airplanes. Access to flight-test airplanes off the critical path of a certification program enables engineers to “learn by doing” and make viability assessments faster. All ecoDemonstrator programs have evaluated different types of sustainable aviation fuels.

In 2016, Boeing and Embraer jointly flight tested new technologies onboard an E170 regional jet, aimed at improving airplane safety and environmental performance. The collaboration was part of a cooperation agreement to create value for both companies and their customers. The combined technical expertise of the two manufacturers accelerated the developing of improved technologies more efficiently than approaching them separately.

Technologies tested in 2016 included:

- Ice-phobic paint for ice release and reduced washing.
- Slat noise cove fillers that reduce unsteady air flows and community noise.
- Light Detection and Ranging (LIDAR) optical air data system that measures air data parameters to improve airplane performance.
- Boundary Layer Data System (BLDS) that measures air flow on laminar surfaces and improves data acquisition to reduce fuel use and emissions.
- Sustainable aviation fuels made from waste Brazilian sugar cane.

In 2018, Boeing worked with FedEx Express to gather information for nearly 40 technologies on a Boeing 777 Freighter. This program marked the first time a commercial airliner was powered with 100 per cent biofuel to reduce emissions. The fuel’s higher energy density also improved performance.

Additional technologies tested in 2018 included:

- Clear air-turbulence detection.
- Ground-collision avoidance.
- Compact thrust reverser designed and manufactured by Boeing to save fuel.
- Flight-deck improvements to make operations at busy airports more efficient.
- Prototype airplane parts using approved recycled materials and additive manufacturing that reduce waste and fabrication time.

To-date, ecoDemonstrator airplanes have tested 112 technologies using a Next-Generation Boeing aircraft: 737-800 in 2012, a 787 in 2014, and a 757 in 2015; in addition to the 2016 Embraer and 2018 FedEx Express airplanes.

About one-third of the technologies tested have transitioned to production programs or in-service solutions for customers. For example, natural laminar flow winglets that improved fuel efficiency on the 2012 737-800 are now standard equipment on the 737 MAX. Another 45 per cent of the technologies have advanced in technology readiness and are still being developed.

Additional technologies are being planned for flight testing in 2019, 2020 and 2021.

Electric, Hybrid, and Hydrogen Aircraft – State of Play

By ICAO Secretariat

INTRODUCTION

The aviation industry has noted a consistent increase in the electrification of aircraft systems, research on electrical propulsion, and investments in electric or hybrid aircraft designs. Projects are also ongoing on liquid hydrogen research for civil aviation purposes. Electric, hybrid and hydrogen aircraft may help ICAO meet its major environmental goals on climate change, local air quality, and noise. This article describes the possible environmental benefits that may result from these new technologies, and provides an overview of the current status of their development and implementation in aircraft.

POTENTIAL ENVIRONMENTAL BENEFITS FROM ELECTRIC, HYBRID AND HYDROGEN AIRCRAFT

Climate change

Substituting jet fuel with electricity or hydrogen can have a notable impact on the climate change impacts of aviation, as the operation of electric or hydrogen aircraft will not be associated with CO_2 emissions from fuel combustion. However, it is important to note that such CO_2 benefits need to be considered on a life cycle basis, and will only occur if the electric energy or hydrogen is obtained from lower carbon sources. For example, as of 2015, 98 airports around the world had installed solar power projects[1], and this number has continued to grow in the years since. The continued expansion of renewable energy capacity and availability at airports could provide an opportunity for hybrid or electric aircraft to recharge in such a way that CO_2 benefits could be achieved. Similarly, such renewable energy could be used to produce hydrogen with a low CO_2 impact on a life cycle basis.

The climate benefits of electric aviation may come not only from its reduced CO_2 emissions, but also from the elimination of contrails - the long, thin clouds that form in the wake of jet engines[2]. Although no scientific consensus exist on the radiative forcing effect of contrails, some studies point out that they may have further warming impacts on the global climate.

Beyond electric and hydrogen propulsion, it should be noted that there are various ways to use electricity and hydrogen in aircraft operations. One example is electric taxiing (E-taxi), which could save almost 33kg of CO_2 per minute of use, according to ICAO's Rules of Thumb[3]. Hybrid aircraft can also help to reduce fuel consumption and contrail generation by using electric motors as a supplementary thrust source during the takeoff phase, which allows the use of smaller and more efficient jet engines during the cruise phase of flight. Airports around the world have also demonstrated the feasibility of hydrogen for ground support/transport vehicles. For example, initiatives in Heathrow[4], Berlin[5] and Los Angeles[6] installed hydrogen fuelling stations that produce hydrogen onsite from renewable energy sources, using the electrolysis process.

1 ATAG. 2015. Aviation Climate Solutions. Air Transport Action Group. September 2015.
2 https://climate.nasa.gov/news/2482/electric-airplanes-batteries-included/
3 ICAO. 2016. ICAO Doc 9988, Guidance on the Development of States' Action Plans on CO_2 Emissions Reduction Activities.
4 https://hydrogeneurope.eu/project/hylift-europe
5 https://www.sciencedirect.com/science/article/pii/S1464285914701221
6 http://www.calstatela.edu/ecst/h2station

Local air quality

Full electric aircraft promise significant benefits for local air quality, as the pollutants emitted on the fuel combustion process are avoided. Hybrid-electric aircraft may similarly help improve local air quality impacts of aviation due to its lower fuel burn. However, while looking at air pollution impacts from all types of aircrafts including electric ones, brake abrasion, in addition to tire abrasion and road surface erosion still needs to be considered as these factors are a source of particulate matter emissions. In addition, similarly to the CO_2 emissions, the source of the electricity should be considered when assessing the local air quality impacts of electrification, since different processes of electricity production may still be associated with air pollution.

Other factors also need to be considered when looking at overall trends. While becoming more fuel efficient, aircraft tend to increase in size and weight, carrying more passengers and more fuel. This increase in carried fuel could offset the fuel reduction achieved through energy efficiency improvements thanks to hybrid systems. Therefore, it is clear that hybrid-electric aircraft help reduce air pollutant emissions when looking at the per-passenger figures, but not necessarily when looking at total figures. Moreover, most hybrid-electric aircrafts are equipped with batteries for electricity storage and supply. Due to battery energy density and the required power supply, these batteries are currently very heavy, thus can substantially increase the weight of aircraft.

A Life cycle approach to electric aircraft could be useful to assess the overall impact of electric aircraft on the environment and its sustainability benefits. This approach goes from inception of an aircraft to its end-of-life, and helps to avoid environmental and social risks. **Batteries** used in electric aircraft are currently made of mostly lithium. Air pollutants emitted during processes associated with the production of lithium batteries may affect air quality and health. Moreover, the lifetime of batteries is still short and induces battery waste containing toxic or corrosive materials such as lithium. This hazardous waste could pose threats to health and the environment if improperly disposed. Nevertheless, there are opportunities for improvements in the batteries' life-cycles that will reduce possible impacts to the environment and health, as their use increases. Sustainable alternatives to lithium batteries are also being developed.

Noise

Electric propulsion may also result in lower aircraft noise levels, since electric engines will not have some of the noise sources associated with jet or piston engines, such as combustor and turbine noise. Depending on the design of the aircraft, jet noise may be also reduced substantially due to the lower jet speeds required for aircraft operation. The lower noise levels associated with electric aircraft may facilitate its use in densely populated areas. For example, the low noise of the Pipistrel Alpha Electro is being used to justify its use by flight schools in urban areas[7], and the Uber Elevate project is aiming at a 15 dB noise reduction when compared with typical helicopter of similar weight[8].

CURRENTLY ONGOING ELECTRIC AND HYBRID AIRCRAFT PROJECTS

The ICAO Secretariat is currently following the industry developments in electric and hybrid aircraft designs by means of the Electric and Hybrid Aircraft Platform for Innovation (E-HAPI)[9]. This website is being maintained with a non-extensive list of projects that have been identified globally, ranging from general aviation or recreational aircraft; business and regional aircraft; large commercial aircraft; and vertical take-off and landing (VTOL) aircraft (also called electric urban air-taxis). Most of them target an entry-in-service date between 2020 and 2030, and some are already commercially available. Four of the projects had their first flights in 2019 (Lilium, City Airbus, Boeing Aurora eVTOL, and Bye Aerospace Sun Flyer 2).

Currently there are no specific ICAO environmental standards in Annex 16 to cover such aircraft types. ICAO is monitoring the developments around these new entrants, and the need for SARPs and guidance.

7 https://www.pipistrel-usa.com/newsletter-115-may-2019/
8 https://s3.amazonaws.com/uber-static/elevate/Summary+Mission+and+Requirements.pdf
9 The most up-to-date version of this table is available at: https://www.icao.int/environmental-protection/Pages/electric-aircraft.aspx

TABLE 1: ICAO Electric and Hybrid Aircraft Platform for Innovation (E-HAPI)

Project	Type	Category	MTOW (KG)	Pax	Target Entry in Service	Cruise altitude (FT)	Cruise Speed (kt)	Payload (KG)	Range (KM)	Engine power (kW)
Airbus/ Siemens/ Rolls Royce E-Fan X	Hybrid-electric	Large commercial aircraft	N.A.	100	2030	N.A.	N.A.	6650	N.A.	2000
NASA X-57 Maxwell	Electric	General Aviation/ recreational aircraft	N.A.	2	2020-2021	9000	149.464	N.A.	160	60 +10
Zunum Aero ZA10	Hybrid-electric	business aircraft	5216.3	12	2020	max. 25,000	295	1134	1127	1000+500
Uber Elevate	Electric	VTOL	N.A.	up to 4	2023	1,000 - 2,000	130	498.96	97	N.A.
Lilium	Electric	VTOL	639.6	5	2025	3300	160	200	300	320
Pipistrel Alpha Electro	Electric	General Aviation/ recreational aircraft	549.8	2	2018	N.A.	85	200	600	60
Kitty Hawk Cora	Electric	VTOL	N.A.	2	2022	up to 3000	95	N.A.	100	N.A.
Kitty Hawk Flyer	Electric	VTOL	N.A.	1		10	17	N.A.	10.7	
Airbus (A^3) Vahana	Electric	VTOL	725.7	1	2020	N.A.	95	113	100	360
Airbus City Airbus	Electric	VTOL	2199.2	4	2023	N.A.	59	N.A.	96	8*100
Airbus/Audi Pop up	Electric	VTOL	N.A.	2	N.A.	N.A.	N.A.	N.A.	130	N.A.
Boeing Aurora eVTOL	Electric	VTOL	798.3	2	2020	N.A.	48.6	N.A.	N.A.	N.A.
Ehang 184	Electric	VTOL	N.A.	1	N.A.	9843	54	100	16	106
Volocopter 2X	Electric	VTOL	450	2	2018	6562	27	160	27	N.A.
Eviation Alice	Electric	business aircraft	6349.8	9	2021	32 808	240	1250	1046	N.A.
Wright Electric/Easy Jet	Electric	Large commercial aircraft	N.A.	at least 120	2027	N.A.	N.A.	N.A.	539	3*260
Extra aircraft/ Siemens Extra 330LE	Electric	General Aviation/ recreational aircraft	1000.1	2	2016	9843	184 (top)	N.A.	N.A.	260
Magnus Aircraft/ Siemens eFusion	hybrid diesel-electric	General Aviation/ recreational aircraft	600.1	2	N.A.	N.A.	100-130	N.A.	1100	60

Solar Impulse 2	Electric	General Aviation/ recreational aircraft	N.A.	1	N.A.	27887	38	N.A.	N.A.	N.A.
Bye Aerospace Sun Flyer 2	Electric	General Aviation/ recreational aircraft	861.8	2	N.A.	N.A.	55-135	363	N.A.	90
Ampaire TailWind	Electric	business aircraft	N.A.	9	N.A.	N.A.	N.A.	N.A.	161	N.A.
Embraer Dreammaker	Electric	VTOL	N.A.	N.A.	2024	2,600-3,300	N.A.	N.A.	N.A.	N.A.
Bell Nexus	Electric	VTOL	N.A.	4	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Boeing Sugar VOLT	Hybrid-electric	Large commercial aircraft	N.A.	135	2030-2050	N.A.	N.A.	N.A.	6482	N.A.
DigiSky SkySpark	Electric	General Aviation/ recreational aircraft	N.A.	2	N.A.	N.A.	162 (top)	N.A.	500	65
Hamilton aEro	Electric	General Aviation/ recreational aircraft	420	1	2017	N.A.	92	N.A.	160	80
Dufour aEro 2	Electric	VTOL	N.A.	2	N.A.	N.A.	173	N.A.	120	N.A.
PC Aero Elektra One Solar	Electric	General Aviation/ recreational aircraft	300	1	N.A.	19600	76	100	600	32
PC Aero Elektra Two Solar	Electric	General Aviation/ recreational aircraft	450	2	N.A.	65616	37.8	200	almost unlimited	23
PC Aero Elektra Solar Trainer	Electric	General Aviation/ recreational aircraft	600	2	N.A.		76.6	260	400	32
Volta Volare DaVinci	Hybrid-electric	General Aviation/ recreational aircraft	N.A.	2+2	2017	24 000	160	N.A.	N.A.	N.A.
Yuneec International E430	Electric	General Aviation/ recreational aircraft	430	2	N.A.	9840	52	N.A.	N.A.	N.A.

Pipistrel Alpha Electro

The Pipistrel Alpha Electro is a 2-seat trainer with an endurance of one hour+30 minute reserve. It is the first certified all-electric aeroplane, with about 60 aircraft currently in operation over the world. Energy-cost associated with its operation is around 1 Euro per hour, which makes it suitable for use by flight schools.

The general aviation/recreational aircraft group consists of aircraft with MTOW from 300 to 1000 kg. These are mostly electric powered aircraft with a seat capacity of two. This category includes aircraft which are already produced and certified, for example the Pipistrel Alpha Electro.

The aircraft under the business and regional aircraft category claims longer flight range close to 1000 km with increased seat capacity (around ten). A full scale prototype of the Eviation Alice was displayed at the Le Bourget Air Show in Paris. Flight testing is expected to start by the end of the year[10].

Significant progress has also been made on the VTOL category over recent years, with seat capacities from one to five, MTOWs between 450 and 2200 kg and projected flight ranges from 16 to 300 km. These aircraft projects are only electric powered and aim to enter into service in the period of 2020-2025.

The large commercial aircraft category includes Airbus and Boeing initiatives focused on hybrid-electric, single-aisle aircraft with seat capacities of 100-135 and targeted entry into service after 2030.

Eviation Alice

The Eviation Alice is being designed to take 9 passengers + 2 pilots up to 650 miles at a cruise speed of 240 knots. It is powered by three 260 kW (350 hp) electric motors developed by the Siemens eAircraft business, which was recently acquired by Rolls-Royce. At 3,700kg, the battery accounts for 60% of the aircraft take-off weight. Eviation announced that U.S regional airline Cape Air is to buy the Eviation Alice, which has a list price of around $4 million each. Eviation expects to receive certification by late 2021, with deliveries predicted for 2022.

References

https://www.wingsmagazine.com/rolls-royce-to-acquire-siemens-electric-propulsion-business/

https://www.cnbc.com/2019/06/18/all-electric-jet-firm-eviation-announces-us-airline-as-first-customer.html

PROSPECTS ON HYDROGEN PROPULSION

Hydrogen powered aircraft were successfully flown in the past. The Tupolev 155 (Tu-155) was tested in the late 1980s powered by cryogenic hydrogen and liquefied natural gas. This aircraft had a number of fundamental differences from the original version (Tu-154), such as a cryogenic fuel tank along with the fuel supply system and an experimental turbofan engine which operated together with the kerosene engines. The cryogenic complex on the plane was operated using several innovative systems, such as a helium control system for the power plant and a nitrogen system to replace the air in the compartments with the risk of cryogenic fuel leakage. To allow that, nitrogen and helium tanks were installed in the cargo compartment

10 https://www.cnbc.com/2019/06/14/in-pictures-the-stars-of-the-2019-international-paris-air-show.html

Airbus E-Fan X

The E-Fan X is an Airbus project, in partnership with Siemens and Rolls-Royce, which is developing a flight demonstrator testing a 2MW hybrid-electric propulsion system. The project aims is to replace one of four gas turbines on a British Aerospace RJ100 with a 2 MW electric motor. Flight testing is expected to start in 2020. With the E-Fan X, Airbus intends to investigate the thermal effects, electric thrust management, altitude and dynamic effects on electric systems, and electromagnetic compatibility issues, as well as facilitate the establishment of certification requirements for electrically powered aircraft.

Lilium Jet

The Lilium Jet is a tilt-jet aircraft with 36 electric motors mounted on its flaps. It will be capable of traveling up to 300 km in 60 minutes, carrying 4 passengers + one pilot. The ducted design of the electric motors is expected to provide noise benefits when compared with traditional helicopter designs. The Lilium Jet completed its maiden flight in May 2019, and is expected to be fully operational in various cities around the world by 2025.

Reference
https://lilium.com/

and cabin area. In the late 1990s, the initiative to create Tu-156 as a serial aircraft was proposed but the project hasn't been completed. However, the Tu-155 flight tests confirmed the possibility of safe operation of the aircraft powered by cryogenic fuel.

To date, several factors still hinder a possible use of hydrogen in commercial flights, such as on-board storage, safety concerns, the high cost of producing the fuel and the need for dedicated infrastructure at airports. Research projects are ongoing to demonstrate the feasibility of hydrogen propulsion and to overcome these challenges, in support of longer term environmental objectives for civil aviation.

One of these projects is the ENABLEH_2 (ENABLing CryogEnic Hydrogen-Based CO_2-free Air Transport)[11], a recently launched project funded by the European Union and led by Cranfield University. This project aims to revitalise enthusiasm for liquid hydrogen (LH_2) research for civil aviation, demonstrate its feasibility, and the need for more R&D into advanced airframes, propulsion systems and air transport operations as part of an LH2 future. The project will include experimental and numerical work for two key enabling technologies: H_2 micromix combustion (for ultra-low NOx emissions), and fuel system heat management (to exploit the heat sink potential of LH_2 to facilitate advanced turboelectric propulsion technologies). These technologies will be evaluated and analysed for competing aircraft scenarios; for advanced short to medium range aircraft and for long range aircraft, both featuring distributed turbo-electric propulsion systems. The study will include mission energy efficiency and life cycle CO_2 and economic viability studies of the technologies under various fuel price and emissions taxation scenarios. ENABLEH_2 will also deliver a comprehensive safety audit characterising and mitigating

11 https://www.enableh2.eu/

hazards in order to support integration and acceptance of LH_2. The project will provide a roadmap to develop the key enabling technologies and the integrated aircraft and propulsion systems to TRL 6 in the 2030-2035 timeframe.

CONCLUSION

New innovative technologies and energy sources for aviation are under development in a fast pace. ICAO is closely following up these developments and its possible benefits in terms of the ICAO Environmental Goals. Much work by ICAO will be required to keep pace with the timely environmental certification of such new technologies, as appropriate.

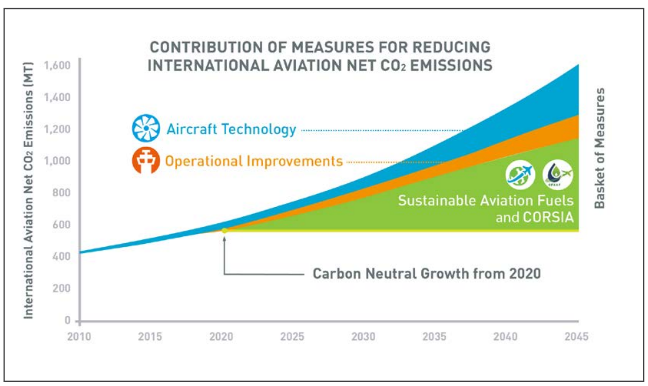
Global ASBU Environmental Benefits Assessment – To 2025

By David Brain

INTRODUCTION

ICAO has developed a comprehensive approach to achieving carbon neutral growth from the year 2020 onward. It involves the implementation of a "basket of measures" comprised of: technical, operational, and infrastructure enhancements; sustainable alternative fuels; a CO_2 standard for aircraft; and the development of a global market-based measure (CORSIA).

FIGURE 1: ICAO Global Environmental Trends on CO_2 Emissions and Contribution of Measures for Reducing International Aviation Net CO_2 Emissions



The CO_2 savings derived from the operational wedge of the basket of measures (See Figure 1) are expected to come from more efficient aircraft operations, and from the implementation of new technologies, concepts and procedures developed under the auspices of the regional air traffic management (ATM) improvement programs such as SESAR (Europe), NextGen (US) and CARATS (Japan). These programs are aligned at the ICAO level under the Aviation System Block Upgrades (ASBU) framework that is detailed in the Global Air Navigation Plan (GANP), ICAO Doc. 9750. The ASBU framework, adopted at the Twelfth Air Navigation Conference in 2012, 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 aims to ensure global interoperability by harmonizing 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.

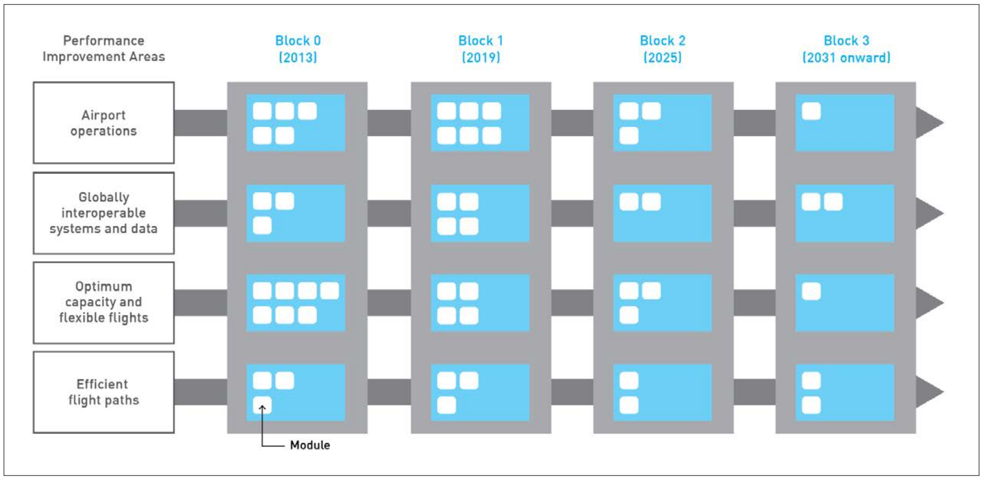
With air traffic growth forecast to increase by 4.3%[1] per year (Compound Annual Growth Rate (CAGR)) for the next 20 years, the ASBU framework is expected to deliver global ATM operations that improve safety and capacity, all while reducing the amount of greenhouse gases on a per flight basis.

ASBU ANALYSIS

The ASBU framework consists of a set of operational concepts or improvements, divided into four performance improvement areas, that are expected to come on-line, or be deployed, in a series of timeframes or Blocks, out to the year 2030 and beyond[2]. As shown in Figure 2 ASBU Block 0 is from 2013 to 2019, Block 1 is from 2019 to 2025, and Block 2 is from 2025 to 2030.

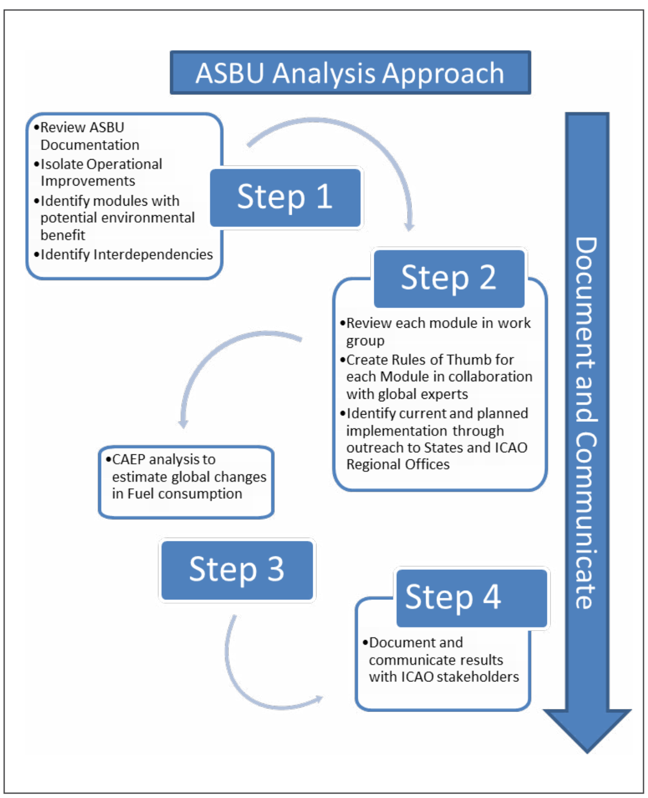
1 https://www.icao.int/sustainability/Documents/LTF_Charts-Results_2018edition.pdf
2 For more information see https://www.icao.int/sustainability/pages/asbu-framework.aspx. Note that the ASBU framework is currently being updated with a new structure to be endorsed at the 40th ICAO Assembly (October 2019).

FIGURE 2: The ICAO ASBU framework (2016)



In 2016, the ICAO Committee on Aviation Environmental Protection (CAEP) reported that the estimated global fuel and CO_2 emissions savings from the implementation of the operational concepts detailed in ASBU Block 0 between 2013 and 2018[3] would be between 2.5 – 4.9Mt in fuel saved and between 7.8 – 15.4Mt in reduced CO_2 emissions. As Block 0 ends in 2019, the 39th Session of the ICAO Assembly requested CAEP to look at the expected fuel and emissions saving benefits of ASBU Block 1 (2019-2025). CAEP subsequently undertook a 3-year analysis of the expected environmental benefits following the planned implementation of Block 1 out to 2025. This analysis concluded that many of the ASBU modules have the potential to reduce the adverse environmental impacts of aviation, and that quantifying these benefits can further support the facilitation and adoption of ASBU globally.

FIGURE 3: ASBU Analysis Approach



CAEP followed the same approach as the previous ASBU B0 analysis, namely, 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*. Figure 3 presents the ASBU analysis approach.

The first step involved the screening of each ASBU module within Block 1 (B1) for potential environmental benefits. At this stage, CAEP concluded that the B1 elements or operational improvements build upon those identified in Block 0, and that the benefits accrue together and should not be separated. Therefore, CAEP decided to undertake a combined Block 0/1 environmental benefits assessment.

The second step was to identify a Rule of Thumb (RoT) fuel saving for a generic implementation of any of the concepts, elements or operational improvements for which potential fuel and emissions savings had been identified.

3 Block 0 was previously defined from 2013-2018.

TABLE 1: Block 0/1 modules, potential environmental benefits and rules of thumb.

B0 / B1 Module[4]	Environmental benefits in OI (Y/N)	Number of RoT(s) defined	B0 / B1 Module[4]	Environmental benefits in OI (Y/N)	Number of RoT(s) defined
ACAS	N		NOPS	Y	*****
ACDM	Y	***	OPFL	N	
AMET	Y	***	RATS	Y	*
APTA	Y	********	RPAS	N	
ASEP	Y	**	RSEQ	Y	***
ASUR	Y	*	SNET	N	
CCO	Y	**	SURF	Y	***
CDO	Y	***	SWIM	N	
DATM	N		TBO	Y	**
FICE	Y	*	WAKE	Y	********
FRTO	Y	******			

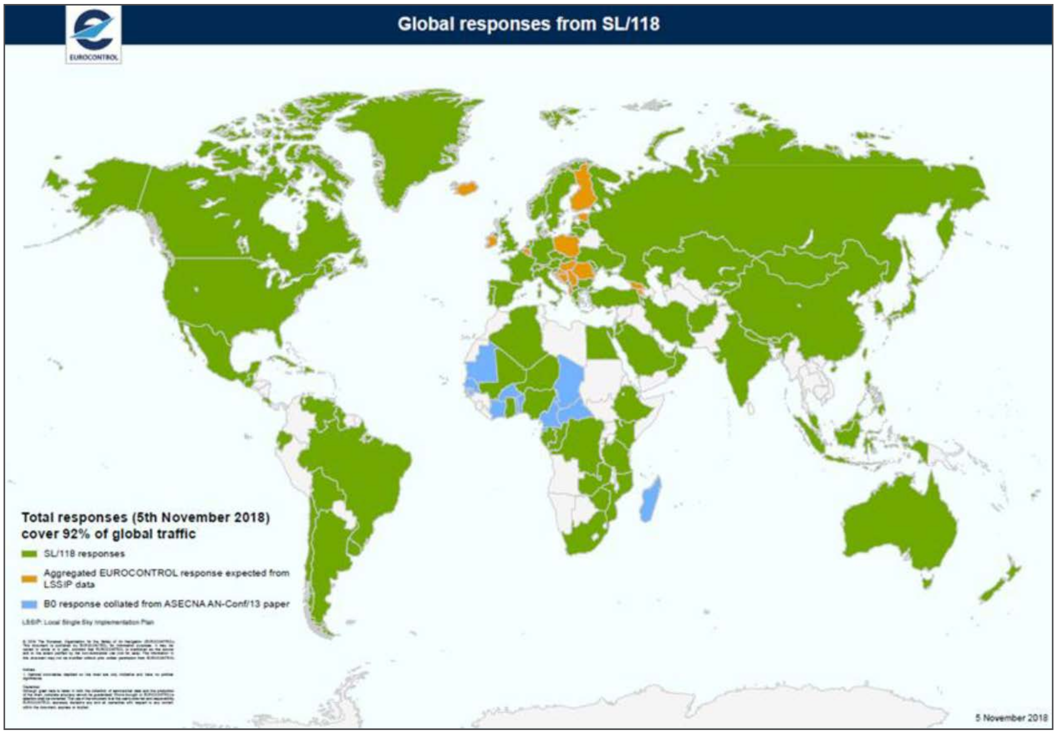
To create a RoT, operational experts gathered data from pre- and post- implementation assessments and used information from studies and trials, combined with their expert judgement to create and agree on the fuel saving benefit attributed to a generic implementation of each operational improvement. The RoT creation process also took into account any interdependencies among the different modules with the objective to follow a conservative approach to avoid any double counting of benefits. For existing Block 0 RoTs, these were reviewed and updated where necessary taking into account the latest information available. In total, CAEP created 51 Rules of Thumb for 15 of the Block 0 / 1 modules (see Table 1).

ASBU IMPLEMENTATION AND RESULTS

To identify the current and planned implementation status of all the Block 0/1 operational improvements for which rules of thumb had been created, a State Letter was sent out to all ICAO States in late 2017. Over the following 10 months, ICAO received more than 100 responses from States detailing their current and future plans for ASBU implementation. In Figure 4, green areas indicate a direct response to the State Letter, orange areas indicate aggregated regional implementation data provided by EUROCONTROL, and blue areas indicate responses from the States of ASECNA (Agency for Air Navigation Safety in Africa and Madagascar) in the form of a Block 0 implementation report to the ICAO's 13th Air Navigation Conference.

4 ACAS-ACAS improvements; ACDM-Airport CDM; AMET-Meteorological information supporting enhanced operational efficiency; APTA-Approach procedures including vertical guidance; ASEP-Air Traffic Situational awareness; ASUR-ADS-B satellite based and ground based surveillance; CCO-Continuous Climb Operations and PBN SIDs; CDO-Continuous Descent Operations and PBN STARs; DATM-Digital Air Traffic Management; FICE-Increased efficiency through ground - ground integration; FRTO-En route Flexible Use of Airspace and Flexible routes; NOPS-Air Traffic Flow Management; OPFL-In-Trail Flight Procedures; RATS-Remote Air Traffic Services; RPAS-Remotely Piloted Aircraft System; RSEQ-AMAN / DMAN; SNET-Ground based safety nets; SURF-A-SMGCS, ASDE-X; SWIM-System Wide Information Management; TBO-Data link en-route; WAKE-Wake vortex.

FIGURE 4: Global ASBU implementation responses



While the 2016 CAEP study on the environmental benefits of the planned implementation of Block 0 compared 2018 ASBU implementation to 2013, the 2019 B0/1 study used 2015 as a reference case because the CAEP modelling team used a new 2015 traffic forecast. Therefore the results of the 2019 B0/1 analysis compared 2015 and 2025 fuel burn data, and are thus likely to be slightly conservative because they do not take into account the increase of the benefits derived from additional Operational Improvements that were implemented between 2013 and 2015.

Depending on how States phased the implementation of the ASBU Block 0/1 modules between 2015 and 2025, potential fuel burn savings were estimated to range between 106 - 204kg per flight. This corresponds to between 5.2 - 10.1Mt in possible global annual fuel savings (16.6 - 32.0Mt in global CO_2 savings) in 2025 resulting from planned ASBU Block 0 / 1 implementations since 2015. 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, it is estimated that an increase in total fuel / CO_2 savings of 1.5 - 2.9% in 2025 relative to the 2015 fuel savings can to be attributed to Block 0/1 implementation.

The implementation of some of the ASBU Block 0/1 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 that is required to 'carry fuel' can also be reduced by the amount of the estimated benefit. As explained in ICAO Doc 10013 - *Operational Opportunities to Minimize Fuel Use and Reduce Emissions*, this 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 reduce fuel burn by a further 4-10kg per flight, resulting in a total average fuel saving of 110 – 215kg per flight globally. Overall, therefore, a total annual fuel saving of 5.4 – 10.7Mt in 2025 (17.2 - 33.7Mt in CO_2 savings) can be attributed to ASBU Block 0 / 1 implementation since 2015, which corresponds to global fuel and CO_2 savings of between 1.6 – 3.0% in 2025 compared with the 2015 fuel savings. These fuel savings correspond to yearly monetary savings of up to €5.6 billion, or $6.4 billion[5].

5 Based on IATA fuel price 24/01/19.

FIGURE 5: Estimated regional fuel savings in 2025 (compared with 2015) from global ASBU B0/1 implementation

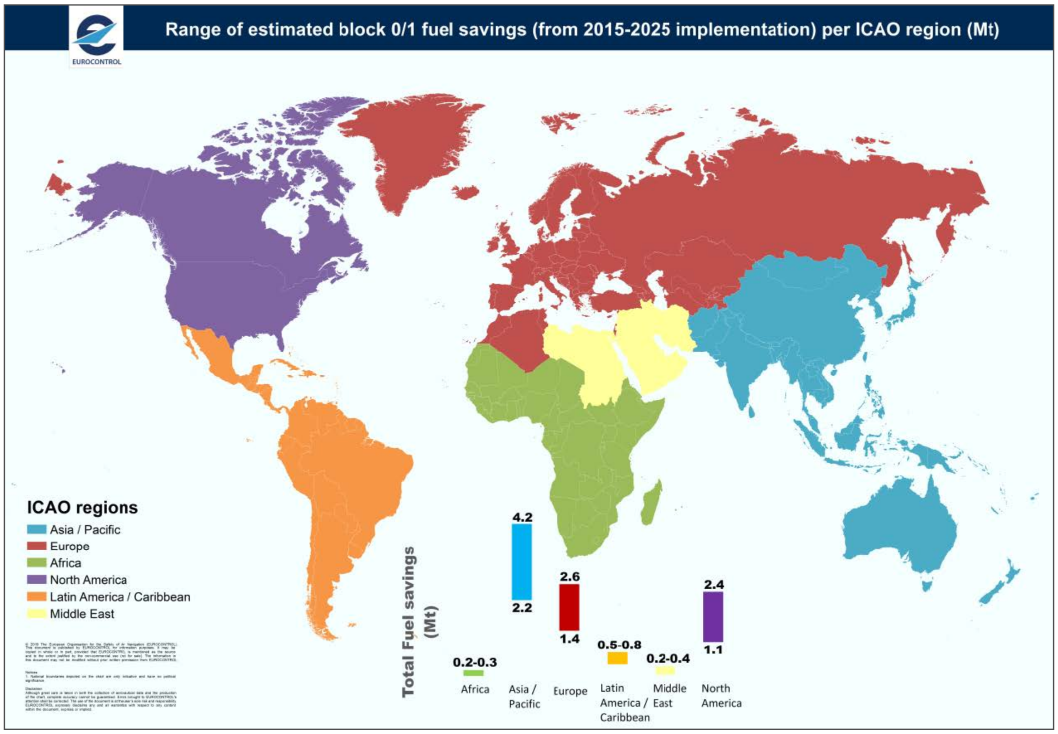
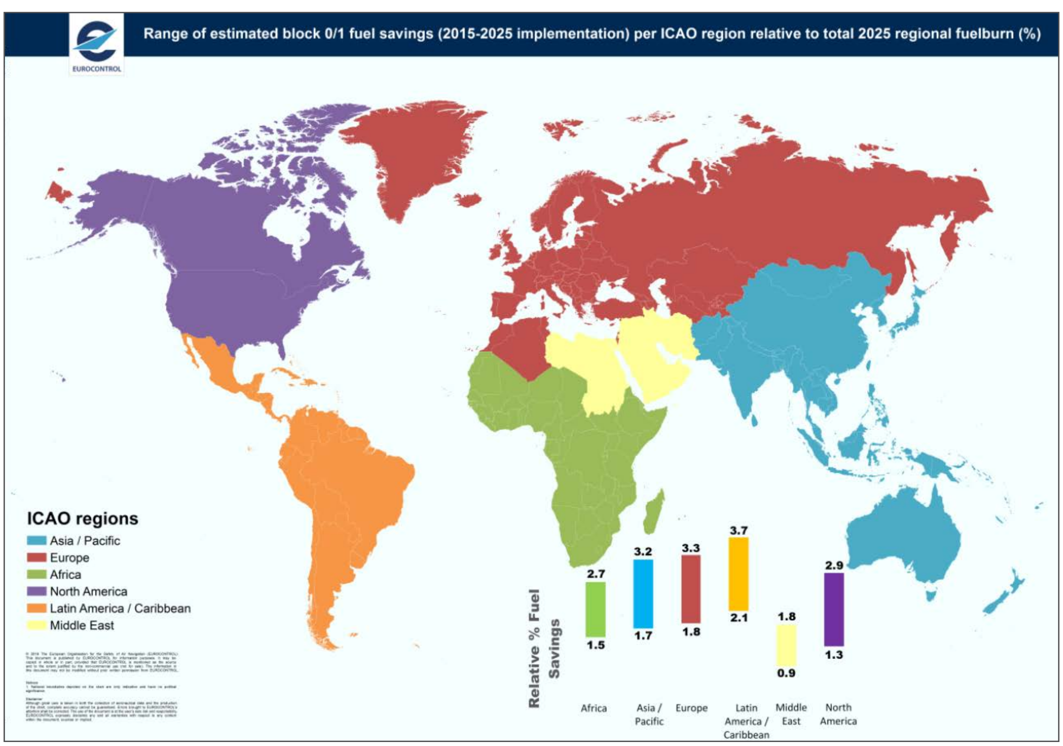


FIGURE 6: Estimated percentage fuel savings in 2025 (compared with 2015) from global ASBU B0/1 implementation relative to total 2015 regional fuel burn



Breaking down the results to the ICAO regional level it can be seen in Figure 5 that there is considerable variance in absolute fuel and CO_2 savings per region.

However, when the estimated fuel and CO_2 savings relative to the total fuel burn per region are compared (Figure 6), with the possible exception of the Middle East region, the total percentage of savings available is similar for all regions. This emphasizes how the ASBU framework supports the ICAO philosophy of 'no country left behind' where the main goal is to ensure globally harmonized implementation so that all States have access to the significant socio-economic benefits of safe, reliable, and efficient air transport.

Even though regional efficiency levels, fuel burn levels, and absolute savings may differ between regions, the picture that emerges from the study emphasizes certain key messages:

- Four ASBU modules (CDO, ASUR, TBO and CCO) together provide close to 60% of the higher range of fuel and CO_2 savings in 2025 compared with 2015.
- A further 6 ASBU modules (RSEQ, ACDM, APTA, FRTO, AMET and NOPS) together provide an additional 37% of the higher range of CO_2 savings in 2025 compared with 2015.
- Two ASBU modules (CDO and CCO) provide two of the top 5 ranked savings in each ICAO region.
- Six ASBU modules (CDO, CCO, ACDM, APTA, ASUR and TBO) provide one of the top 5 ranked savings in three or more ICAO regions.

Therefore, from the environmental and fuel / CO_2-savings perspective, those ASBU elements that provide the higher ranges of global savings should be the focus of ICAO for the development and implementation of deployment programs.

Traffic growth will also contribute to the level of benefits in 2025 by increasing the pool of potential recipients of the fuel and emissions savings provided by certain modules implemented before the baseline. Therefore, in addition to providing an assessment of the environmental benefits of the ASBU modules implemented between 2015 and 2025, this analysis also estimated the global benefits of the planned implementation of all ASBU B0 / B1 modules by 2025, regardless of their date of implementation. Such figures are likely to represent the amount of CO_2 savings that make up the operational wedge of the ICAO basket of measures to reduce CO_2 (See Figure 6 above). 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 were existing concepts that had already provided substantial environmental benefits prior to 2015. The fuel saving benefits from Block 0/1 operational improvement implementations prior to 2015 are estimated to range between 57-92kg per flight.

Therefore, in total, the fuel saving benefits that could be attributed to the operational improvements defined in the Block 0/1 modules that will be implemented by the end of 2025 are equivalent to between 167-307kg of fuel per global aircraft movement in 2025. Additional savings can also be obtained as a result of traffic growth between 2015 and 2025 which increased the pool of potential recipients

FIGURE 7: Range of ASBU Block 0/1 per-flight Fuel Savings by 2025

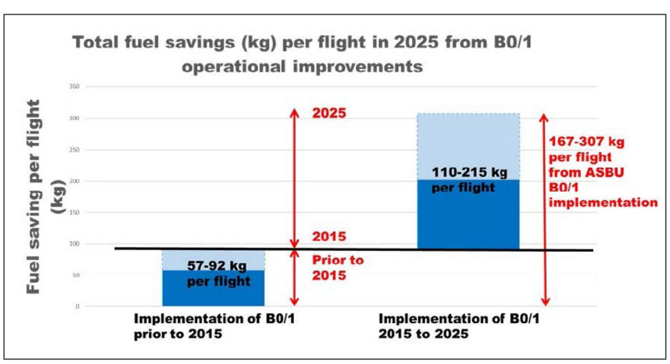
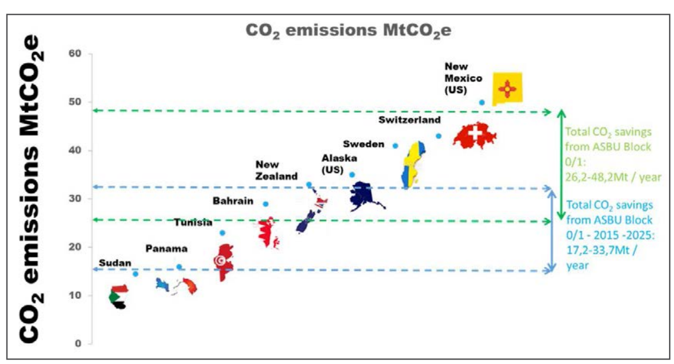


FIGURE 8: Estimated CO_2 savings from planned ASBU B0/1 implementation in 2025 compared with Country and Selected US State emissions



of the environmental benefits from modules implemented before the end of 2015. The total savings are therefore equivalent to avoiding the consumption of 8.3 - 15.2Mt of fuel (which would have generated 26 - 48Mt CO_2) or 2.4 – 4.3% of total global fuel burn in 2025, taking into account the benefits from both module implementation and the increased traffic between 2015 and 2025. These results are summarized in Figure 7.

To put these results into perspective, Figure 8 shows the range of estimated Block 0/1 CO_2 savings when 2025 savings are compared with those of 2015, regardless of implementation date. Also shown are results comparisons from the planned implementation of ASBU B0/1 for national yearly CO_2 emissions of some countries and selected US States.

CONCLUSION

In light of the above discussion, it can be seen that while the operational wedge of the ICAO basket of measures to reduce CO_2 is perhaps the smallest wedge in the basket (See Figure 1), it has the potential to provide annual CO_2 savings of up to approximately 48 million tons. In addition, this wedge represents potential annual fuel cost savings to airlines worth up to $5-9.2 billion (€4.4-8.1 billion).

The ASBU framework provides the concepts, initiatives and operational improvements which ensure that safety is maintained, while future capacity, efficiency, and environmental benefits are maximized. While such concepts may be robustly implemented in those areas of the world where ATM optimization is an immediate concern, it is the interoperability of the framework that ensures that operational solutions are available to all, and able to be implemented if and when the operational need for a solution arises.

In addition, although fuel and CO_2 savings vary among regions which have differing traffic numbers, levels of airspace complexity, and availability of specialist system support; on the whole, it is the same modules and operational improvements that provide the vast majority of the fuel / CO_2 savings. As the focus increases on mitigating aviation-related CO_2 emissions, ICAO's priority needs to be on implementation programs that can be rapidly deployed, especially for those operational improvements that have been demonstrated to reduce fuel burn and CO_2 emissions.

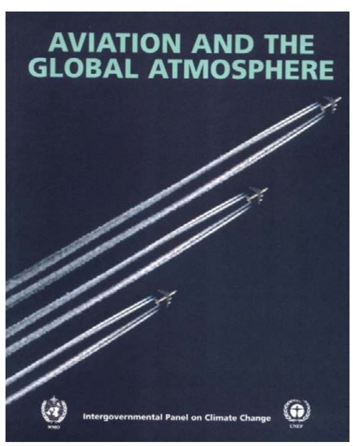
ICAO's Global Horizontal Flight Efficiency Analysis

By David Brain, EUROCONTROL and Nico Voorbach, CANSO

BACKGROUND

The contribution of air traffic management (ATM) operators in reducing the climate change impacts of aviation can best be achieved by enabling aircraft to fly on their optimum 4D trajectory in the climb, on-route and descent phases of flight - the optimum horizontal path from departure to destination flown at the most fuel-efficient flight level. There are several factors however that may influence whether such an optimum trajectory may be flown. One factor is safety, the number one objective in ATM with aircraft separated by different horizontal and vertical separation minima depending upon the type of airspace in which they fly. Another factor is military activity which may restrict the availability of certain airspace. Meteorological conditions such as wind speed and direction may provide more favorable flight conditions away from the most direct route. In addition, airlines may choose to minimize delay over the cost of fuel meaning that they may choose to fly on a less optimal routing to ensure that any delay is kept to a minimum. There may also be other operational, technical and economic reasons why airlines may choose not to file the most efficient flight plan.

FIGURE 1: Aviation and the Global Atmosphere report (IPCC)



Nevertheless, studies of flight efficiency have focused principally on measuring the efficiency of the horizontal plane by comparing the flown trajectory to a theoretical optimum, resulting in efficiency values based on a percentage up to a maximum figure of 100%. For example, an inefficiency of 10% in an aircraft profile indicates a flight profile that is 90% efficient. It is widely understood however that 100% efficiency may never be reached as some latent inefficiency will always be required to enable the aviation system to be optimized at the overall network level. This need to optimize all profiles to the extent possible will invariably mean that interactions to maintain safety, capacity, flight efficiency, and reduce environmental impacts will lead to an inherent level of inefficiency. The key is to minimize these inefficiencies to the extent possible.

Attempts to identify the base case for flight efficiency have been undertaken over the last 20 years with further attempts to measure any performance improvements undertaken at the regional level.

In the 1999 Intergovernmental Panel on Climate Change (IPCC) report, *Aviation and the Global Atmosphere*, it was estimated that improvements in ATM and other operational procedures could reduce aviation fuel burn by between 8% and 18%, thus implying an average flight efficiency of 82% to 92%. That study reviewed the results of available studies on the benefits of an improved ATM system attributable to the implementation of future ATM concepts. The IPCC concluded that addressing these limitations in ATM systems could reduce fuel burned in the range of 6% to 12% with the efficiency improvement to come from ATM improvements which it was anticipated would be fully implemented in the 20 years following the report. This finding assumed that the necessary institutional and regulatory arrangements would be in place by that time.

In 2008, the Civil Air Navigation Services Organization (CANSO) continued that thread of work in its report titled *ATM Global Environment Efficiency Goals for 2050*. That study estimated that the Global ATM system was already between 92% and 94% fuel efficient and that 100% ATM fuel efficiency was not achievable as some inefficiency is unrecoverable due to unavoidable operating constraints and interdependencies, such as: safety, capacity, weather, noise, and fragmentation of the airspace.

FIGURE 2: ATM Global Environment Efficiency Goals for 2050 (CANSO)

CANSO made a first attempt to break down the total efficiency levels on a regional basis and concluded that ATM efficiency varies among regions, ranging from between 89-93% in Europe, to 98-99% in Australia. CANSO also estimated that approximately 75% of the ATM inefficiency could be recovered by improved horizontal flight efficiency (HFE), and 25% by improved vertical flight efficiency (VFE).

In the 8th cycle of the ICAO Committee on Aviation Environment Protection (CAEP) the operational working group made an estimation of the baseline efficiency for all ICAO regions that were not part of the CANSO study, also breaking down the inefficiency within these regions to: horizontal flight inefficiency, vertical flight inefficiency, and delays/flow.

It was estimated that the baseline efficiency in these regions ranged from 90-93% in Africa to 93-96% in Central and South America (see Figure 3).

In conclusion, previous studies on global flight efficiency by the IPCC, CANSO and ICAO have focused on horizontal flight efficiency and have traditionally focused only on those areas where data is available (e.g., North America, Europe and Australia) and not where traffic growth is at a premium (e.g., Asia and the Middle East). In the absence of data, estimations of efficiency levels to date have relied on: IATA technology

FIGURE 3: CAEP/8 IEOGG global baseline and projected efficiency levels (CAEP)

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

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

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

assessments, congestion assumptions, and expert judgements.

CAEP GLOBAL HORIZONTAL FLIGHT EFFICIENCY STUDY – 2018

Since 2010, the above-mentioned studies were not revisited, but with the arrival of new sources of surveillance data, such as *Automatic dependent surveillance*-broadcast (ADS-B), together with modern flight tracker websites with global coverage, CAEP, in 2018, undertook the first truly global horizontal flight efficiency study using a single harmonized surveillance data source, ADS-B.

New Data Available

Flightradar24 provided four one-week sets of ADS-B global movement data for the first calendar week of each of February, May, August and November of 2017. The granularity of this movement data depended upon the phase of flight of each aircraft and varied between approximately 60 second surveillance updates for flights in the on-route phase, down to approximately 6 second updates during the climb and descent phases of flights in which small changes in both the vertical and horizontal profiles may occur.

As ADS-B data is surveillance data, it is only available where ground-based surveillance receivers are available to record it. Therefore, trajectory data is not recorded in oceanic areas and is usually missing over less densely populated areas such as deserts and northern latitudes. Figure 4 demonstrates the geographic distribution of where ADS-B surveillance was recorded in the study, indicating the presence of ADS-B receivers on the ground. Note the availability of trajectory data due to ADS-B receivers in specific locations, e.g., The Azores, Bermuda, St. Helena, and Mahe Island (Seychelles). In addition, note the relative absence of surveillance data over mainland Africa (limited number of receivers), Western China (restricted airspace) and Syria (airspace restrictions).

Data Validation

ADS-B data may be associated with numerous nuances relating to: data source, receiver reliability, and time stamp issues. Therefore, a rigorous data validation process was undertaken with the aid of a tool developed by EUROCONTROL called V-PAT. This tool contains a number of validation steps designed to weed out 'bad' data.

FIGURE 4: Screen shot of the average flight movements over a 7-day period of FR24 data using hexagonal bins (August 2017)

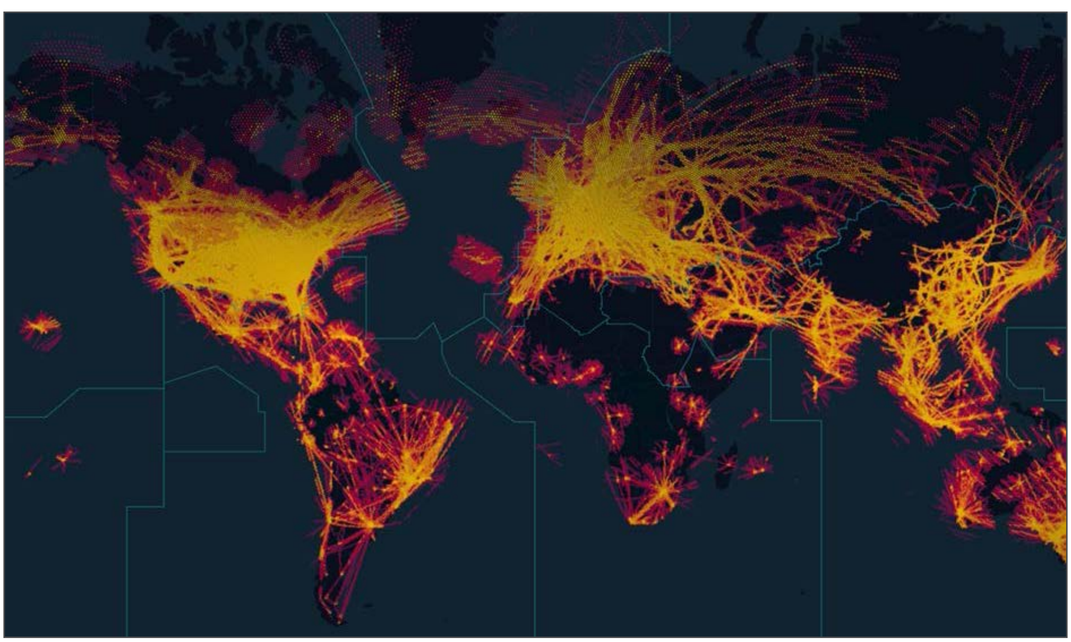
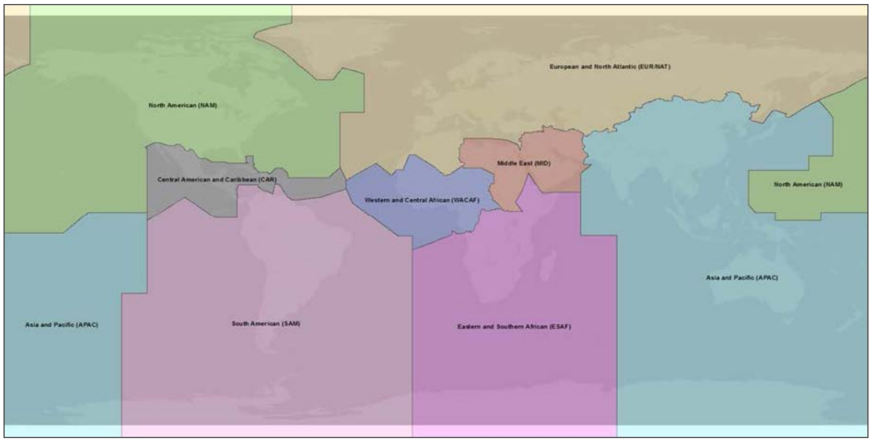


FIGURE 5: ICAO region definitions



The first validation step identified flights with missing departure or destination airports or flights that were outside the scope of the analysis such as: gliders, ground movements, flights with a cruising level of below FL100, and flights with a total number of trajectory points below a selected threshold. The second step used user-defined parameters to exclude flights with missing, incomplete, or corrupt data. The third step identified any trajectory points which exceeded additional user-defined parameters so that trajectories could be smoothed out, and any potential erroneous trajectory points or those with speeds that were out of tolerance eliminated.

Study Methodology

To identify a relevant horizontal flight efficiency methodology to use in the analysis, a literature review was undertaken of available resources relating to the measurement of flight efficiency including: scientific studies, reports, conference papers, websites, and available presentations. These sources were reviewed to select the most appropriate methodology and metric to use. The one methodology that was widely established and considered appropriate for study purposes, and thus subsequently chosen for the analysis, was the mathematical tool at the core of the European Performance Scheme's methodology to calculate 'achieved distance'[1] . This tool is used on an annual basis for the European measurement of horizontal flight efficiency (HFE) in EU/US HFE comparison studies. This performance indicator is a variant of KPI05[2], a potential performance indicator presented in the ICAO Global Air Navigation Plan (GANP) 2016, and is also consistent with the methodologies used by the previous CANSO and CAEP studies to measure horizontal flight efficiency.

This methodology creates a spatial analysis of the flight segment and calculates a radius around each departure airport and arrival airport between which the measurement is calculated. The methodology was adapted to the data type (ADS-B), data availability (typically over continental airspace) at hand and ICAO regional boundaries (as opposed to the normal entry/exit into European airspace).

The achieved distance was calculated for all flights for which surveillance data was recorded. In the absence of surveillance data between two points of a trajectory (above a certain distance threshold), no efficiency was recorded as the HFE methodology assumes a minimal efficiency for that part of the trajectory in the non-surveilled area which would not be zero (the so-called interface inefficiency). In cases where a flight consisted of two or more segments e.g., a flight from Birmingham, UK to New York City (which had two separate trajectory segments on either side of an 'unsurveilled' segment over the Atlantic Ocean), the achieved distance was calculated for each individual segment. This is because the methodology is designed to measure the horizontal flight efficiency of individual segments by default.

1 https://ansperformance.eu/methodology/horizontal-flight-efficiency-pi/
2 KPI05 refers to the 'actual on-route extension' which compares the actual on-route distance flown compared to a reference ideal distance.

Therefore, it is important to highlight that the HFE analysis measures only the HFE values for those segments of global trajectories that can be recorded by ADS-B receivers.

Following analysis of each individual flight with the achieved distance methodology, the horizontal flight efficiency was assessed for each ICAO region. This was achieved by incorporating a map file (see Figure 5) into the calculations of the methodology which allowed the creation of individual intersection points where each trajectory segment crossed a regional boundary which, in turn, allowed the achieved distance of each flight to be calculated per region.

In order to develop results that would be representative of an entire one-year period, the horizontal flight efficiency results for the four weeks of data were extrapolated to be representative of 2017 as a whole. This was achieved by aligning with existing CAEP assumptions for the extrapolation of data.

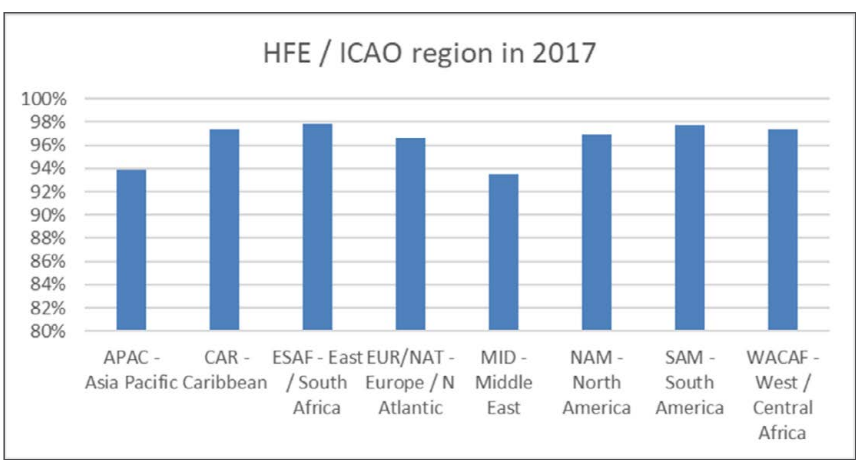
A final validation of results was undertaken. This was necessary because analyses of large traffic samples such as those in this global horizontal flight efficiency study (as large as 100,000+ flights per day), may lead to a small number of erroneous trajectories still not being identified. To combat this issue and in alignment with the same process undertaken during the calculation of the achieved distance KPI in Europe (and proposed as the HFE KPI in the GANP), the top 1% (the highest) of achieved distance values and the bottom 1% (the lowest) of achieved distance values were ignored from the final calculations.

Final Results

The purpose of this analysis was to calculate global horizontal flight efficiency, broken down to the ICAO regional level, for each and every ICAO region, using a harmonized single source of surveillance data. It is important to recognize that while the methodology has been used in the past for various analyses, this study was the first of its kind to use a new global data source, and a global-based analysis, with the potential limitations of using a single parameter to estimate different traffic flow efficiencies on a global level.

The results shown in Figure 6 reveal that horizontal flight efficiency levels in 2017, based on the data studied, vary between 94% and 98%, compared with those estimated by CANSO (92%-94%) in 2008 and CAEP (91%-94%) in 2009. It should be noted however that the efficiencies assessed in both of those studies included an analysis of both horizontal and vertical flight efficiency. As a cross-check, it should be noted that the HFE value for 2017 calculated by the European performance scheme 'achieved distance' methodology was 97.3%. It should also be noted that in this analysis, the EUR/NAT region includes the former Soviet Union States and the North Atlantic airspace (where surveillance data exists).

FIGURE 6: Horizontal flight efficiency results per ICAO region in 2017



In conclusion it would seem that the regional and global HFE values seem aligned with previous studies. This is of course, dependent on what levels of vertical flight efficiency another study using the same data source would find. There are two distinct outliers in the results: the MID and APAC regions. It was not the aim of the study to identify the reasons for regional efficiency levels but it is quite clear that ongoing political instability in the former has contributed to more inefficient routings. Causes for inefficiency in the APAC region are not so obvious but could be linked to large areas of inaccessible airspace (i.e., military areas) or non-optimal airspace structure, or transfer of control points between countries.

To determine the percentage of global air traffic movements that were included in the analysis (and thus assess the percentage of global movements covered by ADS-B surveillance), a comparison was made between the number of movements analyzed in the study per ICAO region (i.e., movements of ADS-B equipped aircraft) and the number of departure and arrival movements detailed in the ICAO Common Operations Database (COD). Based on a comparison between the study and the number of movements in the COD (extrapolated from 2015), it was estimated that globally, the percentage of movements covered by ADS-B surveillance was 68% with the following regional breakdown (Table 1). It should be emphasized that these figures do not represent the % of ADS-B equipped aircraft.

TABLE 1: Movements covered by ADS-B surveillance per ICAO region.

	per departure (%)	per arrival (%)
APAC	84	84
CAR	46	45
ESAF	41	41
EUR/NAT	85	85
MID	95	96
NAM	48	48
SAM	54	54
WACAF	35	36

CAVEATS AND QUALIFICATIONS

ICAO considers it important that the correct messages are passed with these results. Accordingly, the following paragraphs contain a few provisos that need to be taken into account when considering the findings detailed in the article above.

This study assessed global horizontal efficiency. HFE should not be confused with ATM efficiency as HFE may encompass inefficiencies driven by non-ATM factors such as safety, traffic demand, winds, and airspace availability. ICAO considers the HFE assessment as the first step in assessing global flight efficiency.

Since HFE in on-route airspace was estimated as relative to a theoretical optimum, routing restrictions that may have been applicable at the time of flight were not directly addressed. Such routing restrictions may include factors such as convective weather, constraints from other nearby airport flows, or air traffic flow measurement measures. ICAO also agrees with previous studies that state that the air traffic system will always require some latent inefficiency that is very difficult or impossible to remove, in order to enable the system to successfully function while capacity-driven inefficiencies may be embedded in the baseline.

It should be noted that limitations exist related to the use of minimum route lengths (great circle) as an indicator of fuel efficiency and CO_2 emissions. For example, flights across specific airspaces such as the North Atlantic, or between certain city pairs such as Australia and New Zealand, may benefit from wind-assisted routes. Consequently, with strong winds, particularly where jet streams exist, the most fuel-efficient route (i.e., shortest time) is often longer than the great circle distance. It is understood e that wind–assisted routes are more likely to occur in those airspaces where current ADS-B surveillance is not available and thus outside of the analysis. However, the level of analysis does not allow the isolation of only non-wind assisted routes.

In this analysis, there was a general assumption made that those flights equipped with ADS-B are representative of the efficiency of global movements. In addition, data gaps prevented this analysis from addressing any potential differences in HFE for the operations not using ADS-B surveillance, or in those parts of ICAO regions with insufficient ADS-B coverage. The average movement coverage across the ICAO regions ranged from 35% to 95%. Therefore, in regions with lower levels of ADS-B surveillance or equipped fleets, the results were based on a smaller dataset.

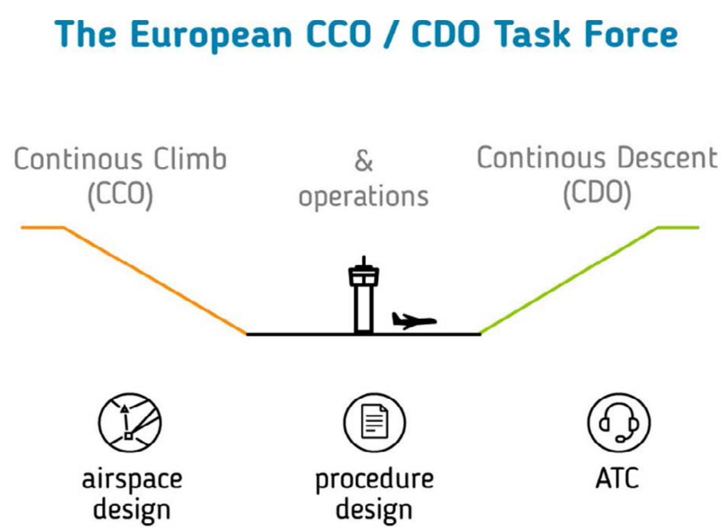
ICAO would like to emphasize that this study should be viewed as the first of a multi-step process on the path to identifying global flight efficiency. Further steps would also need to address such factors as: vertical flight efficiency, the relationship between HFE and VFE, efficiency in terminal airspaces and on airport surfaces around the world, as well as trying to fill those data gaps that were identified in this analysis.

It is recommended that global flight efficiency values be regularly updated. Future availability of global space-based ADS-B surveillance data may provide a source of global data that can support a regular update, or address some of these steps in the multi-step process. In addition, normalizing for demand growth and other non-ATM factors would be other additional steps that could be proposed to isolate benefit opportunities associated with future ATM improvements.

ICAO is currently following up on this study with an assessment of global vertical flight efficiency.

The Benefits Of CCO / CDO Operations – European Task Force Findings

By David Brain And Marylin Bastin



In 2019, ICAO's Committee on Aviation Environment Protection (CAEP) estimated that the planned implementation of the operational improvements detailed in the Aviation System Block Upgrade (ASBU) framework should provide an annual fuel savings of approximately 5.4 – 10.7Mt in 2025 (compared with 2015). In global fuel costs, these figures correspond to yearly fuel savings of up to €5.6 billion or $6.4 billion. In that study, CAEP also estimated that four ASBU modules (CDO, ASUR, TBO and CCO[1]) provide close to 60% of the higher range of fuel/CO_2 savings at the global level in 2025 compared with 2015. These findings are detailed elsewhere in this chapter in the article on *Global ASBU Environmental Benefits Assessment*.

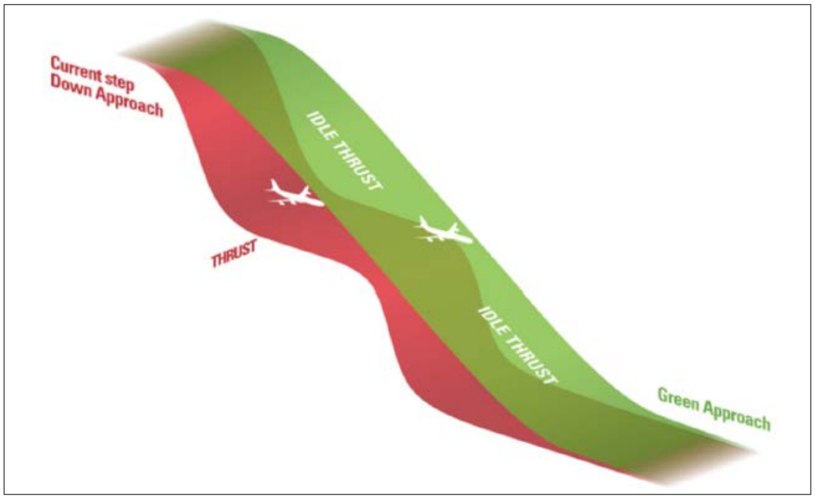
CCO AND CDO DEFINED

Continuous Climb Operations (CCO) and Continuous Descent Operations (CDO) are aircraft operating techniques that are enabled by airspace design and procedure design, and are facilitated by Air Traffic Control (ATC).

CCO and CDO are not new, they are essentially airplane pilot lessons numbers 1 and 2 – how to take-off and how to land. They are, in fact, the optimal climb and descent procedures to be followed in unrestricted airspace for all aircraft, from a 500 ton Airbus A380 to the smallest single seater light aircraft.

1 CDO – Continuous Descent Operations, ASUR - Alternative Surveillance, TBO - Trajectory-Based Operations, CCO - Continuous Climb Operations. ASBU Modules CCO and CDO also contain elements relating to PBN SID / STAR implementation in addition to continuous climb / descent operations

FIGURE 1: Optimal CDO approach (green) versus a non-optimal approach (red)



Not only do CCO and CDO allow aircraft to follow a flexible, optimum flight profile but, as they are flown with optimal fuel flow and in low drag configuration, they minimize fuel burn and fuel costs, while simultaneously cutting gaseous emissions and reducing noise. In addition, this can be done without any adverse effect on safety (see ICAO Doc 9993 and ICAO Doc 9931 respectively).

CDO and CCO operations, respectively, allow arriving or departing aircraft to descend or climb continuously, to the greatest extent possible. Aircraft applying CCO employ optimum climb engine thrust and climb speeds until reaching their cruising levels. With CDO, aircraft apply minimum engine thrust, ideally in a low drag configuration and from top of descent, prior to the final approach fix. With the removal of time flown level at inefficient intermediate altitudes, these techniques result in more time being spent at more fuel-efficient higher cruising levels, hence significantly reducing fuel burn and associated costs, and thus lowering emissions.

BENEFITS OF CCO AND CDO

Stakeholders have long recognized the environmental benefits associated with optimized CCO and CDO. All ATM stakeholder organizations (e.g., ICAO, CANSO, ACI, IATA, etc.) strongly support CCO-CDO and readily promote the benefits of such operational procedures. Across the industry, CCO and CDO have been described as: 'deployment baseline essentials', one of four 'global air navigation priority operational improvements', 'capabilities within our grasp', and 'ASBU Block 0 initiatives that are agreed priorities for States to act upon in both the short- and medium-term timeframe'.

EUROCONTROL, along with industry stakeholders, has championed CDO implementation publications over the years, including:

1. Flight efficiency plan, 2008.
2. CDA implementation guidance, 2009.
3. European Joint industry Action Plan, 2009.
4. A guide to implementing continuous descent, 2011.

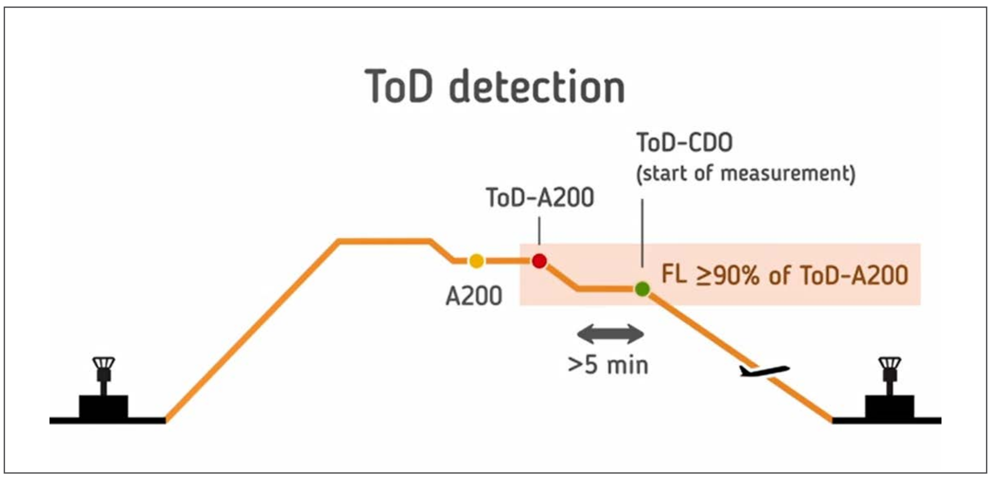
FREQUENCY OF CCO AND CDO FLIGHTS

Despite all of that industry support, in 2015, four years after the publication of the last of these reports (2011), it was still not possible to know how many CCO and CDO operations are actually flown worldwide.

This was because CCO and CDO have traditionally been measured at the local level based on definitions, hours of operation, and ways of measurement etc. which differ according to local stakeholder needs. However, the benefits of CCO and CDO implementation have never been addressed at the network level so the overall performance benefit was unknown.

FIGURE 2: Previous European support to CDO implementation

FIGURE 3: Screenshot from the European CCO-CDO Task Force animation on the harmonized definitions, metrics and parameters for measurement of CCO-CDO



In 2015, EUROCONTROL set up the European CCO-CDO Task Force to solve this issue and developed a set of harmonized CCO-CDO definitions, metrics, and parameters for measuring CCO- CDO, as agreed by stakeholders. These include harmonized definitions of both a fuel CCO-CDO (to top of climb or from top of descent, respectively), and a noise CCO-CDO (from FL75 or to FL105, respectively) lower levels where noise is the primary environmental impact.

The Task Force developed a webpage and animation[2] that details the outcomes of these stakeholder agreed definitions.

All Stakeholders are being encouraged to use the harmonized definitions and parameters of the Task Force when measuring CCO-CDO, especially when measurements are presented at the international level in order to allow for a harmonized comparison of performance.

Based on these standardized definitions and parameters for measurement, an ECAC[3]-wide CCO-CDO study was undertaken by EUROCONTROL in 2018 (see Figure 4 and Figure 5).

2 https://www.youtube.com/watch?v=mUkMPb5eVJI

3 ECAC – European Civil Aviation Conference: Albania, Armenia, Austria, Azerbaijan, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Georgia, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Moldova, Monaco, Montenegro, Netherlands, Norway, Poland, Portugal, Romania, San Marino, Serbia, Slovakia, S lovenia, Spain, Sweden, Switzerland, the Republic of North Macedonia, Turkey, Ukraine and United Kingdom.

FIGURE 4: Average time in level flight for low level CCO-CDO (noise CCO-CDO) for European airports in 2017

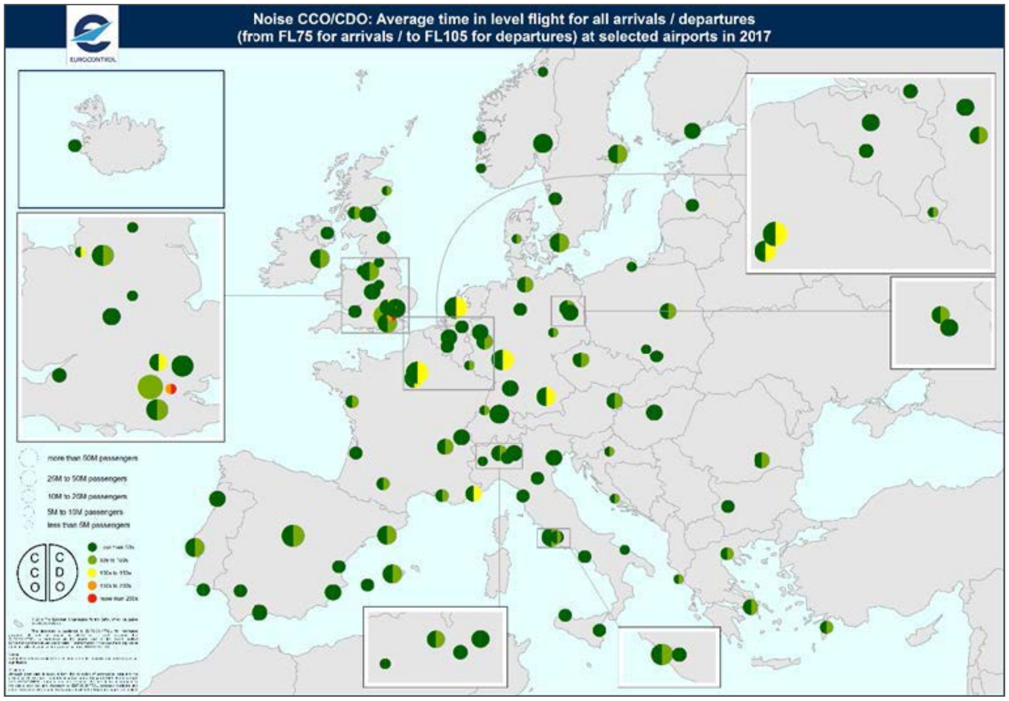
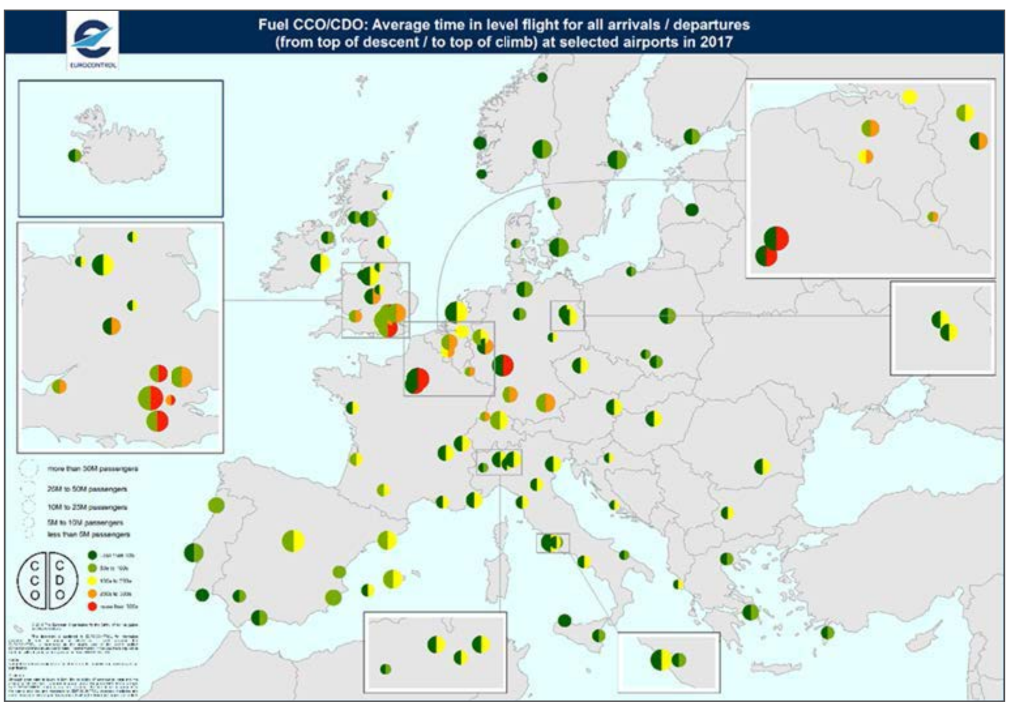


FIGURE 5: Average time in level flight for CCO to top of climb and CDO from top of descent (fuel CCO-CDO) for European airports in 2017



The results of this study revealed that the benefit pool of optimizing CCO-CDO in Europe could result in fuel savings of up to 340,000 tons of fuel per year for the airlines (>1m tons of CO_2) or about 150 million €[4] in monetary savings (see Figure 6).

The main conclusions were:

- There are significant environmental savings that optimized CCO-CDO can provide.
- The amount of time flown level (a proxy for inefficiency) and consequently the amount of fuel savings available from optimizing the descent phase (CDO) is significantly larger (about x10) than the time flown level in the climb phase (CCO); therefore the greatest fuel saving benefits should be realized by optimizing CDO.
- The pool of potential performance improvements is much larger for the fuel CDO (CDO from top of descent) compared with low level (noise) CDO, with the majority of airports having only minor performance benefits available; therefore the focus of performance improvement should be to optimize CDO from top of descent or higher levels wherever possible.

EUROPEAN RESPONSE

The European CCO / CDO Task Force is looking for a step change in the implementation of CCO and CDO in Europe and is developing a CCO / CDO tool kit to support stakeholders in implementation. This tool kit consists of three main elements:

1. An *updated* CCO / CDO Action Plan.
2. A *new* CCO / CDO 'State of Play' Report.
3. Resources (e.g., training material, best practices, guidance material, implementation support, etc.) to enable stakeholders to implement and optimize CCO / CDO procedures – these will all be available in the Task Force webpages.

FIGURE 6: Total benefit pool from optimizing CCO-CDO in ECAC

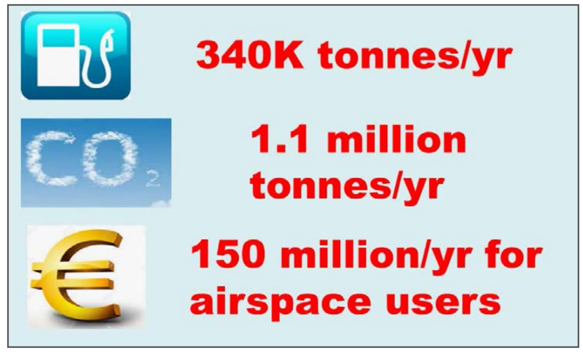


FIGURE 7: The 2019 Joint Industry CCO / CDO Action Plan

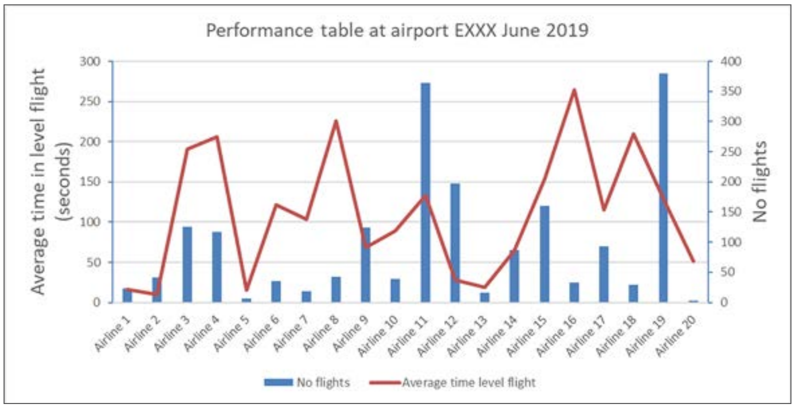
FIGURE 8: The NEW CCO / CDO State of Play Report

The updated 2019 CCO / CDO Action Plan is being developed by the European CCO / CDO Task Force and calls for a step change in the facilitation, promotion, and implementation of CCO / CDO so that the significant noise, emission, and fuel cost benefits of these procedures can be realized by stakeholders. The Action Plan introduces and promotes a set of actions that support CCO / CDO implementation across Europe.

The new CCO / CDO 'State of Play' Report is a supporting document to the CCO / CDO Action Plan. The report addresses interdependencies and the sharing of responsibilities, and also provides case studies of, and mitigations for, the contributory factors that limit optimized CCO / CDO in European Airspace. The 'State

4 Not all of the benefit pool is recoverable as the need to maintain safety and take into account capacity, cost efficiency and environmental impacts will result in non-optimal profiles for some flights and to a certain level of inherent inefficiency. The key is to minimise these inefficiencies to the extent possible.

FIGURE 9: Example of a monthly airport performance table with basic functionality



of Play' report has been described as an enabler to better understand, evaluate and optimize CCO / CDO performance.

The tool kit resources will support stakeholders to implement and optimize CCO / CDO procedures and will include the following:

- As the 'Hawthorne effect'[5] has been demonstrated by NATS to improve CDO performance, EUROCONTROL will deliver monthly performance tables on CCO and CDO for all airports and airlines operating in Europe, together with support for analyzing data. The tables will be based on the harmonized European definitions of CCO / CDO and will allow performance comparisons for an airline at different airports or across all airlines at a single airport. The basic information in the performance tables will be monthly CDO figures from top of descent for the airport/airline selected. Enhanced data sets and functionalities will include the option to slice/aggregate data by aircraft type, country, alliance, type of flight, CCO / CDO, level band, time of analysis, etc. with multiple charting possibilities.

- ATCO (Air Traffic Control Officer) refresher training. The European ATCO Common Core Content (CCC) training material has been updated by:
  - Updating the content to include mandatory content on CCO.
  - Updating CDO Objectives to ensure more ATCO training simulation exercises are spent on CDO.
  - Introducing a specific new objective for ATCO training on aircraft energy management.

In addition, the EUROCONTROL training institute, will create a refresher training module for ATCOs on aircraft energy management in collaboration with the Task Force, based on best practice training material. This will be available to all European ANSPs, and aims to provide feedback to ATCOs on the impact of the provision of ATCO instructions on aircraft and pilot behavior. Sharing specific scenarios and encouraging ATCO/pilot interactions will support the optimization of CCO and CDO.

- The Task Force is currently reviewing the European Route Network Improvement Plan (ERNIP) with the aim of ensuring that:
  - CCO / CDOs are integrated into the airspace design process.
  - The main principles of airspace and procedure design that enable CCO / CDO are detailed.
  - There are links to resources in the plan that can provide support to airspace designers from the CCO / CDO point of view.

The proposals will reinforce the message that CDO should be optimized from the highest levels where possible,

5 The Hawthorne effect is a type of reactivity in which individuals modify an aspect of their behaviour in response to their awareness of being observed.

FIGURE 10: Example of ATCO training material on energy management

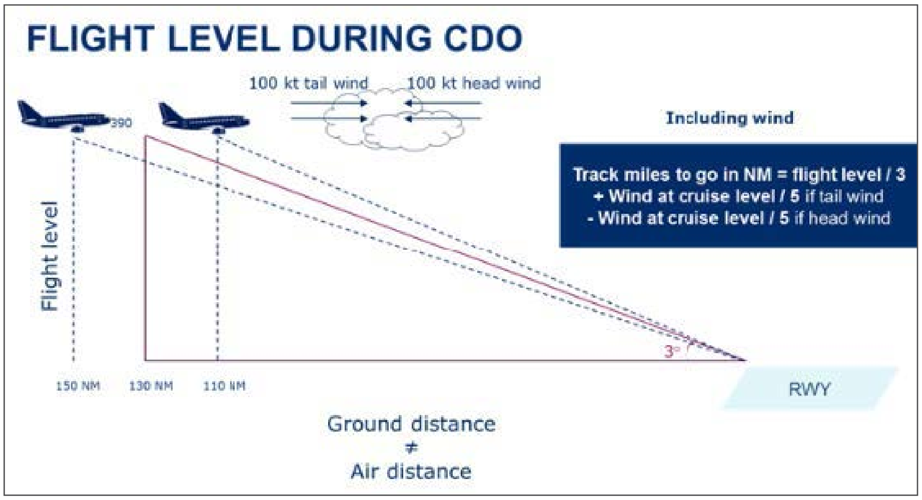


FIGURE 11: ERNIP Plan

together with the requirement to regularly review the individual transfer of control rules between airspace sectors and the consideration of flexible LoAs[6]. The Task Force is also collaborating with stakeholders on airspace change proposals to identify where airspace and procedure design best practices could be incorporated into the airspace change process to develop some fully optimized CDO-enabled airspace changes.

- Harmonized AIP content on CDO – The Task Force has reviewed the AIPs of the top 100 European airports, identifying good practices that promote CDO implementation. AIP information supporting CDO implementation is currently very fragmented. The Task Force, through collaboration with airlines, airports, ANSPs and Computer Flight Plan Software Providers (CFSPs), will develop some harmonized generic structure and content proposals for AIP CDO supporting information. These will be based on best practices identified by the Task Force. The objective is to ensure that airspace users know exactly where to find CDO supporting documentation, thereby eliminating the fragmentation of information.

- Promoting airline best practices - The Task Force recently undertook an airline questionnaire on CCO / CDO. More than 120 responses from 59 different airlines including: 25 European national carriers, 18 of the 20 top European airlines in terms of passengers flown, and the top 5 Low Cost Carriers. The Task Force will be promoting the following best practices:
  - Airline Standard Operating Practices (SOPs) on CDO – only one third of the respondent airlines have SOPs on CDO. The Task Force aims to work with and encourage industry to adopt such best practice SOPs as they reinforce the noise and fuel efficiency benefits and provide support to the pilots in flying optimized CDO techniques.
  - CCO / CDO training for pilots - less than 50% of the airlines surveyed have refresher training in the simulator that includes CCO / CDO operations and techniques. Even fewer airlines use similar material for ab-initio, base and type-rating training. Considering it is the airlines (through pilots flying technique) that may be rewarded with the potential huge performance and fuel-saving benefits, it is a matter for concern just how low this figure is. The Task Force aims to support the airline industry and pilot associations to ensure that, not only is training on CCO / CDO techniques kept high on the airlines agenda, but in addition, that the best practices of existing pilot training material are shared and incorporated into airline

6 Letters of Agreement - negotiated handover conditions between sectors /ATC centres

FIGURE 12: Airlines responding to the Task Force questionnaire 2019

training plans. The European CCO / CDO Task Force promotes the inclusion of CDO as a best practice in both airline initial line-training and conversion-training. This will ensure that a 'CDO mentality' is engrained in the pilot from day one.

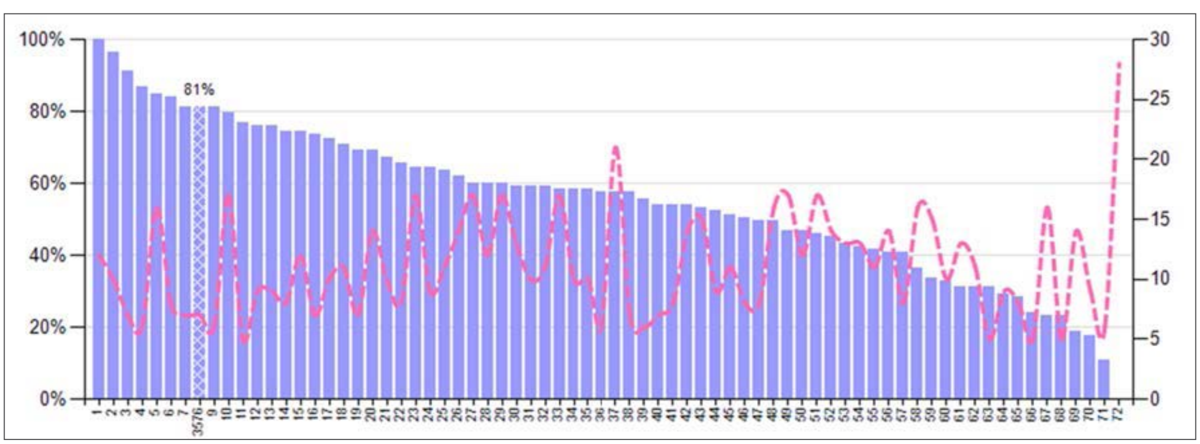
- Airline and pilot CDO performance measurement and performance feedback – The Task Force believes that measuring CCO/CDO performance is an enabler to improve performance at airline or pilot level. In such conditions: optimized techniques can be shared, pilots uncertain of CDO techniques can receive extra training, and a healthy performance 'competition' helps to improve overall performance.
- **Better understanding of the benefits of CCO and CDO.** The airline survey found that less than 30% of airlines measure their CCO / CDO performance let alone individual aircraft/ pilot performance. Many airlines leave it up to individual airports (e.g., London Heathrow) where such performance is measured, to inform them of their performance. There needs to be a step change in the understanding and promulgation of what benefits CCO and CDO can provide to the airline.

- Future concepts - The Task Force is also following emerging concepts that could enable more CDO or optimize current performance levels. This includes identifying parameters for 4D trajectory downlink data to optimize CDO such as the transmission of accurate top of descent position data from aircraft to ATC. The Task Force is also working with stakeholders to identify future sources of data such as Quick Access Recorder (QAR) data that could be used to provide actual fuel burn data for the measurement for CCO / CDO performance.

The Task Force ensures that active collaboration with industry stakeholders is maintained. ; Without the support of these stakeholders, a step change in CDO implementation will not be possible. Given the challenges ahead with traffic growth and short term capacity constraints, the improvements in CCO / CDO performance will not be possible without stakeholder support. It is an ongoing and long term objective.

For more information contact cdo@eurocontrol.int or visit https://www.eurocontrol.int/concept/continuous-climb-and-descent-operations

FIGURE 13: An example of best practice airline CDO performance measurement and feedback to pilots (Wizzair)



Redistribution of Necessary Delay in the US National Airspace System: Benefits from Trajectory-based Operations

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ABSTRACT

"Necessary delay" is the airborne delay imposed on aircraft for maintaining safety and maximizing throughput under unpredictable changes in operating conditions and arrival times. Through experimentations with three years of surveillance data inputs (2016-2018) for 41 key airports in the Continental US, the FAA has developed a standardized methodology for evaluating necessary delay that is currently absorbed in the National Airspace System (NAS). This methodology focuses on aircraft delays during periods when demand exceeds capacity in terminal areas around the NAS, and considers external, non-Air Traffic Management (ATM) factors that also contribute to the necessary delays, including occurrence of convective weather en route, airport meteorological conditions, and equipment outages. The methodology has been used to estimate benefit opportunities from Trajectory-based Operations (TBO) by determining the amount of delay and fuel burn that is currently absorbed in terminal areas, but could be redistributed to an upstream and more cost efficient phase of flight by using TBO tools. In 2018, about 11 per cent of arrivals to the 41 key airports in the US could have derived benefit from delay redistribution, with average fuel savings between 40kg and 245kg per flight. Notably, most delay redistribution is manageable with speed control adjustments. Only three per cent of flights require either en route lateral extensions or ground delay before take-off.

This analysis presents an important example of environmental benefit opportunities from ATM improvements. While smaller in magnitude compared to those from improved technology and alternative fuels, ATM improvements can yield significant environmental improvements as well. The initial investigation focuses on benefits opportunities that are possible under the same efficiency of using the existing airport capacities, and excludes analysis of benefit opportunities during periods with convective weather and better routing options. The FAA will continue to work on both advancing the TBO concept and refining the assessment of the corresponding benefit opportunities.

Introduction

Stakeholders of the US Federal Aviation Administration (FAA), including airlines, US Congress, and the Office of Management and Budget, continue to demand realistic benefit estimates associated with new programs, technologies, and procedures. Enhancements in underlying historical aircraft trajectory data and analysis techniques now make it possible to generate much more realistic estimates of efficiency improvement opportunities in all phases of flight (see Figure 1).

This paper presents a new methodology for empirically estimating necessary delay. The methodology was used to evaluate such delay for arrivals to 41 key airports in the NAS, determine the amount of the delay that could potentially be redistributed by Trajectory-based Operations (TBO), and estimate the fuel savings associated with this more efficient delay absorption.

Necessary delay is the airborne delay that needs to be absorbed by aircraft to maintain safety and maximize throughput under unpredictable changes in schedules and operational conditions. It may not be possible to reduce the necessary delay in magnitude or in cost through improvements in NAS operational efficiency. TBO's potential impact in variable conditions such as convective weather, winds driving a configuration change at the airport, or unpredictable changes in visibility are not addressed with the analytical method described here. This method focuses on underlying inefficiencies caused by demand for services that exceed capacity of the NAS resources, and improvements enabled by air traffic management (ATM) solutions This paper also discusses some key considerations that need to be addressed when translating efficiency improvement opportunities into benefits, such as the contribution of non-ATM factors, including air traffic demand and performance in convective weather.

As a NextGen ATM method for strategically planning and managing flights in the NAS, TBO builds on advanced time-based management (TBM) tools and performance based navigation (PBN) infrastructure, integrates decision-making across domains and systems, and optimizes delivery of aircraft into terminal areas. With more accurate delivery of aircraft into terminal airspace, TBO pushes delays that are currently absorbed in low altitude airspace during busy periods further back, resulting in delays of the same magnitude but lower cost. With new trajectory management tools both in the terminal and en route control facilities, TBO maintains the same level of runway throughput and moves the necessary delay to en route airspace.

Under TBO, decision support tools help controllers with managing converging and diverging aircraft flows through control points. Ground Interval Management – (GIM-S) aids with improving accuracy of meeting scheduled arrival times to the terminal area boundary by suggesting speed adjustments between the extended freeze horizon and arrival meter fix. When speed advisories alone prove insufficient, the Path Stretch tool provides lateral path extensions or shortenings that may be needed for aircraft to meet metering schedules. In addition, En Route Departure Capability (EDC) aids with reserving a spot in an en route flow to a constrained destination, while Integrated Departure and Arrival Capability (IDAC) helps with integration of departures into the overhead flows above departure airports. All of these tools alleviate the need for vectoring in terminal airspace, resulting in a reduction of overall fuel burn while achieving overall equivalent flight times.

FIGURE 1: Phases of Flight

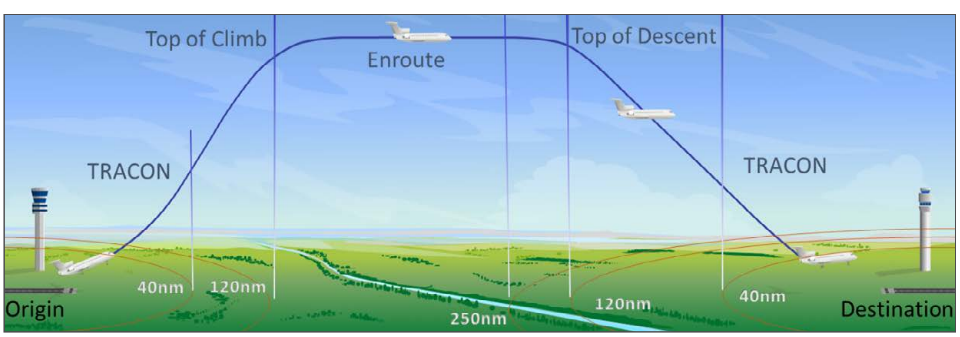
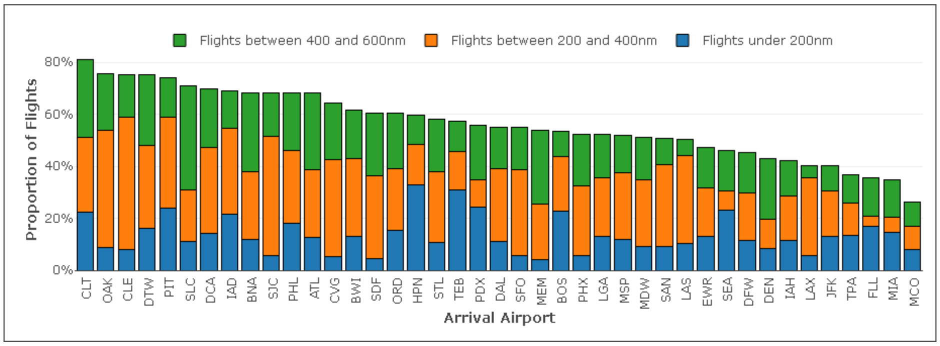


FIGURE 2: Distribution of Arrivals by Great-circle Distance between Origin and Destination



Initial Trajectory-Based Operations (iTBO) is the first phase of TBO that focuses on site-specific deliveries of new capabilities between 2018 and 2023, and on integration of new and legacy capabilities to achieve TBO objectives. Full TBO will complete the development and deployment of TBO capabilities through the end of 2025, and is applicable to all phases of flight. Dynamic TBO includes capabilities that are in the research and development phase that would provide flight-specific TBO capabilities through the end of 2030, which may enable dynamic optimization.

This research touches upon work in four main areas: surveillance data cleaning, flight efficiency, delay redistribution, and fuel efficiency.

Surveillance Data Cleaning

A significant number of runway assignments in the data were either missing or did not align well with actual flight trajectories when plotted. Runway assignments are an important part of our methodology for assessing flight inefficiency; therefore, it was necessary to develop an algorithm for accurate runway assignments. As in Szurgyi[1], arrival runways were determined by comparing the final flight coordinate to a radius around the airport. Classification was performed by extending the runway centerline to the radius around the airport and determining if the flight was within a certain tolerance. At airports with crossing runways, the radial crossing points were sometimes very close, resulting in inaccurate runway assignments. To resolve this, the radius was gradually increased until the radial points from non-parallel runways were far enough apart to allow accurate determination of the runway assignments.

Flight Efficiency

In order to redistribute necessary delay to a more cost efficient phase of flight, the amount of necessary delay at each airport first had to be identified. Over the years, many researchers, including CANSO[2], Kettunen, et al.[3], Knorr, et al.[4], and Gouldey[5], have studied this topic. This study is similar to Gouldey[5], but the approach to defining flows differs slightly, including: corner posts are defined by clustering flight tracks, parallel runway groups are used, and aircraft are not grouped by category. The definition of necessary delay that was used in this study is based on distance flown above the 15th percentile for each flow, rather than 105% of the median track distance (as in Gouldey[5]). Knorr's[4] approach was used to extend the definition of necessary delay, and also to assess vertical inefficiency by determining necessary level-flight, or the amount of level distance that exceeds the 15th percentile of distance in level flight for like-flights.

Delay Redistribution

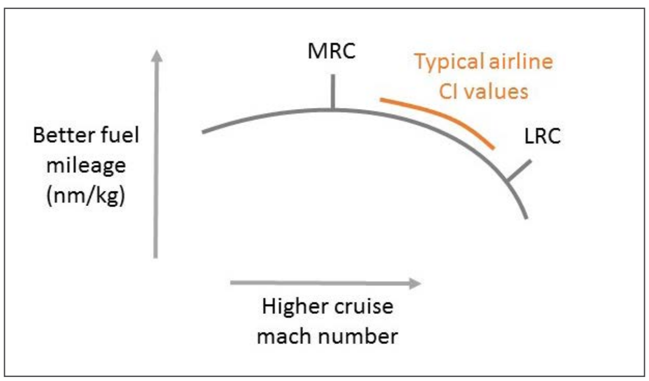
Using speed control en route to achieve fuel savings has been previously studied by Jones et al.[7], Knorr et al.[4], and Xu[8]. In this study, necessary delay, and necessary delay in level-flight, were both used to determine how much horizontal and vertical inefficiency can be moved from the terminal area altitudes to cruise flight by reducing cruise speed while maintaining a more efficient fuel burn rate at the higher altitudes. When combined with reduced speed, the fuel benefit is realized by both removing the low level excess flight distance/time and saving fuel by flying a little slower en route.

Fuel Efficiency

Airlines use Cost Index (CI) – a ratio between the unit cost of time and the unit cost of fuel – to optimize the speed of an aircraft. There are two theoretical speed options for the cruise phase of flight, maximum-range cruise (MRC) speed and the long-range cruise (LRC) speed. With the CI of zero, the MRC speed provides the farthest distance and aircraft can reach with a given amount of fuel. The LRC speed is typically 3-5 per cent higher, and requires about 1 per cent higher fuel consumption (see Figure 3). Airlines typically fly at speeds faster than that of the CI zero; while this may be inefficient in terms of fuel burn, business decisions sometimes require prioritization of time over the cost of fuel. Research into fuel efficiency, such as Folse[6], helped determine limits to speed reduction in cruise to avoid unrealistic increases in fuel burn due to slower cruise speeds when absorbing redistributed time.

STANDARDIZED METHODOLOGY

FIGURE 3: The Relationship between MRC and LRC Speeds



FOR ESTIMATING EFFICIENCY IMPROVEMENT OPPORTUNITIES FOR ARRIVALS

Lateral and vertical efficiency improvement opportunities exist in cases when a flight's actual distance, time and altitude can be better aligned with those of its optimal ground track and vertical profiles. However, efficiency of a flight between the same origin and destination airports can vary greatly with operating conditions including meteorological conditions, en route weather, airspace closures, route availability, and traffic demand levels. Even when evaluated over just a limited segment such as within a terminal area, flight efficiency of aircraft arriving via the same corner post may still greatly vary with demand level runway configuration at the destination at the time of arrival, as well as with demand levels and runway configuration at the nearby-airports.

As a result, optimal trajectory is not a static construct for flights between the same origin and destination, but a variable one and highly dependent on many ATM and non-ATM factors. Moreover, while optimal distance, time and altitude may be known to the aircraft operator or the service provider at the time of operation, they are not recorded in empirical data archives, and need to be estimated for post-operational assessments. Therefore, the study methodology started by investigating flight parameters, applicable operating conditions, and geometries of flown trajectories, to properly categorize aircraft into groups of like-flights. Optimum distance and distance in level-flight are then estimated for each group of like-flights as an *achievable* distance, and distance in level-flight to the runway, respectively. Since it is based on historical inputs, this achievable optimum is not a theoretical but an empirical estimate that is truly achievable in the applicable airspace, and that incorporates restrictions as applicable to the corresponding group of like flights.

Empirical Data for Evaluation of Flight Performance

Cleaning and merging of the terminal area and en route surveillance data is a key component of successful evaluation of empirical trajectories, and estimation of achievable unimpeded paths and the benefit potential for improved operations. Additionally, complex analysis of empirical trajectories is necessary to overcome gaps in archived data, such as runways aircraft used to take off from, or land at, their origin and destination airports.

Also, since this analysis focused on improvement opportunities in nominal conditions, flights conducted during periods with convective weather were filtered out, as were flights delayed by "airport turning" – significant changes in runway configuration that happened within 30 minutes before their actual landing. Note that historical data is stored in quarter-hour time bins, hence the actual configuration change could have occurred in a 16-44 minute window prior to landing. Future analysis will focus on convection and potential improved use of available airspace and airport resources with advanced tools.

The methodology used started with dissecting each empirical trajectory into portions flown within 40nm, and between 40nm and 120nm of both the origin and destination airports. This made it possible to roughly capture the segments flown in terminal areas, and segments applicable to the climb and descent phase of flight. To provide for capturing segments applicable to sequencing and merging before descent and approach, it was necessary to analyze portions of empirical trajectories that were flown between 120nm and 250nm of their destinations. These values – 40, 120 and 250 nautical miles – are somewhat arbitrary, but they provide a good set of values that are standardized across the 41 key airports in the NAS. This allowed for consistent evaluation of the intended segments and the corresponding aircraft performance.

Optimal Horizontal Profiles

For each of the segments flown within 250nm of each arrival airport, flights were categorized into like-flight groups (i.e. those that share the same geometries of actual trajectories), and then study distribution of actual distances flown by each group. For a NAS-wide study that includes flights with significantly different characteristics, using the 15th percentile of actual distance flown assures a reasonable threshold of optimality that has been empirically derived. While the 15th percentile is somewhat arbitrary, it does represent a set of feasible, empirically-confirmed trajectories (see Figure 4). This is illustrated as the red trajectories shown in Figure 5**;** a set of empirical trajectories of optimal length for this group of like-flights.

Aircraft that flew shorter distance than the 15th percentile determined for their corresponding like-flights are considered as efficient as they can possibly be. Efficiency improvement opportunities for the remaining flights are evaluated as the difference between their individual actual distance, and the 15th percentile determined for the like-flight group. Knowing that air navigation service providers strive to provide the most efficient service possible, that may only be second to safety, this improvement opportunity can also be referred to as the necessary delay, or the delay that was necessary to absorb in order to assure safe sequencing and merging of otherwise unrestricted traffic flows. In other words, by evaluating improvement potential relative to an unimpeded distance that was established through historical records, the analysis effectively accounted for the most significant contributors to inefficiency that occur often enough that they cannot be easily eliminated.

FIGURE 4: Example Distribution of Actual Distance for Arrivals at Philadelphia Airport, RWY 27L/R via HOGEY (SW corner post)

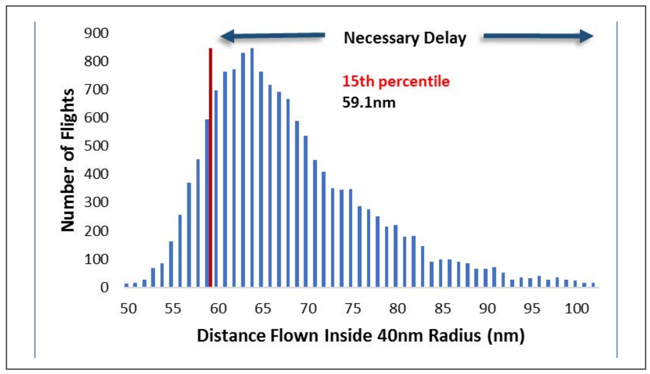
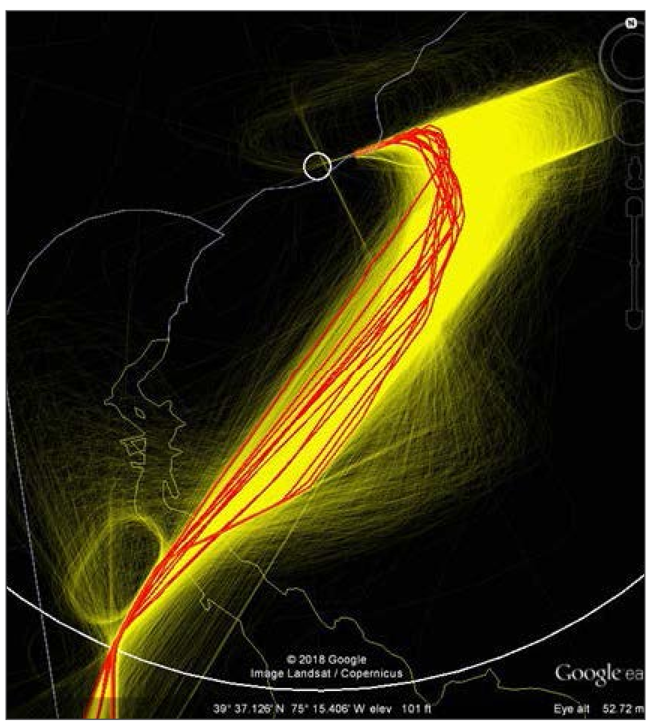


FIGURE 5: An Example of Empirical Trajectories for Arrivals to PHL, RWY 27L/R via HOGEY (SW corner post)

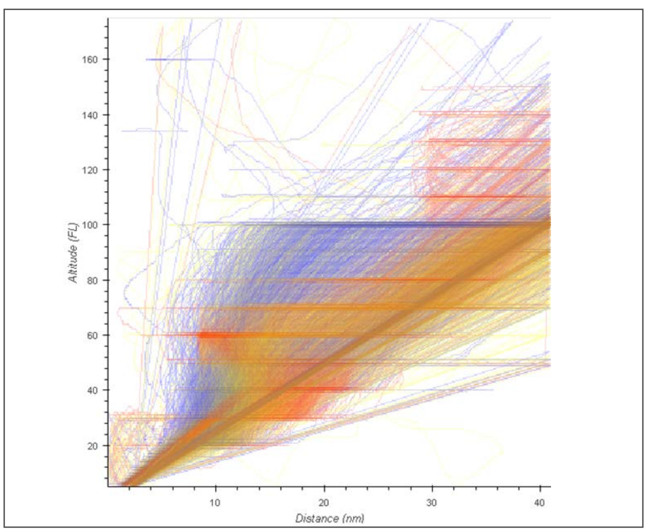


Clearly, a different set of optimal distances and paths would have to be identified for improvements that would enable significant changes in currently flown trajectories. For improvements that rely on the same or similar underlying network of routes, procedures, and fixes, this approach offers realistic and easily customizable thresholds of optimality that are derived from, and validated with empirical records.

Optimal Vertical Profiles

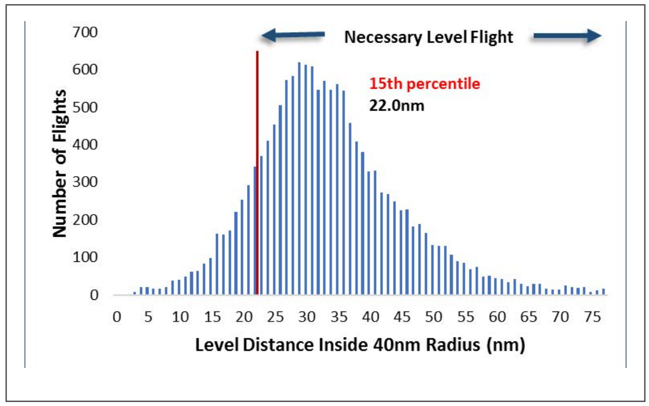
Since improved metering adherence with TBO tools is expected to increase the use of optimal profile descent procedures, the analysis looked for opportunities to improve vertical profiles as well. For example, arrivals from the southwest corner post to PHL 27L/R fly significantly different horizontal profiles (see Figure 5). Likewise, the vertical profiles of these trajectories are also significantly different (see Figure 6); some of these approaches are continuous descents, but most of the trajectories will experience some degree of level flight.

FIGURE 6: Example of Vertical Profiles for Arrivals at Philadelphia Airport, RWY 27L/R via HOGEY (SW corner post)



Similar to the optimal lateral profile, an actual optimal vertical profile is driven by many ATM and non-ATM factors, such as de-confliction of air traffic flow and demand levels, respectively; however, neither the underlying factors nor the optimal profiles are recorded in empirical data archives. Therefore, the same empirical approach to estimate vertical flight efficiency was applied as was used

FIGURE 7: Variance in Empirical Trajectories within Terminal Airspace of PHL for Flights Arriving via HOGEY and Landing on RWY 27L/R during High and Low Demand Levels in 2016



to estimate lateral efficiency—the 15th percentile of actual distance flown in level flight within 40nm of destination (see Figure 7).

It is important to note that, ideally, an aircraft wants to descend without any level-off segments below top of descent. However, interactions between air traffic flow and corresponding procedural restrictions may require aircraft to level-off to remain above departing flows. The empirically derived optimal value prevents overestimating benefit opportunities by allowing some level-offs, as applicable and observed for each like-flight group at each airport.

For the purpose of this assessment, it was assumed that a continuous descent is equivalent to no level-offs longer than 50 seconds inside the arrival terminal area. Additionally, the analysis focused on opportunities to alleviate level-offs below top of descent, which typically happen around 120nm from destination airports.

Non-ATM Factors Contributing to Flight Inefficiency

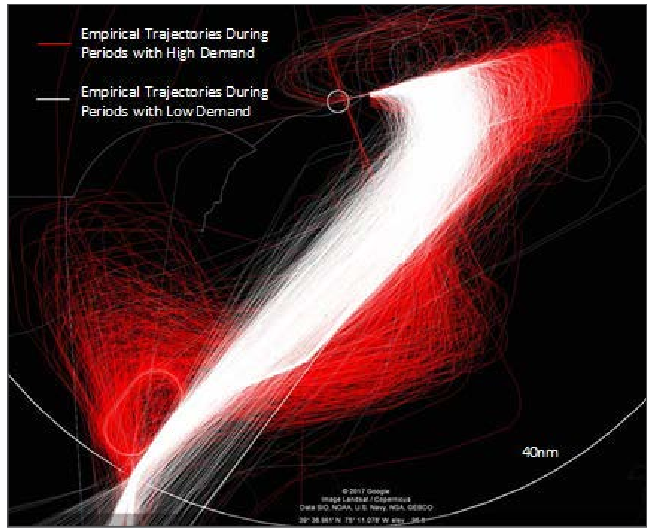
Necessary delays currently observed in the NAS are not equivalent to benefit opportunities. Some of these delays are driven by other significant factors outside of ATM influence, such as demand and meteorological conditions at an airport.

Failure to address non-ATM contributions to necessary delays may result in erroneous perceptions of benefit opportunities. For instance, inefficiency in the form of significant vectoring in terminal airspace and long downwinds on approach can be significantly higher during periods with high demand (see Figure 8). On average, throughout the NAS from 2016 to 2018, when compared to periods with high demand, necessary delay was 33% lower during medium demand, and about 50% lower during low demand.

However, unless an ATM improvement can help by increasing the capacity of the system, or by more efficient use of the existing capacity, the improvement may not be able to alleviate this excess vectoring under the same demand levels. At best, with improved awareness of aircraft positions, aircraft speed management and traffic flow metering algorithms, these delays may be shifted upstream where they are more cost efficient, as they would be absorbed at higher altitudes. However, this type of benefit stems from likely reduction in the cost-of-delay rather than in the magnitude of the delay itself.

On the other hand, benefit opportunities can also be easily overstated if one assumes that ATM improvements may improve operations to the point of aircraft behavior observed during periods with low demand also becoming possible during periods of high demand. Direct-to-clearances are often executed in the NAS during periods of low demand (see Figure 9). These are clearly visible as frequent "corner-cutting" that results in a greater

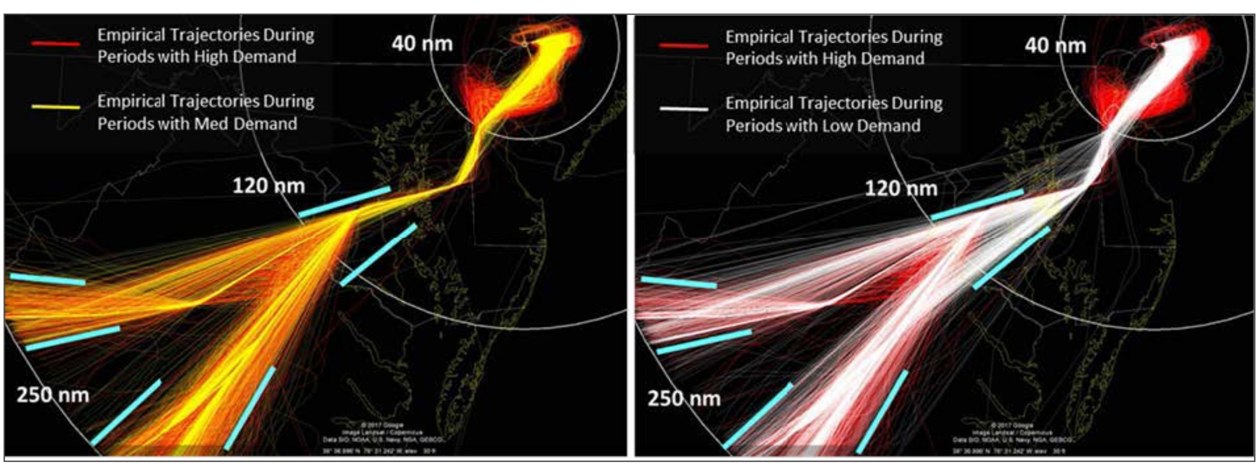
FIGURE 8: Example Distribution of Actual Level Distance for Arrivals to PHL, RWY 27L/R via HOGEY (SW corner post)



variance in empirical trajectories within about 120nm of destination during low demand levels, and therefore shorter overall distances. Also, longer trajectories along predefined standardized arrival procedures are typically flown during periods with higher demand (i.e., clearly outlined by the tight variance in empirical trajectories executed during high and medium demand levels). In addition, similarity in aircraft behavior on descent and approach during periods of medium and high demand may even be greater at other airports.

Hartsfield–Jackson Atlanta International Airport (ATL) is currently one of the most successful users of time-based

FIGURE 9: Variance in Empirical Trajectories within 120nm of PHL for Flights Arriving via HOGEY and Landing on RWY 27L/R during Different Demand Levels in 2016



metering in the US. For instance, there is very little difference in actual trajectories during medium (yellow) and high (red) demand, resulting in a sea of orange with only a few red segments, indicating heavier vectoring and longer down-winds in high demand periods (see Figure 10). Such "predictability" of flown tracks is necessary for the existing metering algorithms to produce a feasible metering schedule. During low (blue) demand periods, evidence of shortcuts exists.

FIGURE 10: Variance in Empirical Trajectories for Arrivals to ATL via NW Corner Post during West Airport Flow and for Different Demand Levels in 2016

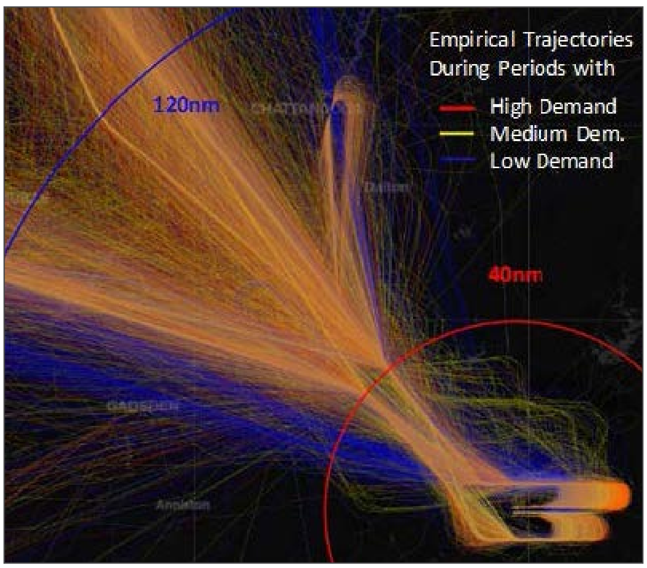
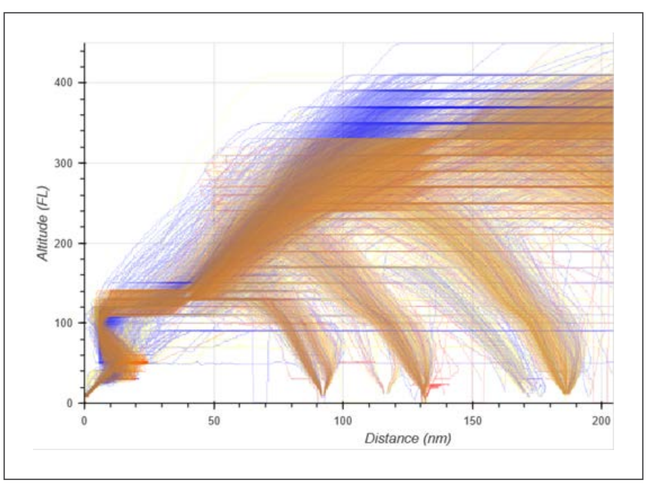


FIGURE 11: Variance in Vertical Profiles of Empirical Trajectories for Flights Arriving to ATL via NW Corner Post during West Airport Flow and for Different Demand Levels in 2016



The vertical profiles tell a similar story (see Figure 11). Again, very similar behavior can be seen during both high and medium pressure periods, while during low demand periods, aircraft remain at a higher altitude for a longer time, and initiate their descents closer to their destinations.

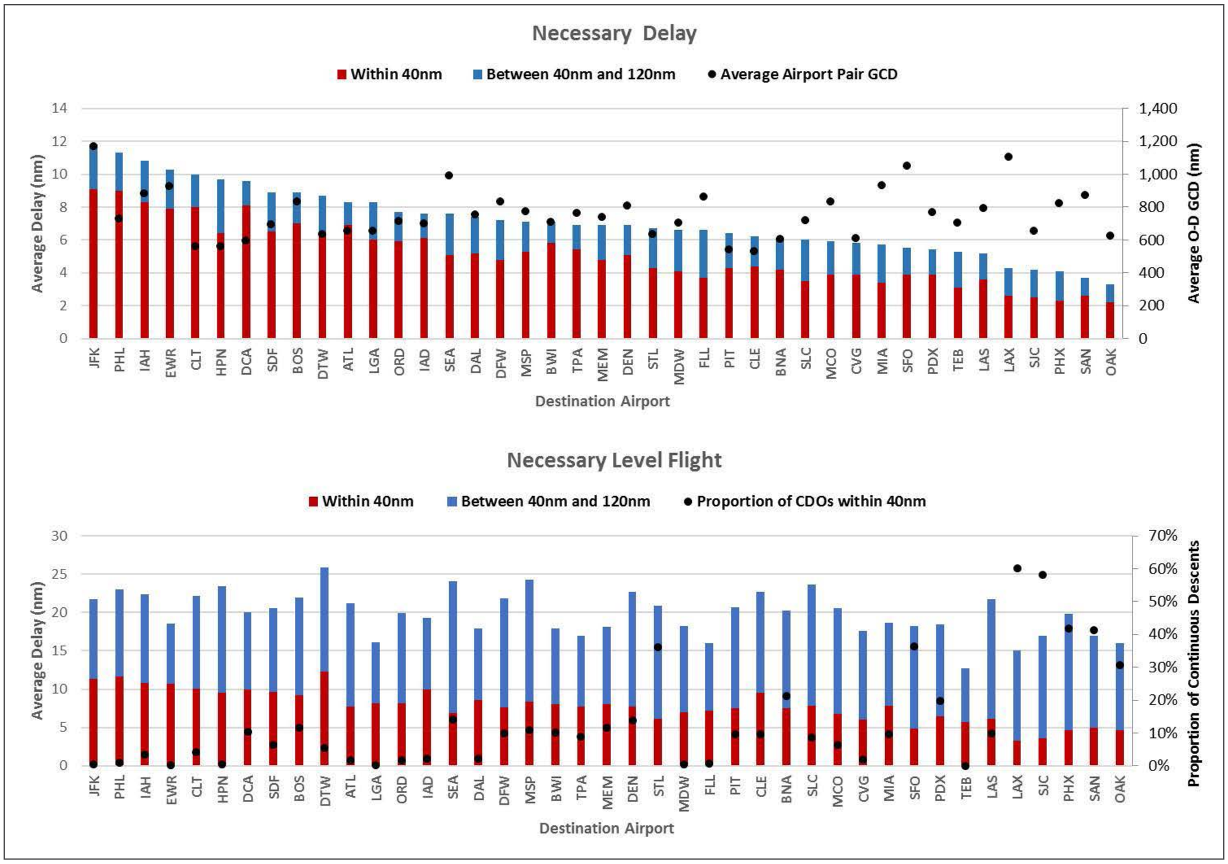
There are two very important points highlighted by the above examples. First, conformance to published procedures sometimes results in longer actual distances; however, as demand builds up, that firm structure, and even the "extra distance", are quite necessary to maintain safe merging and spacing, especially in areas with limited airspace or significant flow interactions. Second, as new ATM solutions are considered for implementation, a great effort must be made to preserve efficiencies that are currently possible because of controller flexibility and the ability to react quickly in the moment. This may translate into a requirement for self-adaptive automation that adjusts to demand and other operational conditions, or for a simpler set of business rules for proper timing of automation use. Either way, further investigations are very much needed to better understand the pros and cons of both of these approaches.

CURRENT NECESSSARY DELAYS IN THE NAS

On average, necessary delay that is currently being absorbed in terminal areas around the 41 key airports in the NAS varies between 2.2 and 9.1nm, and necessary distance in level-flight varies between 3.3 and 12.3nm (see Figure 12). An additional 1.1 to 3.3nm of necessary delay and 7.0 to 17.2nm in distance in level-flight are absorbed between 40 and 120nm of destination.

Airports in the northeast corridor of the US, lead both in terms of average and total necessary delays and distances in level-flight. The highest average delays are observed at George Bush Intercontinental Airport (IAH), Charlotte Douglas International Airport (CLT), Westchester County White Plains Airport (HPN), and Ronald Reagan Washington National Airport (DCA). Total necessary delay and distance in level-flight, however, are the highest at Chicago and Atlanta, driven by the significantly higher operation counts at these two locations.

FIGURE 12: Average Necessary Delay and Necessary Level Flight by Destination Airport



Average distance between origin and destination across all arrivals to an airport is an important indicator of the ability of aircraft to absorb necessary delay en route. That is, the longer the distance between origin and destination for an arrival airport on average, the higher the likelihood that speed reduction will be able to absorb the delays in the en route phase of flight. Of course, this is an issue that needs to be studied carefully by origin-destination pair; however, such theoretical averages at the airport level provide a good "feel" for whether speed reduction could be helpful. The other end of this spectrum is also very important, not only because speed reduction is less likely to be sufficient, but also because of the difficulties with integration of short-haul arrivals into the arrival metering sequence. That is because, long before the short-haul flights are even ready to leave the gate, the arrival metering schedule has already been populated with flights that are already airborne. To assure equity in delay between short-haul and long-haul flights, TBO automation will need accurate information about their planned departure times in order to be able to reserve slots for the flights that haven't taken-off yet but plan to reach the same destination as some of the flights that are already airborne.

The proportion of flights without level-offs within 40nm of destination illustrates vertical efficiencies in the existing system. In fact, at most of the 41 key airports in the NAS, less than 10% of arrivals can descend and land without any level-offs within 40nm of destination. This inefficiency is partially driven by the interaction of air traffic flows to and from the same airport, but also by flows at the nearby airports as well. Clearly, opportunities to improve vertical efficiency through TBO solutions will vary by airport, and depend on their location and air traffic flow complexity.

BENEFITS FROM REDISTRIBUTION OF NECESSARY DELAY

With TBO tools, delays that are currently absorbed in low altitude airspace will be pushed back upstream, and absorbed at higher altitudes with speed-control and flight paths stretched to the extent possible. Any remaining delay will be pushed to the origin airports. In other words, vectoring that is currently observed in terminal airspace will be replaced by speed control and path stretch en route, and ground delays at the origin, resulting in reduced fuel consumption while achieving the same overall equivalent flight times.

Under TBO, time-based metering is conducted by an integrated automation with three key components: extended metering, coupled scheduling, and pre-departure scheduling. Extended metering places an aircraft into an initial metering schedule when it is about 90 minutes away from its destination (up to about 600nm). Coupled scheduling revises that initial schedule as aircraft gets closer to the terminal entry control-point, and integrates short-haul flights into the arrival metering schedule as well (these flights are known as departures within the same center, and are typically up to 400nm long). Pre-departure scheduling automation reserves a spot in the arrival metering list for the short- haul arrivals before they take off from their origins.

Methodology for Delay Redistribution

Even under the best operating conditions, it would be unreasonable to expect arriving aircraft to precisely meet TBO schedules. Among other factors, airborne winds and unanticipated delays of other nearby flights can have significant impact on an aircraft's ability to meet its scheduled time of arrival through a control point. To account for these unpredictable variations between scheduled and actual times through a control-point, as well as to provide means for the controllers to line-up aircraft in tight sequences that keep pressure on runways and fully utilize the existing airport capacities, some of the necessary delay will simply remain in the same phase of flight as currently absorbed in the NAS. In fact, one of the requirements for Terminal Spacing and Sequencing (TSAS) automation is to allow for a variability of +/-30 seconds around scheduled terminal entry times. Therefore, the methodology used for estimating TBO delay redistribution opportunities assumes that arrivals will continue to absorb up to a minute of necessary delay within 40nm of destination, and up to a minute of delay in the region between 40nm and 120nm of destination. While these values exceed the requirements, they provide for a more conservative benefits assessment and they ensure that "pressure" on the runway is maintained, thus decreasing the likelihood of missed slots.

For every flight with a necessary delay within 120nm from its destination, the necessary delay is first converted from distance to time by using the reference speed for the affected aircraft type, and Base of Altitude Data (BADA) inputs. To simplify already complex and resource consuming calculations, the reference speed is selected for the distance-weighted altitude (dwAlt) within the same scope. Distance-weighted altitude is a construct similar to the time weighted altitude found in Vempati[9] and Vempati and Ramadani[10], and represents an average altitude for an aircraft, weighted by the proportion of distance in level flight spent at each level-altitude. It is assumed that up to one minute may remain in the terminal area as needed to manage tight aircraft sequences, and temporarily add the remaining delay to that already observed between 40nm and 120nm of the destination. It is then assumed that only up to one minute of that overall delay may remain in the same region, and the remaining amount is moved to the cruise portion of the flight prior to sequencing and merging – roughly outside the 250nm to the destination.

For every flight shorter than 400nm, the amount of delay that could be redistributed from low altitude airspace further upstream is determined. Due to insufficient distance over which speed reduction could be applied, short-haul flights cannot benefit from speed reduction, and would likely benefit most by absorbing their delays at their origin airports.

For every flight longer than 400nm the analysis attempted to absorb the redistributed delay by reducing aircraft speed during the cruise portion of the flight, and before sequencing and merging is typically initiated. Since the extended metering automation determines aircraft sequence up to about 600nm to the destination, and sequencing and merging usually occurs within 250nm from the destination, speed reduction is first attempted outside the 250nm to the destination and within the cruise phase of up to 600nm of destination. The smallest reduction in speed is applied over the available cruise distance (up to a maximum of 350nm). If the necessary delay to be redistributed is too high for even the 10 per cent speed reduction over the available cruise distance, an attempt is made to absorb the remainder between 250nm and 120nm. Since speed reduction during descent would negatively affect its efficiency and could compromise procedural restrictions, it is assumed that it would not be applicable within the 120nm range. Consequently, any delay that could not be absorbed by speed reduction would need to be managed by other means, such as path stretch or ground delay at their origins.

One of the key premises of TBO is to enable aircraft to fly closer to their optimal trajectories, including optimal vertical profiles. However, it will not be possible to eliminate all instances of level flight in descent or approach. To account for this, the amount of the level distance each aircraft flew within 120nm of destination that is greater than the corresponding 15th percentile of its like-group is calculated. This is the necessary level flight that ideally would be moved further back and onto more efficient altitudes before top of descent. However, if the necessary level-flight is shorter than the necessary delay for the same aircraft, it must be left it in the corresponding scope because these lateral and vertical inefficiencies are intrinsically connected and cannot be alleviated separately from each other. Only if the necessary level-flight is longer than the necessary delay for the same aircraft will the calculation attempt to move the difference between the two onto a more efficient cruise-altitude.

For example, suppose two aircraft fly similar trajectories with roughly the same distances within 120nm of destination resulting in 11nm of necessary delay; one of the two aircraft experiences 16nm in necessary level-flight, while the other experiences only three nm. It is reasonable to assume that vertical inefficiency is taken at the same time as the lateral inefficiency to the extent possible. Therefore, the first aircraft will have five nm in necessary level-flight that can be absorbed more efficiently in addition to the 11nm of necessary delay that has already been redistributed to a more cost efficient phase of flight. On the other hand, the second aircraft will absorb the three nm in necessary level-flight along with the 11nm in necessary delay, so no additional efficiency improvement is possible.

Delay Redistribution Results

In 2018, there were 20 million flights in the NAS, with about 30 perc ent of which arrived to the 41 key airports in the TBO study. Many of these aircraft however, had incomplete records in the data archive used, including:

- Aircraft type was unknown;
- There were surveillance gaps in 4D trajectories;
- The aircraft flew during severe weather, affecting flight times;
- Destination airport changed runway configuration in use, resulting in delays that couldn't be alleviated by TBO; or
- There were insignificant occurrences of other like-flights.

FIGURE 13: Proportion of Long-haul Flights by Delay Redistribution Opportunity and by Arrival Airport

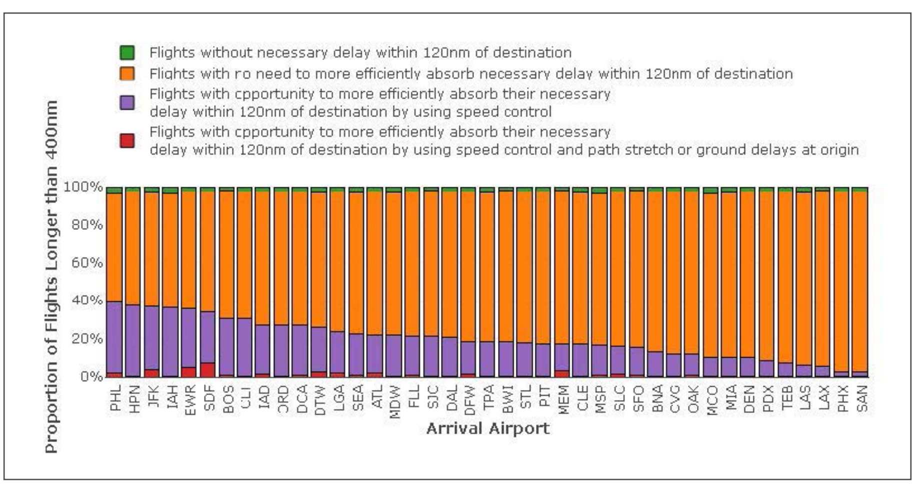


FIGURE 14: Average En route Speed Reduction Required for Redistribution of Delay

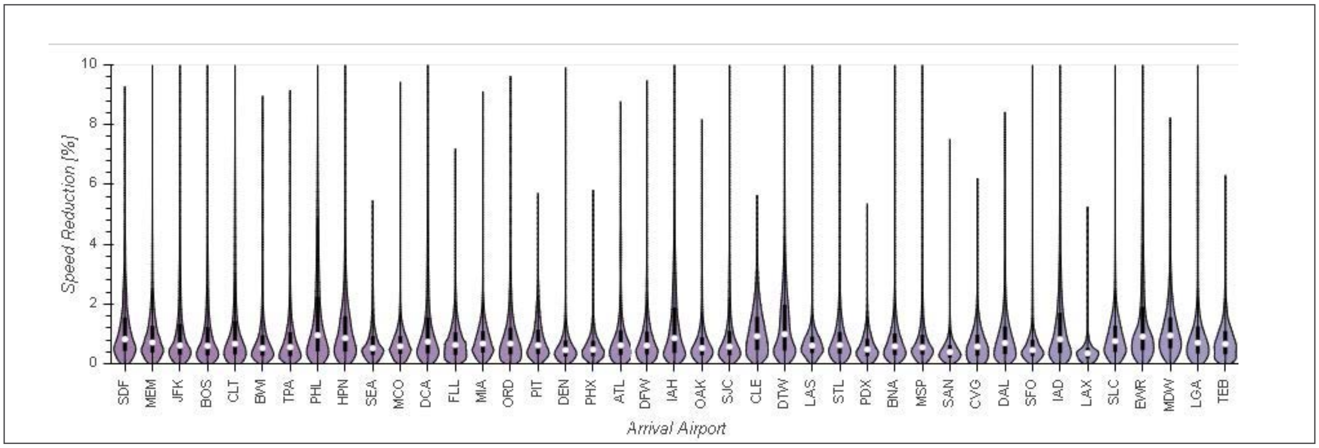
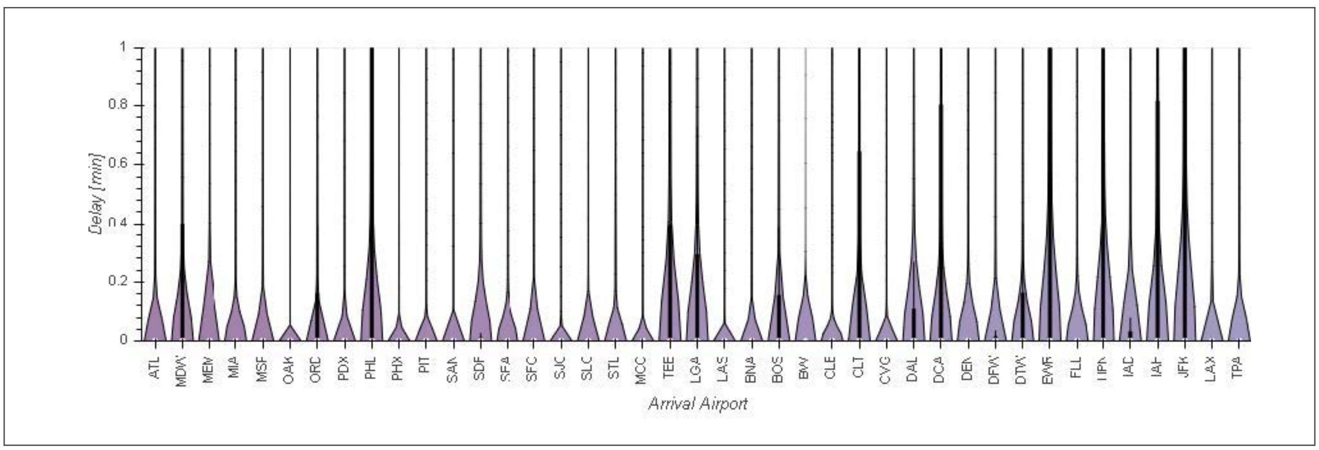


FIGURE 15: Average Redistributed Delay by Arrival Airport for Arrivals Shorter than 400nm



To prevent outliers from potentially skewing the findings, the analysis included only those flights with complete and validated records with a minimum of thirty other like-flights – flights with similar characteristics. Of the almost 3 million flights analyzed, 49 per cent were longer than 400nm.

The study findings are summarized and presented by airport in Figure 13. The average speed reduction by arrival airport for the flights which were required to redistribute delay is shown in Figure 14. Note that the overall average speed reduction was just under one per cent across arrivals to all of the 41 airports. Also, the chart contains the median as a white dot, and the width of each purple bubble represents the distribution of speed control decreases.

On average across the 41 airports, only 17.4 seconds of delay for the short-haul flights could be better managed by redistributing them further upstream. Arrivals to the airports in the northeast corridor suffered the highest inefficiencies with, on average, just under one minute of delay that could potentially be absorbed via more cost efficient means (see Figure 15). The analysis indicated that more than 6,800 hours of delay observed in low altitude airspace in 2018 could have been redistributed through the use of TBO tools such as pre-departure scheduling.

Additionally, about 10 per cent of long-haul flights included in the study required no redistribution of delay simply because their necessary delay within 40nm of destination was lower than one minute, as was the total redistributed delay between 40 and 120nm. For almost 86 per cent of the long-haul flights, the redistributed delay

FIGURE 16: Average Fuel Savings for Arrivals Longer than 400nm by Airport

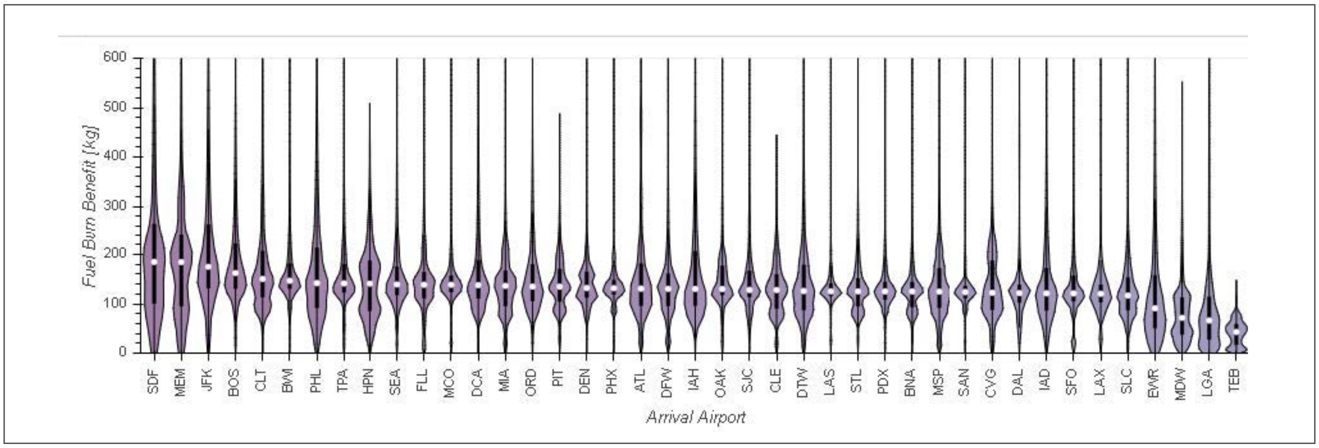
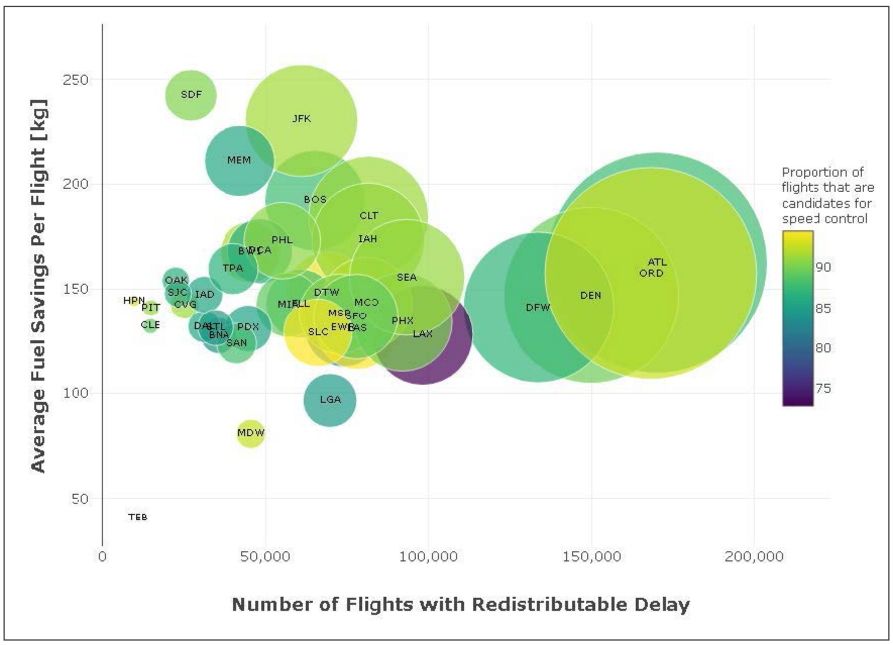


FIGURE 17: Average and Total Fuel Savings Benefit by Airport



was possible to fully absorb in a more efficient manner by applying en route speed reduction. Finally, about three per cent of long-haul flights required other means to absorb the redistributed delay, such as path-stretch or ground delay at their origins.

Finally, for flights longer than 400nm, the analysis indicated that in 2018, about 1,220 hours of delay could have potentially been redistributed using speed control and additional means of delay management such as path stretch and ground delay before departure.

Fuel Reduction Resulting from Delay Redistribution

To process more than 3 million flights in a reasonable amount of time, some simplifications are required. One of these simplifications was to use the dwAlt of a particular scope (i.e., inside 40nm, between 40 and 120nm, on route) to represent the altitude of the trajectory during the entire scope. Another simplification was the use of BADA 3.12 inputs to model the impact of speed decreases. While granularity and lack of accuracy of BADA inputs for very low and very high altitude analyses is a known issue, these inputs are considered a standard in the civil aviation industry, and include more aircraft types than any other sources available. A third simplification was to ignore winds and to substitute BADA reference speed for actual aircraft true air speeds to evaluate fuel flow. Speed reduction was applied in increments of one per cent, up to a maximum of ten per cent.

Interestingly, the highest speed reduction is rarely advantageous as a fuel saving option, and is often not necessary to begin with. With BADA data, some aircraft types and altitude combinations resulted in no beneficial speed reduction at all. If an aircraft is flying at optimal fuel flow during cruise, speed reduction will result in higher fuel consumption at that flight level. In fact, this may even result in increased fuel burn in cases when the difference between the fuel flow at reference and at the reduced speed in cruise is higher than the fuel burn for the same amount of necessary delay when flown in low altitude airspace.

It was assumed that under TBO, delay redistribution and absorption through speed reduction would only be attempted if resulting in decreased fuel burn; otherwise, such delays would attempt be absorbed at origin and before take-off. The resulting fuel savings by airport are displayed in Figure 16.

Fuel savings results for flights in this study vary from an average of nearly 245 kg per flight (which had necessary delay and excess level flight) at Louisville International Airport (SDF) to about 40 kg per flight at Teterboro Airport (TEB). Figure 17 displays the average fuel savings per flight for each arrival airport. The color of the circle represents the proportion of flights that are candidates for speed control for each arrival airport. The size of the circle indicates the total fuel savings for each arrival airport.

CONCLUSIONS

This study was the first ever of its type that involved the magnitude and complexity of processing three years of NAS surveillance data. It involved controlling for numerous variables including: air traffic demand levels, severe on route and terminal weather, airport meteorological conditions, changes in runway configurations, etc. Through simple adjustments in parameter values or aircraft grouping and filtering, these empirical outcomes lend themselves to investigations of additional improvement opportunities, such as the gap in performance during IMC and VMC at an airport, including the extent to which this gap may be closed. In this first application of the new methodology however, the focus was on how much of the current necessary delay in the NAS could be more efficiently absorbed from the fuel consumption and cost of operation perspectives. Since the analysis described above included only those flights for which there was complete, validated and statistically significant records – about half of all the arrivals at the 41 key airports in the NAS in 2018 – the findings presented herein are a conservative estimate of delay redistribution opportunities and the corresponding fuel savings.

Nevertheless, significant work remains to determine if and how such redistribution of delay could be handled by the system. For instance, can the system truly keep the pressure on runways and fully utilize airport capacity given the variability between scheduled and actual times through a control point? Or, can the on route airspace structure and controllers handle additional complexity of delay being absorbed on route? How much of the redistributed delays of short flights can be absorbed on the ground at each origin? Which of the airports needs additional gate or apron capacity to handle such increase in ground delays? Could redistribution of delay lead to a new, unforeseen bottleneck in the system and potentially result in even higher delays?

As new requirements and solutions are perfected through field evaluations and operational use of initial TBO capabilities at select facilities across the NAS, the FAA continues to work on these truly complex and challenging analyses, as it aims to continue to improve both the TBO concept and its assessment of the corresponding benefit opportunities.

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Airport Carbon Accreditation – Empowering Airports to Reduce Their Emissions

By Marina Bylinsky, Head of Sustainability, Airports Council International (ACI) EUROPE

In the context of new scientific evidence on the urgency to address the Climate Emergency and rising societal and political expectations -specifically in relation to the climate footprint of aviation - the airport industry has a key role to play. While airport related emissions are estimated to represent only 2% to 5% of the global aviation emissions, airport operators are a critical interface between various aviation and non-aviation stakeholders. By actively reducing their emissions, they can act as a role model and also facilitate or even drive effective emissions management by these stakeholders. This is a challenging exercise, requiring a lot of creativity and commitment from the airport operator. Encouraging it is the purpose of *Airport Carbon Accreditation* – a voluntary carbon management programme launched by ACI EUROPE back in 2009.

Airport Carbon Accreditation assesses and recognises the efforts of airports to manage and reduce their carbon emissions according to four ascending levels of certification – 'Mapping', 'Reduction', 'Optimisation' and 'Neutrality'. Throughout these levels, airports have to comply with increasing obligations, in particular by including emissions from third party stakeholders operating at the airport in their carbon management, notably airlines, ground handlers or retailers. The ultimate certification level - carbon neutrality - requires that the airport offsets those remaining CO_2 emissions under its direct control that cannot be further reduced. It is a key feature of the programme that airport operators have to first reduce their own emissions as much as possible, before being allowed to compensate the rest.

This year, the programme is celebrating its 10th anniversary. From an exploratory initiative that began with 17 of the environmentally most advanced airports in Europe in the first year (2009-2010), it has become a global industry standard for airports all over the world, with 274 accredited airports worldwide as of June 2019. These airports are located in 71 countries across all continents and welcome close to 44% of global air passenger traffic - almost every second passenger in the world is travelling through a *Carbon Accredited* airport today. They are small and large, commercial hubs and general aviation airports, situated in the biggest countries of the world and in the small island States. They are at different stages in the carbon management journey. *Airport Carbon Accreditation* provides a general framework and beacons, but the exact path is charted by each airport individually, as is the pace of its progress.

Airport Carbon Accreditation has come so far thanks to three main reasons.

First, its methodological robustness and relevance for airports came as a big advantage. *Airport Carbon Accreditation* is based on international, cross-industry standards for emissions management – translated into airport language. There are actually many airports for which *Airport Carbon Accreditation* was the starting point for developing and continuously improving their carbon management.

Second, by showing year on year quantified results in terms of emissions reductions, the programme is proving its effectiveness. In the last programme year (May 2017-May 2018), accredited airports worldwide have demonstrated a reduction of 347,026 tonnes of CO_2, or minus 5.3 % compared to the baseline. Such reductions are typically achieved through the use of low carbon fuel or electricity for ground support equipment, renewal of vehicle fleets, efficiency improvements in lighting and heating/air conditioning systems in terminal buildings and the procurement or direct generation of electricity from renewable sources. Furthermore, 672,000 of CO_2 have been offset.

Last but not least, while *Airport Carbon Accreditation* has been designed specifically for airports and by airports, the day-to-day administration of the programme, including the decisions on certifications, is performed by an independent third party: the environmental consultancy WSP which has been supporting the programme since its inception. Furthermore, airport applications must be independently verified on a regular basis, before being submitted to the administrator; they are thus subject to a double quality control.

It is therefore not surprising that *Airport Carbon Accreditation* has won praise from the most authoritative institutions in the area of aviation and climate change, such as ICAO, the United Nations Framework Convention for Climate Change (UNFCCC), the European Commission and the US Federal Aviation Administration (FAA).

While the 10^{th} anniversary of *Airport Carbon Accreditation* certainly offers many reasons to celebrate the programme's success, it is also the right time to reflect on what it can do more or better. Since the publication of the IPCC Special Report on Global Warming of 1.5°C and with the imminent entry into force of the Paris Agreement, an increasing number of airports are looking to step up the ambition of their climate action, including with regard to their business partners and stakeholders. *Airport Carbon Accreditation* needs to ensure it provides the relevant guidance and recognition for this.

At the same time, the programme will have to continue engaging airports from various regions and at different stages in their carbon management journey. It is about recognising that depending on the region they are located in, airports all over the world are not equally empowered to take action against their emissions. For instance, access to sustainable alternative fuels or electricity generated from renewable sources is not equally developed in all countries. *Airport Carbon Accreditation* has to remain a tool that also accommodates the needs of these airports – similar to ICAO's principle of "No Country Left Behind". Ultimately, this is what represents the force of a truly collective industry effort.

For all the latest information, visit www.airportCO2.org and follow @AirportCO2 on Twitter.

ICAO

CHAPTER FIVE

Climate Change Mitigation: Sustainable Aviation Fuels

Sustainable Aviation Fuels

By ICAO Secretariat

As described in the opening article of Chapter 4, sustainable aviation fuels (SAF) are one element of the ICAO basket of measures to reduce aviation emissions, which also includes technology and standards, operational improvements, and the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA).

This article provides a background on ICAO's activities in SAF, including those conducted through the ICAO Committee on Aviation Environmental Protection (CAEP), the establishment of policies and measures, the organization of events, the facilitation of information sharing and best practices, and the assistance on the development of SAF feasibility studies. It also provides an overview of ICAO's plans to foster the future of SAF deployment.

BACKGROUND

The first ICAO Assembly Resolution reference to SAF was registered during its 36th Session (2007). At the time, initial studies on the technical feasibility of these fuels were being conducted, and the Assembly *recognized the importance of research and development in fuel efficiency and alternative fuels for aviation that will enable international air transport operations with a lower environmental impact*. The Assembly also encouraged the Council to promote improved understanding of the potential use, and the related emissions impacts, of alternative fuels.

In 2009, the First ICAO Conference on Aviation and Alternative Fuels (CAAF/1)[1], held in Rio de Janeiro, Brazil in November 2009, endorsed the use of sustainable aviation fuels as an important means of reducing aviation emissions and recommended the development of life cycle methodologies and sustainability criteria for these fuels. CAAF/1 also recommended the creation of the ICAO Global Framework for Aviation Alternative Fuels (GFAAF)[2], a global platform where information on worldwide initiatives and actions on SAF are shared. More details on GFAAF are provided later on this article.

Following up on these conclusions, the 38th ICAO Assembly (2013) acknowledged the need for SAF to be developed and deployed in an economically feasible, socially and environmentally acceptable manner and requested States to recognize existing approaches to assess the sustainability of all alternative fuels in general, including those for use in aviation which should: achieve net GHG emissions reduction on a life cycle basis; respect the areas of high importance for biodiversity, conservation and benefits for people from ecosystems, in accordance with international and national regulations; and contribute to local social and economic development, and competition with food and water should be avoided.

The Assembly also requested States to adopt measures to ensure the sustainability of alternative fuels for aviation, building on existing approaches or combination of approaches, and monitor, at a national level, the sustainability of the production of alternative fuels for aviation.

Since 2009, significant progress has occurred, including six certified conversion processes for SAF production, more than 180,000 flights using a blend of SAF, six airports regularly distributing SAF, reductions in production costs, and evolution on the sustainability aspects of these fuels.

To follow up on these developments, the Second ICAO Conference on Aviation and Alternative Fuels[3] (CAAF/2) was held in October 2017 in Mexico City, Mexico. This

1 https://www.icao.int/Meetings/caaf2009/Documents/CAAF-09_SD003_en.pdf
2 https://www.icao.int/environmental-protection/GFAAF/Pages/default.aspx
3 https://www.icao.int/Meetings/CAAF2/Pages/default.aspx

second Conference endorsed the 2050 ICAO Vision for Sustainable Aviation Fuels[4], which calls on States, industry and other stakeholders for a significant proportion of sustainable aviation fuel (SAF) use by 2050.

ICAO WORK ON SAF

The Assembly requests related to SAF are being pursued by the ICAO Secretariat and the ICAO Committee on Aviation Environmental Protection (CAEP). In 2013, CAEP established the Alternative Fuels Task Force (AFTF) to provide technical support to ICAO work on aviation fuels and the environment. Due to the valuable input that AFTF has provided to ICAO's work, in 2019 CAEP agreed to evolve AFTF into a permanent CAEP group, called the Fuels Task Group (FTG). CAEP has been focusing on the development of processes and methodologies for consideration of aviation fuels under CORSIA, including globally-accepted sustainability criteria and life cycle methodologies. These developments are detailed in the Chapter 6 article on CORSIA Eligible Fuels, which provides specific details on how SAF is considered under CORSIA.

ICAO STOCKTAKING SEMINAR 2019

The CAAF/2 noted that progress on SAF development and deployment should be periodically reviewed through a stocktaking process, including the organization of regular workshops and seminars. Such a stocktaking process will lead to the convening of CAAF/3 no later than 2025, with a view to updating the 2050 ICAO Vision to include a quantified proportion of SAF use by 2050, as well as the associated carbon reductions.

In response to this decision, the first ICAO Stocktaking Seminar toward the 2050 Vision for Sustainable Aviation Fuels[5] (SAFS2019) was held in Montreal from 30 April to 1 May 2019. A questionnaire was shared with ICAO member States and international organizations, aiming to identify the current status and future trends on SAF deployment. As a result, 25 questionnaires with information on SAF deployment were received prior to the event and 26

FIGURE 1: Evolution of Commercial Production of SAF

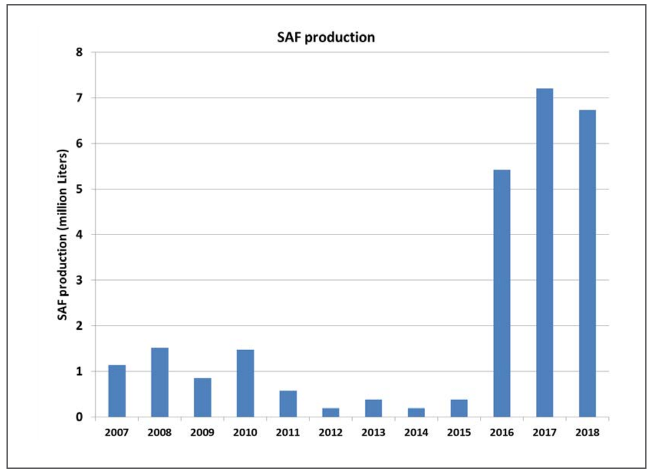
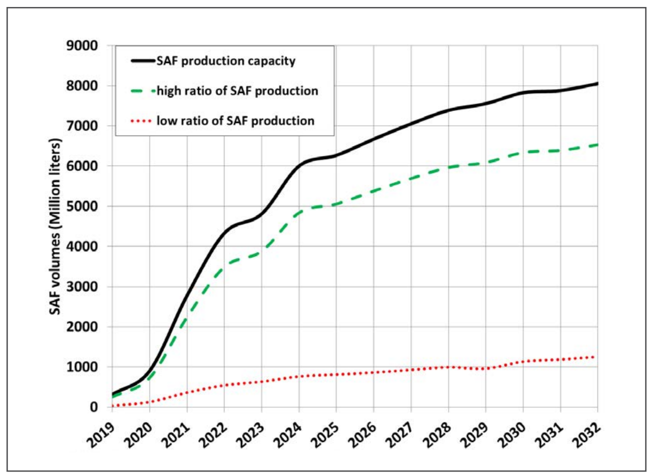


FIGURE 2: SAF Production Capacity Trends Based on the 2019 SAF Stocktaking Exercise

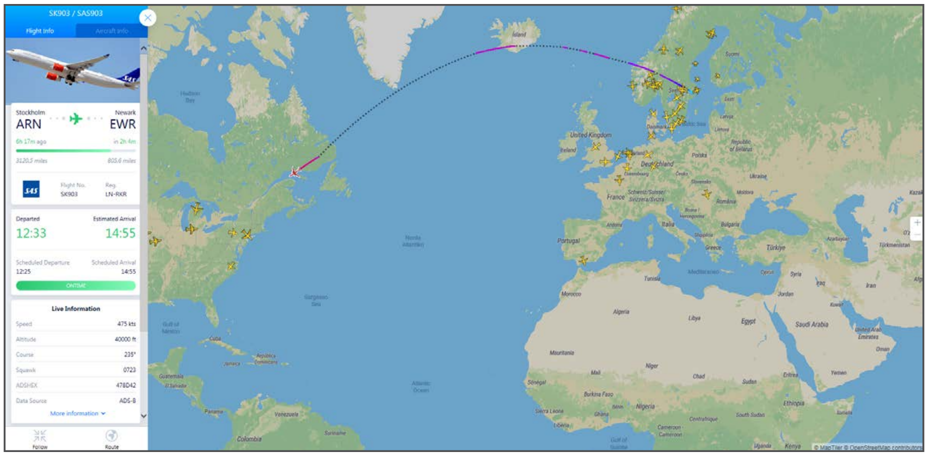


presentations (many with quantified information) were provided through the Seminar. All of the data was aggregated in order to provide a view on SAF deployment progress. The data showed that commercial production of SAF increased from an average of 0.29 million litres per year (2013-2015) to 6.45 million litres per year (2016-2018), as shown in Figure 1.

Looking to the future, the Stocktaking results showed that up to 6.5 Mt (8 billion litres) per year of SAF production capacity may be available by 2032. However, there is significant uncertainty on the share of this capacity that will be directed to SAF compared to other fuels. In this

4 https://www.icao.int/environmental-protection/GFAAF/Pages/ICAO-Vision.aspx
5 https://www.icao.int/Meetings/SAFStocktaking/Pages/default.aspx

FIGURE 3: Live Feed of Sustainable Aviation Fuel Flights



regard, the CAAF/2 encouraged States to promote policies that strive to establish a level playing field between aviation and other transportation sectors on the use of sustainable fuels. Figure 2 provides this future trend on SAF production capacity, together with scenarios of 10% and 80% SAF production ratios.

The second ICAO SAF Stocktaking Seminar will be held from 28 to 29 April 2020. This event will provide States with an opportunity for additional stakeholders to provide input to the SAF Stocktaking process and for stakeholders that have already submitted information to provide updates on their progress.

SHARING OF INFORMATION AND BEST PRACTICES

The ICAO GFAAF, established after a recommendation of the ICAO CAAF/1, is recognized as the online database for sharing information related to sustainable aviation fuels. It contains links to over 600 news articles dating back to 2005, details of past and ongoing initiatives, facts and figures, answers to frequently asked questions, and links to additional resources. It also includes a live feed of flights using sustainable aviation fuels, as illustrated in Figure 3.

As part of the ICAO-UNDP-GEF assistance project "Transforming the Global Aviation Sector: Emissions Reductions from International Aviation", a "Sustainable Aviation Fuels Guide"[6] was developed to inform ICAO Member States on how sustainable aviation fuels can be deployed to reduce CO_2 emissions from international aviation activities. The guide describes fuel production pathways, usage constraints, environmental and other benefits, and policy perspectives on the use and development of SAF.

Four successful feasibility studies on the use of SAF were also developed as part of the ICAO-EU assistance project "Capacity building for CO_2 mitigation from international aviation". These studies are detailed later in this chapter. As a result, other ICAO States expressed their willingness to undertake similar SAF feasibility studies. ICAO is encouraging States to express such interest in their State Action Plans to reduce CO_2 emissions (see Chapter 9 for more information), and to support the development of such feasibility studies.

CONCLUSIONS

Sustainable Aviation Fuels can play a major role in reducing international aviation emissions. This article described the various activities being pursued by ICAO to foster the deployment of SAF. This work will continue steadily in the next triennium, in support of the ICAO goal of limiting or reducing the impact of aviation greenhouse gas emissions on the global climate.

6 https://www.icao.int/environmental-protection/knowledge-sharing/Docs/Sustainable Aviation Fuels Guide_vf.pdf

Climate Change Mitigation

By Robert Boyd (IATA)

The aviation industry is committed to mitigating and reducing its environmental impact. A robust sustainability strategy provides the industry with the license to operate and grow while delivering the social and economic benefits of air connectivity.

All sectors of the economy are increasingly being challenged to address their environmental impact.

The aviation industry is responding in all aspects and has a long-standing four-pillar strategy to mitigate its environmental impact built on improvements in operations, infrastructure, and technology, together with market-based measures to offset any remaining emissions.

One of the industry's targets to improve fuel efficiency by 1.5% every year has been constantly met and exceeded averaging a 2.4% annualized improvement since 2009. The aim is to be carbon-neutral by 2020 and to halve net emissions by 2050 compared with 2005.

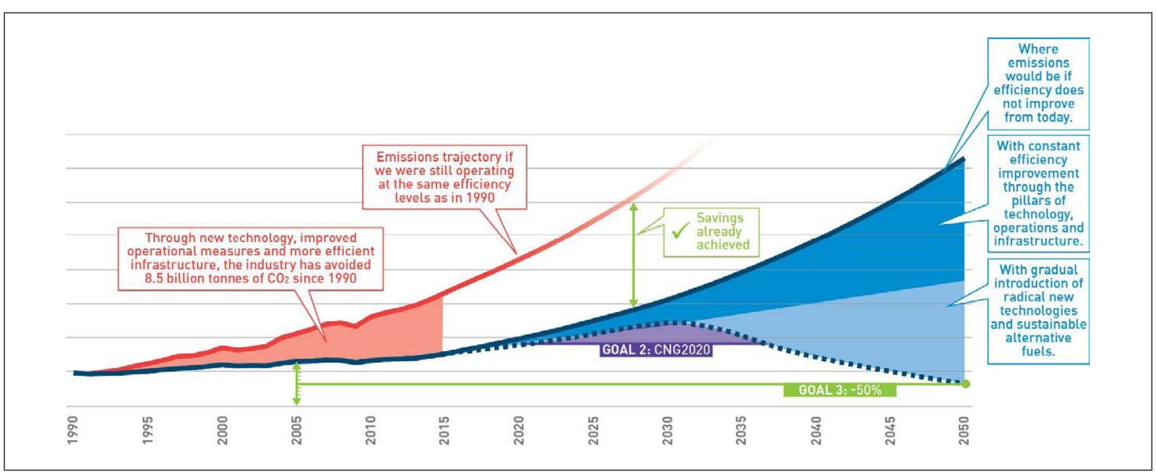
The Carbon Offsetting Scheme for International Aviation (CORSIA) will prove crucial in this respect. This will ensure aviation offsets its carbon emissions (2020-2035) and is the first global agreement of its kind, demonstrating the industry's commitment.

Over the longer term, IATA believes that the more substantive reductions in net CO_2 from aviation will have to come from sustainable aviation fuels (SAF). Understanding what quantities might be available is an important element for evaluating aviation's sustainability trajectory towards 2050.

To aid the advancement of SAF, IATA supports research, development and deployment, including the promotion of these fuels that meets environmental, societal and economic sustainability criteria. IATA follows sustainability developments closely and is a member of the International Sustainability and Carbon Certification (ISCC) and the Roundtable on Sustainable Biomaterials (RSB). RSB has developed the most comprehensive sustainability standards for biofuels.

At the 73rd IATA AGM in Cancun, 2017, IATA members unanimously agreed a resolution on the deployment of SAF, including calling for constructive government policies, and committing to only use fuels which conserve ecological balance and avoid depletion of natural resources.

FIGURE 1: The Industry's Carbon Goals



SUSTAINABLE AVIATION FUELS IN PRACTICE

Since the first flight on SAF in 2008, considerable progress has occurred in all aspects of production, certification and deployment. Today SAF are being produced and used in commercial flights every day. While the current volumes being produced are low (<1% of total jet fuel demand), these volumes can be substantially increased with coordinated support including effective policy frameworks.

To date, about 40 million liters of SAF has been produced and each of the five technical pathways to produce SAF have been used for commercial flights. These technical SAF pathways to produce SAF typically deliver a 60-80% reduction in CO_2, which is equivalent to 25,000 cars being taken off the road since regular use began in 2016.

Despite this good news, it must be noted that the 10 million liters of SAF per annum represents just 0.01% of total fuel uptake. Clearly, the production of SAF needs to increase dramatically to make a more substantive environmental impact.

Main milestones so far:

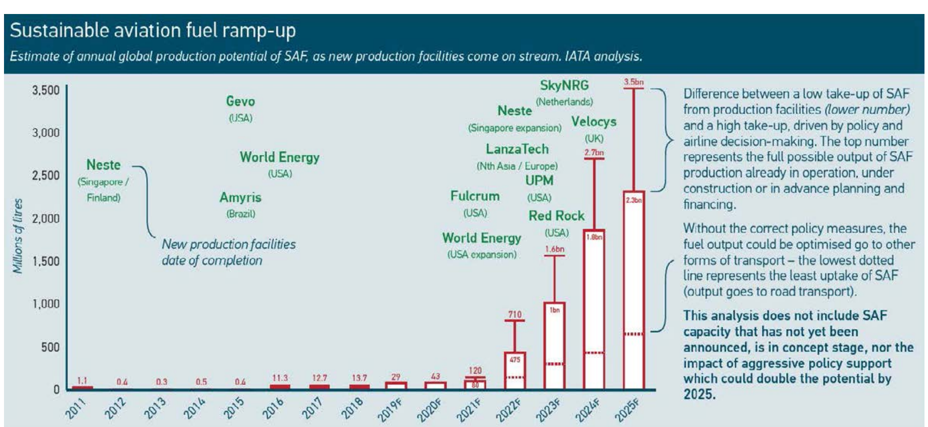
- 2008 – The first test flight with biojet fuel was performed by Virgin Atlantic.
- Between 2011 and 2015 – 22 airlines performed over 2,500 commercial passenger flights with blends of up to 50% biojet fuel from feedstock including used cooking oil, jatropha, camelina, algae and sugarcane.
- Jan. 2016 – Regular sustainable aviation fuel supply through the common hydrant system started at Oslo Airport with renewable fuel producer Neste and supplier SkyNRG as well as Air BP involved.
- Mar. 2016 – United became the first airline to introduce SAF into normal business operations by commencing daily flights from Los Angeles Airport (LAX), supplied by AltAir (now World Energy).
- June 2019 –More than 180,000 commercial flights using SAF have been performed and greater than 40 different commercial airlines have gained experience using SAF.

Over the past 18 months there has been considerable commercial SAF activity with the announcement from airlines of new forward purchase agreements and new commercial construction activity which has included both new SAF plants as well as the expansion of existing facilities.

The below chart (Figure 2) provides a guide and estimate of the likely commercial development of SAF based on publicly released information. Looking out to 2025, publicly announced projects alone could push SAF uptake in aviation to 3.5 billion liters annually. It is not unreasonable to assume that as-yet-unannounced projects will double that number, representing nearly 2% of total fuel demand by 2025.

Further increases in SAF production and uptake will be aided by the technical approval of new fuel pathways,

FIGURE 2: Commercial production chart



investment in production capacity, and innovative collaborations. All these factors require a stable policy framework. In essence, companies need to know that the supply of, and demand for, SAF will be there.

More information can be found on these specific projects at: https://aviationbenefits.org/environmental-efficiency/climate-action/sustainable-aviation-fuel

LOOKING TO THE FUTURE

IATA believes that to reach a commercialization tipping point (around two per cent of commercial operators fuel supply by 2025) will require some seven billion liters of SAF a year. As demonstrated above, current estimates show that production facilities to meet half that volume have already been announced. However, it is vital to ensure that the output from those facilities is directed to aviation and not road transport which should be transitioning to electricity. Governments must play a key role in setting the right policy track that enable the acceleration of SAF supply while recognizing the unique challenges for aviation including avoiding competitive fuel price distortions and any unintended environmental consequences.

Further supporting the importance of SAF commercial deployment is that unlike the ground transport sector, which can use electric energy, aviation has no near-term alternative to liquid hydrocarbon fuels (electric commercial aircraft are unlikely before 2040). Technical impediments for the acceleration of the deployment of SAF are few. SAF can be safely mixed with conventional jet fuel, can use the same supply infrastructure and do not require adaptation of aircraft or engines. 5 technical production pathways have been certified under ASTM d7566 meeting the equivalent or higher technical specifications as conventional jet fuel. Additional certification are expected and methods to expedite future certifications based on historical learning will help with adding additional supply options, increasing competition and further lowering the unit cost of production.

IATA's SAF Strategic Vision

Industry actions

- Developed an industry roadmap (2015) highlighting best practice for technology adoption, policy and regulation, economics, sustainability and accounting standards.
- Provide industry leadership on best practice concerning: sustainability standards, accounting procedures, logistics, communication, effective policy and business case development.
- Influence policy negotiations to ensure aviation can opt in to existing ground transport policies and build understanding for the importance of directing feedstock towards hard to abate sectors such as aviation.
- Several airlines have concluded long-term offtake agreements with biofuel suppliers, most of which are reported as commercially competitive. IATA will continue to work with aircraft operators to educate, prepare and encourage additional forward purchase commitments.

Role of governments

- Take a leadership role in managing the aviation energy transition.
- Adopt globally-recognized sustainability standards and work to harmonize global standards.
- Ensure existing policy incentive frameworks designed for ground transport, also include aviation and evaluate higher incentives for aviation over ground transport which has other energy alternatives.
- Encourage user-friendly sustainable aviation fuel accounting methods and work to harmonize global standards.
- Support sustainable aviation fuel R&D and demonstration plants.
- Implement policies that de-risk investments into sustainable aviation fuel production plants.
- Engage in public-private partnerships for sustainable aviation fuel production and supply.
- Commit to policy certainty or at a minimum policy timeframes that match investment timeframes.

Business Aviation and Sustainability: An Industry With a Good Story to Tell

By International Business Aviation Council (IBAC) on behalf of the Business Aviation SAF Coalition

Environmental responsibility, and wider sustainability matters, are important areas of focus for companies, citizens and industries around the world, including throughout the global aviation sector. While it does not often make headlines, one segment of the aviation industry in particular – business aviation – has made significant investment and progress in these areas.

Global business aviation operations represent 0.04% of anthropogenic CO_2 emissions – nevertheless, our industry has demonstrated a serious commitment to the ongoing exploration of new methods and technologies to significantly reduce this figure, and a pathway has been established for reducing greenhouse gas emissions from aircraft in our sector.

Indeed, business aviation has long been on the forefront of technological innovation, including efficiency gains – business aircraft were the first civil aircraft to use winglets, advanced aerodynamics, state of the art avionics, and to demonstrate improved fuel burn from engines. Manufacturers are firmly committed to continue on this path of improvement.

Our industry inherently seeks ways for flying more efficiently, as part of meeting business-transportation challenges. This efficiency-focused philosophy carries over into carbon-emissions reduction, driven by the efforts and commitment of a variety of business aviation stakeholders; that said, assistance is needed from governments and policy makers.

As the International Civil Aviation Organization (ICAO) prepares for its 40th Triennial Assembly in 2019, it is important to recognize some significant milestones in this commitment, and why they are so important not only for business aviation, but also the broader global aviation industry and citizens around the world.

A DECADE MARKED BY A REDOUBLED COMMITMENT TO SUSTAINABILITY

Business aviation has long made strides on reducing emissions, and one major, additional, milestone in this area was crossed ten years ago, when the International Business Aviation Council (IBAC) and General Aviation Manufacturers Association (GAMA) announced and published the Business Aviation Commitment on Climate Change (BACCC), a programme outlining a continued effort in reducing the industry's carbon footprint.

Given the global nature of our industry, and its prevalence of international operations, stakeholders in the BACCC identified a critical need for a globally harmonized environmental policy that ensured safe, efficient and balanced operations. Among the tenets of that commitment, which grew to include signatories from business aviation stakeholders worldwide, was a pledge to a 2% improvement in fuel efficiency per year from 2010 until 2020, with carbon-neutral growth from 2020 onwards and a 50% reduction in carbon emissions by 2050, compared to 2005 levels.

When the plan was unveiled, the signatories noted that achieving these goals would require improved technologies, including sustainable aviation fuel, operations, infrastructure and market-based measures.

Companies utilizing business aviation – along with aircraft and engine manufacturers, fuel providers and other stakeholders – have long sought to improve their own environmental footprint and the efficiency of their products and operations. The BACCC represented the first industrywide, united effort to reduce carbon emissions, and a significant amount of work has been undertaken in the years following that pledge to identify the most effective paths forward in achieving its goals.

SUSTAINABLE FUELS KEY TO INDUSTRY'S CO_2-EMISSIONS PLAN

One of the most promising avenues for fulfilling the commitment to reduce CO_2 emissions with today's business aircraft is through the use of sustainable aviation fuels (SAF), derived from renewable feed stocks and other sources. Multiple technology paths exist to produce such fuels, and innumerable flights over the past decade have consistently demonstrated their viability and benefits.

Sustainable aviation fuel – essentially Jet-A with a non-fossil fuel element, blended with up to a currently certified 50% mix – meets the same ASTM standard (D1655) as current aviation fuel; it is a simple "drop-in" for aircraft, indistinguishable from the completely petroleum-based product. The only effects to aircraft performance are beneficial ones: a cleaner burn and commensurate reduction of overall CO_2 emissions over the life-cycle of the fuels' manufacturing process, together with the environmental benefits in sourcing such fuels from renewable resources.

Our industry's united support for SAF was first codified last year, as a coalition of international business aviation organizations joined government officials at the 2018 European Business Aviation Convention & Exhibition (EBACE2018) in Geneva to redouble the focus and effort on advancing the development and adoption of SAF.

At the heart of this initiative was a new resource to benefit the industry: The *Business Aviation Guide* to SAF, focused on raising awareness and adoption of available and emerging sustainable aviation fuel options, and providing a road map for the education about, and use of, the fuels.

The *Guide* was produced with support from IBAC, GAMA, the European Business Aviation Association (EBAA), the National Air Transportation Association (NATA) and the National Business Aviation Association (NBAA), with valuable technical assistance provided by the Commercial Aviation Alternative Fuels Initiative (CAAFI) and the Air Transport Action Group (ATAG).

This initiative also included a new, dedicated website with resources and other information about SAF, futureofsustainablefuel.com, developed by the coalition, supported by committed airframe manufacturers and fuel suppliers, and created to bridge a "knowledge gap" on the safety, availability and use of sustainable aviation fuels.

These combined efforts address three important aspects of SAF use: that such fuels for business aviation are safe, approved and available now; that SAF offer a myriad benefits, including those in support of the sustainability of business aviation, corporate responsibility and reduced emissions; and that such fuels are derived from multiple feed stocks that are sustainable, renewable resources, and are therefore an environmental "win-win."

RAISING INDUSTRY AWARENESS AND INCENTIVES

With the *Guide* spurring industrywide interest in SAF, the next step in raising awareness and promoting education of its benefits came in January 2019, as IBAC joined with a coalition of industry groups to sponsor the first-ever SAF demonstration day in the United States at California's Van Nuys Airport (VNY), which proved the fuels' viability and safety.

The coalition joined with local civic leaders and other industry stakeholders in sponsoring the day-long event at VNY. The airfield's four fixed-based operators fueled aircraft throughout the day with SAF, and the event included participation from local officials who expressed their support for this industrywide, all-voluntary, investment in research and innovation.

"Clean air for everyone is not only clean air for my constituents, but for anyone who lives in and around Van Nuys Airport," noted Los Angeles City Councilwoman Nury Martinez. "The aviation leaders gathered here today…are leading in this particular area," she added. "How you are responding to this challenge, and driving the challenge makes an incredible difference," said Los Angeles World Airports CEO Deborah Flint.

The impressive demonstration of SAF's appeal and viability at Van Nuys then paved the way toward the first European SAF demonstration day in May 2019, held at Tag Farnborough London Airport in the United Kingdom (EGLF), ahead of EBACE2019.

Aircraft from major manufacturers including Bombardier, Gulfstream, Cirrus, Embraer, Piaggio, Dassault and Textron Aviation, fueled up on SAF at EGLF, as well as other airports across Europe and the United States – including Caen-Carpiquet Airport in France; Sweden's Stockholm Arlanda Airport; and Republic Airport in Farmingdale in the United States at Sheltair – for in-bound flights to EBACE2019, demonstrating the fuels' viability.

This display of interest in alternative fuels bolstered the unequivocal message that SAF are safe and do not impact aircraft performance, while also offering airport and community benefits. The event, which was followed by a technical panel at EBACE2019, with contributions from experts across the industry that sought to further demystify, discuss SAF use and its availability, also reflected the ongoing commitment by business aviation to aircraft carbon reduction.

Efforts are now underway to significantly expand availability of these fuels as interest continues to grow throughout our industry and more business aviation

operators seek to adopt sustainable fuels to support an extensive variety of missions. Similar demonstrations of the benefits, appeal and viability of SAF are planned later this year and into 2020, including at the industry's largest business aviation event, the NBAA Business Aviation Convention & Exhibition (NBAA-BACE), next scheduled for 22-24 October 2019 in Las Vegas, United States.

IBAC recognizes the support that ICAO lends the industry when it comes to the front-and center issue of sustainability. For the business aviation community to achieve and expand its program for wider use of SAF, it calls for support from governments, and policy leaders, including those at ICAO, to incentivize the use of non-fossil fuel based products, and for States to increase their use of SAF. Looking toward the future, this approach will be key to lowering our industry's dependency on fossil fuels, and reducing the CO_2 output from the industry, and its effect on climate change.

A SUSTAINABLE FUTURE ON THE HORIZON

As previously mentioned, business aviation has always been an early adopter of technologies that have improved fuel efficiency and reduced environmental impact. Sustainable aviation fuels are a new technology available now for use by our innovative community, and their growing use will be a critical component of business aviation's global commitment to mitigate and reduce carbon emissions.

That said, SAF is just one aspect of our industry's ongoing sustainability effort. As we look ahead to the next five, 10 and even 20 years, we know that business aviation will continue to advance toward an increasingly smaller environmental footprint as new aircraft designs and advanced engine technologies bring even greater fuel savings and, with that, a commensurate reduction in carbon emissions.

What it all boils down to is this: Our industry's commitment to SAF is not just about fuels, but about the future, and the business aviation license to operate. It is part of a broader focus on emissions, including the advancement of hybrid gas-electric and, ultimately, fully electric propulsion in urban air mobility and business aircraft applications. These emerging technologies offer the promise that travel within metropolitan areas around the globe – and even to the airport for longer-distance trips – will also be safe, efficient and environmentally-responsible.

Without question, business aviation is well-suited to confront the challenges of global carbon emissions reductions and innovation in sustainability. As the voice of business aviation before the International Civil Aviation Organization, IBAC looks forward to the continued support of ICAO, and advancing this continued story of improvement in the years ahead.

Preparing for Take-Off: RSB and the Role of the Standard in Driving Innovation and Sustainability

By Rolf Hogan and Hannah Walker
(Roundtable on Sustainable Biomaterials – RSB)

The aviation industry requires effective and sustainable solutions to meet its commitments at national and international levels in its global effort to reduce the impacts of climate change. With the implementation of CORSIA regulations, over 85% of global aviation activity will be working to limit carbon emissions through the improved technology and operations, as well as the use of carbon offsets and alternative fuels. The RSB, a global multi-stakeholder organization, works with the aviation industry to support their commitments to climate action through a range of solutions that are grounded in the best-in-class sustainability outlined in the RSB Standard.

Alternative aviation fuels, which can deliver significant reductions in greenhouse gas emissions while requiring no changes to existing aircraft and infrastructure, offer one of the most effective and immediate solutions to an industry looking to decarbonize rapidly. Such fuels have the potential to offer both greenhouse gas reductions and a credible approach to achieving sustainable development goals, and so could deliver key emissions savings to the aviation industry – without compromising social development and environmental protection.

Not only do fuels produced from a range of feedstocks including: crops, production residues, end-of-life materials, and fossil waste produce reduced greenhouse gas emissions, they also do not cause negative environmental and social impacts – such as increased global hunger or the destruction of ecosystems. To ensure that this remains the case, a robust and credible certification scheme has been developed.

The RSB is a multi-stakeholder organization committed to ensuring best practice in the advanced economy. It offers ready-made solutions for the aviation industry as it adopts CORSIA, via certification to its best-in-class

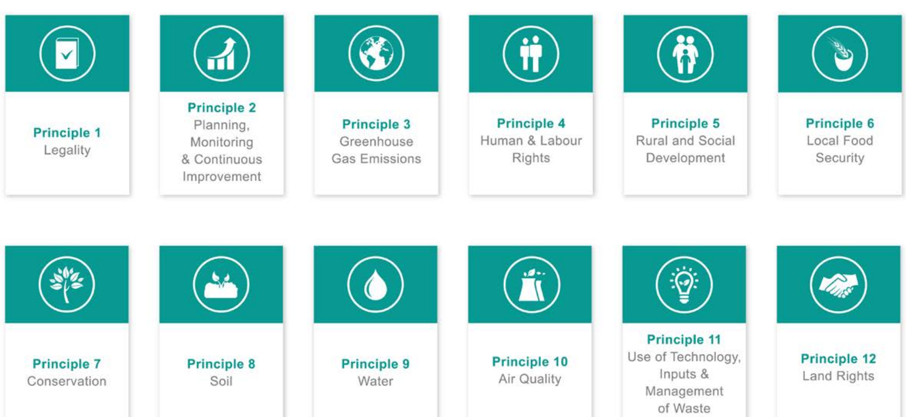
LanzaTech's demonstration plant with Shougang in China, converting steel mill gases to ethanol, was the first RSB-certified biofuel plant in China, and the first of its kind anywhere to receive this key certification for industrial carbon capture and utilization. Ethanol, from the RSB-certified demonstration plant, was converted to drop in jet fuel, used in a world first commercial flight with Virgin Atlantic in 2018. LanzaTech's first commercial plant is operating today in China, making ethanol from steel mill emissions.

Through utilization of waste emissions, this technology enables local production of low carbon fuels which displace the need for fresh fossil inputs; it creates new green employment at waste sites, and by avoiding combustion of gases, the process reduces criteria pollutants which would impact local communities.

TABLE 1: RSB and CORSIA Requirements

Topic	CORSIA requirement	RSB Coverage
Greenhouse Gases	CORSIA eligible fuel should generate 10% lower carbon emissions on a life cycle basis.	RSB's Greenhouse Gas principle requires at least 50% emissions reduction based on a robust life cycle assessment. RSB has vast experience in operating a reliable auditing and certification system to verify GHG calculations.
Carbon Stock	CORSIA eligible fuels should not be made from biomass obtained from land with high carbon stock.	RSB's Conservation Principle covers the CORSIA requirement on carbon stocks by requiring documentation that proves biomass has not come from land converted after 1 January 2008 that was primary forest, wetlands, or peat lands and/or contributes to degradation of the carbon stock in those lands.

TABLE 2: RSB twelve sustainability principles



standard which is already fully in-line with CORSIA requirements.

The RSB Standard is the strongest and most trusted of its kind, recognized as such by the likes of the World Wildlife Fund (WWF), International Union for Conservation of Nature (IUCN), and Natural Resources Defence Council (NRDC). The standard is being used by the international aviation industry to ensure that real, credible sustainability based on 12 Principles is achieved. RSB-certified alternative aviation fuels, adhering to a holistic approach to a broad range of risks, are ensuring real sustainability and lasting solutions for decarbonizing the aviation industry – without creating other social and environmental challenges. Commitment to producing and sourcing RSB-compliant fuels shows the world that an organization is reaching for the very highest levels of sustainability while aiming for significant climate impact through reduced greenhouse gas emissions.

RSB is already assisting operators to ensure they are prepared to lead the development of a cleaner and more responsible industry. Through comprehensive tools and solutions – including certification, advisory services and a step-wise 'road to compliance' approach – RSB is enabling actors from across the supply chain to prepare for the new regulations and beyond as progress is achieved towards the realization of a truly sustainable industry.

At the forefront of sustainability in alternative fuels, RSB has been involved in several world firsts:

- The first biofuel flight in Africa was made by South African Airways (SAA) using fuel produced from RSB-certified solaris tobacco.
- The first commercial flight using fuel produced LanzaTech ethanol on board a Virgin Atlantic jet, with fuel sourced from the RSB-certified fuel plant in Shougang, China.
- The first commercial scale alternative aviation fuel producer, World Energy Paramount, is RSB-certified.
- RSB developed the first, and only, low ILUC module which enables producers to demonstrate that their production has a low risk of causing indirect emissions elsewhere. UPM Biofuels were the first operator to achieve certification for fuels produced from tall oil and Agrisoma carinata seeds.

The RSB supports the development of sustainable alternative fuels for the aviation industry that promote social and environmental sustainability and safeguard food security. This is done by partnering with aviation fuel initiatives worldwide, engaging airlines through membership, and helping supply chain companies achieve RSB certification for their alternative fuels.

Beyond certification, RSB leverages the power of its standard to support the most exciting and innovative projects to ensure that environmental and social sustainability, as well as real GHG emission reductions, are built into their very foundations. It works with partners across the aviation industry globally to develop innovative solutions to the challenges and issues that face those organizations operating on the cutting edge.

Working with RSB, members of the aviation industry are mapping the availability of sustainable resources in different regions in order to answer the key question of *where is all this feedstock going to come from?*

RSB also works with its partners to develop sustainability protocols for their supply chains and to manage credible

The first commercial alternative aviation fuel producer worldwide, World Energy Paramount, is RSB certified.

World Energy is a global leader in the development of alternative aviation fuels – and is instrumental in driving the scaling of supply chains, technical capability, and global supply and demand for cleaner fuels.

By delivering fuels that are RSB certified and demonstrate a minimum 60% GHG emissions reduction against the petroleum-based products they replace – while ensuring other social and environmental impacts are minimal or positive – RSB-certified producers are having a very real impact on the industry's ability to tackle climate challenges.

FIGURE 1: RSB's Involvement with Worldwide Aviation.

stakeholder consultation processes, and more. All of this can lead to RSB Certification or provide a roadmap for achieving it as markets grow. On a larger scale, RSB works at regional or national levels to do the following: develop indicators which benchmark local policy against the RSB Standard, identify crossover and gaps, reduce the time and effort involved in attaining certification, and help governments understand where to direct legislative efforts.

The benefits of integrating the RSB Standard into an operation – whether via certification or other partnerships – are many and extend beyond compliance with CORSIA regulations. RSB enjoys widespread NGO support and its member community and governance structure ensure that social and environmental NGO parties have an equal voice at the table.

The RSB worked with Airbus in Mobile, Alabama to assist the aircraft manufacturer in developing a sustainable vision for the development of sustainable alternative aviation fuels in the region. Working in close partnership with Airbus, RSB conducted a *sustainable feedstock resource assessment* to map the potential for agricultural feedstocks, as well as waste and residues, and to estimate current and potential future production capacity in Alabama and surrounding states. The results of this project are being used by Airbus to shape its commitment to a sustainable aviation industry, and to the economic development of the Mobile, Alabama region.

The RSB Standard is well-aligned with the UN Sustainable Development Goals (SDGs). For example, RSB enables businesses to demonstrate a tangible impact on climate change and SDG 13 (Climate Action) – by demonstrating 50% greenhouse gas emissions reduction as a minimum, as well as Goal 7's Affordable and Clean Energy.

Additionally, bio-economy stakeholders across the supply chain that incorporate RSB's 12 Principles are supporting a number of UN SDGs as follows:

- SDG 6 - Clean Water and Sanitation; by implementing RSB's most rigorous approach to water (as rated by WWF).
- SDG 1 - No Poverty; by ensuring that all production and processing in regions of poverty are tied to meaningful community development, labor rights, food security, and rural and social development.
- SDG 15 - Life on Land; by requiring a rigorous approach to soil conservation, biodiversity and land rights.

In fact, nearly all SDGs are supported by the RSB Standard.

Preparing for Take-Off: RSB and the Role of the Standard in Driving Innovation and Sustainability

By continuously innovating, RSB is able to support stakeholders across the aviation industry to address future challenges before they impact the industry. On the forefront of the very latest technological and sustainability developments, RSB developed an approach for certifying the sustainability of advanced fuels. These fuels are those produced not only from traditional biogenic sources, but also end-of-life products, by-products, and residues (including fossil waste). RSB's Standard for Advanced Fuels, with its groundbreaking approach to managing the sustainable use of waste & residue materials, is the first of its kind. It has been developed to allow the most innovative fuel producers to stay ahead of the sustainability curve – ensuring robust traceability for waste, residues, and end-of-life materials, as well as real sustainability in processing units with a particular focus on the specific risks in play at these facilities, such as the management of water and effluents.

RSB is the first system to develop a methodology for measuring displacement emissions. These are the indirect emissions caused by redirecting a waste feedstock into fuel production from another pathway – thus requiring a new feedstock to be exploited for the original use and potentially causing more emissions.

From certification to research, projects, partnerships, and continuous development of our standard, RSB solutions are geared towards industry leaders that are committed to combatting climate change, promoting environmental health, and ensuring social responsibility across their supply chains. RSB is committed to ensuring it is aligned with CORSIA so that these solutions not only demonstrate the highest level of commitment to environmental and social outcomes – including the UN Sustainable Development Goals – but also compliance with all reporting requirements. With these solutions and cutting edge approaches to the latest sustainability challenges, and a proven track record in supporting the industry, RSB is helping partners to use the best-in-class sustainability and credibility of its standard to drive innovation in the aviation industry – from field and factory to tank.

RSB worked with WWF South Africa on a report conducted in collaboration with the International Institute for Applied Systems Analysis (IIASA) and supported by the Boeing Company to understand the potential for the production of sustainably certified alternative aviation fuels in sub-Saharan Africa. The report found that there is a small, but not insignificant, potential for the production of alternative aviation fuels in sub-Saharan Africa in compliance with RSB's robust sustainability requirements.

RSB works with Boeing and WWF to grow a sustainable bioeconomy in Brazil

As part of a project between RSB and WWF, powered by Boeing's Global Engagement Portfolio, Boeing will invest $1 million into the Brazilian bioeconomy via a commitment that will focus on identifying suitable feedstocks and supporting small-scale farmers across the country achieve RSB certification for the production of biomass for alternative fuels. Boeing aims to develop a truly sustainable aviation industry that will maximise the environmental, social and economic benefits of the bioeconomy – and RSB's approach to sustainability is key in guiding this investment.

Boeing is supporting RSB and WWF's work in Brazil to ensure sustainability in feedstock options and farming practices in order to increase the capacity for sustainable production for the aviation sector. The project will also support a diversification of production that will fuel the broader regional bioeconomy.

CORSIA SAF Certification with ISCC – The International Sustainability and Carbon Certification Scheme

By Gernot Klepper (ISCC-Association), Norbert Schmitz (ISCC-System)

INTRODUCTION

Supporting the objectives of the Paris Agreement to keep the rise in global temperatures to 2 degrees Celsius or less within this century poses a great challenge to the world community. This is especially true for the transport sector. The International Energy Agency expects two thirds of the future oil demand to come from the transport sector .Especially air travel has experienced the highest growth rates in the past and is expected to continue to grow. The need to deal with CO_2 emissions has been recognized by ICAO and the aviation industry, and has led to the adoption by ICAO Member States of the global aspirational goal of carbon neutral growth after 2020. Many measures to achieve this goal will be needed, among them the use of Sustainable Aviation Fuels (SAF). They are of paramount importance in ICAO's basket of measures to reduce GHG emissions. Intensive research activities are now underway to develop new SAF, yet the most prominent and readily available SAF still come from biomass based fuels. Biofuels use an established technology with significant reductions in their carbon footprint, and a proven record in the road transport sector.

The ICAO Assembly acknowledged the need for SAF to be developed and deployed in an economically feasible, socially and environmentally acceptable manner. In many sectors, Sustainability Certification Schemes (SCS) have been implemented to verify compliance of economic operators with voluntary or mandatory sustainability criteria that address this need.

On the current CORSIA Framework, SAF need to comply with sustainability criteria that include:

- A SAF must achieve at least 10% GHG emission reduction on a life cycle basis. There are two ways of assessing such reduction:
  - Default life cycle emissions values provided at the ICAO Document "CORSIA default life cycle emission values for CORSIA eligible Fuels" (to be agreed by the ICAO Council; or
  - SAF fuel producers may calculate actual life cycle emissions values using the methodology to be defined in the ICAO Document "CORSIA Methodology for calculating actual life cycle emissions values"
- A SAF cannot be obtained from biomass obtained from high carbon stock land that was converted after 1 January 2008.

As defined in ICAO Annex 16, Volume IV, compliance with those criteria will be confirmed by Sustainability Certification Schemes (SCSs) to be approved by the ICAO Council. Such SCSs will need to comply with the requirements from the ICAO Document "CORSIA Eligibility Framework and Requirements for SCS".

Essentially, the International Carbon and Sustainability Certification (ISCC) is a SCS which is already in operation. The following section details the background and relevant experience of ISCC, aiming to illustrate typical aspects of sustainability certification that are representative to CORSIA requirements.

BACKGROUND OF ISCC

ISCC is a multi-stakeholder initiative governed by an association of more than 100 members from over than 30 countries. The program began operations in 2010 and has issued more than 20,000 certificates over the past eight years. Currently, more than 3,300 companies in 100 countries are ISCC certified. A continuous multi-stakeholder dialogue on the global and regional level is of fundamental importance for the further development of the scheme.

Currently, ISCC offers two certification schemes to address different market requirements:

- ISCC EU is recognized by the European Commission for proof of compliance with the legal requirements of the Renewable Energy Directive (RED) and the Fuel Quality Directive (FQD) in all Member States of the European Union (EU).
- The ISCC PLUS scheme is a voluntary certification for non-regulated markets and covers food, feed, and industrial applications on a global scale, as well as biofuels for non-EU markets. For instance, in 2018 ISCC PLUS was recognized by the Government of Japan for the verification of compliance of imported biofuels with Japan's mandatory sustainability requirements. ISCC is also accepted for the verification of compliance with certification requirements of the Liquid Fuel Supply Regulation of Queensland, Australia, since January 2017.

ISCC is committed to an environmentally, socially, and economically sustainable production of biomass and products derived from that biomass. For that, the ISCC certification requirements reflect the ten principles of the UN Global Compact with respect to human rights, labour, environment and anti-corruption. ISCC actively supports many of the United Nations Sustainable Development Goals (SDGs) by aligning the certification requirements with the associated targets, and by endorsing and implementing sustainability projects.

The ISCC Sustainability Requirements are divided into six principles and are applied to the most environmentally and socially sensitive activities on farms and plantations (see Figure 1).

FIGURE 1: ISCC Sustainability Principles

All kinds of agricultural and forestry feedstocks, as well as waste and processing residues can be certified by ISCC. Currently, around 50 million tons of agricultural feedstock and 10 million tons of waste and processing residues are certified under ISCC. Used cooking oil and animal fat make up the majority of waste and processing residues.

Traceability in supply chains must be ensured. According to the International Organization for Standardization (ISO), the term traceability describes the ability to identify and trace the origin, distribution, location, and application of products and materials through supply chains. This is obtained in the ISCC system through the individual certification of every supply chain element. Relevant product properties and related sustainability characteristics are forwarded through the supply chain by using sustainability declarations.

Chain of Custody is a general term used for making a connection between the sustainability claims of economic operators along the value chain. The combination of both traceability and chain of custody requirements ensures that the physical flow of materials can be traced back and forth throughout the supply chain, thus guaranteeing the integrity of sustainability certificates. This also ensures that sustainability characteristics can be assigned to individual consignments of material, and that the amount of sustainable material withdrawn from the supply chain

FIGURE 2: Forwarding of sustainability information in an ISCC certified supply chain for HEFA

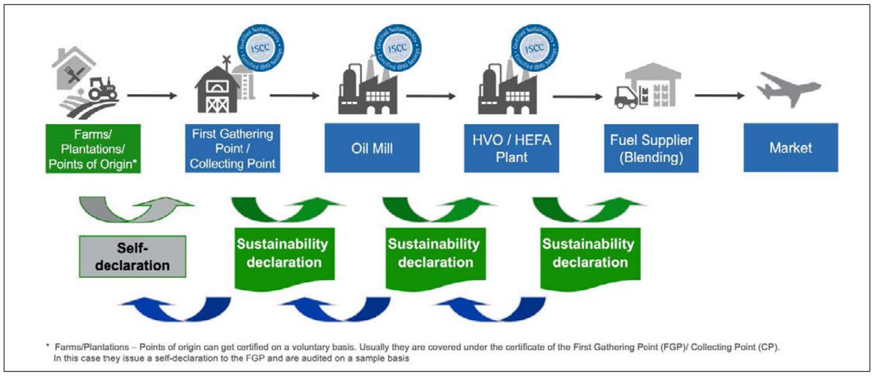
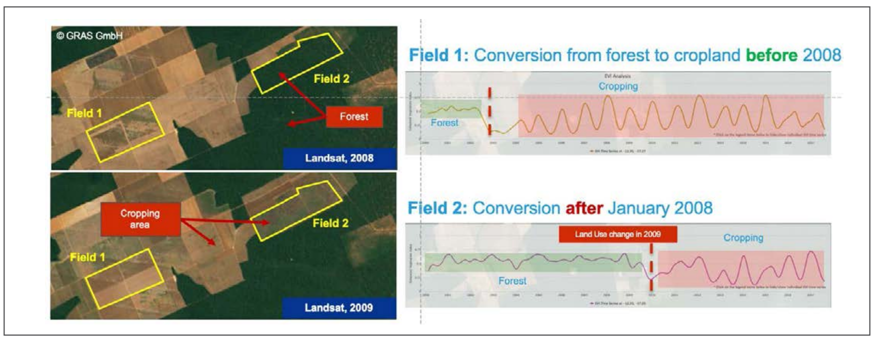


FIGURE 3: Analysis of the EVI time series indicates the exact time of the land use change and the type of land cover before and after the conversion



at any stage does not exceed the amount of sustainable material supplied. The Mass Balance methodology allows the physical mix of sustainable and non-sustainable products at every stage of the value chain. The specific properties of sustainable material are determined via bookkeeping.

ISCC ACTIVITIES IN THE AVIATION SECTOR

Many ISCC compliant products are associated with renewable energy uses, including fuels.. So far, ISCC certified fuels have been mainly used in road transportation. The experience gained in that market is of high value for the deployment of SAF. ISCC is also a member of the Aviation Initiative for Renewable Energy in Germany (aireg). Most jet fuel producers and feedstock suppliers are members of the ISCC association or are active users of the system. ISCC-certified jet fuel has been used by Lufthansa in a pilot program. ISCC is also involved in a practical project aimed at analyzing the reporting and monitoring requirements in supply chains that involve multi-blends of fossil and sustainable jet fuels, as shown in Figure 2.

Experience Gained With Verification of Land Use Change

The Sustainability Criterion 2 of CORSIA requires that SAF, "... should not be made from biomass obtained from land with high carbon stock". Such high carbon stock areas and direct land use change can be identified by using appropriate databases and satellite images.

ISCC uses the latest remote sensing technologies to support the verification of land use change and to ensure that supply chains are deforestation-free. Based on the Enhanced Vegetation Index (EVI), changes in vegetation cover can be detected. Different types of green cover can be distinguished to understand the land use history, and most importantly determine the type and exact point in time of a land use change that may be in conflict with sustainability requirements (Figure 3).

This method allows a credible and cost efficient verification of compliance with carbon stock sustainability requirements.

GHG Emission Calculations and Reductions

ISCC certification covers the GHG emissions of all elements of the supply chain, from raw materials production to distribution of the final product, including cultivation, collection, and conversion processes, as well as the transport and distribution of intermediate and final products. ISCC offers a choice of using default or actual life cycle emission values. The number of certificate holders using actual values is constantly increasing, indicating a rising market relevance of GHG performance of renewable fuels.

While in the beginning there was only little known about the impact of GHG emissions and how GHG savings can be achieved, ISCC system users are now well-versed in analyzing their energy balances and in taking actions to reduce GHG emissions. This is not only apparent in the clear trend towards the use of actual values, but also in the improvement of the GHG savings of biofuels used in the EU market as is illustrated in Figure 4.

ISCC has implemented a comprehensive set of measures to guarantee a high quality GHG calculation and verification. Specific measures consist of the following:

- Specific ISCC GHG training sessions for auditors and system users.
- Audit procedures with detailed guidance on GHG requirements.
- Specific system updates on ISCC GHG requirements.
- List of Materials eligible for certification under ISCC (i.a. to support classification of feedstock).
- ISCC Integrity Program with focus on GHG calculations.
- Application of the GRAS tool with lists and maps of regional agricultural crop GHG values and carbon stocks.

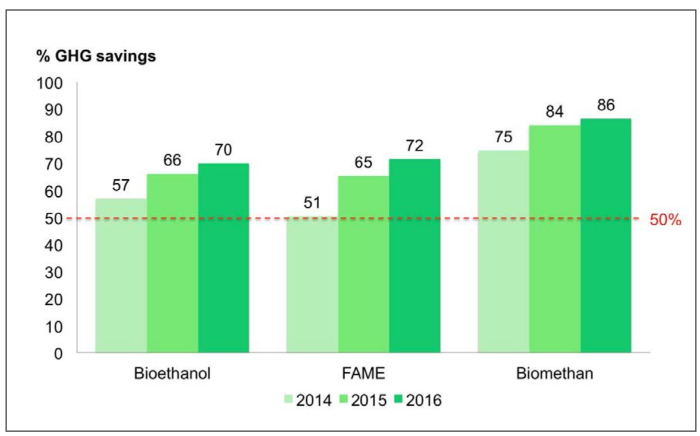
Outlook: How SCSs Can Support the Implementation of CORSIA

Many economic operators **such as agricultural producers, waste collectors, traders and fuels producers in** potential SAF supply chains are already certified and are familiar with sustainability requirements and GHG calculations. On a global scale, large volumes of certified feedstocks that can be used for the production of SAF are already available. In 2018, ISCC certified approx. 70 million tons of agricultural and waste feedstocks. In the same year, approx. 18 million tons of ISCC certified renewable fuels were sold to the markets.

The use of existing SCS for compliance with CORSIA, as defined in Annex 16 vol IV, will help to bring commercial SAF quantities to the market. It also reduces the organizational and cost burden on companies in the supply chain, and thus will increase acceptance.

ISCC is a well experienced SCS with innovative tools to verify in a reliable way sustainability requirements set by CORSIA. ISCC is prepared to further support the CORSIA process and to contribute to a successful deployment of SAF in future.

FIGURE 4: GHG savings from biofuels in Germany - 2014 – 2016 (Source: German Federal Office of Agriculture and Food). (FAME - Fatty-Acid Methyl Esters)



Sustainable Aviation Fuels – Progress through Collaboration

By International Coordinating Council of Aerospace Industries Associations (ICCAIA)

The development and use of sustainable aviation fuels (SAF) is critical for aviation to meet its commitments to greenhouse gas emissions reduction. Climate change is a global challenge that affects the whole planet, and is driven in part by the actions of all participants in the aviation value chain. The development of SAF is an effort that requires a similarly broad set of stakeholders to work together toward common goals in a coordinated manner. It also necessitates stable policy frameworks to incentivize its capacity and production.

The original equipment manufacturers (OEM) that supply the aviation industry, and work together under the banner of the International Coordinating Council of Aerospace Industries Associations (ICCAIA), are not users nor producers of significant volumes of SAF. However, they have a strong interest in the successful commercialization of large-scale supplies of these new fuels, as the continued growth and social license to operate for the OEMs' customers depends upon that outcome. Therefore, OEMs have recognized the need for partnership and collaboration as a key strategy in addressing their strong, but indirect, interest in SAF's success.

EXAMPLES OF COLLABORATION

OEMs have been active members of a range of different partnerships for collaborative action over the last decade of SAF development. The following are a few important examples, but are by no means an exhaustive list. They are presented here to illustrate the range of partnerships that have helped move the industry toward its SAF aims, and the types of engagements that have been developed to address important market barriers.

CAAFI: One of the first coordinated multi-stakeholder collaborative was the Commercial Aviation Alternative Fuel Initiative (CAAFI). Launched in 2006 in the United States, CAAFI is a coalition of aviation operators, OEMs, biofuel companies, technology providers, researchers, and U.S. government agencies. This public-private partnership has coordinated action across industry and government to "build relationships, share and collect data, identify resources, and direct research, development, and deployment of alternative jet fuels"[1]. Although the focus and center of gravity of CAAFI's membership is the United States, it does draw on an international membership and actively engages with a range of parallel and connected stakeholder groups in other regions of the world.

SAFUG: In a more direct display of support for their customers, several OEMs are affiliate members of the Sustainable Aviation Fuels User Group (SAFUG) founded in 2008. Boeing, Airbus and Embraer have joined 28 of their customer airlines in SAFUG, along with Honeywell UOP and Aeropuertos y Servicios Auxiliares. This organization strongly signals market demand for SAF from buyers of nearly a third of the global jet fuel market, and places a clear emphasis on the importance of sustainability in the provisioning of these fuels.

ASTM: One clear example of the important role OEMs have in easing market barriers for SAF is in their collaboration with the wider aviation fuel community in the working of the standard-setting body ASTM International. Novel fuel

1 http://caafi.org/about/caafi.html

types are assessed and approved by subcommittee D02.J0 on Aviation Fuels in ASTM International Committee D02 on Petroleum Products and Lubricants, which consists of more than 2,000 members representing 66 countries. Within this subcommittee, the evidence supporting the development of new specifications is synthesized and presented by SAF producers. OEMs then review the properties of the fuel and whether it is fit for purpose, before a new specification goes to a vote across the whole subcommittee. This broadly inclusive process is a model of collaboration around ensuring that the top priority of the aviation industry — safety — always comes first in the deployment of new fuel solutions.

In order to support this certification and enhance its efficiency, OEMs are also strongly involved in collaborative research projects dedicated to the better understanding and modelling of fuel interactions with all aircraft parts. Projects such as JETSCREEN (JET Fuel SCREENing and Optimization) in EU or ASCENT NJFCP (National Jet Fuel Combustion Program) in the US are excellent examples of such efforts.

ICAO: Through membership in ICCAIA, OEMs participate in the work of ICAO in supporting its member states to achieve the 2050 ICAO Vision for Sustainable Aviation Fuels. ICCAIA is an observer and has participated in the establishment of the CORSIA scheme and its rules by which SAF will be eligible for inclusion and credit. The deliberations over CORSIA have encompassed the opinions and expertise of representatives from countries across the globe, aviation and energy industry experts, NGOs and OEMs. In addition, again through membership in ICCAIA, OEMs such as Bombardier participated in the technical committee of the working group assessing and defining sustainability criteria based on scientific based life cycle analysis (ICAO Alternative Fuels Task Force (AFTF)). This is an example at the truly global scale of collaboration necessary to ensure that aviation's environment goals are met, and that sustainable fuels are a component of that solution.

Business Aviation: our Sustainable Alternative Jet Fuel (SAJF) Guide was launched by a consortium of five of the sectors' associations led by GAMA, with support from EBAA, IBAC, NBAA and NATA, and with significant contributions from Bombardier, Gulfstream, Av Fuel and World Fuel. The guide seeks to demystify the use of alternative fuel for our operators and sets a path to ensure the wider use of alternative fuel across our sector. Business aviation has already completed and plans further demonstration events, working closely with business aviation specific airports to further the wider use and take-up of this important technology that will help the sector achieve its long-term climate goals as set out in the Business Aviation Commitment on Climate Change.

CASE STUDY – COLLABORATION FOR FUTURE OPPORTUNITY – ECODEMONSTRATOR 100% BIOFUEL FLIGHT

As mentioned above, OEMs have a unique position in being the key gateholders of verifying technical performance of novel SAF technologies. By collaborating with technology providers, OEMs can evaluate the performance of novel fuel chemistries, blends or production processes. Boeing's ecoDemonstrator program has, over the past few years, provided such an opportunity. Across platforms such as Boeing's 737, 757, 787 and 777 and Embraer's E170, novel biofuel technologies have been tested and demonstrated in a fully operational environment. In 2012, a 737 used a blend of biofuel sourced from used cooking oil supplied by Dynamic Fuels via SkyNRG. Green diesel biofuel was used for the first time in an airplane, when Neste-provided fuel was blended at 15% and flown on 787 and 757 ecoDemonstrators in 2014 and 2015, respectively. A blend of Brazilian-sourced SAF was used to power the 2016 ecoDemonstrator, an Embraer E170. Then, most recently, Boeing demonstrated the first flight using 100% SAF on a commercial airliner, by using a completely paraffinic biofuel in a 777 Freighter.

PRIVATE-PUBLIC PARTNERSHIP ON SAF DEPLOYMENT

The industrial development of sustainable alternative fuels implies a strong collaboration between all private actors (aerospace industry, fuel producers, biomass suppliers, airports, airlines etc.) but also with public bodies in order to remove potential barriers and support this deployment. As an example, the French initiative of ECV

("Engagement pour une Croissance Verte" – bio-jet fuel Green Deal) gathers main French industries (Total, Suez, Safran, Airbus, Air France) and French administrations (Environment, Transport, Industry) in order to study the technical, administrative and financial conditions that would allow the deployment of a SAF pathway in France. In Germany, the initiative for jet fuel made from renewable energy AIREG – Aviation Initiative for Renewable Energy in Germany e.V. – combines commitment, knowledge and years of experience from industry, business and science in the aviation sector. AIREG drives the research, production and usage of sustainable aviation fuel in Germany.

COMMERCIAL COLLABORATION

As the Sustainable Aviation Fuel enterprise is transitioning from pre-commercial activities in developing and maturing technologies — and addressing market barriers — toward now entering commercial deployment and routine application, the mode of collaboration is also changing. Contractual relationships and partnerships are emerging as companies are positioning themselves within the value chain.

A key lever that airframe OEMs have seized to help drive scale and affordability in supplies of SAF has been to enter into purchase contracts with first moving biofuel producers, so that their own operations in production, support, certification and the delivery of aircraft to their customers can be fueled sustainably. In this regard, Airbus has partnered with Air Total, Gulfstream has partnered with World Fuel Services, and Boeing has partnered with World Energy LLC and EPIC Fuels. Gulfstream recently announced it would offer SAJF to their customers using its Long Beach, CA facility. These contracts help demonstrate commercial feasibility, and contribute to the demand that will help drive greater scale in production of SAF.

Additionally, the General Aviation segment has becoming increasingly active in publicly demonstrating that SAJFs is reliable and safe to use. A dynamic coalition established in May 2018 that encompasses the International Business Aviation Council (IBAC), the General Aviation Manufacturers Association (GAMA), Bombardier, the National Air Transportation Association (NATA), the European Business Aviation Association (EBAA) and the National Business Aviation Association (NBAA) has triggered key projects involving fuel suppliers and distributors with FBOs and OEMs as well as owners and operators to increase visibility and availability of SAF. This was highlighted on 17 January 2019 at Van Nuys, CA at business jet event called "Business Jet Fuel Green: A Step Toward Sustainability". Similar events highlighting business aviation's commitment are expected in the future.

Some manufacturers have worked at the level of delivery flights to airline customers. Since 2016 Airbus has initiated concrete aircraft operations including sustainable aviation fuels in regular delivery flights from its Final Assembly Lines across the world. Since then more than fifty flights of several types (A320s, A330s, and A350) have been successfully performed by five airlines.

Some aviation industry companies have demonstrated an even deeper commitment to not just being a buyer of SAF, but actually being financially involved in the companies and projects that produce these fuels. For example, Cathay Pacific, United and Japan Airlines have taken equity positions in Fulcrum BioEnergy, which is developing a municipal solid waste-to-fuels business. Fulcrum has also demonstrated the benefits of collaboration and partnership in the development of its business, formalizing a wide range of partnerships across the waste-to-fuels value chain, aside from the aviation industry entities already mentioned. Companies as diverse as Waste Management, Praxair, Marubeni and BP have all been brought into the development of Fulcrum's business plan. This breadth of collaboration, and the novels connections made in establishing it, illustrate the necessity and advantages of cross-sector collaboration in the SAF space.

CONCLUSION

The development and commercialization of sustainable fuels for aviation has been an effort that has brought together a breadth of collaboration that is unprecedented in the history of aviation. It has encompassed not only airlines, OEMs, and energy companies, but also agricultural, forestry, and waste management stakeholders. There have been contributions from researchers, NGOs and government actors, as well as strong buy-in from the flying public. Collaboration among all these stakeholders, as they have strived together towards common goals, has been the key to the progress made over the last decade of SAF development. For the future, it will be crucial to tackle issues linked to SAF commercialization and economic viability. The cost differential between fossil fuel and renewable jet fuel remains very high and stable policy frameworks are required to incentivize renewable jet fuel capacity and production.

SkyNRG – Moving Toward a Sustainable Future for Aviation

By Martin Struijker Boudier (SkyNRG)

Flying is essential for individuals and businesses globally, but the carbon footprint of aviation is significant and growing rapidly. Sustainable aviation fuel (SAF) is the only known way to significantly reduce the dependency on fossil jet fuel in the near term and thereby create a sustainable future for aviation. By building a new industry for SAF, all stakeholders in the aviation industry can work together to create a sustainable future for aviation.

In order to secure significant SAF volumes for the future, SkyNRG also focuses on developing regional SAF supply chains -e.g., DSL-01, that offer a real sustainable and affordable alternative to fossil fuels. Project DSL-01, which was announced by the company in the first half of 2019, will be the first European dedicated production plant for sustainable aviation fuels and is part of this new path forward.

SKYNRG MILESTONES AND ACHIEVEMENTS

SkyNRG is global market leader in sustainable aviation fuel solutions, having supplied over 30 airlines on all continents. The company's mission is to make SAF the new global standard. SkyNRG sources, blends and distributes SAF, while guaranteeing sustainability throughout the supply chain. It also helps to co-fund the price gap over conventional jet fuel and is involved in the commercialization of new conversion pathways.

The SAF industry has made impressive advancements since its inception in 2009 and SkyNRG has been at the forefront of these developments. What started out as SkyNRG supplying a few barrels of SAF for the world's first biofuel flight in 2011, has led to the company currently supplying large volumes of SAF directly into airport tank farms. SkyNRG has a long term off-take with World Energy and a partnership with Shell Aviation. In 2018 and 2019 the company supplied SAF to Air Canada, ANA, Bombardier, JAL, KLM, the Royal Netherlands Air Force, SAS, Singapore Airlines, and Swedavia.

NEXT STEPS TOWARD SAF

Now that the industry has moved beyond the demonstration phase to a stage where SAF is produced commercially and used on a daily basis, the next challenge is to scale-up. For project DSL-01, and future DSL's, there are some key enablers that are essential to create an investable business case. These essentials are key priorities guiding the company's and the industry's activities going forward:

1. **Bridge the price gap to create a market**. Involve the different stakeholders, including governments and end-users, to create demand for SAF.
2. **Continue to ensure sustainability**. Sustainability is a precondition for doing business; SkyNRG's Sustainability Board goes above and beyond regulation.
3. **Build self-sustaining networks of regional supply chains (DSLs).** Enabled by the demand, and within the sustainability framework, SkyNRG is developing SAF supply chains (DSLs) using commercially available technology.

4. **Quality assurance and efficient downstream operations.** To optimize logistics, the company further integrates SAF supply with existing jet fuel supply chains.
5. **Innovate to diversify SAF production pathways.** New feedstock and technology combinations are needed for future production facilities; SkyNRG is involved in commercialization tracks.

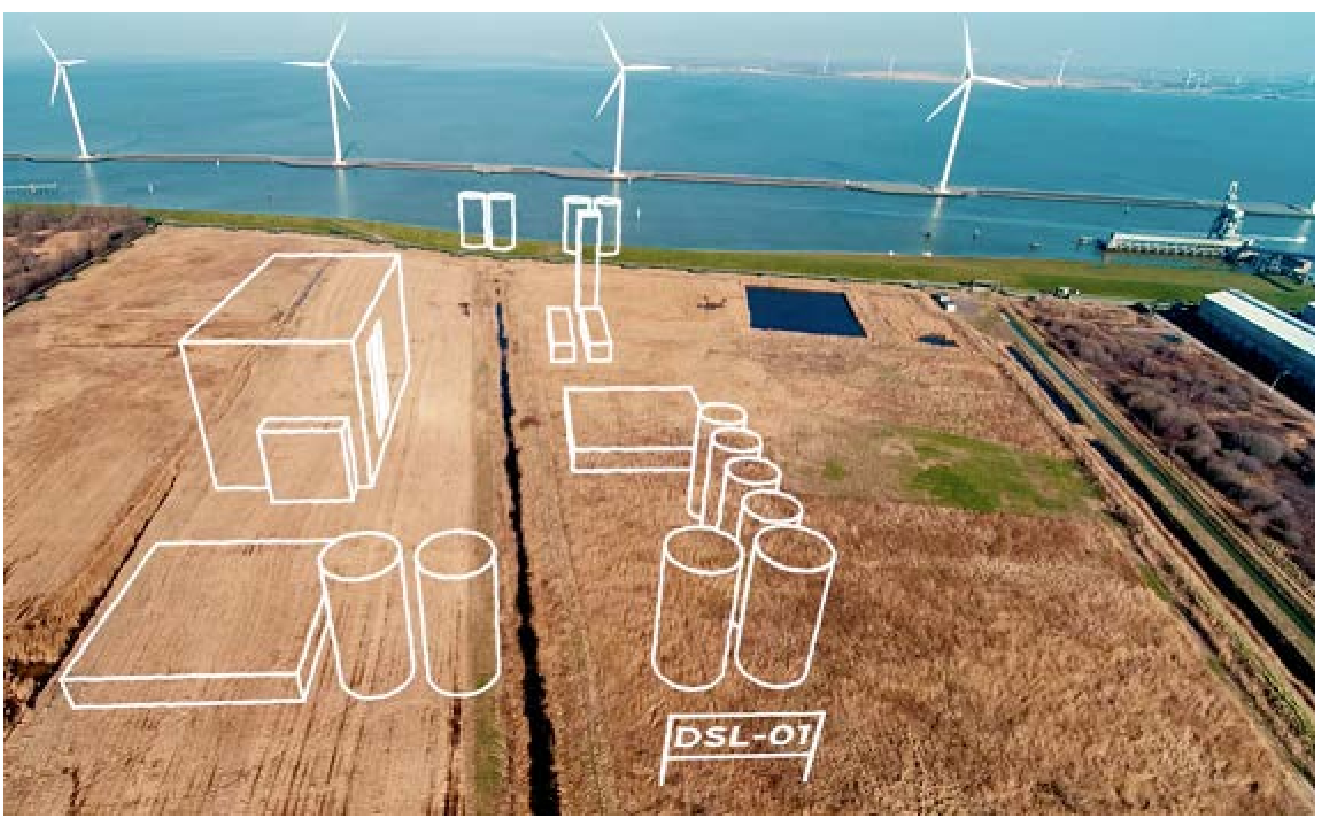
Together with its partners, SkyNRG is working to overcome current challenges and grow the market for SAF in pursuit of aviation's climate mitigation goals. The following sections explain how this can be achieved.

1. CLOSING THE PRICE GAP

Although prices have dropped significantly in the past decade, sustainable aviation fuels are still more expensive than conventional jet fuels. At present, SAF is approximately two to three times more expensive, depending on the feedstock, technology and set-up of the supply chain. The price premium, the price gap between SAF and fossil jet fuels, has been the biggest challenge limiting large-scale uptake of SAF to date.

To compete with fossil fuels and build this new industry, government involvement is crucial. A level playing field needs to be created with the road transport sector through the drafting and implementation of stable and effective policies. As seen by recent project announcements, one of the most impactful measures to lower the price premium and increase supply, are government incentives. It is essential that governments worldwide realize that they can and must play an important role in providing the right instruments for the aviation sector.

Currently, SkyNRG covers part of the premium with innovative co-funding mechanisms where it collaborates with airlines, airports and companies. Over the past decade, SkyNRG has initiated a variety of customer programs (e.g., KLM Corporate BioFuel Programme, Fly Green Fund). These types of programs enable, companies, individual travelers, governments, and NGO's to fly on sustainable aviation fuels, thereby reducing their travel emissions and supporting the growth of an industry that provides a sustainable alternative to fossil fuels.



Organizations from around the world are stepping up by choosing to fly on SAF through such programs. With their commitment they do not only reduce carbon within the aviation sector, rather than compensate elsewhere through existing offset programs. They also stimulate development of new production capacity, bring down the price premium and spur technology development that is needed for the energy transition in aviation.

In order to make these programs successful, SkyNRG needs the help of both governments and ICAO for alignment on the measurement and accounting of aviation-related CO_2 emissions. On national and international levels, the carbon reduced by the use of sustainable aviation fuel is measured inconsistently, using different standards for different targets. ICAO needs to be aware of the different ways that the carbon reductions from SAF usage are measured by different countries on various continents. The accounting procedures of CORSIA need to be aligned with the accounting procedures which are already in place. Another concrete way to support these programs and the industry at large, is of course by countries and organizations voluntarily committing to fly on SAF.

2. GUARANTEEING SUSTAINABILITY THROUGHOUT THE SUPPLY CHAIN

SkyNRG believes that the impact of bioenergy on social and environmental issues varies depending on local conditions and the design and implementation of a project. In order to make sure that every feedstock used and fuel delivered is truly sustainable, the company has established three measures that exceed the sustainability criteria set out by the European Union's latest Renewable Energy Directive (RED II).

RSB Certification

All SkyNRG operations and products are certified by the Roundtable on Sustainable Biomaterials (RSB). The RSB is a multi-stakeholder organization that has established the most encompassing certification scheme to guarantee social-and environmental sustainability.

Independent Sustainability Board

Every time SkyNRG considers a new feedstock, or when it needs advice on the true GHG-performance of a certain feedstock-technology combination, it consults the members of its Sustainability Board to share their knowledge and opinions. That Board, which includes representatives from WWF International, European Climate Foundation, Solidaridad Network, and the Energy Research Centre in the Netherlands

Non-Governmental Organization (NGO) Network

The last measure entails SkyNRG's ongoing dialogue with its extensive NGO network. The company is involved in projects all over the world and is well aware that different regions face different sustainability challenges. Constant dialogue with local NGO's is essential to make sure that important information is not overlooked. These organizations keep SkyNRG abreast of the current challenges, opportunities, and the latest developments in the various regions.

Through these measures, it is the intent of SkyNRG to step up its game and lead by example. Sustainability is constantly evolving, and merely relying on policies and standards often means that one is not up to date with the latest developments. Being on top of sustainability also means the development and implementation of strict policies when it comes to feedstocks. For example, SkyNRG primarily uses waste and residue streams to produce its fuels. Crops which can be used for feed or food are not used. Displacement emissions are avoided, and indirect displacement effects are carefully considered. SkyNRG has not and will not use palm, soy, or any of their derivatives as feedstocks for its fuels. There is not enough sustainable palm (or palm residue) products on the market to satisfy the enormous demand for palm (or PFAD). Therefore, the company believes that buying these products, even if certified, will result in increased usage of uncertified and untraceable products in other markets. This will cause further deforestation and pollution. For that reason, these feedstocks will not be used for its fuels.

3. DIRECT SUPPLY LINES

SkyNRG has set out to build a self-sustaining network of regional supply chains, known as Direct Supply Lines (DSL's). A DSL is a supply chain for sustainable aviation fuel that consists of local feedstock, a commercial fuel production plant, and long-term offtake partners.

Supported by EIT Climate-KIC, SkyNRG has installed 'Team DSL', a dedicated team of experienced professionals who will analyse, finance, and develop a network of DSL's throughout Europe. Team DSL focuses on selecting a location, feedstock and technology for DSLs and ensuring that they are developed as replicable and profitable business models. To capture all environmental and socio-economic benefits of the selected DSLs, the team is advised by SkyNRG's Sustainability Board and adheres to the company stringent sustainability standards.DSL-01

The first of these Direct Supply Lines, DSL-01, is currently being developed in Delfzijl, The Netherlands. Partners to this project include KLM Royal Dutch Airlines, SHV Energy, Schiphol Airport, and many others.

The feedstocks used for production will be waste and residue streams, such as used cooking oil, coming predominantly from regional industries. The facility will run on sustainable hydrogen, which is produced using water and wind energy. DSL-01 is expected to start production in 2022.

But our ambition doesn't stop there, if we want to meet the industry's CO_2 emission targets we need to rapidly increase the supply of SAF. That is why SkyNRG has already identified opportunities for further DSL's whereby we can replicate the DSL blueprint. These DSL's might use different types of sustainable feedstocks and different conversion technologies. This technology-agnostic approach allows us to adapt to the regional context and stakeholder preferences.

Each DSL will be a high impact, high visibility project and SkyNRG is continuously looking for strong and reliable strategic partners throughout the supply chain (feedstock suppliers, technology providers, locations & sites, EPC companies, customers, financiers, etc.).

4. QUALITY ASSURANCE AND DOWNSTREAM OPERATIONS

SkyNRG has been responsible for most SAF supplies since the introduction of SAF in 2011 and set up the respective supply chains. SAF supply chains are tailor-made solutions based on customer demand and economic and sustainability criteria. SkyNRG works together with its production, logistics and quality partners to deliver SAF to airports globally in a safe and sound way. Quality assurance is a key element – the company ensures that: neat SAF complies with ASTM D7566 specifications, the SAF is blended with fossil Jet A/A-1, and the blended SAF complies with conventional jet fuel standards ASTM D1655, DEFSTAN 91-091 and EI1530 JIG guidelines.

Early SAF supply chains were characterized by extensive segregated operations to fuel specific aircraft. However, today SAF is integrated into the existing jet fuel infrastructure as much as possible to increase efficiency and reduce costs. As a result, a growing number of airports have received SkyNRG's SAF into their commingled fuel system, including Los Angeles (LAX), San Francisco (SFO), Oslo (OSL), Stockholm (ARN), and Toronto (YYZ).

To assure quality and efficient downstream operations, SkyNRG and Shell Aviation have a long-term strategic partnership to promote and develop the use of SAF in aviation supply chains. The collaboration combines Shell Aviation's technical and commercial expertise, world-class supply chain, and carbon management operations, with SkyNRG's proven track record of supplying SAF, and its in-depth knowledge of this market. The agreement is a multi-year collaboration, with both companies acknowledging that the path to lower carbon emissions in aviation requires long term commitment. The collaboration will focus on joint development and funding of new opportunities to extend the use of existing SAF supply chains and the establishment of more resilient supply chains in the future.

5. INNOVATION

It has been proven that SAF production is feasible on a commercial scale and with high-level CO_2 emissions reductions. However, to reach large-scale market penetration, there is a need to diversify the feedstock and technology base for SAF production. This is a maturing area of research and many alternative production pathways are being developed. It is widely recognized that there is no one "silver bullet" solution, and that a mix of technologies is needed to reach global aviation's CO_2 emission reduction targets.

SkyNRG believes that the only way to get insights into the viability of these emerging tracks is to get directly involved with these developments. The company is therefore currently involved in roughly a dozen innovation projects. As such, it works closely in consortia with partners that represent the entire supply chain towards the common goal of finding commercially viable SAF production pathways. This could include such initiatives as the development of a pilot project or a demonstration facility, or an effort towards ASTM certification of the fuel.

Over the past decade this work has yielded valuable knowledge and experience for all potential SAF production pathways. Some initiatives proved not to be viable, but other initiatives were successful and SkyNRG continues to develop these pathways. Through experience, the company knows which pre-conditions are required to have a viable business case for each technology. Eventually, some of these long term development tracks will result in future DSLs. Because SkyNRG is not tied to any particular technology, it has the flexibility to adapt to a specific regional context and it knows that future plants will require different technological solutions than the ones available today.

ALWAYS SEEKING NEW PARTNERS

To meet future demand for SAF, large-scale investment is needed. This will result in the necessary economies of scale required to make the shift from conventional jet fuel to SAF possible. To make the aviation industry a sustainable one, the understanding, support, and investment of governments, entrepreneurs, and pioneers is required.

SkyNRG is continuously looking for new partners to help accomplish its mission to create a sustainable future for aviation. Although the company has many partnerships already in place with airlines, airports, governments, NGO's, and companies, it is always looking for additional partners.

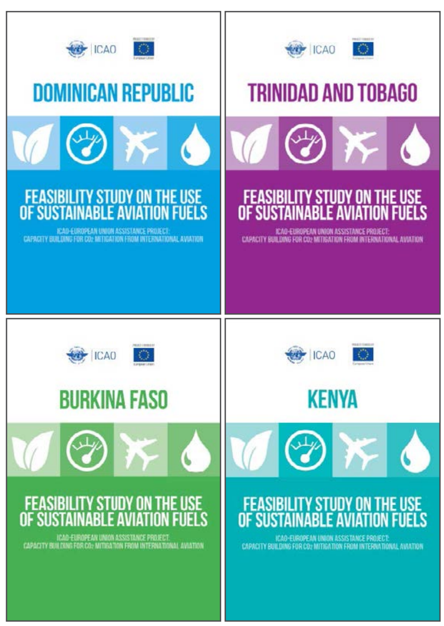
Capacity Building for CO_2 Mitigation from International Aviation

Results of the feasibility studies on SAF: Africa and the Caribbean

By ICAO Secretariat

BACKGROUND

From December 2013 to June 2019, ICAO and the European Union have cooperated under the "Capacity Building for CO_2 Mitigation from International Aviation" partnership. This partnership, referred to simply as the "ICAO-EU Project", is a project funded by the EU and implemented by ICAO to support fourteen selected States in Africa and the Caribbean with the development of their State Action Plans (see Chapter 9 for more information on State Action Plans), the installation of tailor-made CO_2 emissions reporting software (the Aviation Environmental System (AES)), and the implementation of pilot mitigation measures and commissioning of feasibility studies.



The feasibility studies developed within the context of the ICAO-EU Project included studies on the use of sustainable aviation fuels (SAF) in the Dominican Republic, Trinidad and Tobago, Kenya, and Burkina Faso. While SAF are only one of the mitigation measures that can be considered for reducing a State's CO_2 emissions from international aviation, broader environmental, economic, and social benefits can stem from the establishment of a SAF supply chain within a State. In order to assess the potential benefits, it is important for States to consider their specific national circumstances. Therefore, conducting a feasibility study can be a valuable first step toward the establishment of a SAF supply chain, and a valuable tool to include more States from across the ICAO Regions as suppliers of SAF, hence escalating the production of such SAF.

In order to identify the national conditions of the State, each feasibility study began with an assessment of the regulatory context, the existing infrastructure, key stakeholders, roles of government and industry, and on-going and implemented actions in the field of alternative fuels. The main objectives were to define the potential capacity and demand for such fuels, while also taking the environmental, economic, and social impacts into account.

These SAF feasibility studies each include a proposed roadmap for the State to develop a SAF supply chain, which has been validated at the national level with all the stakeholders from the government and the industry. These detailed roadmaps include specific actions that the State can take in order to achieve their SAF goals. While each study focuses on the unique context of a single State,

FIGURE 1: Suitable land for sugarcane cultivation (Dominican Republic Feasibility Study on the Use of Sustainable Aviation Fuels, 2017)

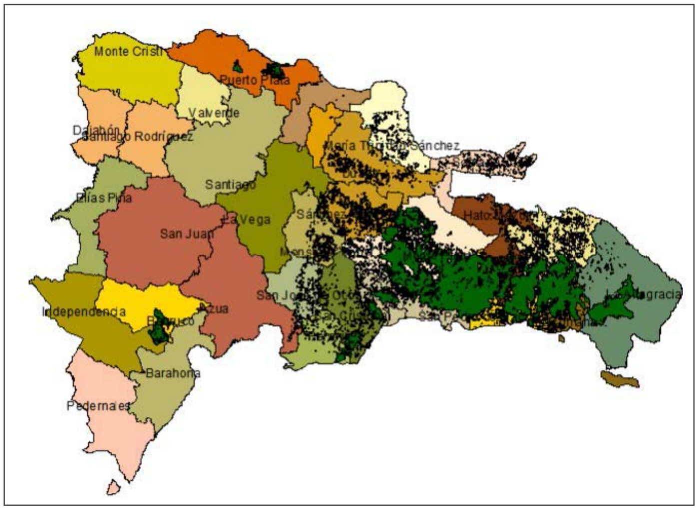


FIGURE 2: Declaración de Punta Cana (Dominican Republic Feasibility Study on the Use of Sustainable Aviation Fuels, 2017)

DECLARACIÓN DE PUNTA CANA

IMPLEMENTACIÓN DE UNA HOJA DE RUTA PARA EL DESARROLLO Y USO DE COMBUSTIBLES ALTERNATIVOS SOSTENIBLES PARA LA AVIACIÓN EN LA REPÚBLICA DOMINICANA

Los representantes del Estado Dominicano, reunidos en Punta Cana, República Dominicana, el 16 de Diciembre de 2016, conscientes de la importancia y trascendencia de las cuestiones de medio ambiente y cambio climático, y alentados por las iniciativas globales para el desarrollo y uso de combustibles sustentables para la aviación, como una estrategia a largo plazo para el transporte aéreo;

these documents can provide guidance to other States that are interested in conducting feasibility studies or establishing SAF supply chains.

DOMINICAN REPUBLIC[1]

The first feasibility study under this project was conducted in the Dominican Republic. While several potential feedstock types were analysed, sugarcane was identified as the feedstock with the most significant potential for the State. Importantly, the use of sugarcane as a SAF feedstock would not displace other crops or interfere with the use of sugarcane as a food crop.

As an outcome of the study, the Dominican Republic has created a national committee for environment and aviation to facilitate information sharing related to SAF at the national level. This cooperation has led the major Ministries and government institutions of the State to sign the “Punta Cana Declaration” which includes a commitment to pursue the main actions outlined in the feasibility study roadmap.

In the medium-term, the feasibility study recommended that the Dominican Republic prepare a framework for potential investments in the production and use of SAF. This can be accomplished through adapting existing regulations and standards to include SAF, disseminating information to national stakeholders about the relevance of SAF for the State, and by increasing research and development on feedstock capacity in order to guarantee a sustainable and affordable supply for a production facility.

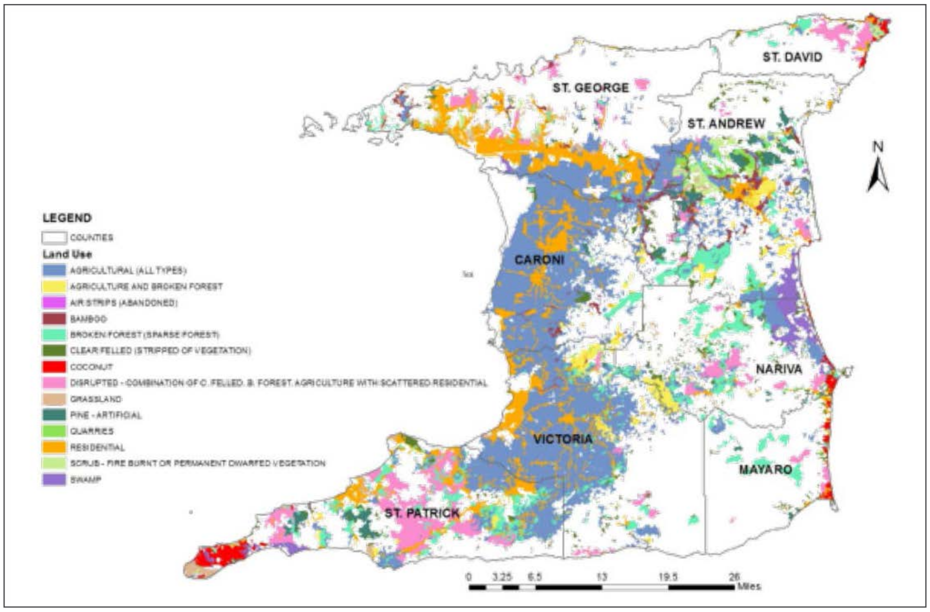
Once the regulatory market is favourable for the use of SAF, and there is reliable information on the availability of feedstock, the Dominican Republic would be prepared to define the actual implementation of SAF production from 2020, including the establishment of stable demand through the definitions of technology and incentive measures. The support defined within the Punta Cana Declaration will be instrumental to achieving these implementation goals.

TRINIDAD AND TOBAGO[2]

The feasibility study developed in Trinidad and Tobago was particularly unique, as the study found that the current volumes of feedstock available within the State are insufficient for commercial scale production of SAF with

1 https://www.icao.int/environmental-protection/Documents/FeasabilityStudy_DomRep_ENG_Web.pdf
2 https://www.icao.int/environmental-protection/Documents/FeasabilityStudies_TrinidadTobago_Report_Web.pdf

FIGURE 3: Land use by county in Trinidad, 2016 (Trinidad and Tobago Feasibility Study on the Use of Sustainable Aviation Fuels, 2017)



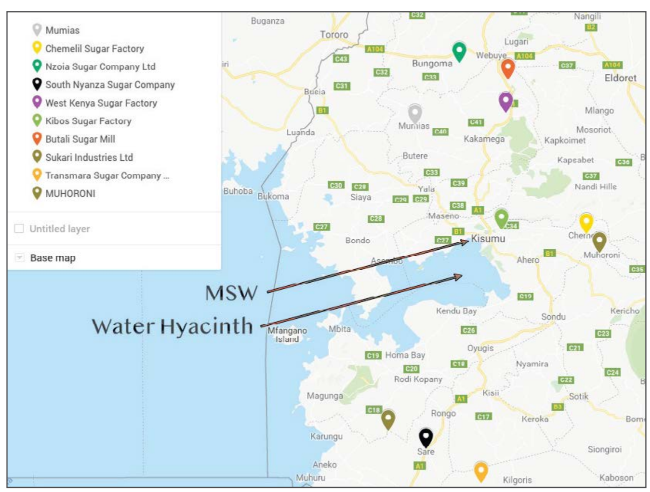
current technologies. Contrary to the roadmaps developed within the other feasibility studies, the strategy developed for Trinidad and Tobago included a recommendation that the State focus on the development of gas-to-liquid fuels from natural gas. While this feedstock is not considered sustainable, it can help the State reduce GHG emissions in the short-term, while work continues to further assess the possibility of using of municipal solid waste (MSW) as a feedstock in the medium-term. This would include improving waste management techniques and related policies, which could support the development of a waste-to-jet supply chain in the long-term.

Trinidad and Tobago also has a significant level of experience in fuel management and processing; thus, in the short- to medium-term, the State could develop strategic partnerships for the production and deployment of SAF. By developing SAF from feedstock available in nearby States, Trinidad and Tobago could play a primary role in the production and distribution of SAF throughout the Caribbean region. This possibility highlights the important role of international and regional cooperation in order to scale-up SAF deployment.

KENYA[3]

While further research is required on potential feedstock yields, sustainability, and techno-economic potential, Kenya has favourable conditions for the development of a SAF supply chain. The feasibility study suggests that specific attention be given to used cooking oil

FIGURE 4: Proximity of Three Feedstock Types to Kisumu (Kenya Feasibility Study on the Use of Sustainable Aviation Fuels, 2018)



3 https://www.icao.int/environmental-protection/Documents/FeasabilityStudy_Kenya_Report-Web.pdf

(UCO) as a feedstock in the short- and medium-term, while other feedstocks, such as MSW, agricultural waste from sugarcane harvesting, and water hyacinth could be considered in the long-term. Initial analyses suggest that up to 200 million litres of SAF could be derived from UCO by 2030.

In order to attract project developers, the study highlights the importance of developing strong governance and policy. Specifically, the study recommended that the Biofuel Department of the Ministry of Energy and Petroleum take the lead on advancing the study's recommendations. Such definitions of stakeholder roles are a fundamental aspect of feasibility studies, in order to ensure that the recommendations of the study are carried out.

Additionally, the feasibility study provided a list of potential funding sources that may be able to support the further research that is required. This list of resources could also benefit other States within the region that may be interested in assessing the potential for developing a SAF supply chain in their own State.

BURKINA FASO[4]

In Burkina Faso, several feedstock types are already available for the development of SAF. The feasibility study in Burkina Faso emphasized the important role that SAF could play in the State's strategies, such as the achievement of energy security; however, considering the experiences of previous projects in the region, the study suggests that the State take a cautious approach when scaling up the production of any SAF feedstock.

In the short-term, the study recommended that the State focus on the production of feedstock and on the conversion of biomass for ground transportation fuels. The development of such infrastructural facilities will be less capital-intensive for the State than it would be to develop SAF production facilities, while these actions could raise awareness of alternative fuels and potentially attract future investors. The ground transportation fuels could specifically be used for airport ground support equipment at Ouagadougou Airport, the State's main airport. Such actions could support the gradual adoption of SAF in the long-term.

FIGURE 5: Belwet Biocarburant biofuel crushing and biodiesel processing facilities, Kossodo (Burkina Faso Feasibility Study on the Use of Sustainable Aviation Fuels, 2018)

FIGURE 6: SN CITEC in Bobo-Dioulasso (Burkina Faso Feasibility Study on the Use of Sustainable Aviation Fuels, 2018)

4 https://www.icao.int/environmental-protection/Documents/FeasabilityStudy_BurkinaFaso_Report-Web.pdf

Additionally, several of the specific actions recommended for Burkina Faso were highlighted as potentially relevant throughout sub-Saharan Africa. The replication of such actions would further multiply the related positive environmental, social, and economic impacts of moving towards the adoption of SAF.

CONCLUSIONS

The SAF feasibility studies developed through the ICAO-EU Project demonstrate how assistance can lead to concrete actions for CO_2 mitigation, and proved that SAF can be a catalyst to reach decision-makers and mobilize political support for SAF projects. The process enabled close interactions with key stakeholders, which were subsequently translated into political support from various government institutions, and ultimately became a part of the national strategy on environment.

ICAO, other international organizations, and donors continue to play an important role in the success of such initiatives, through the planning stages to actual implementation. Further technical assistance and outreach will be instrumental for similar initiatives to succeed in the future, in order to ensure that they continue to be supported within States at the political level. ICAO encourages the dissemination of similar experiences, in order to promote the replication of such projects in other Member States and to support the development of a more environmentally sustainable aviation sector.

In this regard, it is paramount that States, while preparing their State Action Plans to Reduce CO_2 Emissions Reductions, identify their assistance needs and their willingness for developing such feasibility studies. In addition, under the 2050 ICAO Vision for SAF (see the Chapter 5 introductory article from the ICAO Secretariat) and as part of the ongoing SAF Stocktaking process, States are invited to express their willingness to undertake similar SAF feasibility studies, as Buddy Partnerships are being encouraged to facilitate this process.

CHAPTER SIX

Climate Change Mitigation: CORSIA

Introduction to CORSIA

By ICAO Secretariat

Addressing climate change requires cooperation among all States to reduce the impact of greenhouse gas emissions on the global climate. The international civil aviation sector plays a key role in the global efforts to address climate change. While it presently accounts for about 1.3% of the global CO_2 emissions, its contribution is projected to increase in the coming decades as the world becomes more connected. ICAO and its Member States have recognized the impact of the emissions from international aviation on the global climate, and have resolved to minimize this impact, while ensuring the sustainable growth of international aviation.

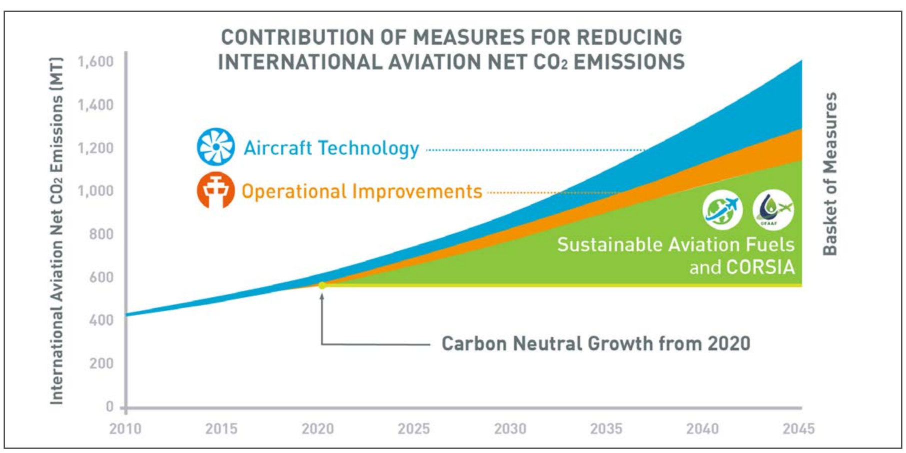
In 2010, the 37th Session of the ICAO Assembly adopted two aspirational goals: i) to improve energy efficiency by 2 per cent per year until 2050, and ii) to achieve carbon neutral growth from 2020 onwards. These goals are to be met with the implementation of a basket of measures that includes technological innovations, operational improvements, sustainable aviation fuels, and market based measures.

Since the 2010 Assembly which requested the Council to explore the feasibility of a global market-based measure scheme for international aviation, various options for such a global scheme were discussed and analyzed by the Council and experts around the world, in light of key principles such as environmental integrity, cost effectiveness, and simplicity of such a scheme. Following the important milestone at the 2013 Assembly, which decided to develop a global market-based measure for international aviation, further discussions on its design features and implementation mechanisms were undertaken, including possible means to address special circumstances and respective capabilities of States.

At the 39th Session of the ICAO Assembly in 2016, States finally adopted a global market-based measure scheme for international aviation, in the form of the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), to address the increase in total CO_2 emissions from international aviation above the 2020 levels (Assembly Resolution A39-3).

CORSIA is the first global market-based measure for any sector and represents a cooperative approach that moves away from a "patchwork" of national or regional regulatory initiatives through the implementation of a global scheme that has been developed through global consensus among governments, industry, and international organizations. It offers a harmonized way to reduce emissions from international aviation ensuring that there is no market

FIGURE 1: ICAO Global Environmental Trends on CO_2 Emissions and Contribution of Measures for Reducing International Aviation Net CO_2 Emissions



distortion, while respecting the special circumstances and respective capabilities of ICAO Member States.

CORSIA complements the other elements of the basket of measures by offsetting the amount of CO_2 emissions that cannot be reduced through the use of technological improvements, operational improvements, and sustainable aviation fuels (Figure 1) with emissions units from the carbon market. It is estimated that between 2021 and 2035, the international aviation sector would have to offset about 2.5 billion tonnes of CO_2 emissions to achieve carbon neutral growth.

HOW CORSIA WORKS

CORSIA will be implemented in three phases: a pilot phase from 2021 through 2023, a first phase from 2024 through 2026, and a second phase from 2027 through 2035. For the first two phases (2021 to 2026), participation is voluntary. As of June 2019, 80 States – representing 76.63% of international aviation Revenue Tonne-Kilometres (RTKs) – have announced their intention to participate in the CORSIA from its outset. From 2027 onwards, participation will be determined based on 2018 RTK data. Specifically, CORSIA will cover all States with an individual share of 2018 RTKs higher than 0.5 per cent of total RTKs or whose cumulative share in the list of States from the highest to the lowest amount of RTKs reaches 90 per cent of total RTKs. According to Assembly Resolution A39-3, Least Developed Countries (LDCs), Small Island Developing States (SIDS) and Landlocked Developing Countries (LLDCs) are exempt from participation (even if they fulfill these RTK conditions), but they can participate in the Scheme on a voluntary basis.

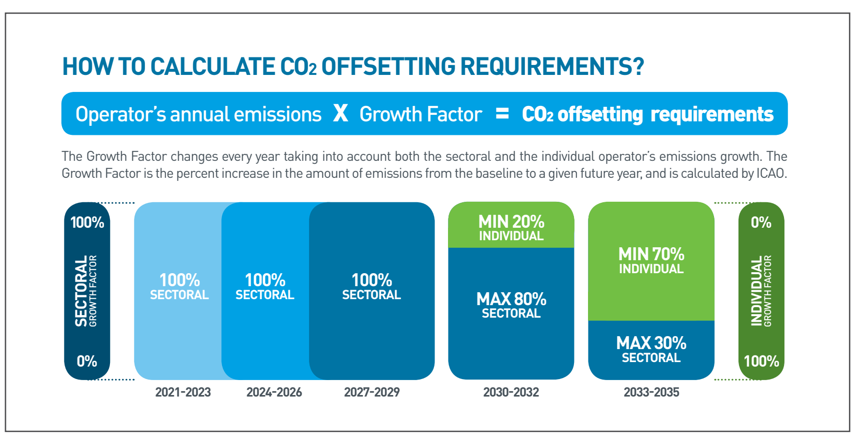
To eliminate market distortion, emissions coverage under CORSIA is based on a route-based approach. This means that emissions from <u>**all**</u> aeroplane operators performing international flights between two States where both the origin and destination States participate in CORSIA are covered by the offsetting requirements of the Scheme. In contrast, emissions from international flights between two States where the origin and/or destination States do not participate in CORSIA are excluded from the offsetting requirements of the Scheme. The route-based approach ensures that all aeroplane operators with flights on the same international routes are treated equally irrespective of whether the States to which they are attributed participate in CORSIA. According to Assembly Resolution A39-3, exemptions also apply to aeroplane operators with less than 10 000 tonnes of annual CO_2 emissions, to aeroplanes with less than 5 700kg take-off weight, and to humanitarian, medical and firefighting operations.

Once participating States and routes covered by the CORSIA are defined (starting in 2021), the amount of CO_2 offsetting requirements for individual aircraft operators is calculated, as follows (see Figure 2):

a) from 2021 through 2029, the amount of CO_2 offsetting requirements is calculated by multiplying the operators' annual emissions with the international aviation sector's growth factor every year, following a so-called 100 per cent sectoral approach; and
b) from 2030 onwards, the amount of CO_2 offsetting requirements is calculated taking into account both the sector's growth factor and the growth factor of an individual operator; the individual factor's contribution to the calculation will be at least 20 per cent from 2030 to 2032; and at least 70 per cent from 2033 to 2035.

Starting in 2022, CORSIA will be periodically reviewed, every three years, by the Council. The review will include, among other features, the assessment of its impact on

FIGURE 2: Calculation of offsetting requirements under CORSIA



the growth of international aviation, and the results of this assessment will serve as an important basis for the Council to recommend, as appropriate, adjustments to the scheme for the consideration by the Assembly.

CORSIA IMPLEMENTATION

The success of the implementation of CORSIA relies on the establishment of a robust and transparent monitoring, reporting and verification (MRV) system, which includes procedures on how to monitor the fuel use, collect data and calculate CO_2 emissions; report CO_2 emissions data; and verify CO_2 emissions data to ensure accuracy and avoid mistakes.

At the request of the 39th ICAO Assembly in 2016, the Council requested the Committee on Aviation Environmental Protection (CAEP), to develop Standards and Recommended Practices (SARPs) and related guidance material to facilitate the implementation of the MRV system under the CORSIA. Part of the CAEP work included the development of criteria for the eligibility of emissions units that are to be purchased and cancelled by aeroplane operators for the purposes of the Scheme.

In fact the implementation of CORSIA required a "package" of CORSIA-related SARPs and guidance which comprise of three distinct but interrelated components:

a) Annex 16, Volume IV, which provides the required actions by States and aeroplane operators (the "what" and "when") to implement CORSIA;
b) Environmental Technical Manual (Doc 9501), Volume IV, which provides the guidance on the process (the "how") to implement CORSIA; and
c) Five CORSIA Implementation Elements, which are reflected in 14 ICAO documents and are approved by the Council prior to their publication. These ICAO documents are directly referenced in Annex 16, Volume IV and are essential for the implementation of CORSIA.

The Council adopted the First Edition of Annex 16, Volume IV in June 2018. Following its adoption, the First Edition of Annex 16, Volume IV became applicable on 1 January 2019.

The First Edition of the Environmental Technical Manual (Doc 9501), Volume IV was issued under the authority of the ICAO Secretary General in August 2018. This manual will be periodically revised to make the most recent information available to administrating authorities, aeroplane operators, verification bodies and other interested parties in a timely manner, aiming at achieving the highest degree of harmonisation possible.

The ICAO Council has been undertaking work, with the contribution of the CAEP, on the development of the five CORSIA Implementation Elements, namely:

- **CORSIA States for Chapter 3 State Pairs** is the list of States participating in CORSIA and will be used to define route-based emissions coverage every year from 2021 onwards;
- **ICAO CORSIA CO_2 Estimation and Reporting Tool (CERT)** aims to simplify the estimation and reporting of CO_2 emissions from international flights for those operators with low levels of activity to fulfil their monitoring and reporting requirements under CORSIA (for more details, see the dedicated article in this chapter);
- **CORSIA Eligible Fuels** cover aviation fuels used for the purposes of CORSIA to reduce the offsetting requirements of aeroplane operators (for more details, see the dedicated article in this chapter);
- **CORSIA Eligible Emissions Units** are emissions units from the carbon market that can be purchased by aeroplane operators to fulfill the offsetting requirements under CORSIA (for more details, see the dedicated article in this chapter); and
- **CORSIA Central Registry (CCR)** is an information management system that will allow the input and storage of CORSIA-relevant information reported by States, as well as calculations and reporting by ICAO, in accordance with the CORSIA MRV requirements as contained in the Annex 16, Volume IV (for more details, see the dedicated article in this chapter).

In June 2018, to ensure that *No Country is Left Behind*, the Council endorsed the ICAO ACT-CORSIA (Assistance, Capacity-building and Training for the CORSIA) Programme, emphasizing the importance of a coordinated approach under ICAO to harmonize and bring together all relevant actions and promote coherence to capacity building efforts related to CORSIA implementation.

By the end of June 2019, CORSIA buddy partnerships under ACT-CORSIA had been established, involving 15 donor States and 98 recipient States. For more details on ACT-CORSIA see the dedicated article in this chapter.

CONCLUSIONS

CORSIA offers a success story of firsts: the first sector-wide carbon offsetting programme; the first such programme to tackle emissions from a single industry on a global level; the first time international aviation will experience carbon neutral growth; the first global partnership to help build capacity on CORSIA in all countries of the world. But being first also comes with great challenges that the Organization was able to address with the support of its Members States, industry, other actors and society as a whole.

While ICAO celebrates its successes over the last 75 years, it also acknowledges the challenges ahead. Starting in 2019, ICAO and its Member States are working together to implement the first stages of CORSIA focusing on ensuring that States have in place the necessary regulatory frameworks to facilitate the smooth implementation of CORSIA. More activities are scheduled and will continue over the coming years and decades. The international aviation sector is ready to tackle the future challenges and ensure that international flights are going to be built on a much greener foundation, but this will only be possible with the cooperation and support of all stakeholders involved.

ACT-CORSIA: A Coordinated Approach for Assistance and Capacity-building on CORSIA

By ICAO Secretariat

INTRODUCTION TO ACT-CORSIA

While conceptual discussions were being undertaken on the global market- based measure to be adopted for international aviation in order to reach its post-2020 carbon neutral growth aspirational target, capacity building was already a must-have element for any decision on the matter. Therefore, just after adopting the CORSIA-related SARPs (Annex 16, Volume IV) in June 2018, the ICAO Council endorsed the ICAO Secretariat's plan for the CORSIA-related outreach and capacity building activities, on the understanding that the plan should continue to evolve with the implementation features of CORSIA. The ACT-CORSIA (Assistance, Capacity-building and Training for CORSIA) Programme was launched during the ICAO Seminar on CORSIA, which was held in Montréal, on 2 and 3 July 2018. A number of ICAO Member States need targeted assistance in order to prepare for the implementation of the CORSIA monitoring, reporting and verification (MRV) system as per the SARPs requirements, and time was of essence as the CORSIA-related SARPs were to become applicable on 1 January 2019.

The ACT-CORSIA Programme is composed of various elements, which are intended to facilitate better understanding and the access to information on CORSIA, including: the establishment of CORSIA Buddy Partnerships, the availability of model regulations, Frequently Asked Questions, Brochures and Leaflets, Videos, the CORSIA Seminars and Workshops, Online Tutorials, and other Background Information.

Complete information about the ACT-CORSIA Programme is reflected on ICAO CORSIA public website[1] .

ACT-CORSIA BUDDY PARTNERSHIPS

When endorsing the plan for CORSIA-related outreach and capacity-building activities, the Council emphasized the need for a coordinated approach to undertake the global capacity building initiative under ICAO, and that any bilateral or multilateral partnerships among States should be informed and coordinated with ICAO, so that the global progress of such coordinated efforts would be monitored. In this regard the Council encouraged the establishment of "buddy partnerships" among States themselves to help each other to prepare for CORSIA implementation, in particular with regard to the development and approval of aeroplane operators' Emissions Monitoring Plans, and the establishment of national and/or regional regulatory frameworks for CORSIA implementation.

CORSIA Buddy Partnerships are a cornerstone of ICAO's plan to support States to prepare for CORSIA implementation. Under the first phase of the partnerships, technical experts provided by donor States worked together with the CORSIA Focal Points of recipient States to provide on-site training, and to closely follow-up on the preparation and implementation of the recipient States' CORSIA MRV system; in particular on the development and approval of Emissions Monitoring Plans, as well as on the establishment of national and/or regional regulatory frameworks.

1 www.icao.int/corsia

FIGURE 1: ACT-CORSIA Buddy Partnerships as of 30 June 2019

By 30 June 2019, a total of 15 donor States are providing support to 98 recipient States under ACT-CORSIA Buddy Partnerships. Figure 1 provides information on the established Buddy Partnerships as of 30 June 2019; the most up-to-date information is provided on ICAO CORSIA public website.

Typically, the assistance is in the form of a donor State offering expert(s) on CORSIA to provide individual training to and undertake the necessary follow-up with, the CORSIA Focal Points of the recipient States, in close coordination with the ICAO Secretariat. ACT-CORSIA Buddy Partnerships follow a three-step approach. In step 1, both the experts from donor States and the CORSIA Focal Point from recipient States prepare for the training activities, including the necessary travel arrangements; in step 2, the donor State expert travels to the recipient State and delivers an on-site training; and in step 3, the donor state expert provides remote follow-up to the recipient State CORSIA Focal Point.

It is important that each expert has in-depth knowledge of all relevant documentation relating to the implementation of CORSIA. To ensure the consistency of assistance pro vided and relevant materials used through the first phase of CORSIA Buddy Partnerships, the involved technical experts were trained by the ICAO Secretariat to the CORSIA requirements. In the initial phase of the CORSIA Buddy Partnerships, training focused on the preparation and implementation of the recipient State's CORSIA MRV system, and in particular, on the development and approval of Emissions Monitoring Plans and the establishment of a national regulatory framework. To ensure a coordinated approach under ICAO, and the consistency of the assistance provided and the materials used, the ICAO Secretariat developed training materials to be used by the donor State experts, including model regulations for CORSIA implementation, and organized the first "Training of Trainers" event in Montréal, Canada from 29 to 31 August 2018, during which experts from donor States were trained to be ready to deliver on-site training to recipient States starting from September 2018 (Figure 2). Using this coordinated approach ensures that in the framework of ICAO's No Country Left Behind initiative, all States are receiving the same high quality training.

FIGURE 2: Photo from the first ACT-CORSIA Training of the Training event in Montréal, Canada from 29 to 31 August 2018

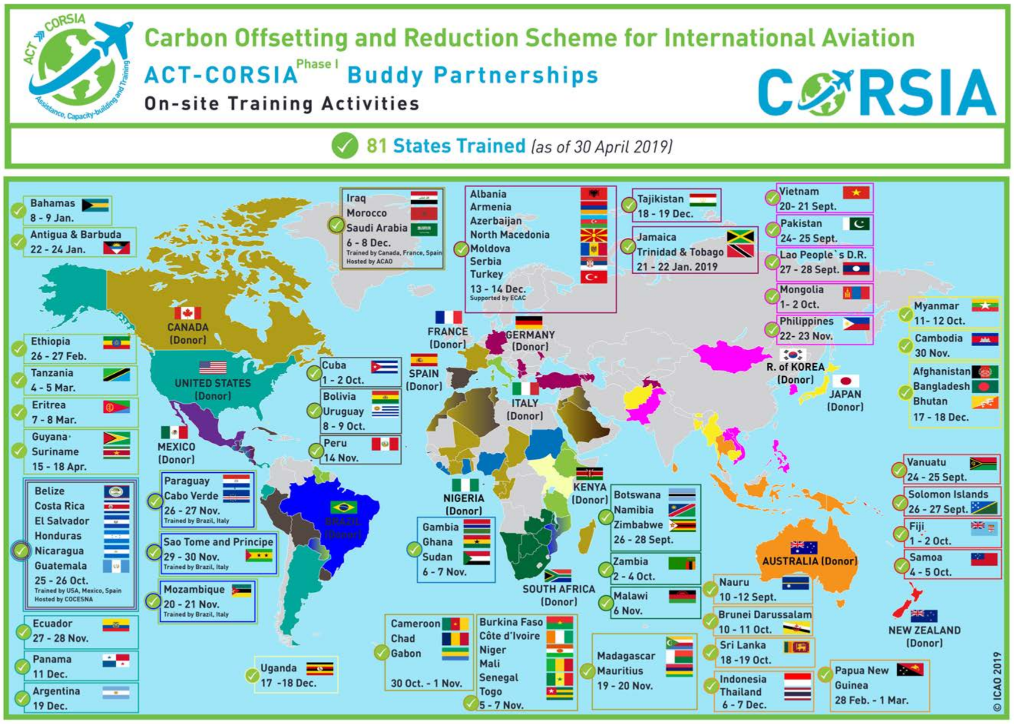
The on-site training is the main part of the ACT-CORSIA Buddy Partnerships activities. A typical ACT-CORSIA Buddy Partnership training takes place over the course of two days. The ICAO Secretariat provided a suggested schedule for the trainings, however, the actual sequence of training activities was agreed between the donor State experts and the CORSIA Focal Point of the recipient State, taking into account the availability of the individuals to be trained, and specific questions of the recipient State. Approximately 80 recipient States have received training under the ACT-CORSIA Buddy Partnerships (see Figure 3).

Following-up with the CORSIA Focal Point of the recipient State and other individuals, as agreed during the on-site training, is a crucial part of the ACT-CORSIA Buddy Partnerships. It provides the opportunity for the donor State trainer to assess if the necessary progress has been made within areas covered by the training and to provide further guidance/assistance to the recipient State. Follow-ups were mainly being provided on a remote basis, however, follow-up on-site training sessions are also being organized as needed to assess the progress achieved and to provide further support.

TOWARDS THE SECOND PHASE OF THE ACT-CORSIA BUDDY PARTNERSHIPS

The 2019 ICAO CORSIA Regional Workshops were organized in all ICAO regions from 21 March to 12 April 2019. Following the initial stage of CORSIA capacity-building which focused on the development of Emissions

FIGURE 3: ACT-CORSIA Buddy Partnerships: On-site Training Activities



Monitoring Plans, and on the establishment of national regulatory frameworks, the objective of the two-day regional workshops was to provide further information on the upcoming CORSIA implementation requirements. Particular focus of the Regional Workshops was on any pending issues regarding the monitoring of CO_2 emissions in 2019, including the approval of Emissions Monitoring Plans, as well as on reporting and verification of CO_2 emissions from international aviation to support States in complying with the related provisions of the CORSIA SARPs by early 2020.

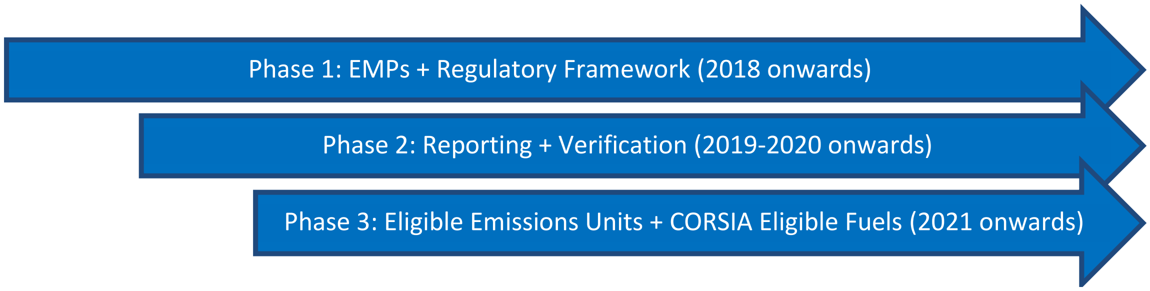
A total of five Regional Workshops were organized, in the following locations:

- Asunción, Paraguay, 21 to 22 March 2019, for South American + North American, Central American, and Caribbean Regions;
- Helsinki, Finland, 26 to 27 March 2019, for European and North Atlantic Region;
- Seoul, Republic of Korea, 1 to 2 April 2019, for Asia and Pacific Region;
- ICAO MID Office, Cairo, Egypt, 7 to 8 April 2019, for Middle East Region; and
- Dakar, Senegal, 11 to 12 April 2019, for Eastern and Southern Africa + Western and Central African Regions.

The Regional Workshops gathered together experts from donor States as well as CORSIA Focal Points from recipient States, and provided an opportunity to reflect on the experiences from ACT-CORSIA Buddy Partnerships in all ICAO Regions. During the Workshops, experts from donor States shared their experiences in providing training on Emissions Monitoring Plans and national regulatory frameworks, and CORSIA Focal Points from recipient States expressed their views on the training received. The importance of ACT-CORSIA Buddy Partnerships to provide assistance and capacity-building to States was highlighted by the Workshop participants, and States were encouraged to partner together in order to renew and add more Buddy Partnerships.

Whereas approving the Emissions Monitoring Plans and finalizing the national regulatory frameworks remain a priority for States in implementing CORSIA during 2019, States also need to get ready for the reporting and verification aspects of CORSIA. Thus, the Second

FIGURE 4: Three Phases of ACT-CORSIA Buddy Partnerships



Phase of ACT-CORSIA was launched during the 2019 ICAO Environmental Symposium (14 to 16 May 2019), with a specific focus on reporting and verification of CO_2 emissions under CORSIA. In this connection, the second Training of the Trainers event was organized in Montreal on 13 and 14 May 2019, during which the experts from donor States were trained by the ICAO Secretariat to provide harmonized capacity-building to the recipient States during the second phase of ACT-CORSIA Buddy Partnerships. Additional remote training was provided over the summer on the 2019 version of the ICAO CORSIA CERT tool to ensure that the experts have the latest knowledge on this important CORSIA Implementation Element before commencing the training activities with recipients States, foreseen to take place during the second half of 2019. The plan of activities is accessible on the ICAO CORSIA website for full transparency.

Recognizing the need for continuous capacity-building in implementing CORSIA, the contents of the ACT-CORSIA Buddy Partnerships will be adjusted in accordance with the implementation phases of CORSIA. Figure 4 presents the three phases foreseen for ACT-CORSIA: the first phase from 2018 onwards focuses on the development and approval of the Emissions Monitoring Plans as well as on drafting and finalizing the national/regional regulatory frameworks; the second phase in 2019-2020 focuses on reporting and verification aspects of CORSIA implementation; and the third phase will provide assistance on the aspects related to CORSIA eligible emissions units and CORSIA eligible fuels.

ICAO CORSIA VERIFICATION COURSE

In addition to the training provided under the ACT-CORSIA Buddy Partnerships, and in order to provide the necessary training on how to verify CO_2 Emissions Reports that have been prepared by aeroplane operators in accordance with CORSIA-related SARPs and guidance, ICAO developed a 3-day CORSIA Verification Course. The course targets professionals with experience in the verification of CO_2 emissions using ISO 14064-3:2006 who want to get involved in the verification of aeroplane operators' CO_2 Emissions Reports under CORSIA.

The learning objectives of the course include: performing the CORSIA monitoring, reporting, and verification (MRV) requirements as outlined in Annex 16, Volume IV, and the Environmental Technical Manual (Doc 9501), Volume IV; applying the verification requirements as outlined in Annex 16, Volume IV, and the Environmental Technical Manual (Doc 9501), Volume IV, including materiality threshold, verification criteria, verification scope and objectives and the Verification Report preparation and submission requirements; gaining knowledge to correctly identify the scope of applicability for CORSIA MRV requirements, as well as for CORSIA offsetting requirements; and applying a working knowledge of the fuel use monitoring methods and of the ICAO CORSIA CERT estimation tool as outlined in Annex 16, Volume IV.

The most up-to-date information on the ICAO CORSIA Verification course dates and venues is available on ICAO Global Aviation Training Office's website: https://www.icao.int/training/Pages/training-catalogue-details.aspx?catid=2657&language=0&region=&ITP=1

CORSIA Eligible Emissions Units

By ICAO Secretariat

With the adoption of the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) by the 2016 Assembly, ICAO has placed international aviation on the cutting edge of climate policy. CORSIA represents the first example of an international, sector-wide market-based approach to greenhouse gas emissions reductions. One of the most interesting aspects of the scheme is the use of emissions units to ensure carbon neutral growth from 2020 onwards in the international aviation sector, and that the Assembly requested the ICAO Council to determine eligible emissions units for use by airlines under CORSIA.

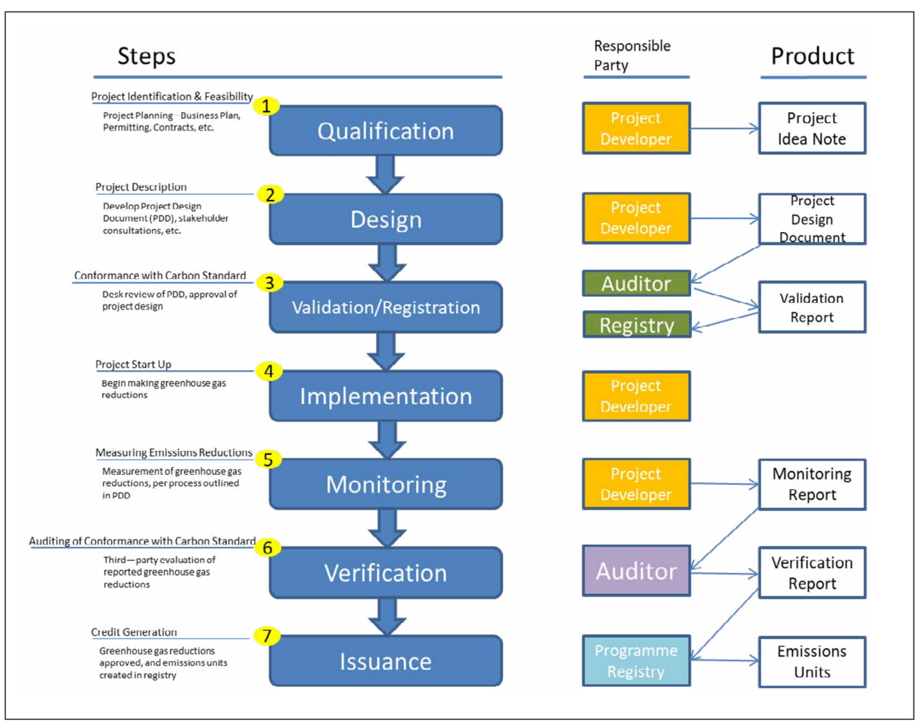
Under CORSIA, airlines will meet CO_2 offsetting requirements with these eligible emissions units, making them an essential part of the ICAO Basket of Measures to achieve ICAO's global aspirational goal of carbon neutral growth from 2020. While it is not possible to know beforehand how many emissions units will be needed to meet the carbon neutral growth goal, it could be on the order of 2.5 billion tonnes for the period from 2021 to 2035.

For decades, economists have recommended using emissions units, also known as carbon credits, as part of a market-based approach to address climate change. The United Nations Framework Convention on Climate Change (UNFCCC) Kyoto Protocol included a mechanism for some States to meet their emissions reductions commitments using emissions units. Similarly, the European Union Emissions Trading Scheme (EU ETS) has used emissions units for over a decade to achieve the European Union's greenhouse gas reduction goals. Other jurisdictions, from the Republic of Korea to the State of California, now use emissions units to reach their greenhouse gas reduction goals.

Emissions units are generated when emissions from a specific project or programme are reduced, compared to a baseline (or business-as-usual scenario), through the implementation of emission reductions techniques/technologies. These projects or programmes can be implemented in various sectors, such as electricity generation, industrial processes, agriculture, forestry, and/or waste management.

There is a multi-step process to generate an emissions unit, as detailed in Figure 1.

FIGURE 1: Process to Generate an Emissions Unit



In general, emissions units are issued, or created, in a programme registry. A programme registry is akin to an online bank for emissions units. Emissions units can only exist within a registry, where they are also traded, tracked, and cancelled.

While emissions units exist within a registry, their owner may change. For example, a project developer may sell them to a compliance buyer, such as an airline registered in a State which participates in CORSIA. This transaction can occur through an exchange, a broker, or a direct bilateral contract between the seller and the buyer.

The compliance buyer will then use the emissions units to meet its obligations. In the context of CORSIA, this means that the airline will cancel the required number of emissions units in the registry.

Importantly, the emissions units which are cancelled must not be counted elsewhere, such as for compliance with another programme or Nationally Determined Contribution (NDC) under the UNFCCC Paris Agreement.

FIGURE 2: ICAO CORSIA Emissions Unit Eligibility Criteria

If the emissions units are counted for another emissions reduction programme, then they cannot also count for CORSIA. An emissions unit can only be counted once as a reduction.

In March 2019, the ICAO Council approved the Emissions Units Criteria (EUC), which will be used to undertake the assessment of emissions unit programmes and to determine eligible emissions units for use by airlines under CORSIA. The approved EUC is available at the ICAO CORSIA website[1].

In order to inform its decisions on CORSIA eligible emissions units, the Council established the Technical Advisory Body (TAB), which will make recommendations on eligible emissions units for CORSIA. The 19 members of the TAB are experts nominated by their State and approved by the Council.

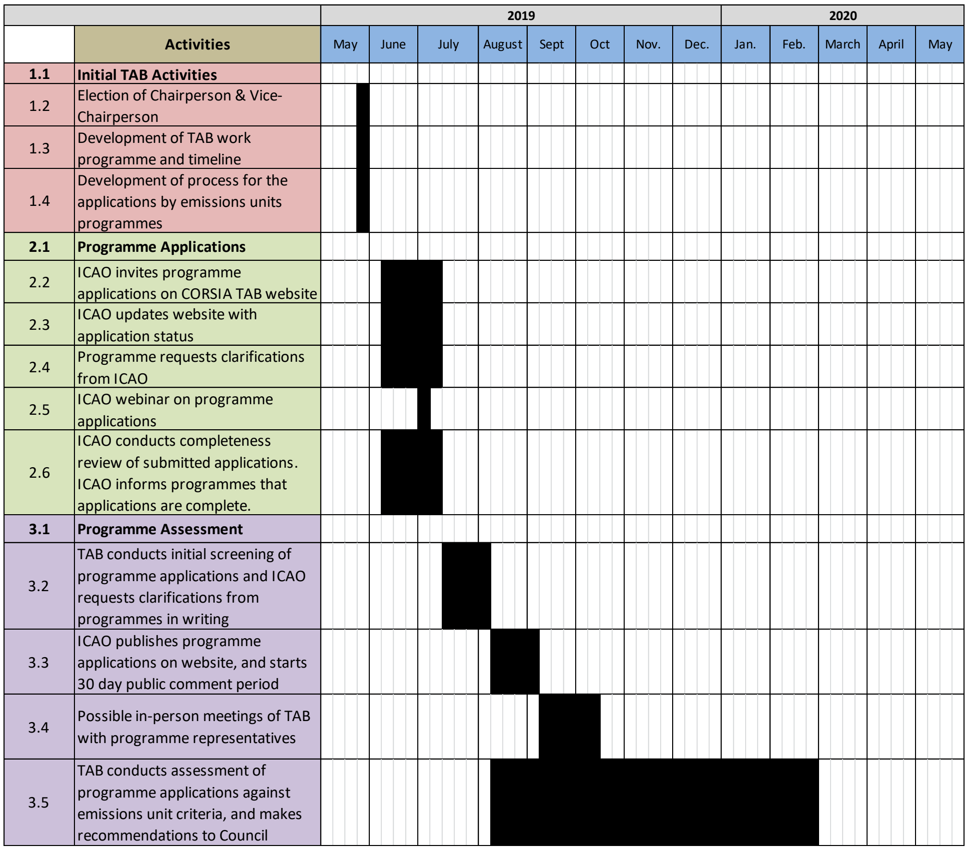
As the TAB's Terms of Reference indicates, the body's main tasks are to:

1. undertake the assessment of emissions unit programmes against the emissions unit criteria; and
2. develop recommendations on the list of eligible emissions unit programmes (and potentially project types) whose emissions unit would be eligible for use under the CORSIA, for consideration by the Council.

The TAB started its process by inviting emissions unit programmes to apply for the assessment by TAB. The public will also be invited to comment on the programme applications. This is an open and transparent process, allowing stakeholders to participate in and follow progress through the ICAO website. The TAB will review the programme applications and public comments, and assess whether the programmes meet the EUC, before making its recommendations to the Council on CORSIA eligible emissions units, by March 2020. The Council will take the TAB recommendations into consideration, and make its decisions on the CORSIA emissions units eligibility. More

1 https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-Emissions-Units.aspx

FIGURE 3: TAB Work Programme and Timeline (as of May 2019)



Note 1: The above TAB Work Programme and Timeline is subject to further changes.

Note 2: The TAB process above is iterative, and the second programme application period is foreseen to begin in March 2020.

information on the TAB process, including the TAB work programme and timeline is available on the ICAO website.[2]

The Council-approved list of CORSIA eligible emissions units will allow airlines to know which emissions units they can purchase for compliance with CORSIA. Such a list will also inform project developers who build and operate emissions reductions projects. These developers will know which projects will produce CORSIA eligible emissions units, and thus which kinds of projects they should develop to meet the demand for emissions units.

The implementation of CORSIA marks a transformation in aviation environmental protection efforts. Starting in 2021, international civil aviation will experience carbon neutral growth, in part thanks to the use of emissions units under CORSIA. This represents a positive example of international cooperation in the efforts against climate change. The large number of States which will participate in CORSIA means that the atmosphere will see greenhouse gas reductions on the scale of billions of tonnes, compared to a business-as-usual scenario.

Now, the ICAO Council has approved the EUC, and the TAB has begun to assess emissions units programmes, and potentially project types. This will lead to a decision from the ICAO Council on which emissions units are eligible for compliance with CORSIA.

There is a clear timeline with concrete milestones that sets the way forward. ICAO and its Member States know what has to be done by when, and together with the invaluable support and contribution of the international aviation industry, are determined to make it happen.

2 https://www.icao.int/environmental-protection/CORSIA/Pages/TAB.aspx

ICAO CORSIA CO_2 Estimation and Reporting Tool (CERT)

By ICAO Secretariat

INTRODUCTION

In an international aviation world where CORSIA is now a reality and where all aeroplane operators are requested to undertake their CO_2 emissions monitoring, the ICAO CORSIA CO_2 Estimation and Reporting Tool (CERT) was developed to provide practical support to users to facilitate their compliance with the CORSIA monitoring, reporting and verification requirements.

CORSIA CO_2 emissions information from aeroplane operators can be obtained either based on actual fuel burn converted to CO_2 emissions or estimated CO_2 emissions generated by the ICAO CORSIA CERT (under certain conditions[1]). Monitoring CO_2 emissions can be challenging if no monitoring system is yet implemented. In a simplified manner, the ICAO CORSIA CERT allows for the monitoring of CO_2 emissions with minimum information to be provided, such as the aeroplane type, an aerodrome pair and the number of flights.

The ICAO CORSIA CERT is a versatile tool. In addition to estimating the CO_2 emissions, each aeroplane operator can generate a summary assessment detailing its specific situation. In addition, from 2019, with the introduction of the 2019 version of the ICAO CORSIA CERT, all aeroplane operators may also generate a complete Emissions Report.

This article aims to introduce the ICAO CORSIA CERT in detail – by providing information on the ICAO CORSIA CERT use eligibility, on the development of the tool and how the tool works – but mainly by demonstrating how a complex task such as the CO_2 emissions monitoring becomes so easy thanks to the ICAO CORSIA CERT.

AEROPLANE OPERATORS ELIGIBLE TO USE THE ICAO CORSIA CERT AND FUNCTIONALITIES

Eligibility – The use of the ICAO CORSIA CERT depends on the level of emissions. All aeroplane operators can use the tool with no restrictions for a preliminary CO_2 assessment. The summary assessment indicates if the aeroplane operator is under the scope of applicability of CORSIA (i.e. if its annual international CO_2 emissions are greater than 10,000 tonnes of CO_2). Furthermore, the summary assessment also indicates if the aeroplane operator is eligible to use simplified compliance procedures. If so, the aeroplane operator may use the ICAO CORSIA CERT as a primary monitoring method, at the condition that its annual international emissions are between 10,000 and 500,000 tonnes of CO_2 for the period 2019-2020 and between 10,000 and 50,000 tonnes

TABLE 1: Aeroplane Operators Eligible to Use the ICAO CORSIA CERT

CERT	Aeroplane Operators International CO_2 Emissions (tonnes) 2019 – 2020*		
Function / Use	≤ 10K CO_2	< 500K CO_2	≥ 500K CO_2
Preliminary CO_2 Assessment	✓	✓	✓
CO_2 Estimation & Reporting	No CORSIA requirement	✓	Not Eligible to use CERT **
Filling Data Gaps	No CORSIA requirement	✓	✓

* Note: from 2021-2035 operators can use ICAO CORSIA CERT to estimate and report emissions if their annual emissions from international flights subject to offsetting requirement are < 50 000 tonnes of CO_2 annually.

** Note: If an Aeroplane Operator uses ICAO CORSIA CERT for 2019 CO_2 estimation and reporting (based on their preliminary CO_2 assessment) but exceeds the threshold of 500 000 tonnes in 2019, the State could permit the operator to continue to use ICAO CORSIA CERT during 2020.

1 See the "Aeroplane operators eligible to use the ICAO CORSIA CERT and functionalities" section of this article for more information on conditions

of CO_2 emissions subject to offsetting requirements in 2021 and onward.

Finally, all aeroplane operators with CORSIA requirement can use the ICAO CORSIA CERT for filling data gaps and for populating the Emissions Report template.

The following table summarizes the use of the ICAO CORSIA CERT by aeroplane operators based on their level of international CO_2 emissions.

Functionalities – Over time, new functionalities will be added to the ICAO CORSIA CERT. Since 2018, the tool has offered the possibility for aeroplane operators to estimate their international CO_2 emissions for the determination of simplified compliance procedure eligibility. This version also includes the generation of a summary assessment that may be used as a supporting document for the Emissions Monitoring Plan to be submitted by aeroplane operators to the State to which they are attributed.

From 2019 onward, the tool includes the monitoring and reporting functionalities. The estimation of the CO_2 emissions is based either on Great Circle Distance (GCD) or Block Time (BT).

Finally, from 2021, the list of State pairs subject to offsetting requirements will be added and updated once a year.

DEVELOPMENT OF THE ICAO CORSIA CERT

Every year, a new version of the ICAO CORSIA CERT will be developed. The methodology that underpins the ICAO CORSIA CERT will be updated every single year, in order to increase the number of aircraft types covered by the tool, especially the new generation of aircraft entering the market, and to reflect changes in term of fuel efficiencies that may happen over time. Depending on the year, new functionalities may also be added.

In order to support aeroplane operators eligible to use the ICAO CORSIA CERT as a primary monitoring method, ICAO needs support from operators with sophisticated IT systems monitoring their fuel use.

Data Providing Organizations (DPOs), working with ICAO, collect actual fuel burn data from operators and provide that data to the CORSIA CERT Group (CCG), which is a subgroup of Working Group 4 in the Committee on Aviation Environmental Protection (CAEP). All data collected are then consolidated into a database called the CCG Operations and Fuel database (COFdb).

From this database, CCG generates the ICAO CO_2 Estimation Models (or CEMs). In other words, the ICAO CEMs are a set of coefficients used in a formula allowing the estimation of fuel burn for each aircraft type based either on the distance flown or on block time.

After this crucial step, the ICAO CEMs are reviewed by an independent group of experts and in parallel, the ICAO CORSIA CERT, as a tool, is developed. Then, the tool and its technical document are finalized and are both submitted for recommendation to CAEP. If CAEP recommends the release of the ICAO CORSIA CERT, then the tool is submitted to the Council for adoption.

Once the ICAO CORSIA CERT is adopted, the tool and all related-documentations are made available on the ICAO CORSIA website.

Finally, the ICAO CORSIA CERT as a standalone application can be downloaded and used by aeroplane operators eligible to use the ICAO CORSIA CERT and the ICAO CEMs can also be downloaded and integrated into the IT systems of operators, States, Verifiers or Third Party organizations for the purpose of CORSIA implementation.

This cycle, shown in Figure 1, is repeated every year.

HOW DOES THE ICAO CORSIA CERT WORK?

Brief explanation – The ICAO CORSIA CERT is a very simple tool to use and, starting with the 2019 version, comprises a three-step-process. The first step requires the user to enter the aeroplane operator's information such as the name, the address or the aircraft identification of the operator. The second step is dedicated to the CO_2 estimation by entering an aircraft type, an airport-pair and the number of flights if the estimation is based on Great

Circle Distance (GCD). In the case of using Block Time (BT) as input, the total block time per airport pairs is required. The last step is the generation of the summary assessment report if the ICAO CORSIA CERT is used for assessing the eligibility to use the tool as monitoring method, or the generation of the complete Emissions Report ready to be submitted to verification bodies and States.

Detailed explanation – This section will explain how CO_2 emissions are estimated in more detail. The ICAO CORSIA CERT uses the following equations depending on the inputs (i.e. Great Circle Distance or Block Time):

$$Fuel\ Burn\ (kg) = Intercept\ (kg) + Slope\ (kg/km) * Distance\ (km)$$
$$Fuel\ Burn\ (kg) = Intercept\ (kg) + Slope\ (kg/min) * Block\ Time\ (min)$$

The intercept represents the fuel burn at 0 km or 0 min, depending if Great Circle Distance or Block Time is used, and the slope represents the fuel rate in kilogram either per kilometer flown or minutes. The intercepts and slopes are the coefficients contained in the ICAO CO_2 Estimation Models (CEMs).

The estimation of the CO_2 emissions follows a two-step process. The first step is to estimate the GCD and identify the scope of applicability and the second step will use the information generated in the first step to estimate the CO_2 emissions.

Figure 2 illustrates how the ICAO CORSIA CERT calculates the GCD. The tool will start by checking if aerodromes entered are in the ICAO Doc 7910 – *Location Indicators* which is embedded into the tool. If both aerodromes are available then the tool computes the GCD with the coordinates available in Doc 7910, uses the same document to identify the State where the aerodromes are located, highlights if the flight is subject to the scope of applicability of CORSIA (i.e. international flight) and, from 2021, if the flight is subject to offsetting requirements. If one or both aerodromes are missing then the user has to provide information on each aerodrome by entering the name, the latitude and the longitude of the aerodrome plus the name of the State where it is located. In the same manner, the tool then computes the GCD with the latitudes and longitudes provided and identifies the scope of applicability of the flight in the CORSIA scheme.

If Block Time input is provided instead of Great Circle Distance input, the ICAO CORSIA CERT will only use the Doc7910 for identifying the scope of applicability and the user would need to provide the BT information as input.

FIGURE 1: Development of the ICAO CORSIA CERT

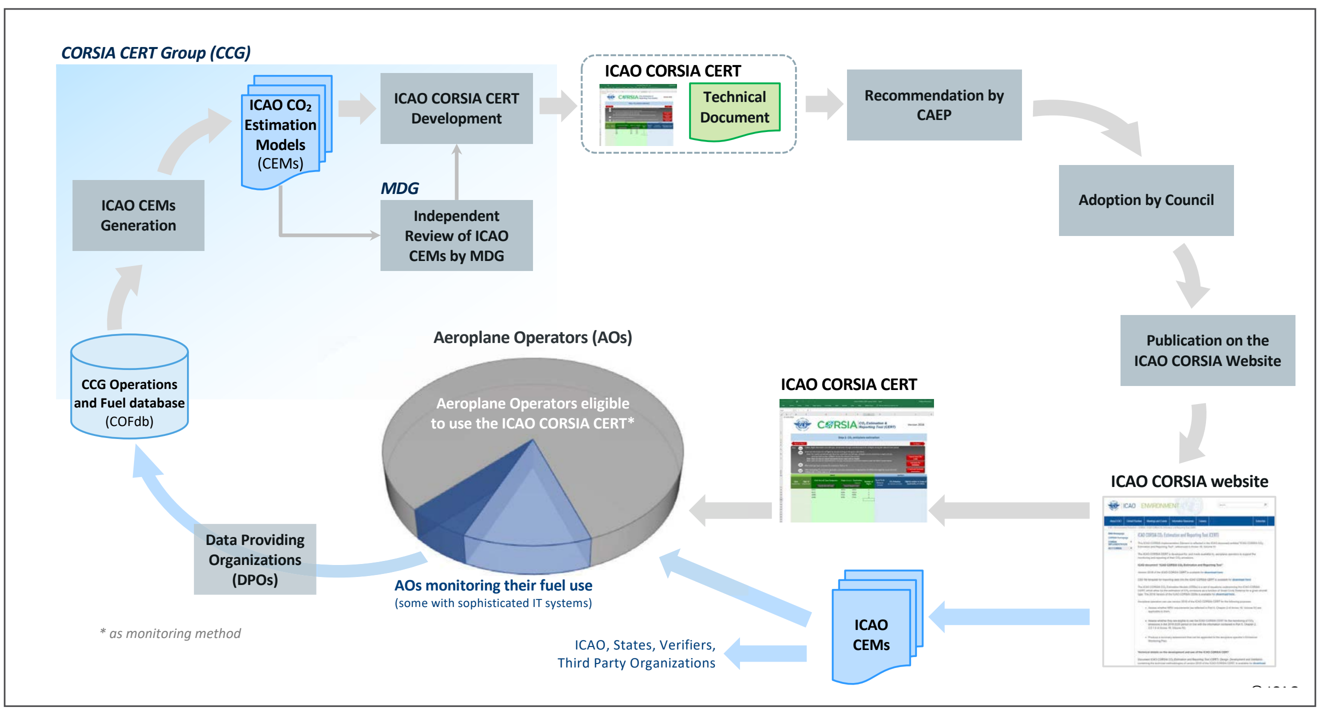


FIGURE 2: Estimation of the CO_2 Emissions with the ICAO CORSIA CERT – Step 1

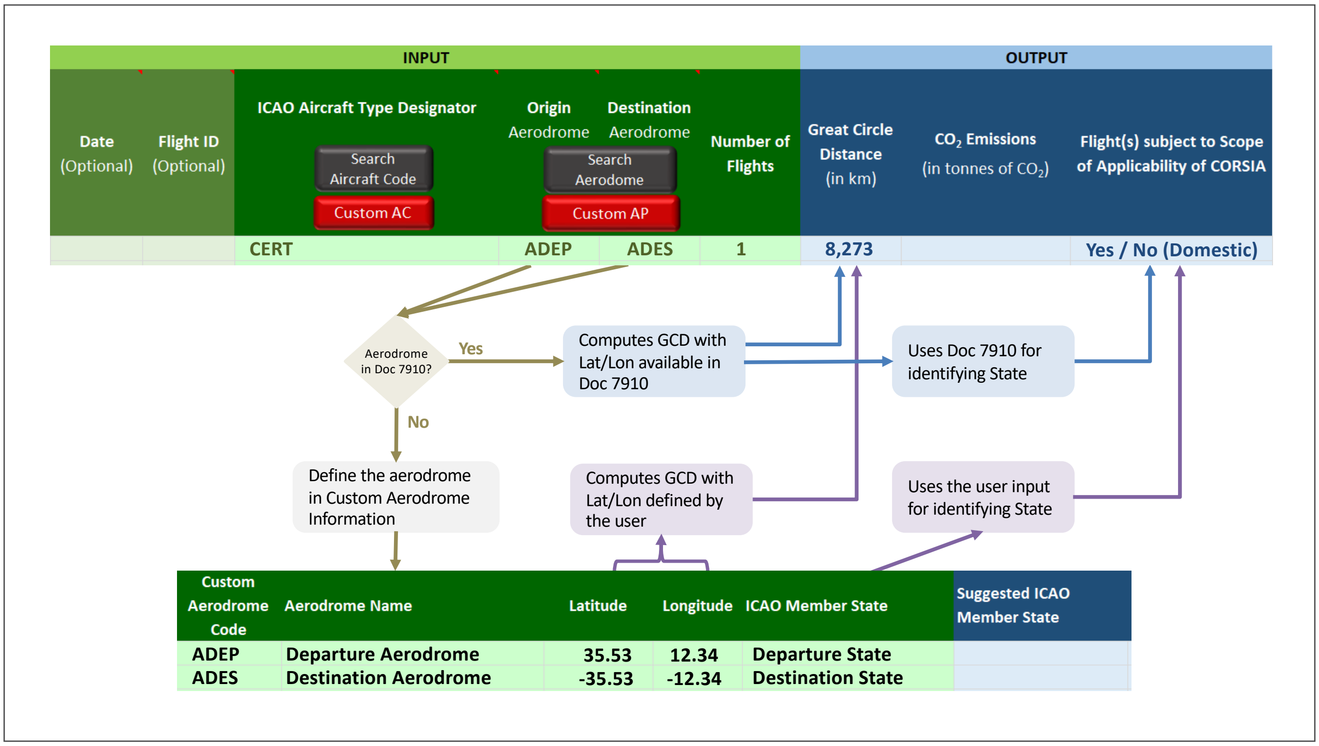
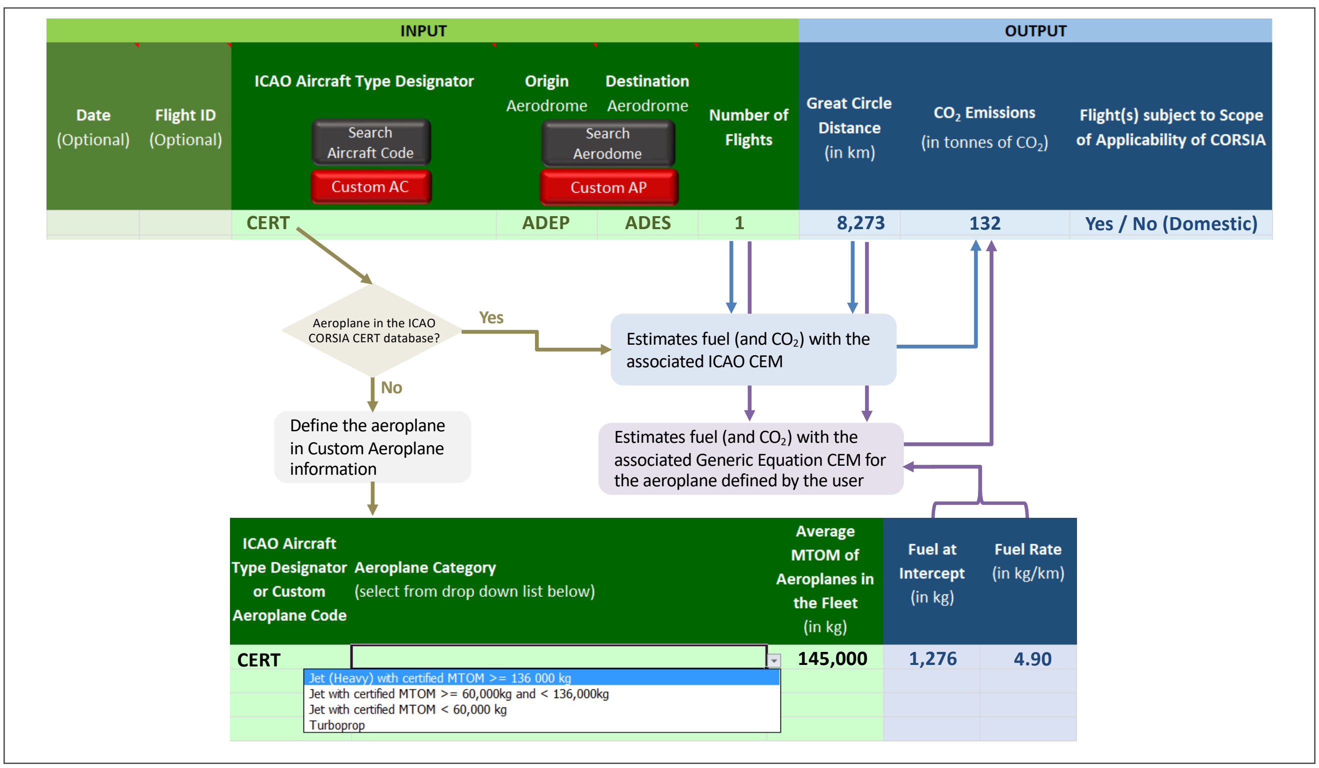


FIGURE 3: Estimation of the CO_2 Emissions with the ICAO CORSIA CERT – Step 2



The second step of the process for estimating the CO_2 emissions, as illustrated by the Figure 3, follows the same logic as the first, except that this step will focus on the type of aeroplane used. The tool will check if the aeroplane is in the ICAO CORSIA CERT database, in other words, if ICAO CEMs exist for this type of aeroplane. If they do, then the system will estimate the fuel burn and CO_2 emissions with the associated ICAO CEM by taking into consideration the number of flights and the GCD/BT. In the scenario where a type of aeroplane is not available, the tool will ask for additional information such as the aeroplane category from a selection of four options (turboprop or three jets with different certified Maximum Take Off Mass – MTOM) and the average MTOM of the aeroplane in the fleet. Based on this information, the ICAO CORSIA CERT will automatically compute a fuel rate and a fuel burn at the intercept. As previously, the tool will estimate fuel burn and CO_2 emissions with the associated Generic Equation CEM and by taking into consideration the number of flights and the GCD/BT.

CONCLUSION

The methodology behind the ICAO CORSIA CERT, as described above, seems to be complicated but from a user point of view, the use of the ICAO CORSIA CERT is very simple.

The main reason for using the ICAO CORSIA CERT is the simplification of the CO_2 estimation tasks for all users such as States, verification bodies and of course aeroplane operators. It is an easy-to-use ICAO-approved tool with a user-friendly interface, available free of charge and which comes with a detailed and transparent technical manual entitled "*ICAO CORSIA CO_2 Estimation and Reporting Tool (CERT): Design, Development and Validation*".

Furthermore, the ICAO CORSIA CERT was developed by, and will continually be updated by talented people and with the immeasurable support of Data Providing Organizations (DPOs). Without the support from those aeroplane operators and States in providing fuel burn data, the ICAO CORSIA CERT would not be as reliable as it is today!

The CORSIA Central Registry

By ICAO Secretariat

INTRODUCTION

The CORSIA Central Registry (CCR) is one of the five Implementation Elements of the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) and in accordance with Annex 16, Volume IV, it is the specific means for States to report CORSIA-related information and data to ICAO.

The purpose of the CCR is to assist States by providing a standardized way to report information on the implementation of CORSIA (see Table 1), while enabling ICAO to consolidate this information and make it publicly available on the ICAO CORSIA website.

States have already started reporting information with the submission of their lists of aeroplane operators attributed to each State, and the list of the verification bodies accredited in each State (due by 30 April 2019)[1]. However, the bulk of the information (CO_2 emissions, etc.) will be submitted starting in 2020.

Using the information reported by States, ICAO will calculate the baseline CO_2 emissions (2019-2020) for international aviation in 2021. Each year from 2022 onwards, ICAO will compile the reported CO_2 emissions for the previous year and determine the Sector's Growth Factor (SFG) for the previous year and report back to the States. States will use the SFG to determine the CO_2 offsetting requirements for each of their aeroplane operators.

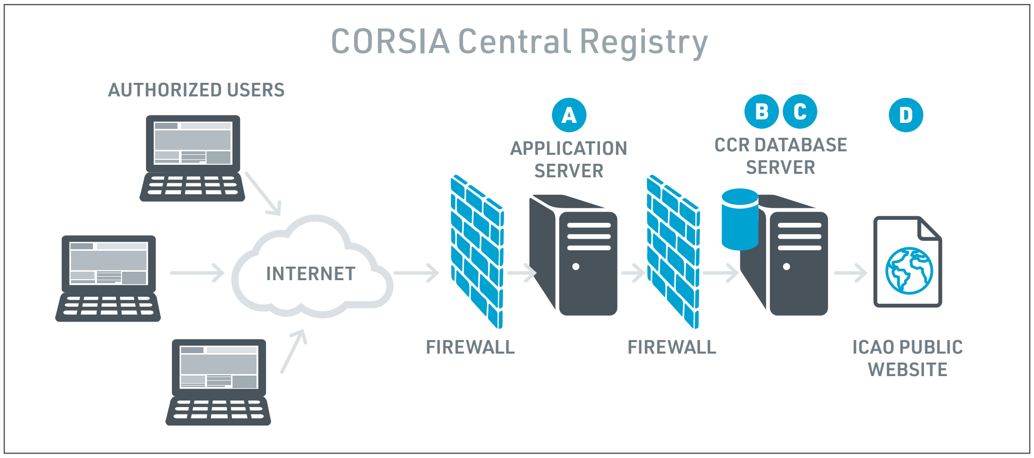
TABLE 1: Summary of CORSIA-relevant Information to be Reported by States to ICAO (2019-2026)

	Baseline		Pilot Phase			First Phase		
Information type	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**
Aeroplane Operators	✓	✓	✓	✓	✓	✓	✓	✓
Verification Bodies	✓	✓	✓	✓	✓	✓	✓	✓
CO_2 Emissions		✓ 2019 data	✓ 2020 data	✓ 2021 data	✓ 2022 data	✓ 2023 data	✓ 2024 data	✓ 2025 data
CORSIA Eligible Fuels*		Optional 2019 data	Optional 2020 data	✓ 2021 data	✓ 2022 data	✓ 2023 data	✓ 2024 data	✓ 2025 data
Cancelled Emissions Units							✓ 2021-2023 data	

** Information can be reported annually or once at the end of each three-year cycle.*

1 For 2019, ICAO developed and made available an online spreadsheet that States have used to submit information on aeroplane operators and verification bodies. The information submitted through the online spreadsheet will be incorporated into the CCR once it is operationalized.

FIGURE 1: Main Components of the CCR



COMPONENTS AND FEATURES OF THE CCR

The CCR is being implemented as an online web application supported by a database and a workflow engine, and comprises of the following components (see Figure 1):

A. Web application with predefined forms and automated checks;
B. Data transfer and storage;
C. Administrative console to perform internal checks and manage data and users;
D. ICAO website for the publication of information.

Each State will have one account on the CCR. Access to this account will be granted only to authorized users, who will be nominated by each State. Each State user will have unique login details (username and password) and will be given access to certain functions of the CCR based on a pre-defined list of permissions (see Table 2).

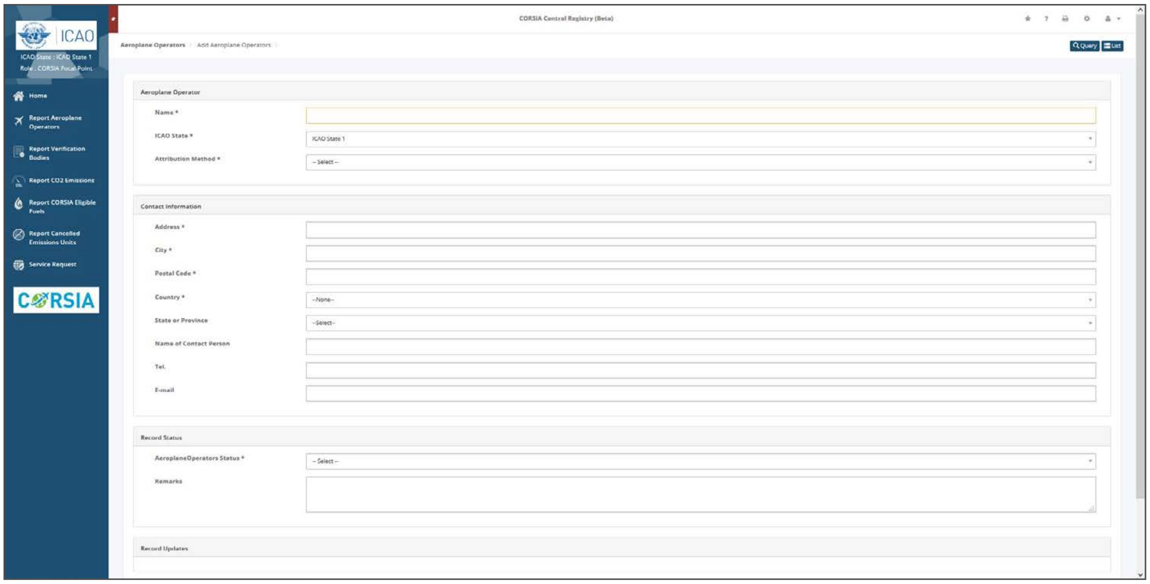
The State users will be able to provide new information and/or update previously submitted information. All user actions will be time-stamped and recorded (including the electronic signature of the State user who initiated an action) to ensure traceability and data integrity. If a State user needs to make changes to previously submitted information, the previous version of the information will not be deleted, but will be archived for future reference. It is important to note that only the CORSIA Focal Point can submit the data relevant to the State to ICAO.

Information and data will be uploaded on the CCR and submitted to ICAO using a secure web interface (web application/portal) through the use of predefined forms (see Figure 2 for an example). These forms facilitate entering information using, where possible, dropdown lists (for example list of ICAO States, attribution options, feedstocks used for CORSIA eligible fuels etc.) to minimize typing errors. Business rules have been created to check information and data before submitting to ICAO; for example, numerical data cannot contain letters or symbols, emissions data cannot be negative numbers etc.

TABLE 2: Examples of Permissions to CCR Main Functions per User Group

	CCR Functions			
User Group	**View Data**	**Add, Edit, Delete Data**	**Submit Data to ICAO**	**Manage Other Users**
CORSIA Focal Point	Yes	Yes	Yes	Yes (State Users)
State User	Yes	Yes	No	No

FIGURE 2: Example of the CCR Form to Enter Information on an Aeroplane Operator



(This image is provided for illustrative purposes based on the alpha version of the CCR and may not be a precise depiction of the final design of the CCR.)

OUTPUTS OF THE CCR

The information and data uploaded in the CCR will be used to produce five ICAO documents that are mentioned in Annex 16, Volume IV. Specifically:

1. ICAO Document "*CORSIA Central Registry (CCR): Information and Data for the Implementation of CORSIA*" is an umbrella document that contains:
    2. ICAO Document "*CORSIA Aeroplane Operator to State Attributions*" that contains a list of Aeroplane Operators and the State to which they are attributed
        - Availability: 31 May 2019 (First Edition published; to be updated regularly)
    3. ICAO Document "*CORSIA 2020 Emissions*" that contains the total 2020 CO_2 emissions to determine the first year in which a new entrant has offsetting requirements
        - Availability: As soon as practicable during the second half of 2021
    4. ICAO Document "*CORSIA Annual Sector's Growth Factor*"
        - Availability: 31 October 2022 (to be updated annually)
5. ICAO Document "*CORSIA Central Registry (CCR): Information and Data for Transparency*" contains:
    - List of verification bodies accredited in each State
    - Total average CO_2 emissions for 2019 and 2020 aggregated for all aeroplane operators on each State pair route
    - Total annual CO_2 emissions aggregated for all aeroplane operators on each State pair (with identification of State pairs subject to offsetting requirements)
    - Information and data for each aeroplane operator
    - Information and data on CORSIA eligible fuels claimed
    - Offsetting requirements and emissions units cancelled (at State and global aggregate level for a specific compliance period)
        - Availability: 31 May 2019 (First Edition published; to be updated regularly)

All five ICAO documents will be published on the ICAO CORSIA website, following their approval by the ICAO Council, in accordance with the above timelines.

DEVELOPMENT TIMELINE

In accordance with Assembly Resolution A39-3 (paragraph 20 g)), the CCR should be established for operationalization no later than 1 January 2021. ICAO initiated the process for the development of the CCR in October 2018 with the publication of the tender document on the ICAO website. The documentation included the terms of reference, which were based on the CCR functional requirements that were approved by the ICAO Council in June 2018.

The successful vendor was selected in early 2019 and following contractual negotiations, the development work started in mid-March 2019. The beta version of the CCR was delivered in early July 2019 for testing by ICAO. According to the agreed timeline, version 1 of the CCR is expected to be ready for deployment in late 2019 or early 2020. After the CCR is deployed, training will be provided to ensure that the potential State users are familiar with all of its functions.

An Overview of CORSIA Eligible Fuels (CEF)

By ICAO Secretariat

As explained in Chapters 4 and 5, the development and deployment of sustainable aviation fuels (SAF) is one element of the ICAO basket of measures to reduce aviation emissions. As a consequence, ICAO is pursuing several initiatives to support the further development and deployment of SAF.

Specifically on CORSIA, the ICAO Assembly Resolution A39-3 requested the development of a methodology "to ensure that an aircraft operator's offsetting requirements under the scheme [CORSIA] in a given year can be reduced through the use of sustainable alternative fuels, so that all elements of the basket of measures are reflected" (Resolution A39-3, paragraph 6).

In line with this Assembly request, Annex 16, Volume IV defines a "CORSIA eligible fuel" (CEF) as a "CORSIA sustainable aviation fuel" or a "CORSIA lower carbon aviation fuel", which an operator may use to reduce their offsetting requirements. This article presents the specific procedures and methodologies that will allow operators to claim emissions reductions from the use of CORSIA eligible fuels, as well as details on how such processes were developed by CAEP.

CORSIA DEFINITIONS

Historically, terms such as "alternative fuels" or "sustainable fuels" have been used in many instances to designate fuels produced from non-conventional processes and, consequently, lower environmental impact. In the context of CORSIA, Annex 16, Volume IV includes the following definitions related to fuels:

CORSIA eligible fuel. A CORSIA sustainable aviation fuel or a CORSIA lower carbon aviation fuel, which an operator may use to reduce their offsetting requirements.

CORSIA lower carbon aviation fuel. A fossil-based aviation fuel that meets the CORSIA Sustainability Criteria under this Volume.

CORSIA sustainable aviation fuel. A renewable or waste-derived aviation fuel that meets the CORSIA Sustainability Criteria under this Volume.

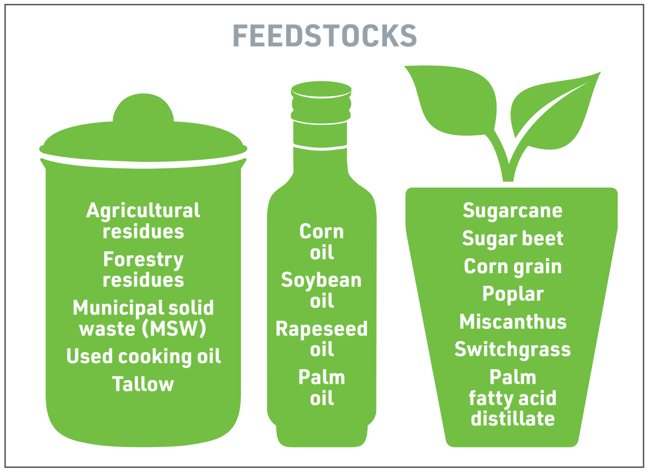
HOW DOES A FUEL BECOME A CORSIA ELIGIBLE FUEL (CEF)?

In order to understand how a fuel becomes a CORSIA eligible fuel, this section will provide an overview of the fuel supply chain – from the feedstock, to the conversion process, to the sustainability certification process, and finally its consideration as a CORSIA eligible fuel.

FEEDSTOCK

Several feedstock types have the potential to produce a CORSIA eligible fuel (CEF). As of February 2019, CAEP has developed default life cycle emission values for CORSIA sustainable aviation fuels produced from sixteen distinct feedstocks, as provided in Figure 1. Work is ongoing in CAEP to develop specific methodologies for the consideration of CORSIA lower carbon aviation fuels. More feedstock types may become available to fuel producers as the CEF industry evolves.

FIGURE 1: Feedstocks with CORSIA Default Life Cycle Emission Values (February 2019)



FUEL CONVERSION

The identified feedstock types are converted into aviation fuel through a fuel conversion process. The international standard-setting organization, ASTM International, has certified six fuel conversion processes for use in aircraft, as listed below (ASTM 7566 and ASTM 1655). This certification relates to the technical specifications of the fuel and ensures that the product is safe for use in an aircraft, by meeting the same safety standards as any other jet fuel.

SUSTAINABILITY CERTIFICATION

Beyond the technical certification process described above, fuels must also go through a sustainability certification process if they are to be used in CORSIA. Following the request of the ICAO Assembly, CAEP developed a sustainability certification process based on existing sustainability approaches, whether regulatory or voluntary, for the sustainability demonstration of aviation fuels.

Many aviation fuels already go through a voluntary or regulatory sustainability certification process, but the method described below refers to the CORSIA-specific process recommended by CAEP.

FIGURE 2: Fuel Conversion Processes Approved by ASTM International

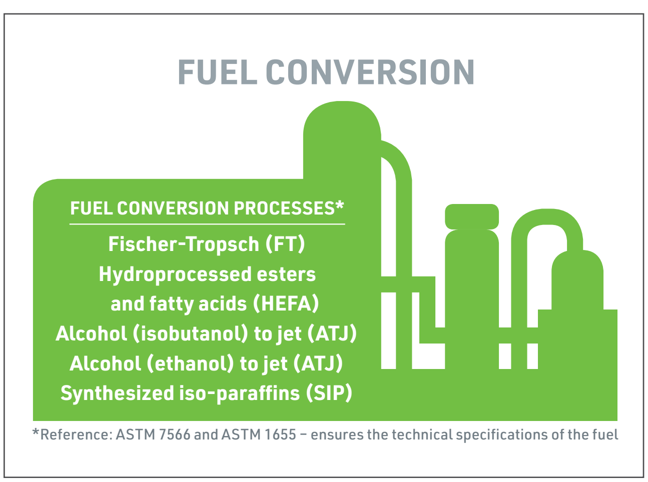
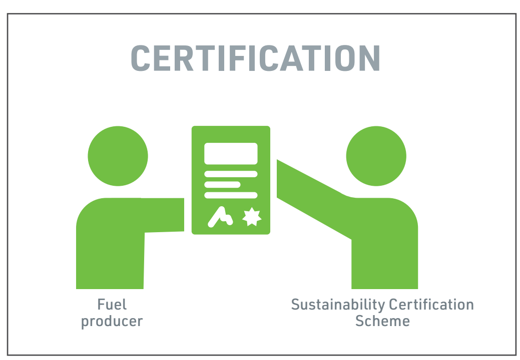


FIGURE 3: Sustainability Certification



LIFE CYCLE EMISSION VALUE (LSf)

The use of CEF can reduce aviation CO_2 emissions on a life cycle basis (i.e., from production to combustion). The reduction of CO_2 emissions from CEF depends on a variety of factors, for example, the feedstock used, how the feedstock was produced, the fuel conversion process used, etc. These factors combine to provide a fuel's life cycle emissions value (LSf).

CORSIA IMPLEMENTATION ELEMENT FOR CEF

The procedures and requirements for a CEF to be considered under CORSIA are defined within five ICAO documents, which are referenced in Annex 16, Volume IV. These documents form the CORSIA Implementation Element for CEF. They are:

1. CORSIA Eligibility Framework and Requirements for Sustainability Certification Schemes (SCS)
   This ICAO document defines the requirements that SCS need to comply with, in order to be approved by ICAO to perform the sustainability certification of CORSIA eligible fuels, as well as to assess the life cycle emission value (LSf) of CEFs.

2. CORSIA Approved Sustainability Certification Schemes
   This ICAO document will include the list of SCSs approved by the ICAO Council, in accordance with the Framework and Requirements laid out in ICAO document (1).

3. CORSIA Sustainability Criteria for CORSIA Eligible Fuels
   This ICAO document presents the Sustainability Criteria that needs to be observed by a given fuel. The first edition of the document, which applies until December 31st, 2023 (end of the CORSIA pilot phase), can be accessed from the ICAO CORSIA webpage[1].

4. CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels
   This ICAO document provides a list of Default Life Cycle Emissions Values for CEFs, as a function of the feedstock, conversion process, and production region. This is the simplest option available to determine the LSf value of a given CEF.

   The CORSIA supporting document "CORSIA Eligible Fuels – Life Cycle Assessment Methodology" (available from the ICAO CORSIA webpage[2]) provides technical information and describe ICAO processes to manage and maintain this ICAO document.

5. CORSIA Methodology for Calculating Actual Life Cycle Emissions Values
   This ICAO document provides methodologies that can be used by fuel producers to calculate Actual Life Cycle Emissions Values. These methodologies allow fuel producers to claim Life Cycle Emissions Values lower than the default values in ICAO document (4), in case they can support that with proper technical information.

Each of these documents will be made available on the ICAO website, as they are approved by the ICAO Council.

SUSTAINABILITY CERTIFICATION SCHEMES

Sustainability Certification Schemes (SCSs) will ensure that a CEF meets the CORSIA Sustainability Criteria (3), and will ensure that the Life Cycle Emission Value of the CEF is obtained correctly (4 and 5). SCSs must be approved by the ICAO Council to perform this sustainability certification process (1), (2).

1 https://www.icao.int/environmental-protection/CORSIA/Documents/ICAO%20document%2005%20-%20Sustainability%20Criteria.pdf
2 https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA%20Supporting%20Document_CORSIA%20Eligible%20Fuels_LCA%20Methodology.pdf

USING CEF IN CORSIA

An aeroplane operator can reduce its CORSIA offsetting requirements by claiming emissions reductions from the use of CEF through the following process:

1. The operator obtains the life cycle emissions value (LSf) of the CEF. This is determined during the CEF sustainability certification process, as described above.

2. The operator calculates the CEF emissions reductions (ERy) as follows:

FIGURE 4: CEF Emissions Reductions Formula

Fuel Conversion Factor, fixed value, 3.16 for Jet-A/ Jet-A1 or 3.10 for AvGas/ Jet B [kg CO_2/kg fuel]

$$ER_y = FCF \times \left[\sum_f MS_{f,y} \times \left(1 - \frac{LS_f}{LC}\right) \right]$$

Total mass of CEF claimed in the year y, by fuel type f [tonnes]

Baseline life cycle emissions, fixed value, 89 for jet fuel or 95 for AvGas [gCO_{2e}/MJ]

Example: If, in 2021, an operator uses 10,000 tonnes of Jet-A fuel produced from Used Cooking Oil (default **LSf=13.9 gCO2e/MJ***), the amount of emissions reductions will be:

$$ER_{2021} = 3.16 \times \left[10{,}000 \times \left(1 - \frac{13.9}{89}\right)\right] = \textbf{26,665 tonnes of } CO_2$$

3. The operator includes information on CEF in its Emissions Report, including:
   - CEF emissions reductions (ERy) claimed
   - Fuel type, mass, and life cycle emissions value (LSf)
   - Evidence of compliance with CORSIA sustainability criteria

4. A verification body verifies information on CEF provided in the Emissions Report. (More information on verification is available throughout this chapter.)

5. The State collects and aggregates verified information on CEF from all aeroplane operators attributed to it, and reports aggregated information to ICAO through the CORSIA Central Registry (CCR).

CONCLUSION

The processes described in this article ensure that an aircraft operator's offsetting requirements under CORSIA can be reduced through the use of CEF. Through CAEP work, ICAO has coordinated with fuel producers, sustainability certification schemes, airlines, States, and additional stakeholders to ensure that the process for using CEF in CORSIA is feasible, while ensuring the environmental integrity of the scheme. As the CEF industry progresses, ICAO will continue to work with these stakeholders towards the achievement of ICAO's aspirational goals.

One tonne of CO_2 in Tokyo shall be one tonne of CO_2 anywhere in the world

Assurance of the Verified CORSIA CO_2 Emissions Reports Through Accreditation

By Chikako Makino, Deputy General Manager, Strategy Planning Division, Japan Accreditation Board, and Co-Chair, IAF GHG and Energy WG

SUMMARY

The International Accreditation Forum (IAF) is supporting developing economies to establish accreditation infrastructures for ISO 14065 *Greenhouse gases -- Requirements for greenhouse gas validation and verification bodies for use in accreditation or other forms of recognition* working together with local accreditation and verification bodies. For the purposes of the International Civil Aviation Organization (ICAO) Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), IAF has established a structured Multilateral Recognition Arrangement (IAF MLA) based on ISO 14065. This MLA provides a harmonized global approach for verification bodies to achieve and maintain accreditation. It also promotes trust and builds confidence among accreditation bodies by ensuring that reports under CORSIA are treated the same way by all verification bodies using the same procedures to both verify them and produce trusted accredited verification statements for the purposes of the global ICAO Scheme.

INTRODUCTION

The International Accreditation Forum (IAF) is a global organization of accreditation bodies, and stakeholders involved in conformity assessment activities which support among others, the following goals:

- the recognition of competent and equally reliable accredited conformity assessment activities through global arrangements;
- the development and harmonization of accreditation practices; and
- the promotion of accreditation as an effective mechanism that provides confidence in goods and services.

The aim of IAF is to develop a worldwide accreditation program that ensures the equivalency of accreditation schemes offered by the IAF members. IAF defines and promotes application documents and provisions for national accreditation bodies while providing oversight of IAF members' accreditation schemes.

As of 30 June 2019, IAF membership totals 112, out of which 84 are Accreditation Body (AB) Members, 22 are Association Members, and six are Regional Accreditation Group Members: AFRAC (African Accreditation Cooperation), ARAC (Arab Accreditation Cooperation), EA (European Cooperation for Accreditation), IAAC (Inter American Accreditation Cooperation), APAC (Asia Pacific Accreditation Cooperation Incorporated), and SADCA (Southern African Development Community in Accreditation). Several other membership applications are in progress.

ACCREDITATION UNDER CORSIA

The international nature of aviation and the overall objective of CORSIA not to introduce market distortions while offsetting and reducing CO_2 emissions has led ICAO to develop an accredited verification scheme that reduces the risk of diverging accreditation and verification standards for the purposes of CORSIA.

IAF has participated in ICAO discussions on the development of Annex 16, Volume IV, specifically on the accreditation scheme for the verification of emissions reports under CORSIA. The accreditation scheme that is included in Annex 16, Volume IV is founded on proposals made by various ICAO States based on ISO 14065 *Greenhouse gases -- Requirements for greenhouse gas validation and verification bodies for use in accreditation or other forms of recognition* working.

The provisions of Annex 16, Volume IV are consistent with the World Trade Organization (WTO) Technical Barriers to Trade (TBT) Agreement[1], which encourages its members to "base their measures on international standards as a means to facilitate trade". Accordingly, for the purposes of CORSIA, the international standards ISO 14065:2013 and ISO 14064-3:2003 *Greenhouse gases -- Part 3: Specification with guidance for the validation and verification of greenhouse gas assertions* apply. ISO 14065 ensures that aeroplane operators receive a technically competent and fair verification with safeguards and respect to confidentiality concerns. In particular, verification bodies should ensure:

- Appropriate competencies with technical knowledge and skills for the international aviation sector.
- Fair verification processes, of a reasonable duration and cost, implemented as planned with sufficient data sampling.
- Communication of responsibilities to a client, appropriate records management and safeguards to address confidentiality of information.
- Insurance arrangements and availability of sufficient reserves to cover liabilities arising from the verification activities.
- Processes to manage, evaluate, take necessary corrective action(s), and make decisions on appeals and complaint are in place along with continuous improvement of service(s) by internal audit and management review processes.

In general, the accreditation process under ISO 14065 involves the assessment of an application by a verification body, a review of the provided documentation to determine whether it is appropriate, an office visit to the verification body premises to evaluate the verification process and determine the competencies of the personnel, and an on-site witness to evaluate the ability to perform the verification. The process is completed with granting accreditation credentials. Initial accreditation, regular surveillance and reaccreditation is based on ISO/IEC 17011 *Conformity assessment -- Requirements for accreditation bodies accrediting conformity assessment bodies*.

IAF member accreditation bodies monitor the performance of accredited verification bodies continuously, and if they identify any fraudulent behavior could decide to perform spot checks, or impose sanctions, or suspension if requirements are not met (for example, this could be the case where a verification body has been found to be manipulating data for the benefit of its clients).

IAF member accreditation bodies that accredit to ISO 14065[2], and grant accreditation for 247 validation and verification bodies globally may be able to demonstrate competence of verification bodies for the purposes of CORSIA. This requires that the IAF members have access to the competent technical assessors and experts, as appropriate, as soon as the CORSIA accreditation assessments start. Accordingly internal accreditation processes need to be analyzed to ensure that the additional CORSIA requirements can be implemented, before endorsement of the new scheme.

1 https://www.wto.org/english/docs_e/legal_e/17-tbt_e.htm#articleVI
2 For example, Austria, Belgium, Bulgaria, Croatia, Czech, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Italy, Latvia, Norway, Poland, Portugal, Rumania, Slovakia, Slovenia, Spain, Sweden, the Netherland, United Kingdom, Canada, Indonesia, Japan, Mexico, Mongolia, Singapore, Sri Lanka and the United States

In addition to this, for those national accreditation bodies starting ISO 14065 accreditation for ICAO CORSIA, e.g., China and India, we expect their ISO 14065 accreditations for CORSIA will be granted in 2019-2020.

THE IAF MULTILATERAL RECOGNITION ARRANGEMENT

IAF member accreditation bodies around the world, the competence of whom has been evaluated by peers, have signed an arrangement, the IAF Multilateral Recognition Arrangement (MLA), that enhances the acceptance of goods and services across national borders.

The purpose of the IAF MLA is to ensure mutual recognition of accredited verification amongst signatories to the IAF MLA, and subsequently the acceptance of accredited verification in many markets based on one accreditation. Accreditations granted by IAF MLA signatories are recognized worldwide based on their equivalent accreditation schemes, therefore reducing costs and adding value to business and consumers.

The IAF MLA now has 73 AB Signatories from 66 economies and 5 Recognized Regional Accreditation Group MLAs. The IAF MLA has four Main Scopes with 10 Sub-Scopes. The Main Scope of the IAF MLA, which demonstrates that accredited conformity assessment results are equally reliable, now covers Management System Certification ISO/IEC 17021-1, Product Certification ISO/IEC 17065, Certification of Persons ISO/IEC 17024 and Greenhouse Gas Validation and Verification ISO 14065.

The endorsed IAF MLA Main Scope 'Validation and Verification ISO 14065' allows regional accreditation groups and single national ABs to demonstrate the ability of ISO 14065 accreditation.

There is a process to evaluate IAF member applicants to become IAF MLA signatories. The national accreditation bodies' applicants cannot become signatories until they have met the relevant requirements, and there is an on-going assessment process to confirm the fulfillment of these requirements. AB members of IAF are admitted to the MLA only after a stringent evaluation of their operations by a peer evaluation team. It is the responsibility of this peer evaluation team to assess that the applicant members comply with both the international standards and the associated IAF documents.

At present three regional MLAs (the EA MLA, APAC MLA, and IAAC MLA) with 32 signatory members have been peer evaluated under the oversight provided by the IAF MLA for ISO 14065 for these regional MLAs and their signatories for ISO 14065 as appropriate. It is critical to this arrangement that a comprehensive peer evaluation process is established, under which IAF MLA national accreditation bodies undergo regular evaluations to ensure consistent application of the international standards. The MLA will be an effective tool for ensuring the consistent application of the CORSIA verification provisions worldwide as it will ensure that the accreditation scopes of IAF MLA national accreditation bodies for CORSIA is identical.

In October 2018, the IAF General Assembly endorsed the extension of the IAF MLA under the Main Scope of Validation and Verification for CORSIA for Level 4 and Level 5 Sub-Scopes.

The IAF MLA for CORSIA provides confidence that verification bodies accredited by IAF MLA's national accreditation bodies and their verification activities are assessed equally and consistently by all IAF MLA national accreditation bodies against ISO standard and ICAO standards e.g., CORSIA SARPs.

In practical terms, accreditation under CORSIA through the provisions of the MLA will ensure that an aeroplane operator receives the same verification services whether it uses a verification body accredited in its own or in a different state. The MLA therefore increases the availability of the verification bodies resulting in improved services and lower costs while maintaining the verification provisions contained in the CORSIA Standards and Recommended Practices (SARPs) related guidance included in the Environmental Technical Manual.

In 2018, 32 IAF AB members and 5 IAF Regional Accreditation Group members offered ISO 14065 accreditation; this means that 37 ICAO States may be able to receive the local accredited verification by IAF AB members and the related Regional Accreditation Group members. In addition, nine more IAF AB members are ready to start ISO 14065 accreditation. The prerequisite for these 46 IAF AB members and related Regional Accreditation Group members to start the accreditation for CORSIA is to receive the appropriate training for the CORSIA requirements. It is expected that the regional MLAs will start to extend the scope to sub-scope for CORSIA in 2019, and the first signatories of the IAF MLA for CORSIA are expected for 2020. Usually, the transition of an IAF MLA Main Scope to a Sub-Scope (such as for CORSIA) takes two to three years.

Signature of a Memorandum of Understanding (MoU) between IAF and ICAO, expected in the near future, will enhance the capacity of accreditation bodies and verification bodies by providing training for the CORSIA-specific verification requirements. In addition, through this MoU, IAF and ICAO with share information on CORSIA requirements and future updates of the Annex 16, Volume IV, IAF requirements and accreditations of IAF AB members in relation to CORSIA, including the above IAF MLA scopes and related CORSIA monitoring, reporting and verification requirements adopted by the ICAO Council and endorsed by IAF.

CORSIA – En Route and On Time

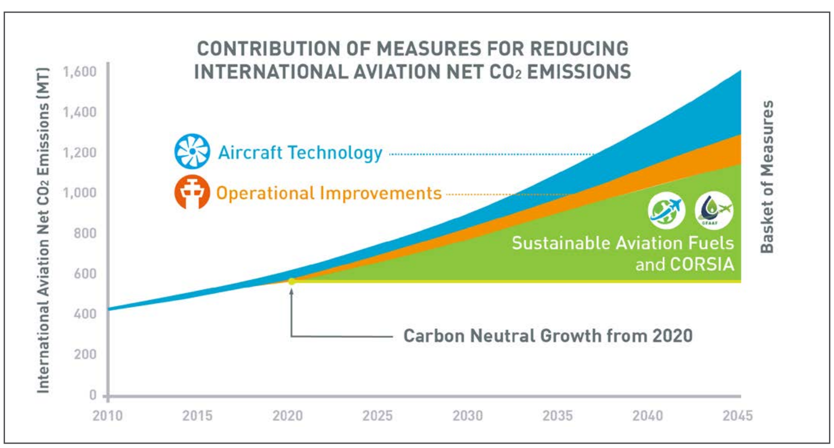
By Eva Weightman, International Emissions Trading Association (IETA)

The adoption of the Carbon Offsetting and Reduction System for International Aviation (CORSIA), the world's first global sector-wide emissions reduction system, was hailed as a great step towards tackling aviation's rising emissions. Carbon market participants and stakeholders have kept an even closer eye on developments since then. Now the key question everyone wants to know the answer to remains unanswered: what kind of emissions units will be eligible for CORSIA compliance.

CORSIA has been developed in order to achieve ICAO's aspirational goal of carbon neutral growth in the aviation sector from 2020. It represents only one part of a so-called basket of measures, which also includes improved aircraft technology, operational improvements, and the use of sustainable aviation fuels. These three are sometimes referred to as the non-market-based measures. While ICAO has been clear that the non-market-based measures are the preferred long term tools to ensure carbon neutral growth, it has also accepted that in the next 15 years they may not be sufficient. That is why a market-based mechanism, CORSIA, is needed.

Over the last couple of years, ICAO has assisted both states and aircraft operators with preparations for CORSIA. The main focus has so far been on getting the monitoring, reporting and verification (MRV) requirements in place. This is crucial as the baseline will be determined by emissions in 2019 and 2020. Aircraft operators that exceed this baseline in subsequent years will have to buy emissions units to offset this increase.

The CORSIA discussions are taking place at the same time that international carbon markets have seen increased interest, following the adoption of the Paris Agreement in December 2015. Article 6 of that Agreement allows for the cross-border trade of reduction units as well as establishing a new emissions mitigation mechanism to encourage sustainable development. In December last year, governments gathered in Poland to finalise the Paris Agreement Rulebook but, despite the best efforts, the rules for Article 6 remained unfinished. However, despite the disappointment there is a silver lining: Article 6 will receive negotiators' full attention and will play a key role at the UN talks later this year in Chile. IETA feels optimistic that an agreement can be reached.



SOURCE: ICAO website, www.icao.int

CORSIA has provided another reason for optimism. In March 2019, the ICAO Council announced the approval of the emissions unit criteria (EUC) and establishment of the Technical Advisory Body (TAB). Both are critical steps in defining what kind of emissions units will be eligible under CORSIA. EUC provide principles which will help determine the eligible emissions units under CORSIA. The TAB will assess candidate programmes seeking to supply such emissions units to the CORSIA market against these criteria. These announcements did not come as a surprise, as both are envisaged in the Assembly resolution itself. However, it sent an encouraging signal to market participants to see things staying on track for a timely completion.

The published EUC consist of two parts. The Program Design Elements refer to the rules and procedures expected to be in place by programmes that will apply to become CORSIA-eligible emissions units providers, while the Carbon Offsets Credit Integrity Assessment Criteria define the qualities that ICAO expects the eligible emissions units to have. The aim is to ensure delivery of real and verifiable emissions reductions, as well as preventing the double-counting of reductions. The criteria are robust enough to provide the confidence of environmental groups as well as market participants. Now it is the TAB's task to make the assessments of programmes in achieving the criteria.

But the clock is ticking. Generating emissions reductions often takes years — from the start of construction of a project through to the first issuance of carbon credits – and time is in increasingly short supply as far as climate change is concerned.

CORSIA EMISSIONS UNITS CRITERIA (EUC)

In March 2019, the ICAO Council approved the CORSIA emissions unit eligibility criteria, consisting of **Program Design Elements** and **Carbon Offset Credit Integrity Assessment Criteria**. The CORSIA emissions unit eligibility criteria should apply at the program level.

Program Design Elements:

1. ***Clear Methodologies and Protocols, and their Development Process***
2. ***Scope Considerations***
3. ***Offset Credit Issuance and Retirement Procedures***
4. ***Identification and Tracking***
5. ***Legal Nature and Transfer of Units***
6. ***Validation and Verification procedures***
7. ***Program Governance***
8. ***Transparency and Public Participation Provisions***
9. ***Safeguards System***
10. ***Sustainable Development Criteria***
11. ***Avoidance of Double Counting, Issuance and Claiming***

Carbon Offset Credit Integrity Assessment Criteria:

1. ***Carbon offset programs must generate units that represent emissions reductions, avoidance, or removals that are additional***
2. ***Carbon offset credits must be based on a realistic and credible baseline***
3. ***Carbon offset credits must be quantified, monitored, reported and verified***
4. ***Carbon offset credits must have a clear and transparent chain of custody within the offset program***
5. ***Permanence***
6. ***A system must have measures in place to assess and mitigate incidences of material leakage***
7. ***Are only counted once towards a mitigation obligation***
8. ***Carbon offset credits must represent emissions reductions, avoidance, or carbon sequestration from projects that do no net harm***

SOURCE: ICAO's CORSIA At a Glance Series, There is a steady supply of emissions units from projects developed in accordance with programmes around the world, some of which are already accepted for compliance markets. These systems have been developed over many years and apply a level of rigour comparable to the EUC. Allowing airlines access to these markets for CORSIA compliance would help keep down compliance costs, provide a ready-made stream of credits, and support innovative projects which benefit those most in need.

Tapping an existing market for emissions units instead of designing a new system, with all the accompanying methodologies, rules and procedures, would also allow for more energy to be spent on the more technical issues, such as calculating the industry baseline based on reported emissions. This will be critical in firming up the market's understanding of the amount of demand they will need to satisfy. But this will change over time, as the system begins to operate. Project developers are keenly focused on the TAB's progress, because it will signal the types of supply they need to produce.

Market analysts are beginning to assess these supply and demand dynamics for CORSIA, but they cite a number of variables involved and many uncertainties to evaluate. Are there going to be restrictions on project types? Will some emissions units only be eligible for compliance in the Pilot/First phase? How well will the other measures work to deliver efficiency improvements and biofuels? These are common themes in any emissions market analysis. But importantly, once the market gets clarity on these fundamentals, participants will respond with investment, project development and emissions units deliveries.

When the Kyoto Protocol's Clean Development Mechanism (CDM) was developed, it took several years to finalise the rules. But the first project developers started looking at early project opportunities far sooner. This meant that, once the rules were adopted and the institutions started operations, projects developed rapidly. The service sector around the project development – like project verification and legal drafting – also became vibrant. In those early days, it could take more than a year to get the project approved by a government, implemented, verified by a third party and registered.

This project cycle should be better for CORSIA. It can benefit from the lessons of the CDM and other markets; we're no longer starting anew, but with two decades of experience under our belts. During this time, carbon markets have evolved significantly and adapted to the user's needs, from the EU's cap-and-trade system to Colombia's tax and offset programme. The inherent flexibility of market mechanisms enables them to achieve real emissions reductions, quickly and at lowest cost. IETA itself is celebrating its 20th anniversary this year and, despite the occasional bump in the road since our inception, we are confident that market-based mechanisms are the right tool to deliver the climate ambition the world needs.

Ensuring sufficient supply of emissions units while maintaining the environmental integrity of the market system is a fine, but achievable, balancing act. The elements are all there – the experience, the robustness, the project pipeline, the investment. Time is of the essence to ensure CORSIA achieves what it is intended to.

CORSIA: The Airlines' Perspective

By Michel Adam, International Air Transport Association (IATA)

FROM 2009 TO 2019

Reducing fuel use (and associated emissions) has been a priority for airlines since the start of commercial air travel. With fuel costs representing about a quarter to a third of operating costs, improving fuel efficiency has been an evident strategic choice for airlines. At today's price of fuel (as of April 2019), when an aircraft emits 1 tonne of CO_2, it burns over USD200 worth of fuel.

But fuel costs are not the only incentive for airlines to mitigate their emissions. Airlines recognize that air transport contributes to climate change - currently 2% of man-made CO_2 emissions - and they are taking the responsibility to lessen this impact extremely seriously.

In 2009, under the umbrella of the Air Transport Action Group (ATAG), representatives of the entire aviation industry adopted three targets for the sector:

1. An improvement of its fuel efficiency by an average of 1.5 per cent per annum from now through 2020;
2. Capping the growth of its net carbon emissions from 2020 (carbon-neutral growth from 2020); and
3. Halving its net emissions by 2050 compared to 2005 levels.

Ten years after the adoption of these targets, the sector is more resolute than ever to deliver on its commitments. The short-term goal to improve fleet fuel efficiency by an average of 1.5% per annum from 2009-2020 is on track, with current analysis showing a 2.3% improvement on a rolling average – an efficiency improvement of 17.3% since 2009 (source: IATA/ATAG). And while fuel efficiency improvements will not be sufficient to stabilize emissions at 2020 levels in the short- to medium-term, ICAO's Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) and sustainable aviation fuels will enable the sector to achieve carbon neutral growth.

However, both our short-term efficiency goal and the CORSIA project will not be enough by themselves for our industry to play its part in the global response to climate change – our long-term goal and the associated *reductions* in CO_2 from the sector will be required.

COUNTDOWN TO CORSIA

The implementation of CORSIA has raised a few challenges for the airline and business aviation community. It is estimated that close to a thousand operators worldwide fall within the scope of CORSIA's obligations, with many of them being small operators with limited resources.

In 2017, the Air Transport Action Group (ATAG) and IATA, in coordination with IBAC and regional airline associations, launched "Countdown to CORSIA". The "Countdown to CORSIA" campaign included workshops, guidance materials and information toolkits. Close to 700 participants, representing more than 270 aircraft operators, took part in the workshops held in 2017 and 2018. More workshops will be held in the second half of 2019.

Another challenge some airlines have faced in their initial preparations for CORSIA has been to ensure their systems are appropriate to handle the significant amount of data that will need to be collected and reported. To offer a solution to interested airlines, IATA developed FRED+, a system which operators can use to store, handle and compile data for CORSIA. The system also allows data to be transmitted from operators to states and verifiers and can be paired with the fuel management software that airlines already use. This complements the ICAO CO_2 Estimation and Reporting Tool and other systems that airlines will be able to rely on to facilitate compliance with CORSIA.

The Countdown to CORSIA campaign and capacity building efforts have been a very successful joint-effort from the aviation community. Together with the efforts of ICAO and its Member States to prepare administering authorities under the ACT-CORSIA initiative, they have created a solid foundation for the implementation of CORSIA.

AVIATION AND OFFSETTING

For airlines, the implementation of CORSIA does not distract from the attention put on fuel efficiency measures. Offsetting is not intended to replace advances in technology, operations and infrastructure within the sector. Nor would CORSIA make fuel efficiency any less of a day-to-day priority. Rather, CORSIA can help the sector achieve its climate targets in the short and medium term by complementing emissions reduction initiatives within the sector.

While the airline community views CORSIA and offsetting as a necessary element of its climate change strategy, the large support from airlines is also related to the contribution carbon offsetting projects will make to communities and the Sustainable Development Goals. Indeed, there are many ways to achieve emissions reductions that can be used as offsets, many of which bring other social, environmental or economic benefits relevant to sustainable development.

The demand from aviation for carbon offsets will trigger a lot of investment in new climate mitigation. It is forecast that CORSIA will mitigate around 2.5 billion tonnes of CO_2 between 2021 and 2035, representing an investment in climate projects of at least USD40 billion.

In addition, strong criteria, based on principles commonly applied under existing trading mechanisms and well-accepted carbon offset certification standards, have been adopted by ICAO to determine eligible offsets and will ensure that CORSIA is an effective climate measure.

TARGETING 2050

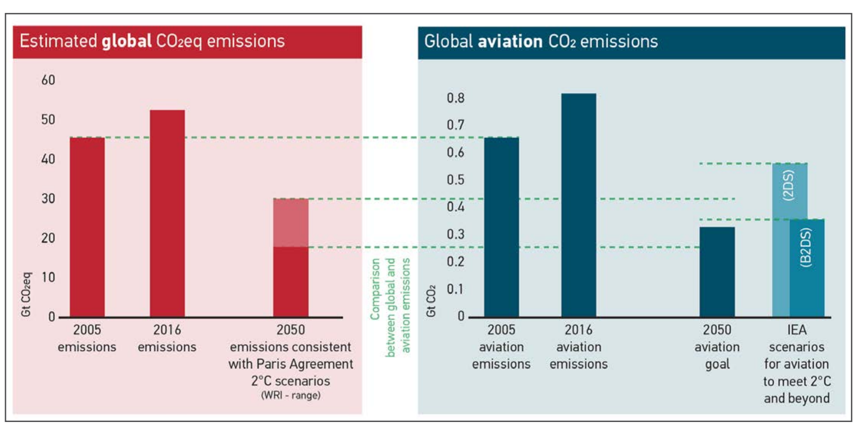
The focus right now is on the success of CORSIA and this work is pressing. However, airlines are on course towards their long-term target of halving net CO_2 emissions by 2050, compared with 2005 levels.

While international aviation was not included under the Paris Agreement's nationally-determined contributions, this does not mean that our sector does not have to play its part in reaching the Paris Agreement's ambitions. On the contrary.

In its 2017 *Energy Technology Perspectives*, the International Energy Agency (IEA) estimates that emissions from the aviation sector should decline to 0.3 $GtCO_2$-eq by 2060 under their "Beyond 2°C Scenario". The IEA notes that this is consistent with the industry's long-term target to halve its net emissions by 2050, compared to 2005.

Naturally, airlines and the broader industry need to put all efforts into ensuring the sector does not deviate from its course. This will require airlines to implement all available fuel efficiency measures and take part in the long-term

FIGURE: Comparison of the aviation industry 2050 goal vs. global emissions levels expected to result from implementation of the NDCs under the Paris Agreement and IEA 2°C scenarios (source: ATAG)



energy transition of air transport towards sustainable aviation fuels. Also, as the fuel efficiency improvement potential of current aircraft configurations is likely to be reduced in the next decades, the development of radically new aircraft, and their seamless integration in future operations, needs to materialize. From 2035 onwards, radical technological innovations with higher fuel efficiencies including new aircraft configurations and new forms of propulsion such as battery or hybrid electric power, can become a reality. Some airlines have already partnered with technology start-ups and research establishments, on some of the over 100 electric aircraft projects currently under investigation. This shows the sector's increasing interest in new technologies.

But the industry cannot achieve its long-term goal on its own. Governments need to support investment in research and development in academic institutions and with joint research programmes with industry. Governments must also foster policies that help support the growth in sustainable fuel deployment and promote their use for aviation, either by providing a level playing field with other uses or by prioritising its use in air transport.

WHAT WE CAN ALREADY LEARN FROM CORSIA

The experience gained in the development and initial implementation of CORSIA is that multilateralism and cooperation between all stakeholders are key to the sustainable development of air transport.

In 2016, ICAO's Member States were able to agree on the first-ever global carbon pricing instrument for a sector.

In less than three years, ICAO was able to adopt international standards to regulate the implementation of the scheme. These standards were drafted jointly by experts from governments, industry, environmental non-governmental organizations and the European Commission and they were adopted by ICAO's Council for their universal implementation in 193 member states.

ICAO, Governments and industry then engaged in large-scale capacity efforts to support all actors involved in the implementation of CORSIA.

And what will be achieved through a global mechanism such as CORSIA – the mitigation of over 2.5 billion tonnes of CO_2 and over USD 40 billion in finance for climate projects - cannot be achieved by a Government, a regional group, or an industry on their own.

While we can be proud of our past and current achievements, aviation cannot ignore the challenges ahead and all stakeholders must preserve the spirit of international cooperation and multilateralism that brought us to where we are. The next necessary milestone: the adoption of a long-term goal by Governments in ICAO, hopefully at the 41st session of the ICAO Assembly.

Zambia's Climate Change Mitigation: Implementing the Carbon Offsetting and Reduction Scheme for International Aviation

By Mr. Cuthbert Lungu (Zambia)

BACKGROUND

Zambia is a landlocked developing country with a population of approximately 14 million people, which is situated in Southern Africa between the longitude of 22°to 34° East and latitude of 8° to18° South. It is a member state of the International Civil Aviation Organization (ICAO), and also a member of ICAO's Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). The country voluntarily joined CORSIA and successfully submitted its first Aviation Emissions Action Plan to ICAO in November 2017. Zambia belongs to the ICAO East and Southern African (ESAF) regional group.

IMPLEMENTING CORSIA

The project which Zambia has embarked on to reduce its carbon footprint has focused on the Civil Aviation Authority working in collaboration with the aircraft operators registered in Zambia. The Civil Aviation Authority has been leading the way in aircraft guiding the operators to reduce their fuel burn for each International flight. It also assists them in monitoring, reporting, and verifying their fuel use, for onward reporting of that information to ICAO.

Since voluntarily joining CORSIA, Zambia has made great strides in its efforts to attain carbon neutral growth (CNG) by the year 2020.

The Civil Aviation Authority (CAA) was mandated by an Act of Parliament in 2012 to undertake all aviation related activities in the country. Since then, the CAA has assumed a leading role in guiding the aviation industry and explaining the benefits of CORSIA.

In 2017, Zambia's Civil Aviation Authority took the initiative and collaborated with ICAO, the African Civil Aviation Commission (AFCAC), and the Southern African Development Community (SADC), and hosted a CORSIA workshop which took place in Lusaka in August 2017.

The seminar was officially opened by Zambia's Minister of Transport and Communications, Dr. Brian Mushimba and for the first time in Zambia, CORSIA received considerable publicity. Seminar participants included officials from neighboring countries such as Tanzania and Zimbabwe. The event was an opportunity for the Civil Aviation Authority to promote and publicize the relatively new concept of CORSIA to all stakeholders within Zambia and beyond. Proflight Zambia, a major aircraft operator in Zambia that operates international flights was also present at the seminar. Other stakeholders that attended were: Zambia Environmental Management Agency (ZEMA), Energy Regulation Board (ERB), and Indeni oil refinery.

The journey towards carbon neutral growth began with the development of Zambia's Aviation Emissions Action Plan which was based on the ICAO Resolution A38-18. That resolution called for consolidated statements of continuing ICAO policies and practices related to Environmental protection and climate change. The ICAO assembly agreed on a comprehensive strategy to advance all elements of its "basket of measures" namely: technology, operations, alternative fuels, basket-based measures, and regulatory measures. Pursuant to ICAO's basket of measures, the Civil Aviation Authority of Zambia organized a series of stakeholder meetings with the major aircraft operator in Zambia, Proflight Zambia, which operates international flights. During those consultative meetings, that company was asked to choose which of ICAO's basket of measures could be applied to Proflight Zambia. As a result of that consultation process, Proflight Zambia chose to implement the following measures:

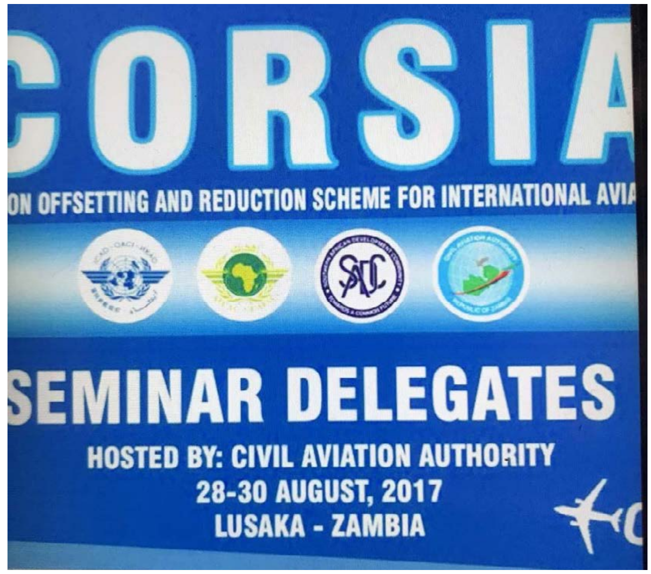
1. **Improved air traffic management (ATM) and infrastructure use.**

   Under this measure, Proflight chose to improve its optimum flight levels, and the use of optimum routings, and to also employ continuous climb/continuous decent operations.

2. **More efficient operations.**

   Under this measure, Proflight chose to minimize aircraft weight by introducing a number of measures including: paperless cockpit, reducing inflight magazines, limiting duty free items, and reducing catering equipment and commercial portable water. Other measures agreed to are: minimizing use of reverse, using single engine taxi operations, re-training pilots, optimizing aircraft maintenance such as engine washes, and selecting the aircraft best suited for the mission.

The implementation of the above mitigation measures selected by Proflight Zambia is projected to collectively result in the reduction of approximately 1,240 metric tonnes of CO_2 emissions from international aviation annually. In terms of more efficient operations, it is estimated that implementation of these measures will



account for about a 79% reduction in CO_2 emission by Zambian aviation by the year 2040.

THE ICAO BUDDY PARTNERSHIP PROGRAMME

Under the umbrella of the ICAO Assistance, Capacity building and Training for CORSIA (ACT-CORSIA) Programme and related Buddy Partnerships, Zambia received training from South Africa. Other recipient States which are receiving support from South Africa are; Lesotho, Botswana, Zimbabwe, Namibia and Malawi. The training assistance which Zambia received included development of an Emissions Monitoring Plan (EMP) and development of CORSIA regulations based on ICAO Annex 16, Volume IV. Under the Buddy Partnership Programme, Zambia invited its major aircraft operator (Proflight Zambia) and the airport operator to participate in the workshop. The training was conducted by South Africa's Ms. Chinga Mazhetese.

After the training, it was evident that Zambia needed to develop a time-bound activity plan as shown in Table 1.

Using the activity plan in Table 1, the CAA's Aviation Emissions Working Group was able to develop draft regulations which were submitted to the stakeholders for comment. Stakeholders responded positively and the

TABLE 1: Zambia's Activity Plan for CORSIA

	ACTIVITY	PROPOSED START DATE	ACTUAL COMPLETION DATE	STATUS QUO
1	Meet Zambia Bureau of Standards	09/10/2018	09/10/2018	Completed
2	Hold a meeting with committee members to draft activity plan	10/10/2018	10/10/2018	Completed
3	Recess for drafting of national regulations on CORSIA. Committee will seat with legal team	22/10/2018 to 26/10/2018		Completed
4	Committee to have a workshop with stakeholders to explain the new requirements and receive comments from stakeholders	5/11/2018 to 7/11/2018		Completed
5	Make inclusions to national requirements (if any)	12/11/2018		Pending
6	Submission to Director General CAA for approval of requirements	19/11/2018		Pending
7	Promulgation of requirements through a NOTAM and Aeronautical Information Circular (AIC)	1/12/2018		Pending

document is now in the final drafting stages and will be promulgated before the end of April 2019.

Under the guidance of the Civil Aviation Authority, Proflight Zambia has already started collecting fuel data which will be reported to ICAO at the end of 2019.

Another Zambian registered aircraft operator, Mahogany Air, has expressed interest in flying international flights by end of April 2019. In preparation for that, a one-day workshop has been planned for Mahogany Air called "Introduction to CORSIA" which will be conducted at CAA headquarters.

Recently, Proflight Zambia was successfully guided by Civil Aviation Authority to develop its first Emissions Monitoring Plan (EMP). That plan was approved by the CAA who shared it with Zambia's Buddy Programme partner, donor state South Africa.

It is expected that over the next three years more aircraft aeroplane operators will come on board and will require oversight from the Civil Aviation Authority. Therefore there will be need for the CAA to develop a standard one day workshop program which will cover modules "Introduction to CORSIA" and "Developing an Emissions Monitoring Plan". These two activities have been identified as essential for new entrants to: appreciate the need for CORSIA, how to go about developing the necessary documentation, and how to be compliant with CORSIA requirements.

CONCLUSION

Zambia's Civil Aviation Authority has embraced ICAO's CORSIA scheme and has been working hard to implement it. The CAA will do its best to guide the aviation industry and will use all the available resources under the ICAO Buddy Partnership Programme to ensure that CORSIA is a success in Zambia. It will also ensure that all aircraft operators attributed to Zambia understand CORSIA and submit Emissions Monitoring Plans as well as monitoring, reporting, and verifying their emissions and then submitting that info to the Civil Aviation Authority which will in turn submit it to ICAO.

Implementation of the ICAO ACT-CORSIA Initiative in the Southern African Development Community (SADC) Region

Experience of the Republic of South Africa with Buddy Partnerships

By Chinga Mazhetese (South African Civil Aviation Authority)

BACKGROUND

The Republic of South Africa (RSA) is a country at the most southern part of the African continent. The country has modern and well-developed transport infrastructure, with its rail and air networks being the largest on the African continent[1]. The Department of Transport (DoT) is responsible for the regulation of transportation, which covers: public transport, rail transportation, civil aviation, shipping, freight and motor vehicles. The DoT's motto is: ***'Transport is the heartbeat of South Africa's economic growth and social development'***

SOUTH AFRICA'S APPROACH TO REDUCING CARBON DIOXIDE (CO_2) EMISSIONS

South Africa is one of 193 ICAO Member States and fully supports the environmental work being done by ICAO. The country is devoted to providing an excellent transport system that reduces the quantity of Greenhouse Gases (GHGs) and other pollutants emitted by the sector[2]. Emissions from the transport sector are responsible for 10.8% of the country's total GHG emissions. Of this, aviation contributes only 5% of the transport sector's GHG emissions[3]. The National Development Plan (NDP) (Vision 2030), produced by the Department of the Presidency[4], provides an overall guideline on the strategic approach for the country's response to climate change. The NDP proposes the movement towards a low carbon economy. Different spheres of government have various roles to play to fulfil this vision. The DoT's objective in supporting the

1 South African Government, Department of Transport: *Transport Infrastructure Report*, 2017. <http://www.transport.gov.za/documents/11623/39906/6_TransportInfrastructure2017compressed.pdf/5f92a2ff-748a-4f7b-9d09-16a877a768e1>
2 South African Government, Department of Transport: *Green Transport Strategy for South Africa (2018-2050),* 2018. http://www.transport.gov.za/documents/11623/89294/Green_Transport_Strategy_2018_2050_onlineversion.pdf/71e19f1d-259e-4c55-9b27-30db418f105a
3 South African Government, Department of Environmental Affairs: *GHG Mitigation Report*, 2014.
4 South African Government, Department of the Presidency: National Development Plan: Vision 2030.

transition to a low carbon economy is to, 'increase the contribution of transport to environmental protection'. Accordingly, in 2018 the DoT adopted measures to address the significant contribution of all modes of transport to national GHG emissions by developing, a Green Transport Strategy (GTS) that intends to minimize the adverse impact of transport on the environment.

The implementation of the GTS will be the responsibility of the various DoT parastatal organizations. The South African Civil Aviation Authority (SACAA) is one of the agencies of the DoT and it is governed by the Civil Aviation Act of 2009. Its mandate is to control, promote, regulate, support, develop, enforce, and continuously improve, the safety and security levels throughout the civil aviation industry. The SACAA plays a major role in ICAO's work on the environment by its contribution as a Member of the ICAO Council as well as the Committee on Aviation Environmental Protection (CAEP). Accordingly, South Africa participates in aviation environmental protection decisions presented at the highest levels in ICAO. Furthermore, for several years the country has been the only African ICAO Member State that belongs to the CAEP.

REDUCING THE ENVIRONMENTAL FOOTPRINT OF THE SECTOR – SOUTH AFRICA'S PARTICIPATION IN ACT-CORSIA

The SACAA assists other regional States in numerous aviation disciplines such as aviation medicine and aerodrome certification. Under the umbrella of the ICAO Assistance, Capacity building and Training for CORSIA (ACT-CORSIA) Programme, the SACAA volunteered to assist some States within the Southern African Development Community (SADC)[5] region to implement CORSIA. Thus, the ACT-CORSIA initiative paved the way for South Africa, through the SACAA, to also provide assistance with aviation environmental protection. GHG emissions and their impact on climate change are not localized within States. Their consequences go beyond borders and therefore regional and global collaboration is required to produce positive climate change adaptation

FIGURE 1: SADC Member States (SADC).

and mitigation outcomes. The SADC region recently bore the consequences of Cyclone Idai, one of the worst tropical cyclones to ever affect the African continent. Two of the States receiving assistance from South Africa, Malawi and Zimbabwe, suffered from the disastrous destruction caused by this intense cyclone. Moreover, in previous years, bad weather has resulted in some flights in South Africa to be diverted from airports like Oliver Reginald (OR) Tambo and Cape Town International. It was no surprise therefore, that in response to the ICAO's State Letter, South Africa volunteered to participate in ICAO's initiative to reduce carbon dioxide emissions by assisting some of the States within the SADC region. South Africa provides assistance to six of the sixteen SADC Member States.

These six States are Botswana, Lesotho, Malawi, Namibia, Zambia, and Zimbabwe. These particular States were selected because of their proximity to South Africa, along with their official language of communication, being the same as that of South Africa. Through the ACT-CORSIA initiative, South Africa is honored to contribute to ICAO's No Country Left Behind (NCLB) campaign by assisting the Recipient States in implementing the Annex 16, Volume IV Standards and Recommend Practices (SARPs). This will greatly contribute to the improvement of aviation environmental performance by aeroplane operators in the SADC region and might, in the long run, contribute to more participation in ICAO's work on the environment by the SADC geographical region.

5 Southern African Development Community (SADC), Overview <https://www.sadc.int/about-sadc/overview/>

ACT-CORSIA Buddy Partnerships were established with these States, and under this initiative, South Africa (as the Donor State) provided the technical expert to work together with the CORSIA Focal Point (CFP) of each Recipient State. To ensure consistency, ICAO provided training to South Africa's technical expert and an ICAO Environmental Officer was assigned to work with, and provide guidance to this technical expert.

ASSISTANCE PROVIDED – IMPLEMENTATION OF THE ACT-CORSIA BUDDY PARTNERSHIPS

The implementation of the ACT-CORSIA Buddy Partnerships involved the following three steps:

Step #1: Training Session(s)

In September 2018, the Recipient States were invited to a three-day training session, which was named 'Joint Implementation Training Session'.

The focus of the training was on the development of Emissions Monitoring Plans (EMPs) and the establishment of CORSIA regulatory frameworks. Three sessions (covering the same content) were conducted and were comprised of two classroom sessions and one teleconference session. The 1st session was in South Africa and the 2nd session was in Zambia. These venues were chosen as the central points to reduce the travel costs for the CFPs and their delegates. States were advised to select the venue that was most convenient for them.

The representatives in the first session were all from the Civil Aviation Authorities (CAAs) in their respective countries. The second session was attended by the Zambian CAA, an aircraft operator (Proflight Zambia), as well the Zambian Airports Corporation Limited (ZACL). Malawi was unable to attend the two sessions that were scheduled for Johannesburg and Lusaka therefore; teleconference training was conducted for them on 6 November 2018. The presentations used in the classroom sessions were sent to Malawi prior to the teleconference. These were then clarified by the expert from South Africa to the Malawian Department of Civil Aviation (DCA) on the day of the teleconference. Concerning Lesotho, it was understood by both South Africa and ICAO, that Lesotho currently has no requirements under CORSIA. Nevertheless, assistance was offered by South Africa through information provision and the offer of invitations to future workshops.

Step #2: Remote Follow-up

Subsequent to the Joint Implementation Training Sessions, South Africa conducted remote follow-ups in the form of emails and teleconferences. Each Recipient State developed an Activity Plan showing the steps they would take to ensure that their aircraft operators developed the EMPs within the CORSIA timelines, and how the CAAs

TABLE 1: Details of the training sessions.

Session	Venue	Dates	Attendees
1	Emperors Palace, Johannesburg, South Africa,	26-28 September 2018	Botswana, Namibia and Zimbabwe
2	Protea Towers Hotel, Lusaka, Zambia	02-04 October 2018	Zambia
3	Remote (Teleconference)	06 November 2018	Malawi

FIGURE 2: Session 1 Delegates at Emperors Palace, Johannesburg, South Africa [*from left: Mr. Filemon Ngwedha (Namibia), Mr. Thabo Mogale (Botswana), Mr. Judah Dube (Zimbabwe), Mr. Kabelo Kgosimore (Botswana), and Mrs. Chinga Mazhetese (South Africa)*]. **[Photo Credit: SACAA]**

FIGURE 3: Session 2 Delegates- Protea Towers, Lusaka, Zambia. [*from left: Mr. Jackson Chirwa (ZACL Zambia), Mrs. Chinga Mazhetese (South Africa), Mr. Cuthbert Lungu (Zambia CAA), Ms. Audrey Sichula (Proflight Zambia), Mr Coster Malambo (ZACL Zambia), and Captain Phil Lemba (Proflight Zambia)*]. **[Photo Credit: SACAA]**

FIGURE 4: Template of the Activity Plan

STEP	ACTIVITY	PROPOSED START DATE	STATUS QUO	PROGRESS NOTES	ACTUAL COMPLETION DATE
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					

would ensure that regulatory frameworks were established in their respective States. The Activity Plans were sent to the Donor State via email.

Teleconferences between the Donor, Recipients, and ICAO were conducted between November 2018 and March 2019. The objective was to check the progress in implementing the Activity Plans and to render any assistance the States may have required.

- 14 and 16 November 2018 (Zambia, Botswana and Zimbabwe)
- 14 and 22 January 2019 (Malawi and Namibia)
- 6 February 2019 (Malawi)
- 5 March 2019 (All Recipient States – experiences gained)

Step #3: Final In-State Training

South Africa provided further assistance to some of the States, like Botswana, which requested that the Joint Implementation Training be extended to their regulation developers as well as their aeroplane operators. On-site training was conducted at the Botswana CAA in Gaborone from 20 - 30 November 2018. Three aeroplane operators attended the training: (Air Botswana, Kalahari Air Services, and Major Blue). Further on-site training is similarly scheduled for the Malawian DCA in Lilongwe from 29 - 30 May 2019. The attendees will be the Malawian DCA and some of the aeroplane operators in Malawi.

ASSOCIATED QUANTITATIVE/ QUALITATIVE BENEFITS - EXPERIENCE GAINED AND THE FUTURE OF BUDDY PARTNERSHIPS

South Africa is honored to have participated in the first phase of the ACT-CORSIA Buddy Partnerships. Both quantitative and qualitative benefits were realized by the donor and recipient States:

- South Africa as the Donor State contributed to ICAO's work on environmental protection and played a role in the ICAO No Country Left Behind initiative.
- The support rendered resulted in an improved understanding of the CORSIA in the region.
- The States had different levels of understanding and implementing the CORSIA. Through the deliberations under the ACT-CORSIA Buddy Partnerships, States that were new to the CORSIA managed to engage and share information with other States that were a step ahead.

- Collaboration is now taking place within the Buddy Partnership on efforts to achieve and enhance responsibility for the CORSIA. Each of the six States is now in a position to engage other States in the Buddy Partnership.
- Most of the Recipient States' aircraft operators managed to develop EMPs.
- Some regional aircraft operators benefited by receiving the training that was offered by ICAO through the Donor State and managed to develop their EMPs.
- The ACT-CORSIA Buddy Partnership campaign served as an information source. State authorities received information on the CORSIA SARPs and model regulations to assist them with regulation development.
- The training was offered free of charge thus catered for the different economic challenges faced by the recipients. In addition, it was provided in the region hence the recipients did not have to incur costs for international travel, accommodation etc.

Despite the very positive experiences highlighted above, there was, however, very little time for the development of regulatory frameworks by 1 January 2019. Different States have very diverse steps to establish regulations. The CORSIA's applicability date of 1 January 2019 made it a challenge for each of the States to develop and establish and implement regulatory frameworks. Nevertheless, each State initiated the framework for the regulation development and work is continuing towards getting the regulations promulgated.

THE FUTURE OF THE BUDDY PARTNERSHIP

South Africa intends to continue providing assistance to the six Recipient States under the ACT-CORSIA initiative throughout the CORSIA compliance cycles. Therefore, South Africa will follow ICAO's directives regarding the next steps in the Buddy Partnership activities. The upcoming support may involve assistance with verification requirements, plus the development of Emissions Reports.

ICAO

CHAPTER SEVEN

Climate Change Adaptation

International Civil Aviation and Adaptation to Climate Change

By ICAO Secretariat

INTRODUCTION

ICAO's policies and activities on climate change have primarily been driven by the imperative of mitigating the emissions from international civil aviation. In this regard ICAO has two global aspirational goals, of 2 per cent annual fuel efficiency improvement and carbon neutral growth from 2020, respectively. To achieve these global aspirational goals, a comprehensive approach has been agreed, consisting of a basket of CO_2 mitigation measures including aircraft technology and standards, the development of sustainable aviation fuels, operational improvements, and the adoption of the first-ever sectoral global market-based measure, the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA).

While the efforts of ICAO are mainly focused on reducing the impact of international civil aviation on the global climate, the impact of climate change to aviation infrastructure and operations has also been identified as a significant risk for the aviation sector and ICAO's work on climate adaptation is the foundation of risk preparedness[1].

The key questions are how should aviation infrastructure be designed and built so that CO_2 emissions are limited, and more extreme temperatures and weather events, water scarcity, sand storms, or any impact attributable to a changing climate, can be withstood; and how to minimize the disruptions to the operation of the air travel network. Indeed, with 100,000 international flights being operated daily in 2019, any disruption in one part of the network can incur multiple delays in others.

The reason why ICAO has been engaged at an early stage on aviation adaptation and resilience to extreme climate-related events is to better understand the nature, the risks and the impacts of climate change on international aviation. This work has primarily focused on identifying impacts, in the air and on the ground and it led to updating ICAO Doc 9184, Airport Planning Manual – Part 2, to include the consideration at a very early planning stage of the risks for new and redeveloping infrastructure. This document is the most comprehensive piece of guidance made available to States, airport planners and developers that wish to integrate the environmental impacts of airport infrastructure and operations as early as the design phase, considering the long lifespan of such infrastructure. This is also the main reason to consider the climate change resilience of the airport and to ensure the permanence of this capital-intensive asset.

In order to ensure the resilience of the international aviation system, the role of ICAO in disseminating best practices and guidance is instrumental. Indeed, the ability to engage all stakeholders effectively, from the airports, airlines, air navigation services providers to the energy suppliers and local authorities is a prerequisite to avoid the creation of islands of resilience, with no connection to the rest of the network. Therefore, ICAO has engaged with a number of organizations, including the World

1 - ICAO Assembly Resolution A39-2 *Consolidated statement of continuing ICAO policies and practices related to environmental protection* requests to identify the potential impacts of climate change on international aviation operations and related infrastructure and identify adaptation measures to address the potential climate change impacts, in cooperation with other relevant international organizations and the industry.
- ICAO Assembly Resolution A39-24 deals with the strategy on disaster risk reduction and response mechanisms in aviation.
- More information available at: https://www.icao.int/environmental-protection/Pages/adaptation.aspx

Meteorological Organization (WMO), in order to enhance the awareness and preparedness of all.

In the meantime, as per the latest scientific information, climate events have increased in frequency and intensity, stressing the imperative to develop a reference document for the sector. In 2019, the Council's Committee on Aviation Environmental Protection (CAEP) recommended the approval of the ICAO's Climate Adaptation Synthesis.

ICAO'S CLIMATE ADAPTATION SYNTHESIS

Methodology

The ICAO Climate Adaptation Synthesis captures existing information on the range of projected climate impacts in the aviation sector to better understand risks to airports, air navigation services providers (ANSPs), airlines and other aviation infrastructure. The scientific content of the report is based on the findings of the Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC AR5) (2014), supplemented with peer-reviewed scientific information, as required.

The synthesis was conducted in two stages:

1. Literature review: the literature review collated information from documents relevant to aviation climate change adaptation issues; and
2. Survey: a survey was designed and sent to all ICAO Member States in order to collect meaningful information on the current level of awareness of climate change impacts, the nature of the impacts and how they will affect international aviation infrastructure and operations, as well as the self-assessed level of preparedness of the various international aviation stakeholders.

Content

One of the key findings showed that 74 per cent of respondents found that their aviation sectors already experience some climate change impacts, while a further 17 per cent expect some impact by 2030.

Potential climate effects on the aviation sector were identified for eight climate impact categories, including:

1. sea level rise;
2. increased intensity of storms;
3. temperature change;
4. changing precipitation;
5. changing icing conditions;
6. changing wind direction;
7. desertification; and
8. changes to biodiversity.

Consideration was also given to potential climate change impacts to business and economics, as well as climate change risk assessment and adaptation planning.

The impacts on the aviation system were identified globally and are shown in the ICAO Global Climate Adaptation Risk Map (Figure 1). The survey showed that 30 per cent of respondents have already implemented climate adaptation measures, while 25 per cent intend to do so in the next five to ten years. Six per cent indicate that they have no measure planned. A climate change risk assessment is required to determine the climate change vulnerabilities, before an adaptation strategy is developed.

Regarding the preparedness of the global aviation sector for climate change impacts, the majority of respondents stated that while the global aviation sector has engaged heavily in climate change mitigation efforts, more effort should be given to climate change adaptation, including the need for more global coordination. Many respondents identified the need for more outreach, training, and capacity-building, as well as increasing the understanding of specific vulnerabilities for the sector. Respondents also thought that the development of adaptation risk assessments, policies and planning for resilience at the global level could be required. The full ICAO Climate Adaptation Synthesis can be found on the ICAO web site[2].

2 https://www.icao.int/environmental-protection/Pages/environment-publications.aspx

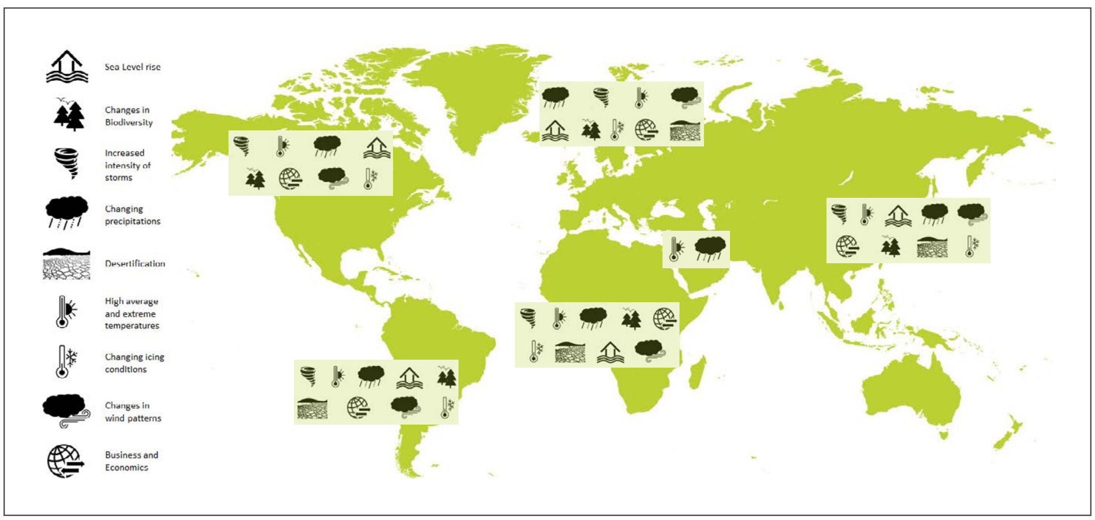
NEXT STEPS

The ICAO Climate Adaptation Synthesis is the first global overview of the climate change risks and impacts that could affect international aviation infrastructure and operations. It is also the only document that reflects the self-assessed level of preparedness of all major international aviation stakeholders, and relays the need for more suitable information and guidance on risk assessment at global level.

ICAO envisages cooperating with international experts to develop the first globally recognized climate change risk assessment methodology. The cornerstone of this methodology will be the identification, characterisation and visualisation of the climate change impacts on international aviation and identification of the risks to which the operations and infrastructure may be exposed based on climate change projections and scenarios.

With this additional resource, ICAO's 193 Member States will have the opportunity to assess their own level of vulnerability and decide with their national and local stakeholders, how to build resilience into their international aviation system. In doing so, they will enhance their ability to assess and mitigate the climate change risks that would compromise the sustainable development of international aviation and the economies that the sector supports.

FIGURE 1: Based on replies from ICAO Member States, the ICAO Global Climate Adaptation Risk Map (ICAO, 2019) shows the nature of the climate change impacts on international aviation.



The main scientific document this synthesis consulted is the IPCC Fifth Assessment Report (AR5), published in 2014. AR5 is recognized by the international scientific community as the most current and comprehensive publication pertaining to climate change science. In 2018 the IPCC published a special report on keeping to 1.5° C of global warming. It looked at if and how we can achieve 1.5 °C and the difference in impacts between 1.5 and 2 °C. However, it did not update the full set of scientific information from the Firth Assessment Report: that will be update in the Sixth Assessment Report, for which the Summary for Policy makers is scheduled for publication in 2021.

Climate Adaptation Synthesis

By Ms. Rachel Burbidge (EUROCONTROL) and Ms. Andrea Freeburg (US FAA)

According to the 2014 UN Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report, there is scientific consensus the climate is changing, and will continue to change for the foreseeable future. Climate change will have impacts across society, including the aviation sector. While aviation currently operates safely and efficiently in a variety of climates, climate change is likely to pose a number of risks for the sector in the future, including increased frequency and intensity of disruptive weather events in some areas of the world, potentially beyond the current capacity for resilience of the aviation system. Despite increasing global climate change mitigation efforts, some degree of climate change is unavoidable. Therefore, action is needed to adapt and build resilience to rising sea levels, higher temperatures, stronger storms, and other potential impacts. For this reason, and in response to a call from concerned Member States, ICAO has been working to provide information on climate change adaptation and resilience to the global aviation sector beginning with the 2013 update of the ICAO Airport Planning Manuel. In February 2016, the triennial ICAO Committee on Aviation Environmental Protection (CAEP) Plenary meeting approved a new task to develop a Climate Adaptation Synthesis report that was subsequently adopted in 2019.

DEVELOPING THE SYNTHESIS

The objective of the Climate Adaptation Synthesis task was to gather existing information on the range of projected climate impacts for the aviation sector so as to better understand the potential risks to planning, infrastructure, and operations. The working group considered impacts at local, regional, and global levels. It also gathered examples of related adaptation and resiliency efforts and actions that may reduce the risk associated with the impacts of climate change, some of which have already been implemented by Member States, local authorities, and aviation sector organizations.

As part of this substantial piece of work, a survey to gather input from States and organizations was developed. Responses were received from States, airports, airlines, ANSPs, and a global organization. At least one response was received from every ICAO Region.

The survey asked respondents the following questions:

- Whether they expect to be impacted by climate change?
- Whether they are already experiencing impacts?
- Which climate change impacts respondents expected to be impacted by?

- Whether they were taking any measures to adapt to the impacts of climate change, such as a climate change risk assessment, or adaptation measures?
- How prepared they think the global aviation sector is for the impacts of climate change, and what further action might be considered?

The key findings from the survey are presented later in this article.

In parallel to analyzing the survey results, a literature review of current scientific and policy documents containing relevant material on the potential impacts of climate change for aviation and possible adaptation and resilience measures was carried out. Some of the documents were global in context, while others were regionally or more locally specific. Each document was analyzed separately and the relevant information on climate impacts, effects on the aviation sector, and adaptation and resilience measures was combined to provide a high-level synthesis of the best available current information.

CLIMATE ADAPTATION SYNTHESIS CONTENT

The Synthesis provides a detailed overview of climate change risk and resilience for the global aviation sector. It contains information on nine physical impacts of climate change:

- sea level rise
- storm surge
- increased intensity of storms
- changing in average and extreme temperatures
- changing precipitation
- changing icing conditions
- changing wind
- desertification
- biodiversity (wildlife and ecosystems)

For each of these impacts, the synthesis describes:

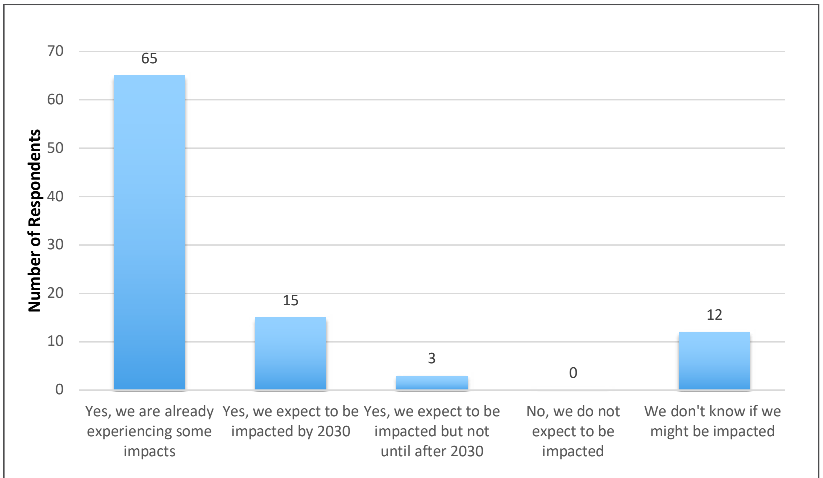
1. What the impact is.
2. Expected timescales for the impacts.
3. Potential effects for the aviation sector.
4. Potential adaptation and resilience measures to address the impact.

The synthesis also identifies business risks for the sector such as changes to revenue. Additionally, the synthesis provides a summary of high-level information on carrying out a climate change risk assessment and developing an adaptation plan based on material gathered during the literature review. Finally, the synthesis provides a qualitative analysis of survey responses regarding the preparedness of the global aviation sector to deal with the impacts of climate change.

CLIMATE IMPACTS FOR THE GLOBAL AVIATION SECTOR

As listed above, nine potential climate change impacts for the global aviation sector were identified. This was done according to the recently updated ICAO Airport Planning Manual Part 2 Land Use and Environmental Management (ICAO Doc 9184), and confirmed by the review of scientific literature. Information for each of these nine impact categories was synthesized separately and included in a regional analysis, so as to provide a comprehensive global picture as to the varying risks to the aviation sector from climate change.

FIGURE 1: Q1 - Do you expect to be impacted by climate change now or in the future?



N=88. Some respondents selected more than one answer to this question.

One of the key findings of the synthesis was that 65% of survey respondents are already experiencing climate change, and no respondents indicated that they did not expect to be affected (Figure 1). This suggests that climate change impacts are a tangible risk for most of the survey respondents.

Of the nine impact categories included in the survey, the three that survey respondents expect to be most impacted by are:

- **Higher Average and Extreme Temperatures:** 91% of respondents stated that they are affected today, or expect to be affected in the future, by higher average and extreme temperatures. Both average global mean temperatures and extreme high-heat days are expected to increase. The impacts to aviation from higher temperatures are wide-reaching. For example, high heat days can stress cooling systems or damage the airfield surface, if temperatures exceed design standards. Higher temperatures can also reduce air density, which can affect aircraft take-off requirements. Additionally, higher temperatures may cause permafrost to thaw in northern regions, destabilizing infrastructure and contributing to erosion.
- **Changing Precipitation:** 89% of respondents stated that they are affected today, or expect to be affected in the future, by changes in precipitation. Changes in precipitation type (e.g., rain, snow, hail), as well as precipitation frequency, potentially leading to extreme rainfall or prolonged drought are expected. There is considerable variation in precipitation forecasts globally, but the International Panel on Climate Change fifth Assessment Report (IPCC AR5) WGI (the physical science basis) states that climate change is likely to bring a change, and potential exacerbation of these conditions to all regions. Extreme rainfall may cause flooding of airport surfaces and infrastructure, while drought may lead to reduced water availability.
- **Increased Intensity of Storms:** 86% of respondents stated that they are affected today, or expect to be affected in the future, by increased intensity of storms. IPCC AR5 Synthesis illustrates how, as temperatures increase, the risk of extreme weather events, such as extreme storminess, will also increase. Increased intensity of storms may cause damage to aviation infrastructure and cause delays or cancelations to commercial air service.

Other key impacts and their potential effects include sea-level rise inundating infrastructure, changes in icing conditions leading to changes to de-icing requirements, changes to wind patterns including changes to the Jetstream which could affect flight times, and an increase in en-route turbulence. Other impacts may include: an increase in desertification and a resulting increase in sandstorms disrupting operations, an increase in wildlife hazards due to changes to biodiversity, and business and economic impacts such as increased costs from delayed and cancelled flights, or changes to tourism demand patterns.

CLIMATE CHANGE ADAPTATION AND RESILIENCE

The synthesis also looked at what States and organizations can do to reduce the risks from climate change impacts. It found that the most common approach is to carry out a climate change risk assessment and then develop a climate adaptation plan. This process involves determining how the climate might change in a given area, and what risks this change may have for aviation, specifically. The next step is to identify appropriate climate adaptation and resilience measures to reduce the risk from the climate change impacts identified, and develop an action strategy in a climate adaption plan that sets out and prioritizes how those measures will be implemented. For example, adaption and resilience measures could include such measures as: increasing surface drainage to accommodate an increase in heavy precipitation, implementing defenses against sea-level rise, relocating infrastructure on higher terrain, increasing terminal cooling capacity, and reinforcing infrastructure to deal with stronger and more frequent storms. Of course, any decision on what measures to implement, and to what extent, are at the discretion of an individual State or organization. Given that climate may change differently or more quickly than current projections, it is important to review adaptation plans and measures at regular intervals to ensure the information is current.

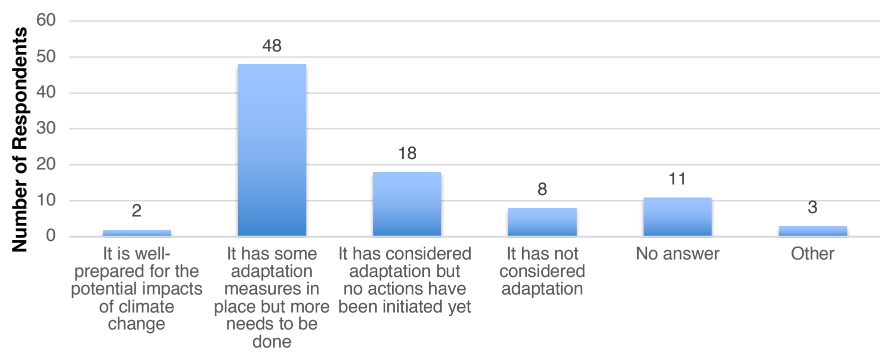
HOW PREPARED ARE WE?

The final section of the Synthesis collates information from survey respondents on how prepared they think the global aviation sector is to deal with the potential impacts of climate change. For example, 55% of respondents said that they think the sector has some measures in place but that more needs to be done (Figure 2) and 20% of respondents indicated that that they thought the global sector has considered adaptation but has not yet initiated any actions. These results indicate most respondents believe that the aviation sector has started to take action to adapt to climate change, but that more may need to be done.

NEXT STEPS

Climate change is a growing global issue. ICAO will continue to work on climate adaptation and resilience in the next CAEP cycle, which runs from 2019 to 2022. Of particular note, future work will focus on making information from the Synthesis available more widely, to support the global aviation sector in taking measures to adapt and build resilience to the impacts of climate change. States and organizations will be able to use this information to support the identification of climate change impacts, the potential effects these impacts may have on their aviation sectors and organizations, and to identify potential adaption and resilience measures to implement to reduce their vulnerability to climate change impacts.

FIGURE 2: Extent to which respondents think the global aviation sector is prepared for the impacts of climate change.



N=88. Some respondents selected more than one answer to this question.

ACI Supports its Members Adapt to Climate Change and Become More Resilient

By Juliana Scavuzzi, Senior Manager Environment, ACI and Jeeyoon Jung, Assistant Manager Environment, ACI

More frequent storms and other adverse weather events have put airports around the world into the spotlight. They have mobilized the aviation community into action to improve the sector's resilience and adaptation to a rapidly changing climate. In October 2018, Kansai Airport was hit by the strongest typhoon in Japan for 25 years. This had severe economic impacts (more than half a billion USD) both to the airport, and also to the local economy.

The impact on one airport can be easily seen, but there are knock on effects on other airports and stakeholders, as delays, cancelations and congestion occur. No one is immune from the impacts of climate change and airports are no exception. This does not mean all airports need to adapt their infrastructure and/or operations, but ACI encourages them to conduct risk assessments and consider including the results of these assessments in their Master Plans.

When a petroleum tanker crashed into the only bridge connecting Kansai International Airport with the mainland, it was not just the 8,000 passengers and staff that suffered. It was the region's overall economy – an economic powerhouse that just ranks below the GDP of

Kansai International Airport hit by Typhoon Jebi on 4 September 2018 Source: Mainichi Shimbun

the Netherlands[1] - that suffered. It took 17 days to fully restore the operation back to normal.

ACI RESOLUTION ON RESILIENCE AND ADAPTATION TO A CHANGING CLIMATE

Recognizing the potential impact of climate change on airport infrastructure and operations as an ever-evolving threat that could become impediments to the industry, Airports Council International (ACI) adopted a resolution on resilience and adaptation to climate change at its World Annual General Assembly in Brussels in June 2018[2]. Members unanimously called for specific actions to address the potential impact of climate change at every level of airport planning and operation: from airport master planning to business continuity planning and disaster risk reduction.

As seen at Kansai International Airport in the aftermath of the typhoon Jebi, the impact to the airport and its surroundings may have significant knock-on effects to the overall resilience of an economy. Furthermore, the global air transport network can be affected, resulting in disruption throughout the network.

ACI agreed to:

- Continue reducing greenhouse gas emissions through the Airport Carbon Accreditation programme and other measures;
- Support international efforts in assessing the potential impacts of climate change;
- Consider the potential impact of climate change in Airport Master Plans;
- Conduct risk assessments on operation and infrastructure;
- Implement follow-up actions in line with overall business continuity management and emergency planning; and
- Collaborate with internal/external stakeholders.

ACI GLOBAL SURVEY ON RESILIENCE AND ADAPTATION

In order to better support members' call for action, the ACI World Governing Board decided to conduct a survey on the status of airports actual and potential future impacts and their related adaptation measures. It is the first global assessment focused on airports, exemplifying the airport industry's determination to make well-informed decisions and to tackle this complex challenge. The survey aims to collect quantitative and qualitative data on:

- Current and prospective exposure and potential impacts from changing climate;
- Level of preparedness and efforts put in place by the industry, including risk assessments and adaptation plans; and
- Financial past and potential impacts, including changes to insurance premiums and financial risks disclosure requirements.

The survey is expected to draw inputs from various departments within an airport, including expertise from areas such as environment, operation, planning, strategy, finance, safety, and others. It aims to also collect members' views on current and potential financial impact from climate change and recent evolution from financial systems including the recommendations from Task Force on Climate-related Financial Disclosures (TCFD).

Considering the multidisciplinary nature of the problem, and the need for a coordinated approach from various departments in airports, ACI's World Environment Standing Committee has been leading the development of the survey with support from other ACI Committees. Once finalized, the survey is expected to inform and guide the airport industry and other aviation stakeholders; and to shed light on the analysis of adaptation efforts from other critical infrastructure and transport systems.

1 https://www.ft.com/content/0df7c4d6-5dea-11e8-ab47-8fd33f423c09
2 https://aci.aero/news/2018/06/22/28th-aci-world-annual-general-assembly-passes-six-resolutions-to-support-world-airports-priorities-and-interests/ (accessed on 28 May 2019)

PUBLICATIONS TO SUPPORT MEMBERS

Policy Brief on Airports' Resilience and Adaptation to a Changing Climate

ACI has published a Policy Brief on Airports' Resilience and Adaptation to a Changing Climate. It provides a high-level summary of potential impacts on airport operation and infrastructure from extreme and slow-onset climate stressors. It encourages airport operators to conduct risk assessment for robust adaptation planning. In particular, it focuses on identifying infrastructure and operational characteristics of airports and their corresponding vulnerability to climate and weather events. This approach was taken to make it easier for the industry to familiarize itself with the issue and start adaptation planning as early as possible.

The policy brief includes a list of airports that have already started work on resilience and adaptation and provides a high-level snapshot of 36 airports and their initiatives in Asia Pacific, Europe, and North America. This will be expanded with the results from the industry-wide survey.

Finally, selected airports' best practice case studies were included to show how adaptation planning can vary between airports. These range from revised design standards to effective coordination and communication from stakeholders. The case study from Changi airport, for example, illustrates how long-term climate scenario analysis informed the government and airport operator to coordinate and integrate additional provisions from the beginning of mega infrastructure projects.

Schiphol's case presents a successful partnership with national research programme to better analyze and develop adaptation strategy and flood-proof the airport: it is already located well below sea level.

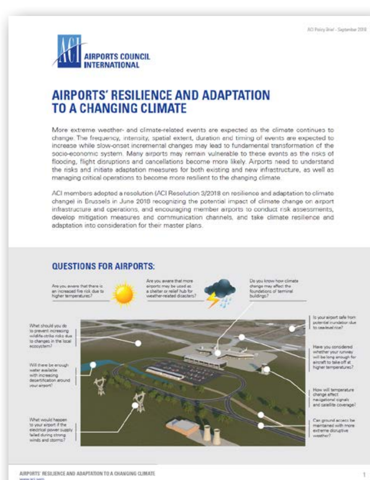
Early moves to assess risk and update design requirements and standards in a cost-efficient and effective manner was highlighted in the Avinor and Brisbane Airports cases. The newly opened Istanbul Airport's case study shows how climate adaptation can be incorporated from the very beginning of airport planning.

Last but not least, Hong Kong Airport's experience provides that climate adaptation and resilience does not only mean the change in infrastructure but also requires effective operational planning. This includes rapid response and recovery in the face of natural disasters for better business continuity management.

Handbook on Airport Business Continuity Management

The publication of ACI's Handbook on Airport Business Continuity Management will guide its members in developing enhanced business continuity management. With inputs from industry experts on airport facilitation, environment, safety and security, this handbook covers many situations and unplanned incidents that go beyond natural disasters expected to become more frequent by the changing climate.

With adverse weather conditions and more frequent natural disasters expected in the future, the potential for disruption on "normal business operations" at airports creates the need for more robust business continuity management plans. The handbook will help airports to reflect on their organizational capability for fast recovery and how they can maintain the flow of passengers and goods, enable the delivery of services to customers, sustain commercial revenue streams and protect their infrastructure.



WAY FORWARD TO A MORE RESILIENT FUTURE

During a pre-conference session on Climate Adaptation and Resilience at the ACI World Annual Conference and Assembly in April 2019, Kansai International Airport reflected on their experience from the typhoon as a valuable learning experience. Kansai Airport is one of the world's leading airports with the first 'resilience certification' from its government and design standards that have catered for the potential impact from climate change. Yet, disruption from one of the biggest typhoons in history was significant to introduce new unforeseen impacts and encourage the airport to start considering how to address these if they ever happen again in the future.

The lesson is clear for the airport community.

Handling risks from climate change should involve actions that go beyond improving infrastructure design standards or making adjustments to operational planning. It must also include close coordination with local authorities and organizations because, at the end of the day, communities rely on airports for their connectivity and as an engine for economic development. ACI welcomes the current work of ICAO CAEP on adaptation, such as the Climate Change Adaptation Synthesis and the future CAEP/12 work, particularly regarding risk assessments. Capacity building will be essential to support airports, and all aviation stakeholders, affected by more adverse weather in the near future.

ACI will continue to help and guide members on their journey to a more resilient future.

Climate Change Resilience Strategy – Redefining Flood Protection At Kansai International Airport

By Mr. Sebastien Lacoin (Kansai Airport)

On the 4th of September 2018, Typhoon Jebi swept across Shikoku Island, Japan and continued tracking over Osaka Bay, leaving in its wake thirteen fatalities and extensive damage to the region. Kansai International Airport (KIX), which serves Osaka, was heavily damaged by that major weather event. At the peak of the storm, five meter high waves spilled over the seawalls, resulting in severe flooding on the island and the airport. As a direct consequence to the typhoon, the airport was closed for three days but resumed partial operation on day 4 and full passenger operations after 17 days, on September 21st.

FIGURE 1: Kansai International Airport after Typhoon Jebi (Source: Mainichi Shimbun)

This article summarizes what happened at Kansai Airport as a result of the typhoon and presents some lessons learned and the resulting strategies that will be implemented to deal with such events in the future. The article covers three main subjects:

- The damages sustained by the airport due to typhoon JEBI.
- Defensive strategies against flooding for use at the airport design and construction stage.
- Strategies that have been adopted to protect the airport against future flood events.

DAMAGE EXTENT AND IMPACT OF DAMAGE

The damages to Kansai International Airport that were caused by Typhoon JEBI were severe and of three main types: physical, operational, and economic.

Physical and Operational Damage

As shown in Figure 2 the cargo area was completely flooded and cargo operations were unable to resume until after a complete clean-up of the cargo area was finished at the beginning of November, 2018.

As shown in Figure 3, the main access bridge to/from the airport was severely damaged during the typhoon and reopened its train access on September 18th while public traffic reopened October 1st , with restrictions. It was not fully reopened until April 8th, 2019, a full seven months after the storm.

Initially, the physical damage to the access bridge delayed the evacuation of stranded passengers and staff, an operational scenario which had never been foreseen. Operational staff first had to re-establish access via the bridge on an emergency basis to evacuate passengers and personnel. After that, they had to set up procedures to allow for the limited reopening of the bridge on September 7th.

The following chart details the recovery of airport operations over a five-week period.

ECONOMIC DAMAGE

Direct and indirect economic damage to both the airport and the Kansai region were significant as a result of the partial operation of the airport during the period of recovery. In addition to the lost revenues by all stakeholders due to suspended operations, the costs of recovery operations themselves were significant.

FIGURE 2: Flooded Air Cargo Area after Typhoon Jebi – Kansai International Airport

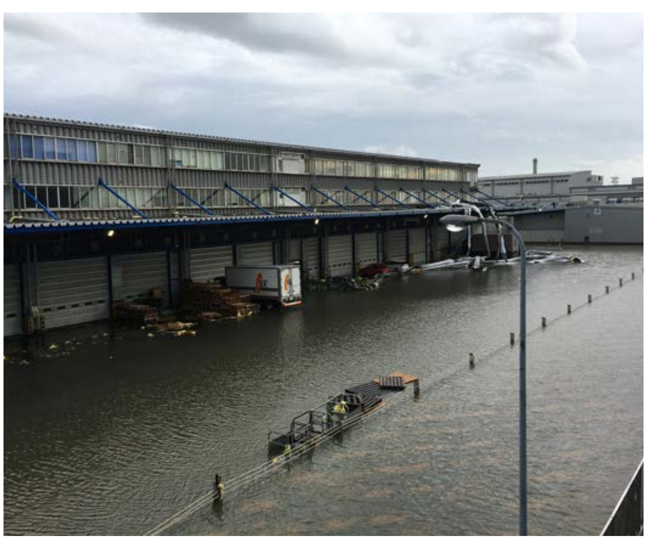
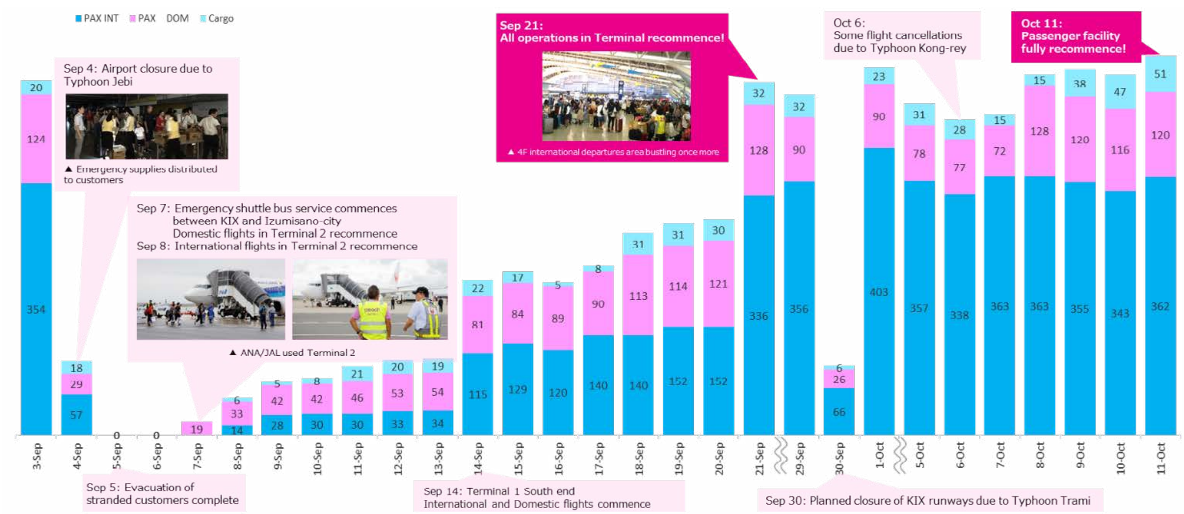


FIGURE 3: Damaged Access Bridge caused by Typhoon Jebi – Kansai International Airport

FIGURE 4: Timeline of Physical and Operational Recovery Operations After Typhoon Jebi – Kansai International Airport



The Kansai Region is one of the main gateways to Japan for tourism and industry. The Asia Pacific Institute of Research has estimated that the impact on the region was some 60 bnJPY (USD$ 500 M) as a consequence of the airport closure. That is equivalent to 0.3% of the entire Kansai Region GDP.

IMAGE DAMAGE

Immediate wake of the typhoon and during recovery operations, criticisms were raised by airline passengers, airlines and other airport businesses because the airport's response to dealing with the crisis did by not fulfill their expectations. Both airport management and local authorities were criticized heavily for alleged mismanagement of the situation.

The damages to the Kansai economy and to the airport stakeholders, demonstrate the critical nature of the airport in the region. The Typhoon Jebi disaster has made it abundantly clear the airport community has a definite social responsibility towards the local community to better plan for and manage such crisis situations. In fact, the airport operator has a duty to plan for these extreme events. And it starts with the initial design of the facility, including all subsequent modifications to the design.

INITIAL DESIGN ASSUMPTIONS – KANSAI INTERNATIONAL AIRPORT

Kansai International Airport (KIX) was designed as an innovative man-made island. The main technical challenge in its design was to allow for an expected settlement of the soil of around 12 m. However, since 2005 the settlement at KIX has exceeded initial estimates and is already at about 14 m. The original design allowed for what was believed at the time to be adequate elevation above sea level that would prevent any possible flooding. Adequate elevation coupled with a gravity drainage system, was believed to be sufficient defense against the sea. However, due to the additional two meters of soil settlement this is not anymore the case and the criticality of the sea defense and drainage are now of prime concern. The infrastructure design needs to be modified.

The Intergovernmental Panel on Climate Change (IPCC) now predicts sea level rise beyond which was taken into account at the design stage for KIX. IPCC projections on sea level rise do not include storm surges that occur when a severe storm/typhoon such as the one which struck KIX.

ADAPTATION OF THE DESIGN

Revising the Business Contingency Plan (BCP)

In view of the consequences of typhoon JEBI and the risk of recurrence of such an event, the airport operator has revised its Business Contingency Plan (BCP) to further promote the direct involvement of stakeholders in the response to such a crisis. In addition, the airport operator has evaluated not only the weakness of the airport, but also of all airport stakeholders in the context of a possible future flood event. This will better address the public interest and the continuity of operations of all stakeholders.

Revision of the Design Parameters

Obviously the design parameters have been revised to take into account the newly measured values. In addition, climate change effects have been partially incorporated into these values by:

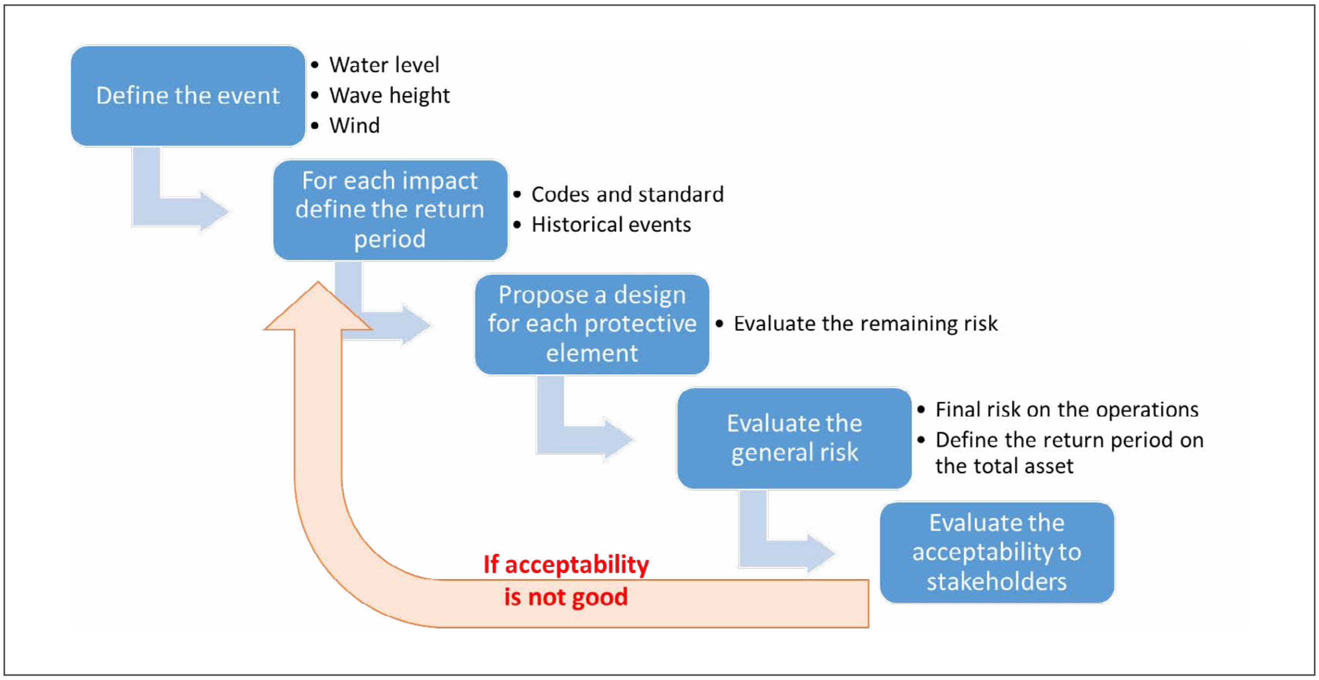
- Including some allowances for rises in sea-level.
- Adopting a conservative approach when estimating storm surge wave heights.
- Setting design parameters higher than what is required in the technical design standard.

Definition of a Resilience Strategy

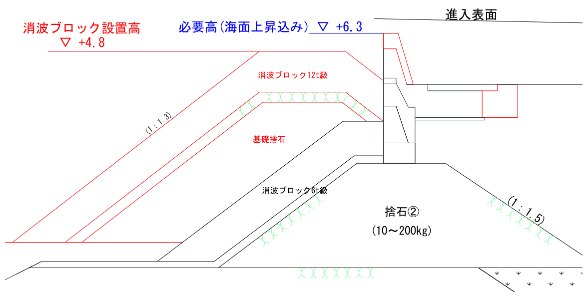
Even if the new or modified structures are based on the current design standard, the infrastructure will be adapted to be more resilient to deal with future extreme events, in order to ensure the acceptability by all of the stakeholders.

The decision process for evaluating possible events and developing a corresponding resiliency strategy is presented in Figure 5 below.

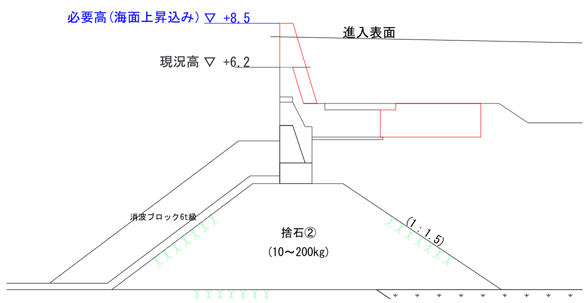
FIGURE 5: Flow Diagram for Developing an Infrastructure Resiliency Strategy



For instance, the overtopping rate required as per the Japanese standard can be achieved following several defense strategies. Following is the cross-section of the protective barrier with a raised tetrapod and protective seawall.



Below is the cross-section of the protective barrier with a raised protective seawall only.



A comparison of the overtopping rate based on different wave conditions is shown below.

<table>
<tr><td colspan="2">Cross section design parameters</td><td>Design 1: With raised tetrapods</td><td>Design 2: Seawall raise only</td></tr>
<tr><td colspan="2">Design wave height
(50 years return period)</td><td colspan="2">3.9m
(WSW)</td></tr>
<tr><td colspan="2">Seawall height</td><td>CDL+8.5m</td><td>CDL+6.3m</td></tr>
<tr><td rowspan="3">Overtopping m³/m/s</td><td>50 years</td><td>0.02</td><td>0.02</td></tr>
<tr><td>100 years</td><td>0.044</td><td>0.035</td></tr>
<tr><td>200years</td><td>0.103</td><td>0.063</td></tr>
</table>

The retained solution (with raised of tetrapods) is the one which will provide the best resilience in case of an event that is greater than the design standard.

Conclusion

The flood protection in KIX is being revised from the infrastructure point of view to integrate new factors that are linked to climate change:

- Sea level rise
- Frequency of events
- Power and Intensity of events

Furthermore, the strategy has been extended to events more powerful than the design level in order to establish a robust resilience plan.

<table>
<tr><th colspan="3">Typhoon Event</th><th rowspan="2">Volume of water on 1st island</th><th rowspan="2" colspan="3">Airport Functions</th></tr>
<tr><th>Typhoon size VS design</th><th>Return period</th><th>Equivalent Wind speed</th></tr>
<tr><td rowspan="2">Flood > “resist” assumptions ⇒ major damage</td><td rowspan="2">Beyond probabilistic model</td><td rowspan="2"></td><td rowspan="2">10 M m3
2 m in average</td><td>Drainage</td><td>PTB</td><td>Cargo</td></tr>
<tr><td>AFL</td><td>BHS</td><td>Hotel</td></tr>
<tr><td rowspan="6">Flood < “resist” assumptions ⇒ minor damage and early restart

Typhoon > “prevent” assumptions ⇒ some flooding</td><td rowspan="2">1 in 750 years</td><td rowspan="2">89 m/s</td><td rowspan="2">6 M m3
1.2 m in average</td><td>Drainage</td><td>PTB</td><td>Cargo*2</td></tr>
<tr><td>AFL</td><td>BHS</td><td>Hotel</td></tr>
<tr><td rowspan="2">1 in 500 years</td><td rowspan="2">80 m/s</td><td rowspan="2">3 M m3
60 cm in average</td><td>Drainage</td><td>PTB</td><td>Cargo*1</td></tr>
<tr><td>AFL</td><td>BHS</td><td>Hotel</td></tr>
<tr><td rowspan="2">1 in 400 years</td><td rowspan="2">75 m/s</td><td rowspan="2">1 M m3
20 cm in average</td><td>Drainage</td><td>PTB</td><td>Cargo</td></tr>
<tr><td>AFL</td><td>BHS</td><td>Hotel</td></tr>
<tr><td rowspan="2">Typhoon < “prevent” assumptions ⇒ no flooding</td><td rowspan="2">1 in 200 years
(incl. JEBI class)</td><td rowspan="2">63 m/s
(Jebi 46.3 m/s)</td><td rowspan="2">< 0.2 M m3</td><td>Drainage</td><td>PTB</td><td>Cargo</td></tr>
<tr><td>AFL</td><td>BHS</td><td>Hotel</td></tr>
</table>

Istanbul Airport: Climate Change Adaptation Strategy and Action Plan

By Ms. Ulku Ozeren (Istanbul Airport)

Istanbul Airport project area lies over an area of 76.5 million square meters to the north of Istanbul, 35 km away from the city center. Airport development will be completed in four phases. The first phase of the airport has three runways and a main terminal that serves 90 million passengers per year. Once all phases are completed, the airport will have six runways and two terminal buildings and three air traffic control (ATC) towers and will host flights to more than 300 destinations with an annual capacity of 200 million passengers. The airport is neighbored by the Black Sea, which has very important assets, namely, the fuel jetty and fuel pipeline systems that feed fuel farms with a 300.000m^3 fuel storage capacity.

INTRODUCTION

IGA's Climate Change Adaptation Strategy and Action Plan aims at developing an adaptation response to the risks identified by this study, which have been determined and prioritized through:

- A consideration of the scale and importance of the risk in terms of likelihood and consequence for IGA[1] in the short- and medium-/long-term.
- An appraisal of the adequacy of the current control measures in place to deal with that risk.
- Consideration of the timescales involved both in terms of when the risk may occur and how long it may take to implement adaptation measures.

Purpose

Infrastructure assets are under specific threat especially in densely populated zones due to extreme weather conditions based on climate change. A strategic approach and long-term planning becomes critical for new projects. In this respect, IGA aims at identification, analysis and management of climate change risks on the planning, construction and operation of the project as part of a climate change adaptation study. Such an assessment and study pose utmost importance as a first of its kind climate change adaptation report for a gigantic infrastructure project.

Rationale

Airports impacted by extreme weather events are on the rise. Rain storms can flood runways and overwhelm storm water systems. Heat waves can damage runways and aircraft tires. Winter storms increase snow removal requirements. Thousands of passengers are left stranded — 70 per cent of airport delays are caused by extreme weather — and the economic impact to airports can be in the billions. And all of these weather events impact passenger, worker and community safety.

Although there is not yet legislation in Turkey for climate change adaptation, IGA has initiated a climate change adaptation plan for this gigantic project. As a result of this work, IGA has comprehensive control measures and contingency plans for managing climate-related risks, and for the most part, they will be considered sufficient to manage climate change risks in the short- and long-term.

1 Istanbul Grand Airport, concessionaire of BOT Contract for İstanbul Airport.

TABLE 1: Sample Worksheet for Analysis of Climate Vulnerability

Adaptation Implementation Worksheet				
Asset	Climate Impact			
	Precipitation	Wind	Temperature	Humudity/Fog
Tower	Damage Risk (Visibility range)	Damage Risk (Destruction)	Damage Risk (Acclimatization)	Damage Risk (Acclimatization, Visibility range)
Aircraft Parking Apron Areas	Damage Risk (Flood)	Damage Risk (Destruction)	Damage Risk (Acclimatization)	Damage Risk (User, Buildings)
Utility Buildings	Damage Risk (Flood)	Damage Risk (Destruction)	Damage Risk (Acclimatization, Fire Risk)	Damage Risk (Acclimatization)
Reservoirs	Damage Risk (Flood)	Damage Risk (Destruction)	Damage Risk (Acclimatization)	Damage Risk (Acclimatization)
RMS	Damage Risk (Flood)	Damage Risk (Destruction)	Damage Risk (Acclimatization)	Damage Risk (Acclimatization)
Water Treatment Plant	Damage Risk (Flood)	Damage Risk (Destruction)	Damage Risk (Acclimatization)	Damage Risk (Acclimatization)
De-icing	Damage Risk (Flood)	Damage Risk (Destruction)	Damage Risk (Acclimatization, Operational Risk)	Damage Risk (Acclimatization)
Energy Distribution System	Damage Risk (Flood)	Damage Risk (Destruction)	Damage Risk (Acclimatization, Operational Risk)	Damage Risk (Acclimatization)
Fuel Farms	Sea level rise	Damage Risk (Destruction)	Damage Risk (Operational Risk)	Damage Risk (Visibility range)
Vehicle tunnels (jet fan)	Damage Risk (Flood)	Damage Risk (Operational Risk)	Damage Risk (Acclimatization)	Damage Risk (Accident Risk)
Transformer Buildings	Damage Risk (Flood)	Damage Risk (Destruction)	Damage Risks (Fire Risk,Explosion Risk)	Damage Risk (Accident Risk)
De-icing	Damage Risk (Flood)	Damage Risk (Destruction)	Damage Risk (Corruption Risk)	Damage Risk (Corruption Risk)
Fuel Storage	Damage Risk (Flood)	Damage Risk (Destruction)	Damage Risks (Fire Risk,Explosion Risk)	Damage Risk (Acclimatization)
Gas Station	Damage Risk (Flood)	Damage Risk (Destruction)	Damage Risks (Fire Risk,Explosion Risk)	Damage Risk (Acclimatization)
Mobile Gas Station	Damage Risk (Flood)	Damage Risk (Destruction)	Damage Risks (Fire Risk,Explosion Risk)	Damage Risk(Visibility range, Acclimatization)
Electrical Infrastructure (ICT)	Damage Risk (Flood)	Damage Risk (Operational Risk)	Damage Risk (Acclimatization, Corruption)	Damage Risk (Acclimatization, Corruption Risk)
Roads / Viaducts, Art Buildings	Damage Risk (Flood)	Damage Risk (Destruction)	Damage Risk (Corruption Risk)	Damage Risk
Lighting	Damage Risk (Flood)	Destruction	Damage Risk	Damage Risk

Scope, Approach and Methodology

The general scope of the study is defined as the first phase[2] of IGA, which has been operational since the 29 October 2018 for parametric change in the pillar years of 2030, 2050 and 2080.

The geographic scope is clearly those years which will cover the assets of the airport. The operational scope will identify the authority of IGA for the operational functions, such as access to the airport.

In this paper, only the climate change adaptation aspects will be given although IGA has the mitigation aspects for the whole climate change action plan content.

CLIMATE VULNERABILITY ANALYSIS

The table below is a worksheet for analysis of climate vulnerability, which has been used for elaboration of risks on assets. Through the parameters explained above, the study looks into potential hazards at the micro level based on assets of the function.

MODELLING THE CHANGE OF PARAMETERS UNDER CLIMATE CHANGE

Models and Scenarios Used:

HadGEM2-ES, MPI-ESM-MR and CNRM-5.1 are chosen as the reference period in order to obtain climate simulations of 50x50km and 10x10km resolution. Then three global climate models selected from the CMIP5 database are downscaled to resolution 50x50 and 10x10 km utilizing the RegCM4 regional climate model. Reference period simulations of the models are matched and compared with the monitored values. All three global models are based on two scenarios; namely, **RCP4.5** and **RCP8.5** (Url-1).

RCPs form a set of greenhouse gas concentration and emissions pathways designed to support research on impacts and potential policy responses to climate change (Moss et al. 2010; van Vuuren et al. 2011).

The simulation results have been evaluated by four parameters, namely; temperature, precipitation, relative humidity and wind anomaly. Additionally, three climate indices have been derived based on simulated atmospheric fields; FD0, TX35 and R25. **FD0** indicates the number of days in a year with freezing temperatures; **TX35** is the number of days in a year in which the temperature exceeds 35°C ; and **R25** is the number of days that receive precipitation of more than 25mm.

2 Main terminal building, 3 runways and auxiliary buildings.

CLIMATE CHANGE ADAPTATION

Infrastructure Design:

During the design of all landside and airside infrastructure components, Q_{100} flows have been considered in the calculations to meet extreme flood events though FAA 150/5320-5D Section 2-2.4 recommends Q_5 or Q_{10} for storm water infrastructure while the Turkish regulation dictates Q_{25} for such large catchment areas.

Superstructure Design:

During the design of the superstructures, static projects have been prepared considering climate change impacts. In this regard, loads of the structural elements have been taken more conservatively than the regulatory standards such as:

Wind: Wind loads have been calculated by carrying out wind tunnel tests for terminal buildings and have been taken as 225 kg/m^2, which is two times higher than the regulatory standard.

Snow: Snow load has been calculated using historical meteorological data. Although, snow load for Istanbul is known as 75 kg/m^2, 125 kg/m^2 has been taken for terminal buildings.

Temperature: Temperature variance has been taken between -24°C and +24°C for the heat effect.

Fuel Jetty and Pipelines:

Fuel jetty and its relevant elements have been designed by considering meteorological data for a 100-year return period as well as expected global sea level rise, which is 110 cm for year 2100. This cumulative 110 cm rise reflects seasonal change, tidal effect, atmospheric pressure and Coriolis Effect, storm surge, wave surge, and global sea level rise due to climate change. Of this 110 cm sea level rise, 50-60 cm is assumed to occur due to climate change impact. The overload test was done with 120 per cent wave height in laboratory conditions. Since there is no national sea level rise assessment study, assumption for sea level rise has been taken from the report of the Intergovernmental Panel on Climate Change (IPCC) for year 2100 that was published in 2013.

According to the guidelines and requirements of the General Directorate of Infrastructures Management under the Ministry of Transportation, the critical cross section of the fuel jetty design feature has been physically tested and the design has been controlled. The critical section is the section in which the highest wave is encountered.

According to the laboratory test results:

- Main breakwater has been widened.
- Crest level has been increased from 9,5 m to 10,5 m.
- The length of the main mole has been increased from 550 m to 650 m.
- Additional armor layers were installed to the round part of the secondary mole. The volume of the round X Block was increased from 12m3 to 16m3. For the Istanbul Airport fuel jetty, the largest x-Block armor layer (16m3) in the world has been used.

Operational Efficiency by Layout of the Airport:

At the Istanbul Airport, the layout of airside is planned to provide the maximum efficiency and operational flexibility while maintaining the highest safety and minimal operational risks. In order to provide maximum efficiency, a wide variety of operational conditions should be considered that include weather related conditions such as low visibility, snow/ice, heavy winds, heavy rains, etc., or operation-related conditions such as maintenance, accidents, emergencies, etc.

In order to achieve the above benefits, planning started with the usual runway and airside design elements such as wind direction and obstruction analysis. Once the direction of runways were identified based on prevailing winds, and the profile of runways were identified based on obstructions, operational considerations then guided the next design decisions. For increased capacity and maximum safety, runways were separated to provide “independent approach” capabilities, and additionally, .each primary runway was paired with an auxiliary runway to provide better air traffic management (ATM) flexibility.

By doing so, the primary runway could be used for arrivals as well as the auxiliary runway, thereby increasing capacity while maintaining safe operations. In addition, auxiliary runways help to maintain capacity during heavy maintenance of primary runways. Details of the runways such as rapid exit taxiways and runway entrance taxiways are designed for minimum runway occupancy time and maximum flexibility durıng aircraft line-ups for take-off. As experience in aviation shows, the drainage concept and infrastructure is quite critical for safe airside operations. The longitudinal profile and cross section of runways were designed to provide the shortest drainage root to minimize any risk of water accumulation that may lead to critical issues from aquaplaning to area flooding.

The next step in the design of the Istanbul Airport airside layout was the arrangement of a taxiway system. Parallel taxiways on both sides of runway pairs allow for independent operation of runways. However, the most critical innovative approach on the taxiway system is utilizing end-around taxiways. An end-around taxiway is essentially a route for an aircraft to taxi around an active runway without stopping or delaying any runway operation. This allows continuous taxiing while preventing any runway incursion risks. This setup creates a highly efficient taxiway system with minimum runway incursion risk. Another important element of the airside taxiway design is to have dedicated taxiways for arrival and departure which again minimize the risk of aircraft traffic clash.

The aprons were designed based on their intended operations. For stands, the MARS approach was used for efficiency enabling either one wide body or two narrow body aircraft to be parked at a MARS). For de-icing aprons, locations were identified based on taxi times between the de-icing apron and runway take-off positions and capacity was identified based on the number of aircraft that may need de-icing simultaneously. The drainage on apron areas was done using slot drains for efficient results. This also allowed proper storage locations for waste management such as de-icing fluid collection or oil separation.

The airside infrastructure is strengthened by the All communications, navigation and surveillance systems (CNS)/ATM systems installed for operations. All primary runways are instrumented as CAT IIIb. In addition, every runway pair is serviced by its own own Doppler Very High Frequency Omni Range (DVOR)/distance measuring equipment (DME), which is a unique feature. The aeronautical ground lighting (AGL) is designed as CAT III with follow-the-green capability. The entire airfield is controlled by Advanced-Surface Movement Guidance and Control System (A-SMGCS) and controllers operate usıng using integrated Controller Working Position (iCWP) with integrated integrated Electronic Flight Strips (EFS). All CNS/ATM and AGL systems are integrated into A-SMGCS allowing controllers maximum sıtuational awareness and controlling capabilities.

Overall, the Istanbul Airport airside layout and the systems installed work as one system for maximum efficiency. The layout may look complex due to the number of taxiways, however when closely reviewed , the operations are actually quite straightforward and simple.

Early Alarm Systems:

LIDAR, LLWAS and C-band radar will be installed at the airport to get early information and to communicate with the airline operators and air navigation systems.

LIDAR (Light Detection and Ranging; Laser Imaging Detection and Ranging):

LIDAR is the observation system that works with the principle of reflection of the laser beam from the object and radar similar to the working principle. LIDAR gives instant information by changing the wind intensity (3-dimensional) with height. Information about wind data measured by LIDAR and wind shear can be transferred directly to the computer screen.

LLWAS (Low Level Wind Alert System):

This system observes the sudden changes in low wind speed and intensity in the final approach. Wind shear can be observed in the atmosphere for many reasons (frontal state, sea ground interaction, convective situation, etc.). In the history of aviation, it is one of the most critical events causing many accidents.

C-band Radar:

In the frequency band between 300 MHz and 1 GHz (i.e. 350-400 km coverage); special radars, such as early warning radar, or wind profile (wind profiler) for meteorological observations, have been developed. These frequencies are minimally affected by meteorological formations such as cloud or rain, thus achieving very long ranges. With this type of radar, the position, speed, direction of movement of the meteorological target can be determined; and the type, intensity and amount of the meteorological incident can be realized.

Management Systems:

The management system includes new technologies and approaches for operating, maintaining, managing, and sustaining the infrastructure like the the Internet of things (IOT)-based management system.

Adaptation of Operations:

The continuity of operations under rapidly changing climate conditions are based on the diligent evaluation of possible damage to basic operational activities and prioritization of risk factors. By definition, the risk is the product of probability and impact, which are both arbitrary from the perspective of those who are managing the risk. For the IGA climate change action plan and the related risk management procedures, the subject climate change model highlights the frequency whereby the operator assesses the impact. The risk or significance of the case is reached by multiplying these two factors.

In addition to these implemented macro scale adaptation measures, IGA has carried out risk analysis and identified vulnerable assets and operations due to climate change impacts with micro scale. These assets and operations will continue to be monitored.

CONCLUSIONS

As the climate change action plan envisions the implications of climate change impacts on infrastructure and the adaptation options for each utility in the project, climate change is a global phenomenon with many local impacts.

This study has evaluated the effects of four climate parameters; precipitation, wind, temperature and humidity/fog on the structures and infrastructure utilities. In addition to major structures, micro scale components of assets and operations have been elaborated and vulnerabilities identified with detailed risk assessments using global and regional climate change models for the pillar years 2030, 2050 and 2080.

For the first phase, major structures at the Istanbul Airport have been constructed taking into consideration climate change impacts. Since the project has further phases, similar studies will be carried out and adaptation

RISK DESCRIPTION		PROBABILITY	IMPACT	SIGNIFICANCE
Temperature	Climatization equipments capacity problems	5	3	15
	Pavement cracks	5	2	10
	Fire	4	5	20
	Increase in health problems	3	3	9
	Operational delays cause of temperature	4	5	20
Precipitation	Flooding damage	4	5	20
	Infrastructure overflows	5	4	20
	Accidents	4	4	16
Wind	Operational delays cause of wind	3	4	12
	Collapse of structures	3	4	12
	Damage of external equipments	3	3	9
	Roof damage	3	3	9
Humidity	Operational delays cause of humidity	3	4	12
	Isolation materials damage	3	3	9
	Damage of climatization equipments	3	3	9

VERY LOW	LOW	MEDIUM	HIGH	VERY HIGH
1	2	3	4	5

requirements will be embedded within the Master Plan. Additionally, the operational Phase 1 climate change risks on assets and operations will be elaborated in further detail with more climate indices that will include CDD (consecutive dry days), CWD (consecutive wet days), FD (frost days), ID (iced days), R99TOT (the most rainy days), T<5 (days with temperatures below 5 ^{0}C) for the years up to 2050 since there are too many uncertainties for the years beyond that point to include them in the plans.

More importantly, a climate change adaptation action plan is an ongoing process in which the operator should take different but concurrent steps to identify new risks, propose risk mitigation strategies, review the existing impact for maintenance in good time while addressing the potential impact, and to offer remedies. The potential risk for loss of operational capacity and business volume due to climate change has to be continuously observed as an aspect of financial and economic management. Staff and executive management awareness for investment in adaptation and greenhouse gas (GHG) emission reduction is necessary, especially for preferential assessment of new technology.

The asset inventory and actual impact on the assets due to climate change and resulting loss of operational capacity should be reported regularly. Disaster risk reduction and management is an important part of the climate change action plan. Strong community engagement and stakeholder participation is essential.

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ICAO

CHAPTER EIGHT

Towards a Circular Economy

Introduction to Circular Economy

By ICAO Secretariat

CONCEPT OF CIRCULAR ECONOMY

Our current economic model relies on the traditional linear economy, which follows the pattern of creation, consumption and disposal of products. However, this linear economy is not sustainable. It leads to an increasing pressure on finite resources and generates significant waste and emissions. Instead, the concept of a "circular economy" was devised with the aim of minimizing waste and pollution and making the most of resources by keeping products and materials in use as much as possible, and by recovering and regenerating products and materials at the end of each service life.

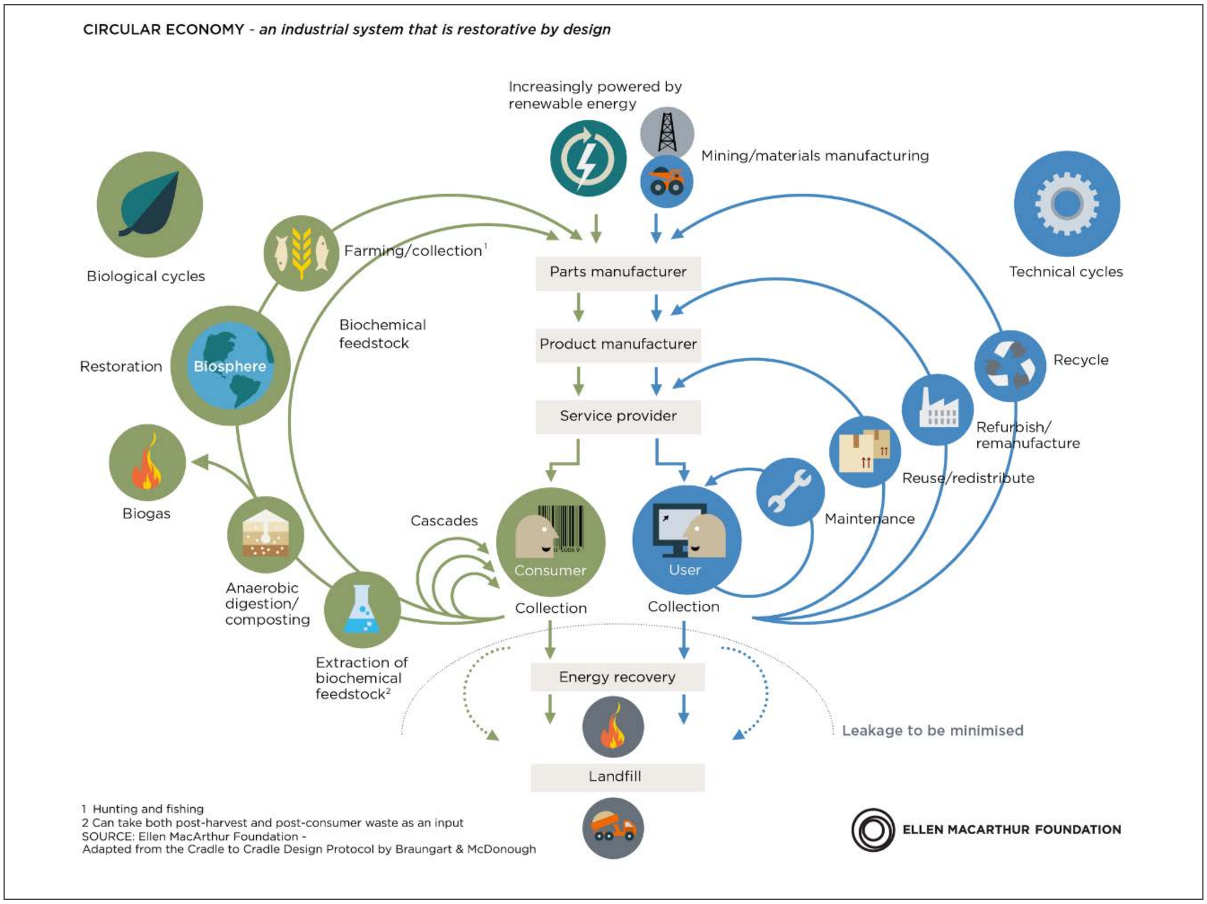
The transition from linear economy to circular economy can put economic growth on a sustainable pathway, by reducing finite resources consumption and minimizing waste and environmental impacts. According to the Ellen MacArthur Foundation[1], the implementation of circular economy is guided by three principles:

1. Waste equals Food – Redefining the purpose of end-of-life products can extend their durability and reduce the environmental impacts of manufacturing new products. Within a closed loop, appropriate maintenance, reuse, refurbishment and recycling can extend the life cycle of products. These products are no longer to be considered as waste, but as essential inputs to manufacturers and service providers (see Figure 1);
2. Use renewable resources – By increasing the utilization of renewable or waste-derived resource and energy, circular economy model could create new types of jobs and reduce environmental impacts, including carbon emissions.
3. Build resilience through diversity – In order to achieve the reduction of virgin material consumption and waste generation, supply chains need to be developed to reorient products from one manufacturing process into another. Therefore, designing a circular economy model requires bringing together various companies and stakeholders, which serve different functions within a circular economy system.

Currently, the concept of circular economy has been integrated through many national and organizational policies. For example, it was acknowledged as one of China's national development strategies throughout the country's 12th Five-Year Plan (2011-2015) and its Circular Economy Promotion Law of 2009. In 2015, the European Commission launched its own Action Plan for the Circular Economy programme, which sets out a policy framework with measures and targets on waste management. The concept of circular economy is also an integral part of the following United Nations' Sustainable Development Goals:

1 Franconi, E., 2016. A New Dynamic 2: Effective Systems in a Circular Economy. Ellen MacArthur Foundation Publishing

FIGURE 1: Circular Economy System Diagram by Ellen MacArthur Foundation



APPLICATION OF CIRCULAR ECONOMY IN AVIATION

Circular economy has potential to reshape the whole supply chain from product design to end-of-life management, and aviation already utilises some of the concepts associated with circular economy. For example, 3D-printing has been used to manufacture aircraft parts, which not only can be up to 55 per cent lighter, but also could reduce up to 90 per cent raw material consumption. Such techniques can also facilitate the repair, refurbishment and remanufacture of aircraft parts, which increases the circularity and reduces the emissions produced by aviation. Another example is that Bombardier developed environmental product declarations (EPD) for some of its aircraft products, which consisted of an environmental performance evaluation of the entire aircraft life cycle.

For the aviation sector, circular economy is an emerging concept and while its application is still not widespread, the utilization of circular economy concepts could provide valuable learning opportunities for the future. Aviation is a sector expecting substantial growth, with the annual world air traffic expected to double by 2035, with an average annual growth rate of 4.4 per cent. According to Boeing and Airbus, the projection of new delivered aircraft by 2034 would be 38,050 and 32,585, respectively. All these estimations indicate a potential increase in resource consumption, waste and emissions generation in global aviation. The transition from linear economy to circular economy could contribute to the reduction of the adverse environmental impacts and associated economic costs.

The application of the circular economy principles to the aviation sector would primarily focus on two elements: aircraft and airports. For aircraft, the circular economy model can be applied into aircraft operations and for the management of aircraft end-of-life.

Since 2015, Air France-KLM Group adopted circular economy strategy in their flight operations. The strategy entails four components of the circular economy as follows:

- Redesign: Redesigning the catering services to separate the waste correctly;
- Reduce: Reducing the mass of food packaging and switching manuals from hard copy to digital;
- Reuse: Reusing the seats and on-board entertainment systems in other systems; and
- Recycle: Recycling the reusable equipment, including trays, drawers, blankets and trolleys, etc.

To handle end-of-life aircraft, Boeing and Airbus have developed their individual management approaches. Airbus launched the PAMELA project (Process for Advanced Management of End-of-Life Aircraft), which includes three stages: decommissioning, disassembly, and smart and selective dismantling. It demonstrated that 85 per cent of an Airbus A300 aircraft weight can be recycled, reused or recovered as secondary raw materials. On the other side, Boeing co-founded the industry association AFRA (Aircraft Fleet Recycling Association), which aims to set-up a new standard for an environmentally responsible management of end-of-life aircraft.

At airports, the application of circular economy has also demonstrated great potential for environmental and economic benefits. Schiphol Airport and Philips developed a partnership and provided a circular lighting solution for airport. In this light service solution, Philips remains the owner of the lamps and fittings. It is possible to replace separate components with ease, thus extending the service life of the lighting fixtures. When lamps reach the end of their service life, Philips will collect and recycle them. This circular solution not only reduces 50 per cent energy consumption by energy-efficient LED lighting and extends 75 per cent service life of the fittings, but also reduces maintenance costs and raw material consumption. The environmental and economic benefit of circular economy has also been demonstrated by redesigned waste management system in Gatwick airport. Through efficient waste collection, sorting and on site utilization, Gatwick reduces £750,000 operation cost per year from saving of onsite energy and water, reduced offsite processing and disposal, and income from increased recycling (from 52 per cent in 2016 to 70 per cent in 2019). In 2018, Gatwick became the first airport to achieve the Carbon Trust's Zero to Landfill certification (more information is provided later in this chapter).

THE WAY FORWARD

Although there are great potential and demonstrated benefits of circular economy applications in aviation, the implementation of a circular economy model remains limited. Many stakeholders have not yet identified the potential scale of aviation-associated waste. Additionally, some stakeholders may not have access to the best available circular economy technologies and applications. Partnerships and assistance programmes could be developed to evaluate the feasibility of circular economy at local level and provide technical, financial and political support to the States that need it the most.

In the spirit of *No Country Left Behind* initiative, ICAO has been raising awareness on circular economy applications through the organization of a Seminar on Green Airports from 8 to 9 May 2019 in Lima, Peru, and the 2019 Environmental Symposium "*Destination Green: the Next Chapter*" from 14 to 16 May 2019 in Montreal, Canada. Both events featured presentations on the possible applications of circular economy models to the aviation sector. Capacity-building activities also entail making sure that guidance is made available, which ICAO has been doing through the Eco-Airport Toolkit e-publication on Waste Management at Airports[2]. The objective is to provide practical and ready-to-use information that is accessible to support the environmentally sustainable planning and implementation of airport infrastructure projects. The publication dedicated to waste management defines three different steps: 1) analysis of material flows; 2) identification of areas for improvements; and 3) implementation of circular business models. Based on this, a global platform could be developed to share the most advanced technologies and applications of circular economy in global aviation. It could give rise to relevant partnerships with experts in the field of aircraft recycling and dismantling, and waste management in airport, along with the one formed between ICAO and the Aircraft Fleet Recycling Association (AFRA).

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Best Practices and Standards in Aircraft End-of-Life and Recycling

By Abdelghafar Elsayed (Egypt), Thomas Roetger (IATA) & Amy Bann (ICCAIA)

INTRODUCTION

Aircraft decommissioning and recycling is a multi-disciplinary process, with environmental, operational, safety, legal and economic aspects, and related challenges. Therefore, it is important that all involved stakeholders in the aviation sector act together to develop and implement best practices in this area. The aircraft disassembly, dismantling and recycling business is an emerging industry rapidly gaining importance. Its global association, the Aircraft Fleet Recycling Association (AFRA) has concluded MoUs (memoranda of understanding) with both ICAO and IATA to strengthen cooperation across the aviation sector.

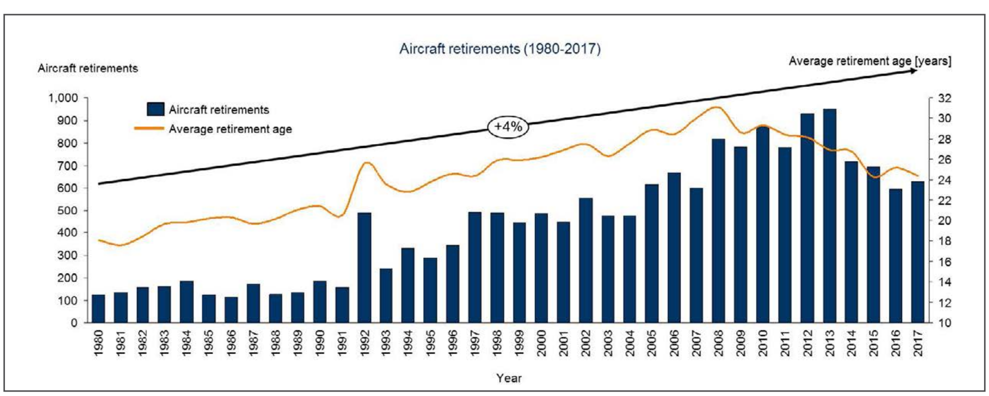
About fifty years ago, with the advent of larger aircraft, commercial aviation started developing into a mass phenomenon. Since then, the number of commercial aircraft has been increasing steadily. In the meantime, these aircraft have aged, and a growing number of them have been retired from service each year. In the light of this growing trend, an increasing number of aircraft operators have begun to focus on the processes to be applied in cases where the retirement of aircraft become relevant. If undertaken in a timely and appropriate manner, aircraft decommissioning can allow recovery of residual value from reused parts and recycled material, while also minimizing environmental and safety risks.

It is highly desirable that all involved stakeholders in governments and industry become acquainted with relevant regulations and business processes, as well as operational experience and best practices in the industry. For this purpose, CAEP undertook a review of existing relevant regulatory documents from ICAO and other international bodies inside and outside the aviation domain, as well as industry best practices and guidance material.

BUSINESS TRENDS

The number of aircraft retirements has been increasing steadily over the last decades (see Figure 1). During the

FIGURE 1: Historical aircraft retirements (1980-2017)



global economic recession starting in 2008, up to about 900 aircraft were retired per year. The current rate is about 600 aircraft per year, and the rate can fluctuate up and down depending on business conditions. The average retirement rate is expected to continue to grow as an increasing fleet is coming of age. Of the more than 27,000 commercial aircraft in service globally, over 20 per cent are older than 20 years and likely to be decommissioned in the coming decade. It is estimated that more than 20,000 commercial aircraft will be retired over the next 20 years.

As indicated in Figure 2, the average age of aircraft at retirement is about 26.5 years. While aircraft retirements for technical lifetime reasons at around 15 years were quite common in the 1980s, this is quite rare today and mostly affects small regional carriers and business aircraft. On the other hand, early retirement for economic reasons is not uncommon today. This occurs when an aircraft is still in satisfactory technical condition, but disassembling it and selling the individual parts is more profitable than continuing to operate it.

Air freighters tend to be retired later than passenger aircraft. Their average retirement age is 32 years, compared with 25 years for passenger aircraft. Many of today's freighters are converted former passenger aircraft. Through freighter conversion, the aircraft in-service time can be extended by typically 10 to 20 years, mostly because the utilization of freighters is normally much lower than that of passenger aircraft.

THE AIRCRAFT END-OF-LIFE PROCESS

As shown in Figure 3, the overall aircraft end-of-life process is divided into two clearly separate phases:

- The first phase, which includes the processes up to the removal of parts for re-use in other aircraft, is part of the aviation domain and subject to the related regulations. During this phase, the retired aircraft is still certified.
- In the second phase, which comprises final dismantling and recycling, the retired aircraft has lost its certification and aviation regulations are no longer applicable.

A well-organized aircraft end-of-life process is carried out as follows:

After the owner's decision to disassemble and dismantle an aircraft, it will enter the disassembly process, the purpose of which is to remove the valuable components from the aircraft. The removed components, depending on their technical condition, will either return to the aviation market directly or need to be inspected and repaired or overhauled by an approved repair shop before returning to service. These activities are performed by competent and authorized/certified actors in the aerospace sector.

FIGURE 2: Retirement age distribution by aircraft usage

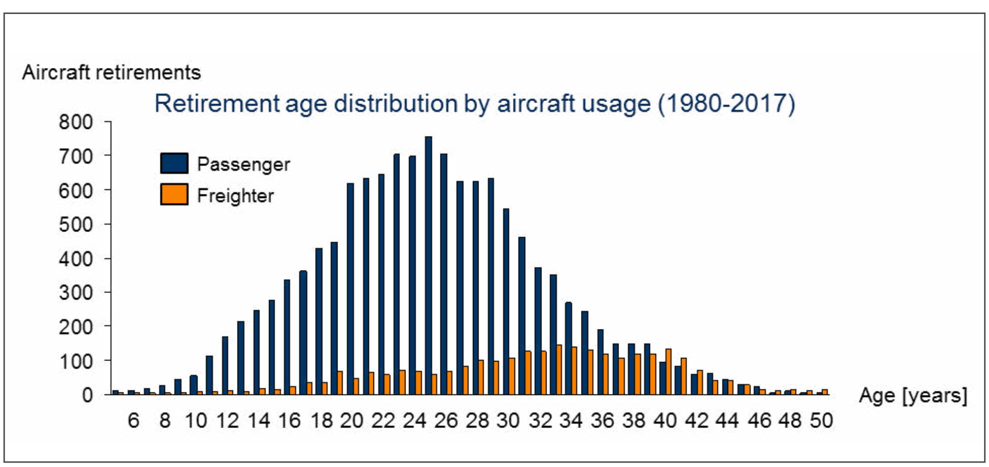
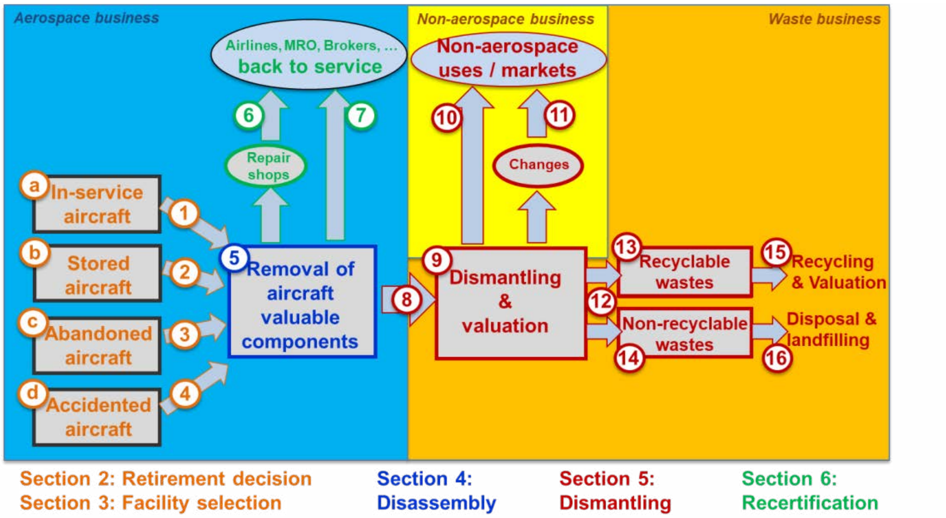


FIGURE 3: Process of aircraft decommissioning



Once the aircraft has permanently lost its airworthiness, it will not be considered as an aircraft under the State of registry's responsibility anymore and may be considered as waste instead. Usually this occurs once the last aircraft owner has sold the aircraft to a dismantling company and all parts intended for re-use have been disassembled. Thereafter, it becomes business waste. Through the process of dismantling, some parts of the aircraft can be re-used for non-aerospace applications, while the rest of the aircraft will be considered as waste and will be extracted and transferred for further treatment. Recyclable wastes will be processed, and batches will be prepared for recycling, and the non-recyclable wastes will be prepared for disposal.

ENVIRONMENTAL ASPECTS

From an environmental point of view, the aircraft end-of-life process presents both risks and opportunities. On one hand, aircraft contain a variety of hazardous materials that must be handled carefully during disassembly and dismantling. On the other hand, the vast majority of aircraft parts can be re-used or recycled without taking special precautions.

Handling hazardous materials requires compliance with national occupational health and safety laws and standards, in order to prevent unanticipated releases of these materials into the environment. Fuel remaining in the tanks, as well as hydraulic oil, waste water, and other fluids must be properly drained before the aircraft can be disassembled and dismantled. Examples of other components requiring special treatment include: emergency oxygen bottles, generators, and halon cylinders. Some aircraft manufactured before the 1980s may contain blocks of depleted uranium, which was used as ballast weight due to its high density. These must be disposed of following nuclear waste regulations, which prescribe special procedures regarding: segregation from other wastes, packaging, transportation, tracking, and final disposal.

End-of-life aircraft that have been abandoned on the edges of airfields present a particular risk of leakage of hazardous material and the contamination of surrounding soils and water. This can be especially problematic if the manufacturer's documentation is no longer available. Because these aircraft are no longer able to fly to dedicated aircraft dismantling facilities, mobile dismantling equipment may need to be used, and particular care is necessary to identify and prevent any contamination risk.

It clearly makes both economic and environmental sense to re-use or recycle parts and components of an aircraft. However, expert knowledge is required to identify which parts of an aircraft can be re-used or recycled, and how much residual value can normally be recovered.

Overall, the current state of retired aircraft treatment is a positive example of responsible environmental practices. Today, 85 per cent to 90 per cent of the weight content of retired aircraft is re-used or recycled, reflecting the fact that both re-usable parts and recycled materials represent significant residual value. It is estimated that between 40 per cent and 50 per cent of the weight of all dismantled aircraft is returned to the parts distribution pipeline. Most of the remaining unserviceable material is recycled and returned to the supply chain as raw materials, although the separation of different structural materials such as various aluminum alloys, titanium, and stainless steel, all require substantial manual work. In some cases, aircraft parts, or even entire aircraft have been repurposed for unconventional uses, ranging from furniture and art work, to hotels inside of an aircraft fuselage (see Figure 4).

Usually, less than 10 per cent of material is treated as waste. Today, the largest part of it is carbon-fiber material, which is more and more widely used for its low weight and related fuel burn reduction. However, there was no method to recycle it in the past, and recycling technologies have been developed only recently. Another type of unrecyclable material consists of cabin interior components such as: insulation blankets, carpets, seat cushions, sidewalls, and ceiling panels. These all contain embedded flame retardants, and safety regulations preclude them from recycling.

In 2018, Boeing, VAS, and ELG Carbon Fibre conducted a joint project to dismantle a Boeing 787. This was notable because it was the first time a composite fuselage had been prepared for recycling. ELG's current process of recovering cured composites for reuse from manufactured components can be utilized for retired aircraft parts as well, which will be useful when more aircraft with large composite pieces begin to retire. Given the long product life-cycles of commercial aircraft, large scale composite structures will not come out of service for at least another decade. The industry is optimistic that today's high recycle rates will be maintained as technology to process the materials continues to mature.

FIGURE 4: Retired aircraft converted into a "Jumbo" hotel in Sweden

Airbus demonstrated a continuous commitment to sustainable dismantling practices when its partner company Tarmac Aerosave dismantled the 140th aircraft since it started operating 10 years ago. Currently, an average of 92% of an aircraft's weight is re-used or recycled.

The Research and Development Committee of the Aircraft Fleet Recycling Association (AFRA) expanded membership, resources and projects to pursue enhanced data, metrics, and innovation for aircraft recycling.

INTERNATIONAL STANDARDS AND REGULATIONS

Aircraft dismantling activities have to comply with existing rules and regulations issued by ICAO relating to aircraft airworthiness, general and hazardous waste management, and recycling activities. CAEP has gathered existing ICAO Standards and Recommended Practices (SARPs), as well as other material of a regulatory nature from various international bodies, including from non-aviation organizations. These bodies include the International Maritime Organization (IMO) and the Basel Convention and the International Telecommunications Union (ITU), which cover aspects of waste management and recycling activities in non-aviation sectors such as shipping and electronics.

It is a very important safety requirement that parts that have been disassembled from a retired aircraft maintain their airworthiness status before being reinstalled in another one. Parts that have been deemed non-airworthy must be recertified by an approved maintenance organization before re-entering service. These companies must ensure that the life history (i.e., operations, modifications and repairs) of the refurbished part is properly recorded. The SARPs in Annex 6 (Operation of Aircraft), and Annex 8 (Airworthiness of Aircraft) to the Chicago Convention on International Civil Aviation, as well as the Airworthiness Manual (ICAO Document 9760) provide related requirements and guidance. Finally, ICAO Annex 14 (Aerodrome Design and Operations) gives guidance in case an aircraft is unable to fly and has to be removed from an airfield.

While ICAO SARPs do not contain specific regulations on environmental aspects of aircraft end-of-life processes, there is material of a regulatory nature coming from other United Nations bodies, including from non-aviation organizations, relevant to waste handling and recycling, such as:

- Guidance on electronic waste treatment by ITU.
- The Basel Convention and related documents on control of transboundary movement of hazardous wastes and their disposal.
- Documents from IMO related to dismantling, waste treatment and recycling of ships, which has some similarities to the situation in aviation.

Some States restrict the importation and inclusion into their national registries of aircraft above a certain age, which has consequences for the second-hand market of aging aircraft[1].

INDUSTRY BEST PRACTICES

Two global industry associations have produced documents describing best practices in aircraft decommissioning and recycling:

- The Best Management Practices (BMP) by the Aircraft Fleet Recycling Association (AFRA).
- The Best Industry Practices for Aircraft Decommissioning (BIPAD) manual by IATA.

AFRA BMP

The Aircraft Fleet Recycling Association (AFRA) is a membership-based not-for-profit association promoting global collaboration on aircraft retirement. Currently, 35 companies are accredited to AFRA's disassembly and

1 As identified by the ICAO Cross-Border Transferability Task Force (XBT)

recycling standards that ensure use of environmental and safety best practices. Its guide, titled *Best Management Practice for Management of Used Aircraft Parts and Assemblies and for Recycling of Aircraft Materials (BMP)* contain recommendations concerning best practices for the management of parts removed from decommissioned aircraft and for the recycling of aircraft parts and materials. The AFRA BMP Guide is a globally applicable voluntary auditable standard to be met by organizations applying for AFRA accreditation. Requiring decommissioning service providers to be AFRA accredited is an option for aircraft owners to ensure that their aircraft are retired with adherence to strict environment and safety protocols.

IATA BIPAD

IATA has developed its Best Industry Practices for Aircraft Decommissioning (BIPAD) manual with the principal aim of providing guidelines for airlines and other aircraft owners and operators to manage aircraft decommissioning in an environmentally friendly and economically sensible way, while meeting all relevant regulations and avoiding safety and environmental risks. The BIPAD manual covers all phases of the aircraft end-of-life process, from the decision to take an aircraft out of service to the final dismantling, recycling, and re-use of parts. The manual also considers the importance of the multi-disciplinary character of the aircraft end-of-life process and covers the economic, operational, regulatory, legal, safety, and environmental aspects of each process phase.

The Eco Airport Toolkit e-collection

By Thomas W. Cuddy, Environmental Protection Specialist, U.S. FAA and Juliana Scavuzzi, Senior Manager Environment, ACI

INTRODUCTION

Airports are the closest link that communities have to aviation. They connect people through different modes of transportation. Some airports look like cities themselves. These elements combined with the critical infrastructure they provide give airports both the ability and the responsibility to play an ever-growing role in implementing sustainable initiatives at the local level and influencing action at the international level.

Sustainability can be described in different ways, but at the core of any sustainability concept there should be three main elements: environment, social, and economic. For example, the EONS model defines it as a balance of economic viability, operational efficiency, natural resource conservation and social responsibility. Since society is constantly evolving, so is the concept of sustainability. What was considered socially accepted many years ago has changed. The capacity to accommodate these changes has become an imperative.

For an airport, environment (and sustainability) will touch upon several aspects; from the design of infrastructure, through operational efficiency, energy consumption and the ability to use renewable sources, and to the implementation of environment management systems and even new technologies embraced to improve their overall efficiency.

In addition, well-known topics such as waste management have seen a transformation through a series of innovative approaches, including the introduction of the circular economy concept. Moreover, investing in the communities they serve to improve overall quality of life is becoming an integral part of several airports' sustainability strategies. Considering ICAO's outreach capacity and responding to the call from some Member States to expand the availability of ready-to-use online materials on selected environmental topics, CAEP/10 agreed to develop the Eco Airport Toolkit.

SUSTAINABILITY

Each individual airport is unique and their approach to sustainability is different from each other. In spite of that, airports can learn from each other's best practices and sharing these is an important tool to support global action. Some airports also have a local framework which can be a driver for action. These are excellent examples where relevant stakeholders' close collaboration and alignment support further action and commitment.

For example, San Francisco International (SFO) set a goal in its 5-Year Strategic Plan (2017-2021) "to become the very first airport in the world to achieve zero net energy, carbon neutrality, and zero waste" (Cooke, 2017). SFO's goals are supported "by historic leadership in Sustainable Planning, Design and Construction that has curtailed emissions by nearly 33 per cent from a 1990 baseline and has cut water use by 52 per cent and energy use by 25 per cent over the last three years," all despite being one of the fastest-growing airports in the United States.

More recently, ACI Europe launched a Sustainability Strategy in June 2019 based on the vision that "*every airport builds local and global partnerships to accelerate the journey towards fair, prosperous and environmentally responsible societies*", and on the UN Sustainable Development Goals (SDGSs) and the Global Reporting Initiative (GRI). This strategy is expected to be updated with the understanding that sustainability is an evolving concept.

In addition, several airports are currently working to set/redefine their mid and long-term carbon goals. The new IPCC Report published last October has had a catalyst effect on their near future vision.

Sustainability is a positive feedback loop of beneficial actions for an airport that can save money and time leading to an improved environmental profile. Successful examples often start with strong management leadership in developing a mission statement and setting the appropriate goals. In most cases the airport actions to address the goals also lead to improved community relations, more satisfied concessionaires, and better employee wellbeing.

THE ECO-AIRPORT TOOLKIT

Airport sustainability is an exciting area where innovation, best practices, and new technologies continue to evolve. The Eco-Airport Toolkit task is one piece of this dynamic system. It consists of a series of short e-publications on various airport-related environmental topics, and when applicable they also include case studies. Initially, the task consisted of four topics which were developed and approved during the CAEP/11 cycle and four additional e-publications were requested for the CAEP/12 cycle:

Four publications developed and approved by the CAEP/11 cycle:

- A Focus on the production of renewable energy at the Airport site
- An Environmental Management System for Airports
- Waste management at airports
- Eco-design of airport buildings.

Four publications requested for the CAEP/12 cycle:

- Climate resilient airports
- Water Management at Airports (including glycol management)
- Air quality management
- Green airport surface access.

The overall idea behind the Eco-Airport Toolkit is to support airports and their stakeholders at the initial phase of identifying pressing sustainability issues. The toolkit highlights elements to consider as airports strive to achieve the balance of environmental and sustainability measures that is right for them. In addition, the case studies will be able to provide practical examples of best practices and innovative solutions chosen by some leading airports.

Each publication is meant to be a short overview of an individual topic. The papers range from 10 to 20 pages in length, and most have case studies to demonstrate the concepts and nuances of the topic they introduce. The Eco-Airport Toolkit website was launched in the summer of 2018.[1] Three of the papers have been posted online, and more are forthcoming shortly, including their appropriate case studies.

1. A Focus on the production of renewable energy at the Airport site

Energy consumption is a critical element for any airport. It is generally big source of emissions for an airport operator, as well as cost. Renewable energy sources are often lower in emissions and therefore can positively impact local air quality. Besides their environmental benefits, implementing a renewable energy project at an airport can help reduce utility costs, develop a more reliable source of energy, and improve community engagement. Increasingly we see airports improving their energy efficiency, developing onsite-airport renewable electricity generation like solar, wind and/or geothermal. This e-publication provides a high-level overview of the topic, including rationale for investing in renewable energy, which types are available, and basic considerations before a project is started. In addition, case studies provide a series of different examples of successful implementation of renewable projects worldwide.

1 See: https://www.icao.int/environmental-protection/Pages/Ecoairports.aspx

2. An Environmental Management System for Airports

An Environmental Management System (EMS) is a set of management principles intended to identify, evaluate, monitor, and reduce the negative environmental impacts of an organization's activities. This e-publication highlights the basic principles of an EMS; a few examples of internationally recognized systems, including a comparison between them; the benefits for an airport to implement an EMS; the elements they should consider before, during and after its implementation, including lessons learned from different airports while going through a similar process.

3. Waste Management at Airports

Waste management is another relevant topic for any airport, and one which presents many challenges. For instance, waste management requires an overall understanding of the different types of waste an airport produces, and the different stakeholders involved and responsible for that, issues that are also based on national regulations. This e-publication focuses on several aspects: definition of waste, types of waste, waste management principles, approaches, implementation, and finally, waste recycling. The general rule is to avoid, reduce and recycle, but the concept of circular economy has been gradually introduced by some airports where the life cycle of a product is extended and there are additional business models and value for a single product that goes beyond the idea of simply recycling. For example, the concept of airport lighting as a contracted service at Schiphol to minimize waste is one excellent case study forming this publication. Despite being a local issue, there are several local, national and international practices around the globe that can be shared and learned.

4. Eco-design of Airport buildings

This e-publication provides an overview of planning and design elements of an airport building that can positively impact their environmental footprint. Eco-friendly planning and design can improve an airport building's energy efficiency, and save of resources during construction, operation, maintenance, refurbishment, and demolition. For instance, a new terminal project designed to add capacity and reduce aircraft taxi times is also an opportunity to improve water use, heating/cooling efficiency, better lighting, and to save money reusing and recycling construction materials. Technologies like gate electrification and preconditioned air at gates can be planned well in advance and they allow pilots to shut off the auxiliary power unit (APU) on the aircraft while parked, which conserves jet fuel. Electrification and alternative fuel for ground support equipment (GSE) reduce emissions from vehicles and improve the airfield conditions for employees.

FUTURE DEVELOPMENTS

The importance of sustainability shouldn't be underestimated. This is exemplified by the first chapter of Airports Council International's (ACI) Policy and Recommended Practices Handbook, which sets out sustainability as the overarching theme. The principle of sustainability allows airports to continue to operate and grow, while balancing economic, social, and environmental considerations and ensuring community acceptance and permissions to grow.[2]

There has been a lot of interest recently in actions that improve climate resilience, for both extreme events like hurricanes as well as for longer term changes such as sea level rise. This topic will be the first Eco-Airport e-publication to be developed by the CAEP/12 cycle. Other relevant topics for airports such as Local Air Quality and Water management will follow as the 2nd and third e-publications. Last, but not least, we'll be looking at an external component – surface access, because sustainability at airports is also about the surrounding community and the ability and efficiency of their journey to get to and from airports.

Finally, beyond the Eco-Airport Toolkit but still under the sustainability umbrella, forward-looking airports are now asking how they can help airlines meet their

2 ACI Policy and Recommended Practices Handbook, Ninth Edition, 2018. Online: https://aci.aero/Media/2259c3f4-8016-442f-8c7a-8138ebb1eb0c/JWWLuQ/About%20ACI/Policies%20and%20Practices/2018/ACI_Policy_Handbook_Jan_2018_FINAL.pdf

Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) requirements, and are pursuing options to offer sustainable aviation fuels at their facility. These are areas in which the industry may also see creative developments in the near future.

The concept of sustainable airport management is no longer seen as just a nice thing to have, or a practice for those interested in the environment. Sustainability is simply good business, resulting in a combination of benefits that will position airports to be viable and competitive in the future.

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Smart and Sustainable Aviation in the Netherlands

By Ms. Denise Pronk, Head of Sustainability, Amsterdam Airport Schiphol

INTRODUCTION

Royal Schiphol Group (RSG) is a Dutch airport company with an important socioeconomic function. Airports in the Group create value for society and for the economy. Its mission is to connect the Netherlands to the rest of the world as effectively as possible. By doing so, RSG contributes to prosperity and well-being in the Netherlands and elsewhere. It facilitates leading-edge multi-modal connectivity for the benefit of national and regional development, trade, and well-being.

The RSG vision is to safely and seamlessly operate the world's most sustainable hub and regional airports. Sustainability and safety are fundamental principles governing the actions and activities of all aviation and non-aviation activities across the Group. They are also key indicators against which the Group's success and measure performance are measured.

OPERATOR OF THE MOST SUSTAINABLE AIRPORTS IN THE WORLD

Royal Schiphol Group aims to lead by example when it comes to sustainability in the aviation sector. The ambition of the Group is to operate the most sustainable airports in the world. It focuses on four key priorities:

1. Supporting communities
2. Sustainable aviation
3. Energy-positive
4. Circular economy

RSG cares for the well-being of people: its employees, neighbors, passengers, business partners, and future generations. New and existing employees find it important that Royal Schiphol Group is socially responsible. By caring about its employees and surrounding communities, it attracts talented people who add value to the company and to society as a whole and value RSG as a responsible employer. The Group wants to contribute to healthy living and working environments, including to restoring nature.

In a world where the demand for connectivity will grow, RSG wants to balance the aviation demand responsibly. Its long-term vision is to aim for net zero-carbon international aviation emissions. Since the aviation industry still relies on fossil kerosene, radical innovations and breakthroughs are needed. The Group believes that it can work with the aviation industry, knowledge institutes, and governments, towards a net zero-emissions sector. RSG's starting point for innovation is that it believes that stepping up its joint efforts to achieve sustainable aviation at the global level will improve the balance between airports and communities around them at the local level. The goal is to go beyond 'zero' and create value, which can be given back to the environment and communities in the Netherlands.

AVIATION AND SUSTAINABILITY

There are 7.7 billion people living on earth and it is expected that the world population will increase to 9 billion people by 2050. All these people need basic necessities such as water, food, housing, energy, clothes, work, and transport. However, the resources of the planet are finite. The depletion of the earth's resources is nearing rapidly, while air pollution and other contaminations are increasingly becoming a global issue. Humankind has to respect the planet's limits, so the earth must be treated properly and responsibly in a conscientious fashion.

However, because of human activities, there has been a serious increase in CO_2 emissions, resulting in rising global temperatures. These lead to climate change and deteriorating living conditions in many places around the world.

Worldwide, the demand for aviation doubles every fifteen years. People like to explore the world, travel for business, or meet family and friends. To facilitate this growth, natural resources and materials are needed. The aviation sector is responsible for 2 per cent of the CO_2 emissions at a global level and 7 per cent of the emissions in the Netherlands. This relative share will increase if other sectors of the economy reduce their CO_2 emissions and the aviation sector does not.

In 2009 the aviation industry set the target to reduce CO_2 emissions by 50 per cent in 2050 compared with 2005. The International Civil Aviation Organization (ICAO), the UN body which oversees global civil aviation, is responsible for monitoring the emissions of international aviation. ICAO's member states aim for carbon-neutral growth from 2020 onwards, and an additional 1.5 per cent in energy efficiency each year. To deal with this, the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), was initiated by ICAO in 2016. CORSIA is a global market-based measure designed to assist in the achievement of the ICAO's aspirational goal of carbon-neutral growth from 2020 onwards.

European Union Emissions Trading Scheme (EU ETS) is another instrument that internalizes the external costs of aviation. The European Commission started EU ETS to reduce emissions in Europe. CO_2 emissions from aviation have been covered by EU ETS since 2012. Airlines that operate flights within/between EU Member States have to monitor, report, and verify their emissions and surrender allowances to offset their emissions. Royal Schiphol Group actively monitors the developments at the European Emission Trading System for aviation and the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA).

The carbon emissions of airport operators are covered in the Paris Agreement (2015). The Paris Agreement states that to keep the circumstances manageable, the rise in temperature should stay well below 2 °C. For the Netherlands, the following goals have been derived from the Paris Agreement: 49 per cent CO_2 reduction by 2030 compared with 1990 and 95 per cent CO_2 reduction by 2050 compared with 1990. Emissions from domestic flights are part of the national emissions as well, and are therefore covered by the Paris Agreement. The Intergovernmental Panel on Climate Change (IPCC) report (2018) has urged that the emissions should be net zero in 2050 to keep the rise of the temperature at 1.5 °C.

The aviation sector should also strive for net zero emissions in 2050. In the last decade there have been developed multiple policies and measures and these need to be adjusted to come in line with the net zero goal. The awareness that the aviation sector has to do more has already led to several initiatives.

SMART AND SUSTAINABLE ACTION AGENDA

Twenty Dutch transport organizations, including research institutes, knowledge institutes, and Royal Schiphol Group, have joined forces to express their concerns about climate change and the environmental impact of the aviation sector in particular. In 2018, they jointly set up the action agenda 'Smart and Sustainable' with a goal to decrease aviation emissions in the Netherlands to 2005 levels by 2030.

According to the action plan, the aviation sector will consume 5.5 million tons of kerosene in the Netherlands in 2030, if no action is taken, which amounts to 17.3 million tons of CO_2. By pursuing this action plan, CO_2 emissions from air transport in the Netherlands will be approximately at the level of 2005 (11 million tonnes of CO_2) by 2030. Owing to the integrated nature of the plans they will also contribute to the welfare and prosperity of the Netherlands by bringing about an improvement in the human environment at and around airports, as well as the accessibility to airports. The action plans will also generate new insights and foster the development of new markets, such as the production of sustainable aviation fuel. In so doing, the Dutch aviation sector will contribute towards the transition to sustainable energy which will benefit society at large, and will also strengthen the competitive edge of the Netherlands.

The consortium will achieve this reduction by focusing on seven themes:

1. Optimizing flight paths and procedures.
2. Incentivizing the use of cleaner aircraft through airport charges.
3. Greater utilization of sustainable aviation fuel.
4. Radical fleet renewal.
5. Use of international train services and other sustainable modes for short distances.
6. Working towards zero-emission airports.
7. A swift and sustainable journey to and from the airport.

The following paragraphs explain the seven themes of the Smart and Sustainable action agenda, and provide additional background information.

1. Optimizing Flight Paths and Procedures

The Single European Sky (SES) initiative advocates a single, unified European airspace free from national borders that will be able to support the region's long-term aviation capacity needs. Royal Schiphol Group and its European partners actively promote the accelerated introduction of SES, which has the potential to modernize Europe's air traffic control system and drive efficiency across ground processes, aircraft handling and airport use which will result in a decrease of carbon emissions.

2. Incentivizing the Use of Cleaner Aircraft Through Airport Charges

Newer aircraft types are quieter and more fuel-efficient. Better fuel efficiency results in lower CO_2 emissions, thus "cleaner" aircraft. Royal Schiphol Group has built a strong sustainability element into the new airport charges structure at Schiphol. Take-off and landing fees give preference to aircraft that are quieter and more environmentally friendly. RSG views the new structure as a crucial step towards airport charges that directly address environmental impact. The new structure took effect on 1 April 2019 and runs until 31 March 2022. It effectively raises the discount rate for more sustainable aircraft by the difference between the noisiest and most silent categories. Under the new system, airlines pay 180 per cent of the basic rate for take-off and landing fees for the noisiest, most polluting aircraft by 2021. Take-off and landing charges for the cleanest, quietest aircraft is 45 per cent of the basic rate. This policy also applies to night flights and will be made even more punitive for the noisiest night flight categories. RSG is monitoring the initial implementation phase and will consider a further evolution of the new fee structure for the following charges period.

3. Greater Utilization of Sustainable Aviation Fuel

RSG's vision is that clean aviation is possible. The development of sustainable aviation fuels, both bio kerosene and synthetic kerosene, is an important measure to lower aviation emissions. They have a double positive effect, because their use results in lower emissions of both CO_2 and NOx, which is better for climate at the global level, and air quality at the local level. Multiple organizations and knowledge institutes are conducting research into the feasibility of sustainable aviation fuels, including feedstock and scale-up opportunities. Via the joint action agenda Royal Schiphol Group committed itself to having 14 per cent sustainable aviation fuels available at its airport locations in 2030. RSG has signed a multi-party agreement to study the production of synthetic kerosene. RSG contributes financially and with know-how. RSG invest financially in the design phase to build a plant for the production of bio kerosene in the Netherlands. The plant is expected to take in operation in 2022. In the coming years, the Group expects an increase in the production of bio kerosene and an acceleration in the development of synthetic kerosene.

4. Radical Fleet Renewal

Radical fleet renewal is another means to reduce emissions. It involves both using newer aircraft types and accelerating the development of hybrid and electric engines. Via the climate round table network on sustainable aviation, Dutch knowledge and research institutes spur innovation, together with the partners in the aviation sector. RSG stimulates research and development and has partnerships with universities and research institutes.

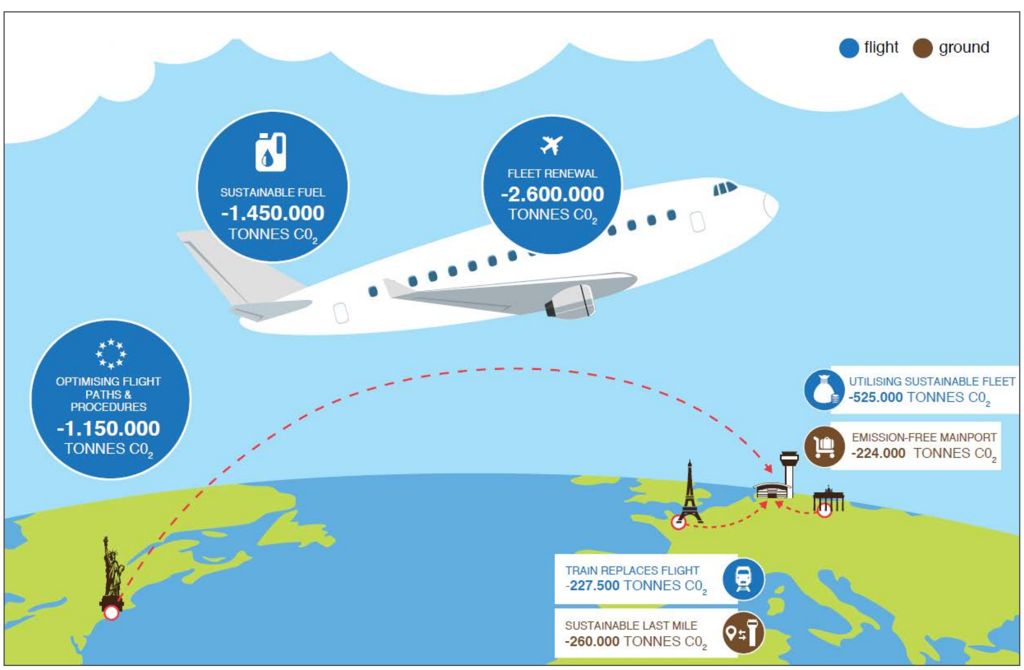
5. Use of International Train Services and Other Sustainable Modes for Short Distances

While clean aviation is expected to become a reality, it does not mean that the aviation sector can grow without limits. Royal Schiphol Group has to balance which routes and destinations have added value for people's well-being and the economy. In addition, passengers have their own responsibility to decide whether taking a flight is necessary. Travelling could be avoided by using digital solutions like videoconferencing. On some routes, an alternative mode of transport could be available. The further development of landside transport alternatives such as high-speed trains, autonomous road transport, and Hyperloop systems will increasingly provide options for short-distance journeys. Particularly for short distance trips within Europe, the train could be a good alternative to air travel. Substitution has several advantages: it lowers aviation emissions, helps balance scarce airport capacity, improves connections, reduces travel time, and increases frequencies; the latter two of which will increase the chance that passengers will opt for non-aviation modes of transport. To make substitutions possible, the ease with which customers can buy integrated Air-Rail tickets has to be improved. RSG contributes by improving the seamless journey for passengers using several transport modes. The extension of Amsterdam's North-South Metro line above ground is another interesting option to further develop Schiphol as a multimodal hub. This development will create space for international trains in the Schiphol tunnel. Furthermore, there are other sustainable alternatives that can be developed further for routes with smaller traveler volumes.

6. Working Towards Zero-emission Airports

Royal Schiphol Group is committed to reach zero-emissions by 2030 without offsetting. This goal means that no carbon and particulates will be emitted while using energy and fuel for the own operations, as well as from related ground operations at airside. RSG runs on Dutch wind power and decreases the use of diesel and natural gas. In the Smart and Sustainable action agenda the goal is that the activities at the entire airport locations should be carbon neutral. At an airport, many activities are operated by third parties. That situation complicates carbon management, since many of the emission sources are not under the control of the airport operator. Other users of airports, including airlines, concessionaires, and ground handlers, must also play an important role in improving overall emissions at airside and landside and the airport operator has a coordinating role.

FIGURE 1: Smart and Sustainable Action to decrease International Aviation Emissions in the Netherlands



7. A Swift and Sustainable Journey To and From the Airport

The journey to and from the airport – the so-called "first & last mile" has a number of disadvantages: it takes time, is sometimes unnecessarily complicated, causes traffic jams, and contributes to CO_2 emissions. Passengers currently choose to travel by car or public transport, but RSG believes that it should be possible to develop alternatives that are more customer-oriented, integrated, energy efficient, and intermodal. Such solutions should also be available for workers in the sector to make commuting more sustainable. The busses that run to and from the airport in the airport region are electric and RSG offers car sharing with electric cars.

FOLLOW UP

This action plan shows that sustainability and economic considerations go hand in hand when it comes to jointly tackling important societal, economic, and sectoral issues. If this action plan is to succeed, however, it is necessary to coordinate the efforts of all involved, because the process is complex. None of the parties has influence over all process elements, and some of the interests, including financial aspects, may be in conflict with one another. All of this demands strong coordination during the development and implementation process, as well as support at the European and global levels for d the amendment of existing laws and regulations. The consortium therefore believes that the Dutch government is an essential partner in this process.

The "Smart and Sustainable" action agenda has provided input for the discussions round tables on sustainable aviation. The Dutch government has established five national round tables to investigate how the Netherlands can achieve the goals of the Paris Agreement. The Mobility round table has established a 'subsidiary' round table on sustainable aviation. The Ministry of Infrastructure and Water Management leads this round table, in which Royal Schiphol Group actively participates. Recently the Ministry has published a draft Government Agreement on sustainable aviation and the consortium is working towards a net zero emissions goal. The Smart and Sustainable goal for 2030 is the first milestone – to reduce international aviation emissions by 50 per cent by 2050. The short-term focus is to collaborate with partners to investigate, implement, and execute measures from the "Smart and Sustainable" joint action agenda and the climate round table on sustainable aviation. Six months after the launch of the joint action agenda, the consortium published the first update in April 2019. The organization plans to produce a more substantial update on an annual basis.

Besides the partnerships at the national level, Royal Schiphol Group has forged strong ties with (trade) organizations at the European and global level to discuss new developments and regulations. RSG collaborates with airports that have the same sustainability vision and supports airports in becoming more sustainable. The Group believes that by setting ambitious targets, and by leaving the own comfort zone, RSG will arrive at innovations and new insights that will help reach the long term goals. The Group conveys the viewpoint in international forums and articles to raise awareness for sustainability. Global collaboration is a prerequisite to transform the international aviation sector into a sustainable one.

Circular Economy at Amsterdam Airport Schiphol

By Ms. Denise Pronk, Head of Sustainability, Amsterdam Schiphol Airport

INTRODUCTION

Royal Schiphol Group (RSG) is a Dutch airport company with an important socioeconomic function. Airports in the Group create value for society and for the economy. Its mission is to connect the Netherlands to the rest of the world as effectively as possible. By doing so, RSG contributes to prosperity and well-being in the Netherlands and elsewhere. It facilitates leading-edge multi-modal connectivity for the benefit of national and regional development, trade, and well-being.

The RSG vision is to safely and seamlessly operate the world's most sustainable hub and regional airports.

Sustainability and safety are fundamental principles governing the actions and activities of all aviation and non-aviation activities across the Group. They are also key indicators against which the Group's success and performance are measured.

OPERATOR OF THE MOST SUSTAINABLE AIRPORTS IN THE WORLD

Royal Schiphol Group aims to lead by example when it comes to sustainability in the aviation sector. The ambition of the Group is to operate the most sustainable airports in the world. It focuses on four key priorities:

1. Supporting communities
2. Sustainable aviation
3. Energy-positive
4. Circular economy

RSG cares for the well-being of people: its employees, neighbors, passengers, business partners, and future generations. New and existing employees find it important that Royal Schiphol Group is socially responsible. By caring about its employees and surrounding communities, it attracts talented people who add value to the company and to society as a whole and value RSG as a responsible employer. The Group wants to contribute to healthy living and working environments, including to restoring nature. The goal is to go beyond 'zero' and create value, which can be given back to the environment and communities in the Netherlands.

CIRCULAR ECONOMY

Our current world is based on the linear economy: natural resources are mined, produce goods, transport and use them and finally throw them away. By doing so, lots of valuable materials and natural resources are thrown away. At the same time, the rise in world population and the increase of prosperity levels will lead to a higher demand in natural resources. However, the natural resources that the earth can supply are limited.

Therefore humankind needs to shift from a linear economy to a circular economy. Once circular economy would have been achieved, it will be possible to preserve and increase natural resources and their derivative materials for future generations.

RSG is striving to be operating completely circular airports by 2050. The first milestone in reaching this ambition is to operate zero-waste airports by 2030. Zero waste means that all raw materials, components, and products used by Royal Schiphol Group will be reused or recycled to the highest degree possible according the waste hierarchy. This will be achieved preferably at RSG's own locations or as close to those airports as possible. The consequence of this vision is that what has been traditionally treated as waste will now be regarded as "residuals" of the operation of value, rather than as useless waste.

A target of 2030 may seem like the distant future, but RSG assets have long life cycles, and that is why the Group has already spent a number of years working toward achieving its ambition for 2030. In fact, the first zero-waste plan was launched in 2015.

RSG has embraced the circular economy concept both in thinking and acting because it offers significant advantages including: it reduces negative environmental impacts, it creates opportunities for new business models, and it decouples the need for natural resources and materials from economic growth, which in turn leads to more stable commodity prices. As detailed in the next paragraph, the application of RSG's zero waste guiding principles to improving its fixed assets results in various benefits such as: increased speed and flexibility during the construction phase, improved cost control during the facility life cycle, and improved indoor quality of life.

DESIGN

Royal Schiphol Group has developed zero-waste principles, and is gaining experience in applying them to the design and construction of new buildings and the renovation of existing assets. The lifetime of an asset determines the amount of maintenance and renovation needed. RSG wants to achieve the maximum output from its resources by allowing them to "circulate" for as long as possible. Durability is also an important aspect regarding embodied carbon is the carbon footprint of a material. It considers how many greenhouse gasses are released throughout the supply chain (mine – produce – transport – use – waste). The design and construction of assets are key elements in achieving the zero-waste goal.

The Group has learned from experience that it is important to think through the design of an asset from the very beginning in a different way than previously. From the outset, project goals and major requirements should already include circular economy principles. Designing an asset first and then trying to add on circular economy principles later does not work. One has to think several steps ahead about such issues as: what will be the estimated lifespan of the asset, and will it be disassembled after use; and what could be the eventual new purpose for the materials. This last reflection on future use will stimulate the designer to use standard sizes and to rethink the way components are assembled, for instance by using screws instead of glue, so the chance that components will be reused again will increase. The design must also take into account processes and procedures such as future maintenance impacts.

REUSE AND RECYCLING

Apart from construction and renovation of fixed assets such as buildings, insight into incoming and outgoing residual flows is key to closing material loops as well as to reusing and recycling residuals to the fullest extent possible. To "reuse" means that the component will be used again without changing its basic specifications: that is, a chair will remain a chair. The component will keep its value. On the other hand, to "recycle" means that materials will be broken down and blended, and will decrease in value. For instance, a platform made of concrete can be recycled as foundation materials for a new road. Besides operational and infrastructure-related residuals, RSG focuses on preventing food wastage and the responsible use of electronics residual flows.

The Group uses the "waste hierarchy" (Figure 1), or "10Rs approach" to determine the best option with regard to the use of residual waste. The waste hierarchy helps one to visualize the next best application of the material to reduce its environmental impact and ultimately create value.

STRATEGIC RESOURCE MANAGEMENT

The circular economy provides many opportunities for regional and national stakeholders. RSG strongly believes that an organization cannot become circular on its own. Regional partners are important because they can help in reusing material locally, especially when the value of the residual material is low and the costs of transportation would become prohibitive. For instance, concrete has a low value so it is not beneficial to transport it on long distance. One need to recycle it in the local environment. Insights into resource characteristics help with the exchange of materials with the communities around the Group's airports as well as third parties. Material passports capture information about which materials are used in buildings, including the construction method. Ultimately, the idea is to set up a marketplace that will step up efforts towards creating a circular economy together with the stakeholders.

CHALLENGES

There are challenges regarding time, mindset, production processes and technological aspects, since the circular economy principles are gaining attention but are not mainstream yet. One example involves airport terminal buildings for which there are very high standards for fire safety. As a result, materials are impregnated with fire retardant. These are toxic and the materials can't be reused anymore. Industry has to find a way to overcome these kinds of challenges. Another area that has to be explored and developed is the development and presentation of circular economy business cases. It is important to take into account the full net value during the entire life cycle of a facility. In most cases, the capital expenditure for a circular economy facility will be slightly higher than usual. However, maintenance costs will be lower because the smart design and the value at the end of the asset life will be much higher. Financial controllers are not used to thinking about business cases in that way. Together with knowledge centers, RSG needs to develop this new capability. Another challenging topic is the esthetical look of biological materials when incorporated into circular buildings. Most of them are not that fancy and neat, and people have to get used to a new style. This movement has already begun, and industry is currently working hard to develop biological components that also look like what people are used to now.

CIRCULAR ECONOMY PRINCIPLES IN PRACTICE

RSG works according to its zero-waste principles, which it applies to: the design and construction of new buildings, the renovation of existing assets, and the procurement of products and services. Each new project brings circular economy principles into practice. Even when the final results of a project are not entirely circular, every action provides additional insights, and the goal gets closer.

The following five paragraphs describe circular economy programs and projects in which RSG is currently involved.

FIGURE 2: Light as a service; terminal building lighting system

Light as a Service

Philips, Engie, and Schiphol joined forces on this exciting program, inspired by a shared vision and objective. The "light as a service" concept is an arrangement in which Schiphol pays for the light produced, while Philips and Engie remain the owners of the lamps and fittings. Philips and Engie adapted fittings in consultation with Schiphol that made it possible to replace separate components with ease, thus extending the service life of the lighting fixtures. When lamps have reached the end of their service life, Philips will collect and reuse and recycle them.

The above is a good example of how the circular model disrupts the traditional business models which are based on the linear approach of take-make-waste. To create a circular future, the models had to be adapted according to the principles of the circular economy. As a result, the contracts and partnerships with suppliers had to be changed. It was a challenge that took time and perseverance to get everyone on the same page but the payoff was a significant contribution to a more sustainable future, as follows:

- 50% reduction in energy consumption thanks to energy-efficient LED lighting.

- 75% longer service life of the fittings.
- Decline in maintenance costs – components of fittings can be replaced separately.
- Maximum reduction of raw material consumption – complete fittings can be reused.

FIGURE 3: Demountable BREEAM-certified mortuary building

Mortuary

At the morgue, the airport facilitates the process for deceased persons and their friends and relatives, who enter or depart from the Netherlands via the airport. The morgue is located on the limit between airside and landside, which allows the deceased to be transported directly to and from the aircraft. The new morgue was designed to accommodate a range of different cultures and mourning rituals. It is also a place for friends and relatives to say farewell. In addition, the morgue has a viewing room with bathing facilities for cleansing the deceased, a preparation area and an autopsy room for the police.

The new building is ready for disassembly, which means that when a structure's lifespan has ended, the same materials used in building it initially can be easily reused in a new project. The architect designed the building according to the Fibonacci Sequence, which uses mathematical principles to create a sense of harmony. Following this approach, whether one is alone in the mortuary or with a large group, the building always feels respectful and comfortable. This was the main objective when the building was designed.

The mortuary has been awarded via a sustainability building rating system. The rating system used is called BREEAM (Building Research Establishment Environmental Assessment Method) and the certificate obtained is the second highest "Excellent". This level was achieved through insulating and energy-generating applications, such as the climate resilient circular water system that drains away waste water more slowly and filters it, and rain water is captured to flush toilets. Electricity is supplied by solar panels and the building is lit by low energy LED lighting. The building uses a heat pump so no natural gas is needed. The morgue has a green roof and special locations for bees. Housing and protecting bees is an essential part of the RSG ecosystem, and it supports them because bee populations are dwindling worldwide.

FIGURE 4: Demountable car park at Schiphol Airport

Car Parks

The P1 car park at Schiphol Centre was extended in 2017. Schiphol requested a demountable system in the invitation to tender because it anticipates expansion will be required for a 15-year period. The construction is not yet circular; however, because the car park can be dismantled in components, it will be possible to reuse the materials in the future. The P2 car park has been demolished, and 99 per cent of the concrete has been recycled as the foundation for a new platform airside. Charging facilities and payment machines have been relocated to other parking facilities. P2 was located between two important roads at Amsterdam Airport Schiphol, and at the foot of the air traffic control tower – so tearing down P2 with a wrecking ball was not an option. Instead, workers carefully drilled 1,500 concrete slabs loose before cranes lifted the slabs onto trailers, before transporting them to a storage facility. In addition to the concrete, the electrical charging points, ticket dispensers, and barriers, were also carefully removed for later use. Essentially, the building process was carried out in reverse. The P3 long-stay parking garage is fully demountable. The parking garage is constructed out of 90 per cent recyclable concrete and metal.

FIGURE 5: New pier – Schiphol Airport

New Pier

The new pier at Schiphol is over 55,000m² in size, equivalent to 11 football fields. The era of sitting in one of those black chairs and simply waiting in one place until boarding time is almost over. The new pier will have comfortable lounge chairs for relaxation, high-top tables for working, as well as last-minute shopping outlets. The pier's open layout means that travelers can see the boarding process begin – even when they aren't waiting at the gate. There are trees, flowers and plants all around, and the new pier is green in more ways than one. RSG has carefully considered various ways of reusing energy and using reusable or sustainable materials in the design of the new pier. The ceiling is made of reusable plastic marble rubblework tiles, and 5,000 m² of solar panels. Toilets are flushed using rainwater, and much of the floor is made of bamboo. The goal is to achieve the LEED Version 4 Gold certificate for the pier.

FIGURE 6: Refurbished airport lounge furniture

Furniture

The furniture requirements are very stringent at Schiphol Airport. Of course the furniture has to look good and has to fit into the overall Schiphol look and feel design. The furniture also has to last a long time under intensive usage conditions. Schiphol Airport is well known for its black functional design Tecno chairs, and in some pier upgrade projects the Tecno chairs are reused – without any changes. For the project Bus gate at Pier E, the Tecno chairs were upgraded to incorporate electronic charging components into the frames. This is an example of meeting the current wishes and expectations of passengers by upgrading the existing chairs. Thus, by treasuring furniture that was still functional and already available at Schiphol it was possible to restyle the furniture and keep its value.

Next steps

Airports have a direct influence on the circular economy. Therefore, RSG wants to play its role fully and gain more experience in the field of circular economy. The focus will be on design and increase insights in reuse and recycle residual streams. One of the improvements needed relates to the better registration of the residual streams. RSG investigates the opportunities to open a place where materials can be stored and/or exchanged with (regional) partners and RSG has to team up with partners that can close the loops.

Figure 1: The Waste Hierarch

Circular economy

Increasing circularity

	Strategies	
Smarter product use and manu-facture	R0 Refuse	Make product redundant by abandoning its function or by offering the same function with a radically different product
	R1 Rethink	Make product use more intensive (e.g. by sharing product)
	R2 Reduce	Increase efficiency in product manufacture or use by consu-ming fewer natural resources and materials
Extend lifespan of product and its parts	R3 Reuse	Reuse by another consumer of discarded product which is still in good condition and fulfils its original function
	R4 Repair	Repair and maintenance of defective product so it can be used with its original function
	R5 Refurbish	Restore an old product and bring it up to date
	R6 Remanufacture	Use parts of discarded product in a new product with the same function
	R7 Repurpose	Use discarded product or its parts in a new product with a different function
Useful application of mate-rials	R8 Recycle	Process materials to obtain the same (high grade) or lower (low grade) quality
	R9 Recover	Incineration of material with energy recovery

Linear economy

Gatwick's Circular System for Becoming a Zero Waste Airport

By Rachel Thompson (London Gatwick Airport)

OVERVIEW

Gatwick is the world's most efficient single runway airport, handling more than 46 million passengers and 280,000 air traffic movements in 2018. The airport is also home to over 120 operational and commercial businesses. In the past decade, Gatwick has invested over £2 billion in transforming the airport with an ongoing program of capital and refurbishment works.

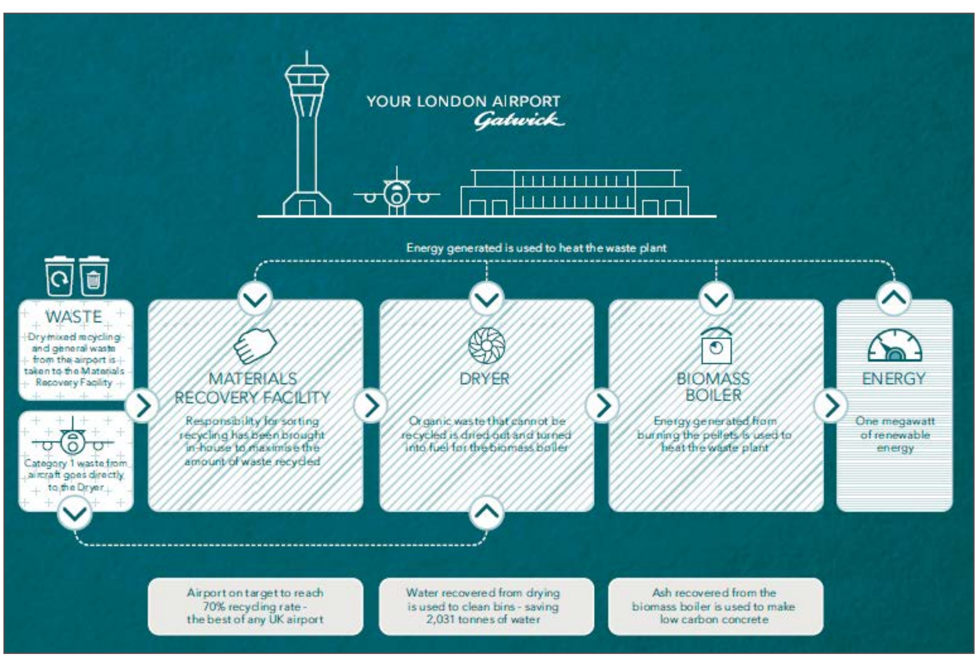
All of these activities generate materials that can be reduced, reused or recycled; some easily, others only with systemic innovation. In 2010, Gatwick launched the Decade of Change sustainability strategy which includes targets of zero waste to landfill and 70 per cent reuse and recycling by 2020.

By 2015 Gatwick had achieved zero waste-to-landfill for operational and commercial waste but the reuse and recycling rate was improving more slowly, rising from 40 per cent in 2010 to 49 per cent in 2015. This is above average performance in the United Kingdom but the aim is to do much better.

The focus now is to transform the way that 'waste' is conceived and processed at Gatwick. To do this, Gatwick adopted the Circular Economy ethos of utilizing as many recovered resources as possible within the airport property; and a "Logistics lens" to ensure that it is done efficiently.

Following a competitive tender, DHL Logistics was selected in May 2016 as Gatwick's partner in the project.

FIGURE 1: Gatwick's onsite Recycling & Reuse Centre deploys circular principles



The initiative commenced with a full review of waste management practices to identify the key opportunities to use resources more effectively across the airport. The resulting circular system approach incorporates four main areas of focus and investment:

- Redevelopment of materials collection sites and redesigned collection and transport logistics.
- New onsite materials sorting and separation facility.
- New onsite biomass boiler to process international catering waste and other organic matter into heat and water for onsite use.
- Ongoing training and awareness campaigns about Gatwick's journey to zero waste.

ECONOMIC AND ENVIRONMENTAL BENEFITS

A key feature of Gatwick's circular system is that it utilizes the same physical footprint as the previous waste 'care center' – a warehouse on the northern side of the airport property – while substantially increasing that site's economic and environmental productivity.

To implement the new system, Gatwick invested £4 million over two years with a return on investment of approximately £750,000 per year from: onsite energy and water cost savings, offsite processing and disposal cost savings, and income earned from recycling.

Gatwick's recycling and reuse performance accelerated, from 52 per cent in 2016 to 64 per cent in 2018; and had increased to 70 per cent by the first quarter of 2019. Consequently, offsite recovery for energy has decreased from 48 per cent in 2016 to 36 per cent in 2018, and to 30 per cent in the first quarter of 2019. Since 2015, Gatwick has sent zero untreated waste to landfill, and in 2018 it was the first airport to achieve the Carbon Trust's Zero to Landfill certification.

KEY FEATURES OF GATWICK'S CIRCULAR SYSTEM

Redesigned collection and transport logistics

Previously, mixed waste from the airport terminals, retail outlets, and offices was collected, consolidated and sent offsite for sorting and reprocessing. This restricts the full recycling potential from being realized because truly effective recycling requires clean dry materials rather than mixed materials that contain residual liquids and foods – the so-called contamination problem.

Now, materials are classified as "Wet" or "Dry" at the point of use and collection. For example, airport food and beverage outlets are required to separate items such as dry paper and card, plastic packaging, empty bottles and food scraps for collection. In the terminals, passengers are asked to put empty bottles, cups and newspapers in

FIGURE 2: Towards Zero Waste: Gatwick's 2018 performance.

"dry recycling" bins, and items containing food scraps or liquids into another bin. In offices and crew rooms, staff are provided with separate bins for food scraps, coffee cups, and dry mixed recyclables.

In addition, by using small baling machines at the Terminals, and then compressing those into large "mill size" bales at various collection points, there are 200 fewer industrial-size waste bin collections per day at the Airport, and a similarly reduced number of lorry vehicle trips to external waste plants.

Onsite materials sorting and separation

This pre-sorting at point-of-use is facilitated by the installation of a manual sorting conveyor at Gatwick's onsite Recycling Centre which began operating in September 2016. All mixed recycling bin bags from across the airport, and from EU aircraft, are sorted by this process. This enables close sorting and separation. For example, an empty coffee cup which can be recycled would be separated by the recycler from one containing congealed liquids which would be rejected. As a result, all dry paper, card and plastic packaging collected at Gatwick, including all empty coffee cups and plastic bottles, are being recycled.

Biomass generation and water reuse

The Facility also incorporates an onsite dryer and biomass boiler to process organic "wet waste" materials such as food scraps and food-contaminated paper and card which cannot be recycled. This material is dehydrated in a Gobi dyer, filtered several times to remove any small plastic shards, and baked into solid biomass fuel.

The process currently generates 4.75 million kWh of renewable heat per annum which is used to operate the drying process and heat the Facility building. The biomass boiler has been designed to operate to emission standards that are stricter than required by EU regulations. Gray water recovered from the drying stage is collected and used to clean waste bins, helping to reduce airport water consumption by 2 million liters per annum.

International catering waste

In a first for the aviation sector, Gatwick was the first airport in the world to undertake onsite processing of Category 1 International Catering Waste from non-EU aircraft, by converting it to biomass to create renewable heat. Category 1 waste comprises food waste and anything mixed with it from non-EU flights. Its disposal is

FIGURE 3: Simon Duggan, Gatwick's Senior Commercial Operations Manager who led development of the Circular system, at the onsite materials sorting line

governed by strict rules that require specialist processing (until now, offsite) to protect against potential spread of disease and infectious material. Around 20 per cent of Gatwick's operational and commercial waste is Category 1.

Approval for onsite processing of Category 1 waste therefore required close collaboration with UK environment and health regulators. From the earliest planning stages onwards Gatwick has worked closely with the national and local authorities, and with airline cleaning contractors, to implement an effective and audited procedure for identifying waste collections from EU flights (Category 3 waste) and non-EU flights (Category 1 waste).

Furthermore, this strict approach to labelling and custodianship means that Gatwick can process rubbish bags from EU flights through the onsite mixed recycling facility sorting line, which extracts all recyclable materials from these bags.

Zero waste to landfill certification

In June 2018, Gatwick became the first airport to achieve the Carbon Trust's new Zero Waste to Landfill accreditation. This standard was established to provide a robust framework for verifying zero waste-to- landfill performance. Commenting on Gatwick's certification, Hugh Jones, Managing Director, Carbon Trust Business Services, said:

> *"We are delighted to be able to recognize Gatwick's achievement of zero waste to landfill certification for the first time. Gatwick is setting an excellent example, showing how a business can improve its operational efficiency and its environmental results at the same time, as well as encouraging higher levels of action elsewhere by positively influencing other companies that operate at the airport site."*

Promoting passenger recycling and reuse

To encourage greater recycling awareness, particularly for plastic bottles and coffee cups, in 2018 the signage on all bins throughout the terminals was standardized. This initiative is now being extended to bins in airport car parks.

Gatwick's passenger website and app, and the signage at the entrance to Security screening areas, provide visible messaging to passengers that they can take an empty bottle through security and refill it at water fountains in the departure lounges. Free water refills are also provided by all of Gatwick's food and beverage outlets.

FIGURE 4: New, clearer recycling signage to encourage waste segregation has been deployed across the airport

FIGURE 5: New, high visibility signage placed at security and in airside areas to encourage passengers to reuse water bottles

Airport staff campaigns

Regular and ongoing engagement with airport staff working in offices, terminal operations, retail outlets, on the airfield and for airlines and cleaning companies is a key feature of the initiative to promote continuous improvement in materials segregation and handling.

Quarterly forums are held with airlines and cleaning companies to increase the segregation of EU waste which can be recycled and to ensure correct handling of Category 1 aircraft cabin waste.

To support retail concessionaires, a standard template has been created to ensure correct set-up of waste sorting and handling systems within every retail unit and back of house area, and process conformity is audited regularly. In addition, training sessions, information packs, and quarterly performance infographics are provided to each retail store.

In early 2019 Gatwick convened an event involving all airport retail concessions to launch the Gatwick Recycling Champions forum. This brings together a staff member from each retail store to create a community of people to champion the right recycling behaviors in retail operations.

FIGURE 6: Lanyard badge, made of recycled plastic, for Retail Recycling Champions forum members

FIGURE 7: Gatwick staff canteen campaign to reduce single use plastics

To encourage recycling by Gatwick staff, clear signage has been printed on bins, and wall posters have been posted in staff canteens, kitchen areas, and crew rooms to promote recycling behaviors. As well, regular team talks are undertaken by the waste logistics manager, sustainability manager, and DHL Logistics.

Gatwick's own business units are expected to identify specific ways to improve their recycling behaviors and performance through annual EHS improvement plans. This includes talks from Gatwick's waste manager to provide information and encourage best practices. The annual improvement plans support Gatwick's annual environment targets, including for recycling and reuse. In FY2018/19, the annual target set for recycling and reuse was 65 per cent which was achieved.

In 2018, reusable coffee cups were provided to Gatwick staff in exchange for a small donation to Gatwick's charity partners. Reusable cups attract a range of discounts at the airport's coffee shops and staff canteens.

LOOKING AHEAD

Gatwick expects to achieve 70 per cent recycling and reuse consistently throughout 2019, thus fulfilling its Decade of Change sustainability goal. In the new decade from 2020, the Airport will continue to focus on becoming a zero waste airport. This will involve attention and action in at least three areas:

1. Maintain and further improve Gatwick's recycling and reuse rate as the airport continues to grow.
2. Continue to seek out innovators in the UK and European materials reprocessing value chain that can help to maximize reuse, recycling and recovery of embodied materials, including by identifying new and higher value re-use and recycling opportunities. For example, some materials that are presently recovered for heat or electricity may provide higher environmental and economic value if used as feedstock for sustainable aviation fuel blends.
3. Continue to promote waste reduction, reuse and recycling initiatives with Gatwick staff and passengers, including further uptake of reusable options for common "on the go" items.

And last but not least, we want to find another word for 'waste', as we wish to abolish it in both word and deed!

CHAPTER NINE

States' Action Plans and Capacity-building

Turning Policy Into Action

Capacity Building and Assistance to Advance Environmental Protection in Aviation

By ICAO Secretariat

Over the past years, since the beginning of ICAO's journey to progress in terms of policy development and standards-setting for environmentally sustainable aviation, ICAO Member States demonstrated that they were interested in taking action and advancing initiatives on environmental protection. However, not all of them had the human, technical and financial resources to do so. To overcome this challenge, ICAO proposed means to resolve these issues.

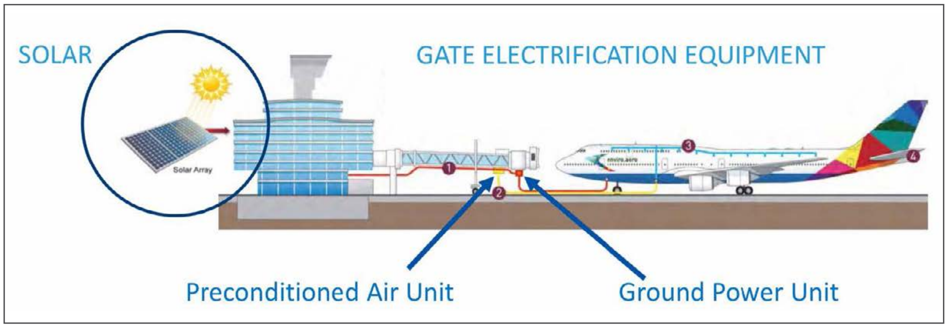
Since ICAO's global aspirational goal of carbon-neutral growth from 2020 was adopted, and Member States agreed on a basket of measures to reduce greenhouse gases in aviation to achieve this aspirational goal, capacity building and assistance became fundamental for the success in turning this environmental policy into action at the State level.

The State Action Plan initiative was launched in 2010, in order to enable all ICAO Member States to establish long-term strategy on climate change for the international aviation sector, involving all interested parties at national level. This process has led to the elaboration of a "do-nothing" scenario, estimating the amount of CO_2 emissions generated by international aviation, should no mitigation measure be implemented. Such a baseline scenario forms a useful starting point for a robust discussion between international aviation stakeholders at national level on a shared vision for the long-term CO_2 emissions of the international aviation sector and on the prioritization of possible mitigation measures. The latter element greatly benefits from the participation of the national authorities in charge of energy, environment, innovation and mobility. In order to support its 193 Member States with the development of their State Action Plans, ICAO has developed a series of guidance documents and quantification tools. ICAO *Guidance on the Development of States' Action Plans on CO_2 Emissions Reduction Activities* (Doc 9988) provides the States' Action Plan Focal Points with a comprehensive understanding of the context, policies and resources available to progress with the States' Action Plans.[1]

Since the 39th Session of the ICAO Assembly, a number of key decisions have been made in the area of environmental protection that have profoundly changed the regulatory and operational environment of aviation stakeholders. The adoption of Assembly Resolution A39-3 and the implementation of the Carbon Offsetting Reduction Scheme in International Aviation (CORSIA) will influence States' activities in CO_2 emissions monitoring, reporting and verification (MRV) ICAO Assistance, Capacity building and Training for CORSIA (ACT-CORSIA), and is covered under Chapter 6. Further developments of the other elements of the basket of measures, for instance, the adoption of a 2050 Vision for Sustainable Aviation Fuels has an impact on the activities that States may wish to include in their action plans. In addition, the capacity building and assistance projects implemented by ICAO in partnership with the European Union (EU) on the one hand, and with the United Nations Development Programme (UNDP) and the Global Environment Facility (GEF) on the other hand, have delivered a series of IT tools, guidance and pilot projects that all aim to provide extensive information to the States and their stakeholders on key aspects of the development of the States' Action Plans. Additionally, a third edition of ICAO Doc 9988 is being finalized with the aim to reflect all these evolutions.

1 https://www.icao.int/environmental-protection/Pages/ClimateChange_ActionPlan.aspx

FIGURE 1: ICAO-UNDP-GEF Assistance Project: Solar-at-Gate Pilot Project



As a result of ICAO's intensive support to its Member States, by June 2019, 114 States representing 93.4% of international air traffic have voluntarily submitted an action plan to ICAO. Such commitment to the State Action Plan initiative once again demonstrates that all ICAO Member States want to take action on environmental protection. To overcome the lack of resources, ICAO has successfully established two partnerships with international organizations to secure funding for the development of specific technical assistance projects in support of its Member States' actions to reduce aviation emissions. These projects started in 2014 and have been implemented by ICAO with great accomplishments.

ICAO-UNDP-GEF ASSISTANCE PROJECT: TRANSFORMING THE GLOBAL AVIATION SECTOR: EMISSIONS REDUCTION FROM INTERNATIONAL AVIATION[2]

This technical assistance project aimed at supporting States implementing emission reduction measures, in particular developing States and Small Island Developing States (SIDS). Funded by the Global Environment Facility (GEF), the project was implemented by ICAO from 2015 to 2018, in cooperation with the United Nations Development Programme (UNDP) (for further information on this project, see the dedicated article under this Chapter).

Through this project, ICAO developed a set of guidance documents for States on how to implement and secure financing for renewable energy and sustainable aviation fuels projects, and also created analytical tools to compare the cost-effectiveness of emissions mitigation initiatives. These guidance and tools are beneficial for the civil aviation authorities and aviation stakeholders for the implementation of the States' Action Plans on emissions reduction and are available on the ICAO website.

The Solar-at-Gate technology

Part of the ICAO partnership with the GEF and UNDP was to define a pilot project that could be fully replicated in ICAO Member States, and particularly in SIDS and Least Developed Countries (LDCs). As energy costs and reliability can represent a challenge in these States, an aviation project using renewable energy was chosen as the pilot project.

Aircraft conventionally use on-board auxiliary power units (APUs) and ground power units (GPUs) to provide electricity and cabin climate control while an aircraft is parked at a gate before departing for their next flight. The "solar-at-gate" technology is an innovative solution, for which a methodology was designed by ICAO in cooperation with the United Nations Framework Convention on Climate Change (UNFCCC) to reduce greenhouse gas emissions by providing solar energy directly to aircraft during ground operations.

A solar facility is installed at the airport premises, which supplies the power demand to operate an electric GPU and pre-conditioned air (PCA) units. The combination of electricity generated by the solar facility and the use of gate electrification equipment eliminates the CO_2 emissions while the aircraft is parked at the gate.

2 https://www.icao.int/environmental-protection/Pages/ICAO_UNDP.aspx

With the funding of the ICAO and UNDP-GEF initiative, ICAO was able to implement the first of its kind "solar-at-gate" project at Norman Manley International Airport in Kingston, Jamaica in 2018. This small-scale (100kWp capacity) demonstration project now serves as a model for other airports to follow as an emission mitigation strategy.

ICAO-EUROPEAN UNION ASSISTANCE PROJECT: CAPACITY BUILDING FOR CO_2 MITIGATION FROM INTERNATIONAL AVIATION[3]

This project has been one of the landmark capacity building and assistance initiatives at ICAO and one of the first projects to fully represent the spirit of ICAO's *No Country Left Behind* initiative. With the financial contribution of the European Union, ICAO supported a group of fourteen States in Africa and the Caribbean to develop and implement States' Action Plans on emissions reduction, and to establish an efficient CO_2 emissions monitoring system – the Aviation Environmental System (AES) - for the collection and reporting of environmental data.

To assist in the implementation of mitigation measures, ICAO selected four pilot projects to be executed with project funding in the beneficiary States based on their carbon reduction potential and replicability, as follows:

- *Two new solar-at-gate projects to power with solar energy aircraft during ground operations at the international airports in Douala, Cameroon and Mombasa, Kenya.* The installed capacity of these projects is of 1,25MWp and 500kWp respectively and they will eliminate over 4,000 tonnes of CO_2 per year and will serve more than 7,500 flights per year; and
- *Design and implementation of continuous climb operations (CCO) and continuous descent operations (CDO) at the international airports of Ouagadougou, Burkina Faso and Libreville, Gabon.* With these new procedures, aircraft can operate without altitude restrictions during departure or arrival phase, and thus optimize their flight profile. As a result, there is less noise exposure and reductions in fuel burn and greenhouse gas emissions.

3 https://www.icao.int/environmental-protection/Pages/ICAO_EU.aspx

In addition to these pilot projects, the project also funded a set of feasibility studies on clean energy and sustainable aviation fuels, which provide the governments of the selected States with policy advice that may unveil new opportunities to get to the edge of innovations for a sustainable aviation sector.

The implementation of this assistance project has been a successful journey for ICAO. From its inception in 2013, ICAO aimed at strengthening capacities of the civil aviation authorities to engage in the development and implementation of environmental protection policy through tailored training, tools equipment, and other resources. ICAO succeeded in transforming the organizational culture towards environment in the aviation sector of the beneficiary States. Environmental Units with dedicated staff have been created in the civil aviation authorities of most of these States. This gives ICAO confidence that the results achieved will be sustainable in the future.

The implementation of such assistance projects should not remain as one-time initiatives but should be part of a long-term strategy in ICAO. Specific funding for capacity building and technical assistance on environment will allow ICAO to ensure that all Member States can contribute to the collective efforts to achieve ICAO's aspirational goals on environment and that *No Country is Left Behind*.

The ICAO-European Union Assistance Project on Capacity Building for CO2 Mitigation from International Aviation – A Success Story

By ICAO Secretariat

FIGURE 1: ICAO-EU Project Objectives

In 2010, Member States of the International Civil Aviation Organization (ICAO) established the Global Aspirational Goal Of Carbon-Neutral Growth From 2020 For The International Aviation Sector. The ICAO Assembly also agreed on a basket of measures to achieve this goal and requested States to develop and submit State Action Plans on Emissions Reduction on a voluntary basis. While several Member States submitted action plans to ICAO, many others require technical assistance to develop their action plans.

The ICAO and European Union Assistance Project on *Capacity Building for CO_2 Mitigation from International Aviation*[1] is a response to the need of assistance for the development of action plans to ensure that all Member States can participate in the collective efforts for the achievement of the aspirational goal on environment agreed by the ICAO Assembly. The ICAO-EU project aimed at assisting 14 selected States in Africa and the Caribbean to develop and implement their action plans, and to establish aviation environmental systems for CO_2 emissions monitoring and reporting. Funded by the European Union, this 6.5 Million Euros initiative was successfully implemented by ICAO from 2014 to 2019, achieving all the expected results and even exceeding the initial targets.

1 https://www.icao.int/environmental-protection/Pages/ ICAO_EU.aspx

The first objective of the ICAO-EU project was to create national capacities for the development of action plans. ICAO organized specific training-seminars, directed the establishment of National Action Plan Teams in the selected States, and assisted each Civil Aviation Authority directly in the preparation of their action plans. By June 2016, the 14 selected States had developed action plans fully compliant with ICAO's guidelines, including robust historical data and a reliable baseline scenario. A total of 218 measures to reduce fuel consumption and CO_2 emissions were proposed by the beneficiary States in their action plans, including aircraft technology, operational measures, and sustainable aviation fuels.

Lack of reliable aviation environmental data in developing States, such as the amount of CO_2 emissions produced by the aviation sector, is one of the challenges for assessing the impact of aviation on climate change and developing national strategies for environmental sustainability. To address this challenge, the ICAO-EU project developed a tool – the Aviation Environmental System (AES), which supports the establishment of data collection processes for environmental information, including CO_2 emissions from international aviation, and it also automates the organization and reporting of environmental data by the Civil Aviation Authorities. To date, all the beneficiary States have the capacity to use the AES to collect the relevant data from their aviation stakeholders and can generate monthly and yearly CO_2 emissions reports for their aviation sector.

In agreement with the European Union, and based on their carbon reduction potential and replicability, ICAO selected four pilot mitigation measures and five feasibility studies to be executed with project funding in the beneficiary States.

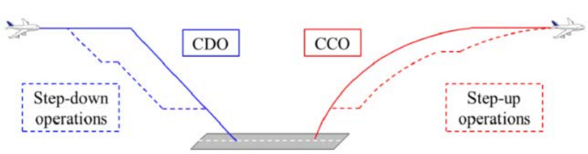
- Two "solar-at-gate" projects, which consist of a solar farm and airport gate electric equipment, to power aircraft with solar energy during ground operations at the international airports of Douala, Cameroon, and Mombasa, Kenya. The combination of electricity generated by the solar facility and the use of gate electrification equipment eliminates the CO_2 emissions while the aircraft is parked at the gate running the pre-departure procedures before departing for the next flight. The installed capacity of these projects is of 1,25MWp and 500kWp respectively, and they will eliminate over 4,000 tonnes of CO_2 per year and will serve more than 7,500 flights per year.

FIGURE 2: The Aviation Environmental System - AES

FIGURE 3: Solar PV system at Moi International Airport. Mombasa, Kenya

- Design and implementation of Continuous Climb Operations (CCO) and Continuous Descent Operations (CDO) at the international airports of Ouagadougou, Burkina Faso and Libreville, Gabon. With these new procedures, aircraft can operate without altitude restrictions during departure or arrival phase, and thus optimize their flight profile. As a result, there is less noise exposure and reductions in fuel burn and greenhouse gas emissions.

FIGURE 4: Continuous Climb and Descent Operations



- Five feasibility studies on the use of renewable energy and sustainable aviation fuels in Burkina Faso, Dominican Republic, Kenya and Trinidad and Tobago, which provide these governments with policy advice to unveil new opportunities through innovation for a sustainable aviation sector.

In addition to these four pilot mitigation measures and five feasibility studies executed directly with project funding, the beneficiary States implemented 90 mitigation measures within the project timeframe, which had been included in their action plans developed under the first project objective. The environmental benefits of the implementation of all these mitigation measures have been quantified in a total of **107,849 tCO_2** emissions reduction per year.

The implementation of the ICAO-EU project was assessed in 2016 and 2017 by a consortium of experts, contracted by the European Union, through independent Results

Oriented Monitoring (ROM) reviews. Four criteria were examined during the ROM reviews (relevance, efficiency, effectiveness, and sustainability) and they confirmed that the project design was logical and well sequenced, that the activities had been carried out as planned and that the project implementation was contributing to the achievement of the specific objectives and expected results, in some cases exceeding the targets. The project was assessed as "Good/Very good" in the four considered criteria.

With the support provided by the ICAO-EU project, ICAO has succeeded in transforming the organizational culture towards environmental protection in aviation in the beneficiary States. An issue that was not regarded as a priority before has now become more relevant for these States. The establishment of Environmental Units with dedicated staff in the Civil Aviation Authorities along with the voluntary decision of seven selected States of the project to join the Carbon Offsetting Reduction Scheme for International Aviation (CORSIA) from its outset is a testimony of the increased awareness and political will for climate action. These engagements can be attributed to the success of the ICAO-EU project and will support the sustainability of the results in the long term.

Capacity Building and Assistance on Environment will continue to be required for the transformation of policy into concrete actions at the national level. Many States have officially communicated their interest to participate in similar assistance initiatives and replicate the positive results of the ICAO-EU project. The availability of further funding will allow ICAO to extend the benefits of this successful project to other Member States so that "No Country is Left Behind".

ICAO-UNDP-GEF Capacity Building and Assistance Project

By ICAO Secretariat

In 2014, the International Civil Aviation Organization (ICAO) established a partnership with the United Nations Development Program (UNDP) to support Member States' requests for assistance in reducing CO_2 emissions from international aviation. Financing for the partnership came from the Global Environment Facility (GEF). This partnership resulted in an assistance project, called *Transforming the Global Aviation Sector: Emissions Reduction from International Aviation*, which aligns with the ICAO State Action Plan initiative and supports States' efforts to increase their capacity to advance the implementation of emission reduction measures. Multiple activities of the project have focused on capacity building to implement emission mitigating technical and operational measures, particularly supporting the needs of developing States and Small Island Developing States (SIDS).

The project had four primary objectives:

I. To develop guidance documents to facilitate approaches to reduce aviation emissions in developing States and SIDS
II. To set up a Low-Carbon Knowledge Sharing Platform
III. To devise an analytical tool for States' use in comparing the cost and effectiveness of emission mitigation initiatives
IV. To demonstrate an easily replicable, low emission installation by way of a pilot project, which serves as an example for developing States and SIDS

DEVELOPING GUIDANCE DOCUMENTS TO FACILITATE APPROACHES TO REDUCE AVIATION EMISSIONS IN DEVELOPING STATES AND SIDS

A number of developing States and SIDS have expressed interest in committing to reducing the environmental impact of international aviation but only have limited human and financial resources to do so. Therefore, ICAO developed four guidance documents that support State's ambition to implement policies and measures that will support their emission reduction plans. While each of these documents focus on supporting developing States and SIDS, the information contained therein can provide support to any ICAO Member State. All of these documents are free to download from the ICAO-UNDP-GEF Project website[1].

Regulatory and Organizational Framework to Address Aviation Emissions

- This guidance document provides details on why it is important to reduce international aviation emissions, the policy options available for doing so, why regulatory and organizational frameworks may be necessary, and the steps States can take to implement the necessary changes. Building upon the experience of several States, concrete actions are presented to create synergies between environmental policies. In addition, the guidance document illustrates how the State can structure its civil aviation authority in order to integrate environmental policies in the most cost-effective way and ensure that the implementation of priority actions is not compromised.

1 https://www.icao.int/environmental-protection/Pages/ICAO_UNDP.aspx

FIGURE 1: ICAO-UNDP-GEF Feasibility Studies

Financing Aviation Emissions Reductions

- This guidance document provides ICAO Member States with an overview of project financing for low carbon technologies, the role of public and private organizations in providing financing, and a list of financing programmes and policies to help them fund their mitigation measures. While recognizing that each State has different challenges and opportunities, this document provides insight into public climate financing programmes and how they may be accessed to provide long-term sustainable growth in the international aviation sector.

Renewable Energy for Aviation

- While ICAO's focus is on international aviation CO_2 reduction activities, developing airport renewable energy projects can also minimize CO_2 from many energy-consuming activities at airports beyond those that relate to international civil aviation. Therefore, this guidance document aims to inform ICAO Member States on how renewable energy can be deployed to reduce CO_2 emissions from international aviation activities at and around airports. The document provides a greater understanding of energy usage in relation to aviation activities, including electricity, heating and passenger mobility. It also explores the close linkage between climate change and energy policies, and emphasizes the necessity to create synergies between both policies, so that their impacts are maximized.

Sustainable Aviation Fuels Guide

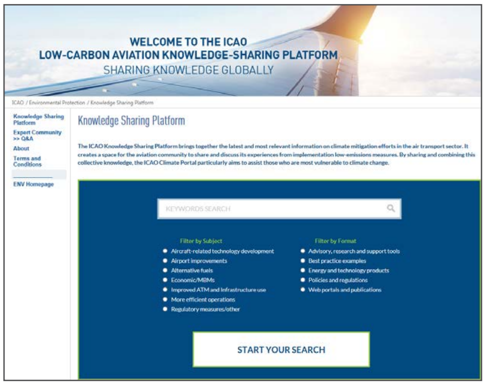
- This document provides a step-by-step guide for each State or international aviation stakeholder that may be interested in producing, commercializing and deploying sustainable aviation fuels (SAF), supported by practical case studies. The document also provides practical guidance on the national conditions that can support the development of a SAF market, while highlighting that "one size does not fit all". It also details the technical characteristics for the production of SAF, introduces schemes for sustainability certification, and highlights that thorough feasibility studies are a pre-requisite to the further consideration of a SAF supply chain.

SETTING UP A LOW-CARBON KNOWLEDGE SHARING PLATFORM

Amongst the many products and guidance materials that ICAO has developed to support States' plans for reducing their carbon emissions is the ICAO Knowledge Sharing Platform. The ICAO Knowledge Sharing Platform[2] brings together the latest and most relevant information on climate mitigation efforts, as well as other environmental issues, in the air transport industry. It can be used to build-up a State's Action Plan or identify a low carbon emission strategy for an individual airport. By sharing and combining this collective knowledge, the ICAO Knowledge Sharing Platform aims to assist ICAO member States and aviation stakeholders reducing their environmental impact and enhancing sustainability

2 https://www.icao.int/environmental-protection/knowledge-sharing/Pages/default.aspx

FIGURE 2: ICAO-UNDP-GEF Knowledge Sharing Platform Preview



The information used to populate the database was drawn from a variety of internal ICAO sources, as well publicly available third party sources. The platform includes more than 1,000 examples of low emission aviation measures from different States across all ICAO regions, such as projects, policies, guidance documents, tools, and outreach initiatives. From the list of search results, individual initiatives can be selected to learn more about that measure and whether it would apply to a State's or stakeholder's circumstances.

DEVISING AN ANALYTICAL TOOL FOR STATES' USE IN COMPARING THE COST AND EFFECTIVENESS OF EMISSION MITIGATION INITIATIVES

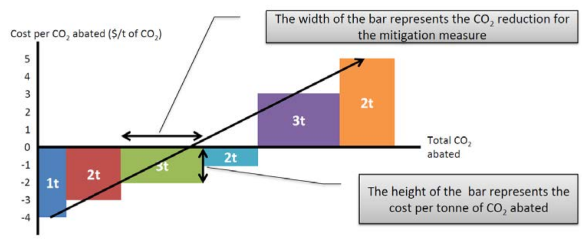
Numerous measures are available to States and their aviation stakeholders seeking to reduce CO_2 emissions from international aviation, but limited financial and technical resources represent a challenge for the implementation of these measures, and as such prioritizing is a necessity. In this context, the ICAO-UNDP-GEF project enabled the development of a tool to support States and their stakeholders in their discussions on the prioritization of the implementation of CO_2 mitigation measures for international aviation.

This tool is based on the concept of the Marginal Abatement Cost (MAC) curve. MAC curves illustrate the relative CO_2 reductions amongst possible mitigation measures on a comparative cost basis. They provide a simple but quantitative way to compare the costs and amount of emission reductions for numerous projects.

Marginal Abatement Costs

Any emissions mitigation project has a limit on the maximum possible CO_2 emissions reductions. Similarly, each proposed measure requires a specific investment to achieve those reductions. Marginal Abatement Cost curves, also called MAC curves, are a way to compare projects on a common basis. By evaluating projects in terms of the cost to reduce one ton of emissions, analysts can readily compare various projects. MAC curves plotted according to cost/tonne (shown as $/tonne) of CO_2 reduced compare multiple project costs while highlighting the total potential emissions reductions.

FIGURE 3: How to Read a MAC Curve



ICAO analyzed emissions mitigation measures, using exert knowledge and the information included in the State Action Plans submitted by its Member States. Using these data, ICAO developed global MAC curves, which can be used to simplify the process of calculating the emission reduction costs for specific projects and so putting the amount of emission reductions in priority order.

MAC Curve Tool

The MAC Curve Tool allows States to conduct a dedicated and tailor-made cost-benefit analysis of the most popular mitigation measures included in the ICAO basket of measures to reduce CO_2 emissions from international aviation. It is simple to use and requires a limited amount of information from the user, adjusting to the specific circumstances of States.

The results of the analysis performed by the tool will guide Civil Aviation Authorities and the national stakeholder teams who developed the State Action Plan, as they

FIGURE 4: ICAO-UNDP-GEF Solar Panel Pilot Project Concept

select and prioritize mitigation measures to be included in the plan. The tool provides a brief overview of potential emission reductions for a given scenario, and since the tool allows the tailoring of MAC curves to the individual reality of States, the implementation of measures can be prioritised in light of a State's particular circumstances.

The ICAO MAC Curve tool is available for State Action Plan Focal Points on the dedicated ICAO Portal Action Plan for Emissions Reduction page[3].

DEMONSTRATING AN EASILY REPLICABLE, LOW EMISSION INSTALLATION BY WAY OF A PILOT PROJECT, WHICH SERVES AS AN EXAMPLE FOR DEVELOPING STATES AND SIDS

One of the main deliverables under the ICAO-UNDP-GEF project was a small-scale project that could be easily replicated, and which would illustrate both the use of clean energy and the associated CO_2 reductions for international aviation operations. After the assessment of a few potential mitigation measures were assessed in different States, the decision was made to implement a solar-at-gate pilot project in Jamaica. While focusing the pilot project on the reality of Small Island Developing States (SIDS), this climate change mitigation action also embeds a climate change adaptation measure, as it was designed to withstand Category 5 weather events.

ICAO implemented this pilot project at two Jamaican airports to demonstrate how SIDS could use renewable energy at an airport to reduce CO_2 emissions from international aircraft operations. Aircraft conventionally use of on-board auxiliary power units (APU) and ground power units (GPU) to provide electricity and cabin climate control while an aircraft is parked at the gate. Gate electrification equipment, comprised of a pre-conditioned air (PCA) unit and a 400 Hz ground power frequency converter, was installed at airport gates used for international flights at Norman Manley International Airport in Kingston and Sangster International Airport in Montego Bay.

A photovoltaic solar power facility was installed at Normal Manley Airport, sized to supply the new electricity demand to operate the gate electrification equipment. The solar power facility planned for at Sangster Airport will be provided by a private supplier to be identified by the airport, thus illustrating the possibility to combine

3 http://portallogin.icao.int/

public and private financing sources. The combination of electricity generated by photovoltaic cells and electric gate equipment used in lieu of fuel-fired equipment completely eliminated the carbon and local air quality emissions from previous operations. The project resulted in 176,000 kg CO_2 emissions avoided per year and 4,400 tonnes of CO_2 over the projects life cycle. To support the public education mission of the project, a computer display showing real-time electricity generation from the solar project and the practical emission reduction benefits presented in cars removed or trees planted is included in the airport terminal.

This small-scale demonstration project now serves as a model for other airports to follow and replicate as an emission mitigation strategy.

CONCLUSIONS

ICAO met each of the ICAO-UNDP-GEF project's four primary objectives, and learned many lessons along the way. In line with ICAO's "No Country Left Behind" initiatives, the tools, guidance and project examples developed through the ICAO-UNDP-GEF Project can provide emissions reductions benefits to all ICAO Member States, particularly developing States and SIDS. All ICAO Member States are invited to explore the outcomes and deliverables of this project, available on the ICAO-UNDP-GEF Project webpage[1]. ICAO Member States are also encouraged to inform ICAO of additional assistance needs concerning CO_2 emissions reductions. Based on the success of this project, ICAO hopes to continue carrying out various capacity building and assistance projects in support of States' efforts to reduce CO_2 emissions reductions from international civil aviation.

ICAO Tools to Support the State Action Plan Process

By ICAO Secretariat

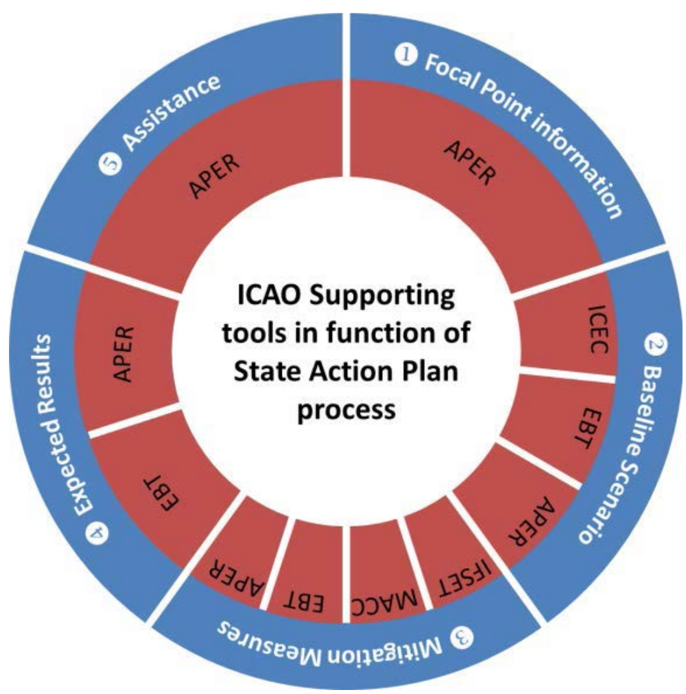
INTRODUCTION

In 2010, the 37th Session of the ICAO Assembly agreed to Assembly Resolution A37-19, which encouraged States to submit their action plans outlining their respective policies and actions, and annual reporting on international aviation CO_2 emissions to ICAO. Over the past nine years, ICAO Member States have actively engaged in the State Action Plan initiative, making it one of the most successful ICAO capacity-building programmes, and a cornerstone of the Organization's environmental Programme. Recognizing the need for States to continue submit new and updated Action Plans to ICAO, Member States have reaffirmed the commitment to the State Action Plan initiative in each subsequent Assembly, through Assembly resolutions A38-18 and A39-2. State Action Plans provide an opportunity for States to showcase specific policies and measures that have been implemented to mitigate CO_2 emissions from international civil aviation activities, and are intended to be individualized and reflective of the specific national circumstances of each ICAO Member State. In order for ICAO to continue to monitor progress achieved by States toward the sector's global aspirational goals of 2 per cent annual fuel efficiency improvement and carbon neutral growth from 2020, States are encouraged to submit an updated State Action plan every three years in order to assess the benefits resulting from the measures implemented.

A State Action Plan should consist of the following five elements in order to be considered complete: **1) Focal Point information**; **2) Baseline Scenario**; **3) list of mitigation measures**; **4) Expected Results**; and **5) Assistance needs** (if required).

Since the launch of the State Action Plan initiative in 2010, ICAO has embarked on a comprehensive and robust

FIGURE 1: ICAO Tools and State Action Plan development process



capacity-building and assistance strategy to support ICAO Member States to develop their Action Plans and to implement measures to reduce emissions from aviation activities. As part of this strategy and to facilitate States' actions, ICAO has published guidance material, namely, Doc 9988, *Guidance on the Development of States' Action Plan on CO_2 Emissions Reduction Activities*, which describes the process for developing or updating an Action Plan, and a series of tools to support the preparation of State Action Plans. Figure 1 summarizes how each tool can be used in the process to develop a State Action Plan.

The following paragraphs describe how each ICAO tool support which part(s) of the State Action Plan development process.

TOOLS

Action Plan on Emissions Reduction (APER) website – To facilitate the State Action Plan development process, all State Action Plan focal points have been granted access to the APER website, a secured, web-based platform that can be used to interact with ICAO, upload administrative and quantified information related to State Action Plans, and consult guidance material, such as Doc 9988, and tools, including the Environmental Benefit Tool (EBT).

ICAO Carbon Emissions Calculator (ICEC) – The ICAO Carbon Emissions Calculator[1] was developed to avoid the proliferation of different tools for calculating the carbon footprint of air travel, which provided inconsistent results, and lacked a clear and transparent methodology that would be necessary to facilitate understanding of the calculations underpinning the tools and the results. Thus, individuals or organizations planning to offset their air travel emissions had to do so on the basis of inconsistent and often inaccurate calculations.

In this context, ICAO embarked on developing a tool that would be user friendly, unbiased and compatible for use with offset programmes. The tool would rely on the best publicly available data and be fully documented, meaning that all calculations would be transparent. The methodology for the calculator was developed through the ICAO Committee on Aviation Environmental Protection (CAEP).

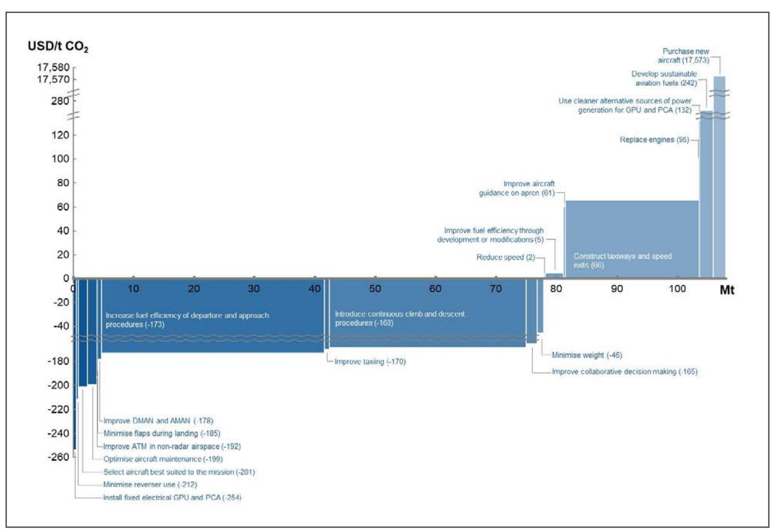
The methodology team in CAEP included experts from the ICAO Secretariat, ICAO Member States, universities, non-governmental Organizations (NGOs), the airlines, and the manufacturers. As a result, the methodology developed is internationally recognized and accepted. Since 2009, the ICAO Carbon Emissions Calculator has been used by the entire UN system for computing their annual air travel emissions inventories in support of the UN Climate Neutral UN initiative. Since 2008, the general public has also had access to the ICAO Carbon Emissions Calculator and in fact it becomes the most popular ICAO tool being daily consulted by the traveling public. The ICAO Carbon Emissions Calculator is available free of charge on the ICAO website.

In order to support States in the preparation of their Action Plans, ICAO has developed a standalone application allowing State Action Plan Focal Points to generate a State-level emissions inventory by simply importing batches of flights containing the airport pair, the number of flights in the year, and the aircraft type. This application uses the same methodology than the one underpinning the ICAO Carbon Emissions Calculator available on the ICAO public website.

As a next step, ICAO is working on the development of a new version of the calculator by offering the possibility of estimating carbon footprint not only for passengers by also for the air freight. This new version of the calculator will also be available on iOS and android.

Marginal Abatement Cost Curve – In 2014, the International Civil Aviation Organization (ICAO) established a partnership with the United Nations Development Program (UNDP) to support Member States' requests for assistance for reducing CO_2 emissions from international aviation. Financing for the partnership came from the Global Environment Facility (GEF). This project

FIGURE 2: Global Margin Abatement Cost Curve for the year 2020



1 https://www.icao.int/ENVIRONMENTAL-PROTECTION/CarbonOffset/Pages/default.aspx

had multiple objectives (for more information, see Chapter 9) and one of them was the development of Marginal Abatement Cost (MAC) Curves for the years 2020, 2030, 2040 and 2050 based on a total of twenty mitigation measures selected from across all elements of the ICAO Basket of Measures. For more information on how to read and use a MAC Curve, see Chapter 9. In addition to developing the four global MAC Curves, ICAO has developed an interactive interface embedded into the APER website, where State Action Plan focal points, together with their relevant stakeholders, can customize multiple MAC Curves at the national level in order to obtain more precise and reliable information for assessing the selection and prioritization of mitigation measures.

ICAO Fuel Savings Estimation Tool (IFSET) – Operational improvements offer an opportunity to reduce fuel consumption and emissions by improving Air Traffic Management (ATM) system efficiency. In support of the performance-based approach of the ICAO Global Air Navigation Plan (GANP), States needed a means to calculate the fuel savings associated with the proposed operational changes.

One of the important elements of the ICAO Basket of Measures for reducing emissions and improving efficiency are operational improvements. Some examples of the specific actions that could be taken under this measure are the implementation of new arrival or departure procedures, reduced separation minima, or reduced taxi time. Some States found it challenging to model such improvements, so in 2006, ICAO provided a series of Rules of Thumb that could be used to estimate the magnitude of the fuel savings associated with such changes. The Rules of Thumb were expressed in terms of fuel burn per minute or mile, and provided a very rough approximation of the benefits.

In 2012, ICAO expanded beyond the Rules of Thumb to develop an easy-to-use tool, known as the ICAO Fuel Savings Estimation Tool (IFSET)[2] to help States refine their estimates. IFSET allows those without modelling and/or measurement capabilities to estimate fuel savings from operational improvements. It is consistent with the ICAO CAEP-approved greenhouse gas models and the ICAO GANP. This tool includes an easy-to-use interface, requires minimal data, and is an improvement over the Rules of Thumb.

Using IFSET, users can estimate the effects of shortening/eliminating level segments on departure and approach, the effects of shorter routes (either in time or distance), the effects of cruising at different altitudes, and the effects of reduced taxi times as part of a process to quantify CO_2 reduction benefit from operational measures selected in the State Action Plan.

Environmental Benefit Tool (EBT) – The EBT could be considered as the transformation of Doc 9988 into an interactive, structured and easy-to-use tool. As mentioned earlier, a State Action Plan consists of five key elements. The EBT allows, with a minimum of input from the State Action Plan Focal Point, to generate a baseline scenario in terms of fuel burn and CO_2 emissions up to 2050, estimate the fuel and CO_2 savings from the implementation of the mitigations measures and finally, evaluate the expected results.

The generation of the baseline scenario is initially based on historical data (i.e. international fuel burn and international revenue tonne kilometres (RTK) from previous years) provided by the user, from which past annual fuel efficiencies are derived. Fuel efficiency is then forecasted by using different regression functions. On the basis of statistical information computed by the tool, the best trend is automatically selected by the EBT for the generation of the baseline scenario.

Once the baseline scenario is completed, EBT users can (again with a limited number of inputs) assess the benefit either in terms of fuel burn or CO_2 emissions from the implementation of the mitigation measures selected. All the Rules of Thumb available in Doc 9988 are embedded in the EBT, therefore minimizing errors from calculations, as all measures are automatically computed by combining a user's input and the Rules of Thumb.

At the end of the process, expected results are generated by subtracting CO_2 savings from the baseline scenario.

2 https://applications.icao.int/ifset

The Environmental Benefit Tool (EBT) is a great tool for State Action Plan Focal Points with no or limited statistical/mathematical background. The tool allows generating a robust and complete State Action Plan with a minimum of information provided by the users.

Other tools – Two other tools have to be mentioned for a complete overview of the environmental tools developed by ICAO. The first tool is the ICAO CORSIA CO_2 Estimation and Reporting Tool (CERT) used as a simplified compliance procedure in the context of CORSIA. For more information on this tool, see Chapter 6.

The second tool is the Aviation Environmental System (AES) developed under the ICAO-European Union Project. This tool helps States involved in this project to collect and consolidate CO_2 emissions from international aviation in order to generate insights. See Chapter 9 for more information on this system.

NEXT STEPS

ICAO is always striving to develop and enhance its tools in order to improve users' experience. In this regard, ICAO has started improving the connectivity between tools and platforms by implementing exporting/importing data functionalities within each tool. For example, a State Action Plan Focal Point will easily generate a historical fuel burn dataset by using the ICAO Carbon Emissions Calculator and then will export the dataset as a CSV file, which will be imported into the EBT. The same approach is being applied to the MAC Curve tool, whereby users may import results into the EBT where it will automatically populate the information as fuel savings. Finally, users will soon be able to upload the baseline scenario, quantified mitigation measures, and expected results into the APER website, with a single click.

Implementation of CCO/CDO procedures at the Libreville Léon Mba International Airport

By Larissa Pamela Dianga Nzengue (Gabon)

PROJECT PURPOSE

Since 2015, Gabon has benefited from the Joint Assistance Project of the International Civil Aviation Organization (ICAO) and the European Union (EU) "Capacity Building for CO_2 Mitigation from International Aviation." Within this context, Gabon submitted to ICAO in April 2016 its action plan for reducing CO_2 emissions from international aviation. The plan contains fifteen mitigation measures from the Basket of Measures proposed by ICAO, with the majority of the measures related to improvements in air traffic management.

It is in the framework of objective 3 of the ICAO/EU Project that in September 2016, Gabon, together with Burkina Faso, was one of the States selected to benefit from technical and financial support for the implementation of a pilot project to establish Continuous Climb Operations (CCO) and Continuous Descent Operations (CDO) at the Libreville Léon Mba International Airport. These correspond to the M3 and M4 measures from the National Action Plan for the reduction of CO_2 emissions.

In order to implement this pilot project, ICAO turned to the Agency for Air Navigation Safety in Africa and Madagascar (ASECNA), an air navigation service provider, given its competence and expertise in the field of air navigation in several African States and in Gabon and for possessing a flight procedure design service. Thus, a Memorandum of Understanding was signed between ICAO and ASECNA and a business plan was agreed upon for the deployment of these CCO/CDO procedures.

This pilot project is organized around three main phases: the initial phase comprising a design part, the design phase and the validation, approval, publication and evaluation phase.

PROJECT'S ENVIRONMENTAL FOOTPRINT AND COST/BENEFIT ADVANTAGE

The ICAO Environmental Benefit Tool (EBT) was used to estimate the amount of fuel consumed from the data provided in 2014 by four Gabonese airlines operating international flights.

The following table shows the results obtained for CCO and CDO operations:

	Total number of operations taken into account	Fuel savings (tonnes)	Emissions reduction* (tCO2/year)
CDO	2005	120.30	380.14
CCO	2005	200.50	633.58
Total	4010	320.80	1013.72

*1 Kg of fuel generating approximately 3.16 kg of CO2

The implementation of CCO/CDO represents environmental benefits equivalent to a reduction of approximately 1013.72 tonnes of CO_2 emissions in the atmosphere per year from international traffic alone handled by these national airlines.

Considering that CCO/CDO will be deployed for all flights to and from Libreville, it is highly likely that the benefits in terms of reducing CO_2 emissions will increase.

IMAGE 1: Involvement of military personnel in the project

IMAGE 2: Communication between a pilot and an air traffic controller

RELATED QUANTITATIVE/ QUALITATIVE BENEFITS

The use of CCO/CDO helps improve safety, flight regularity and airspace capacity, while reducing perceived ground noise, fuel consumption, emissions and the frequency of controller-pilot communications. It also provides better organization of air traffic flows which leads to a reduction in the workload of controllers and pilots.

Aside from the expected benefits mentioned above, this project's implementation has made it possible:

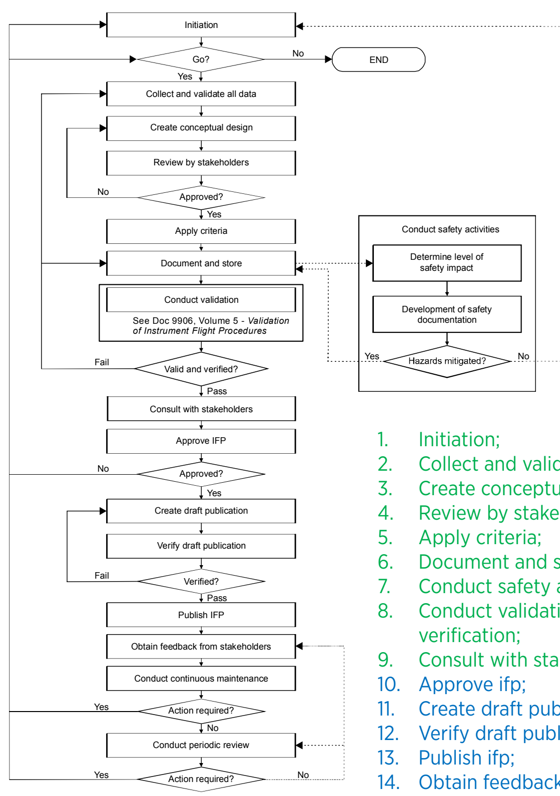
- to strengthen cooperation between civil aviation and military aviation;
- to reinforce cohesion between the appropriate civil aviation authority and the aviation industry;
- to increase communications between controllers and pilots;
- to find significant support for the project from stakeholders, as well as for the events organized by the National Civil Aviation Authority (ANAC) on environmental protection;
- to lead to substantial progress in the implementation of the M10 mitigation measure aimed at implementing flexible procedures for a common use of airspace by civil aviation and military aviation.

PROJECT IMPLEMENTATION

Activities related to the implementation of these operations were carried out in accordance with the provisions of ICAO Doc 9906 — *Quality Assurance Manual for Flight Procedure Design* and were included in the Gabonese Aviation Regulations RAG 7.2.2, Chapter 2 of which defines the reference framework for the process of establishing instrument flight procedures in the context of quality assurance.

The flow diagram below shows the 16 stages of the process. Project implementation is currently at Stage 9.

FIGURE 1: Instrument flight procedure process flow diagram



1. Initiation;
2. Collect and validate all data;
3. Create conceptual design;
4. Review by stakeholders;
5. Apply criteria;
6. Document and store;
7. Conduct safety activities;
8. Conduct validation and criteria verification;
9. Consult with stakeholders;
10. Approve ifp;
11. Create draft publication;
12. Verify draft publication;
13. Publish ifp;
14. Obtain feedback from stakeholders;
15. Conduct continuous maintenance;
16. Conduct periodic review.

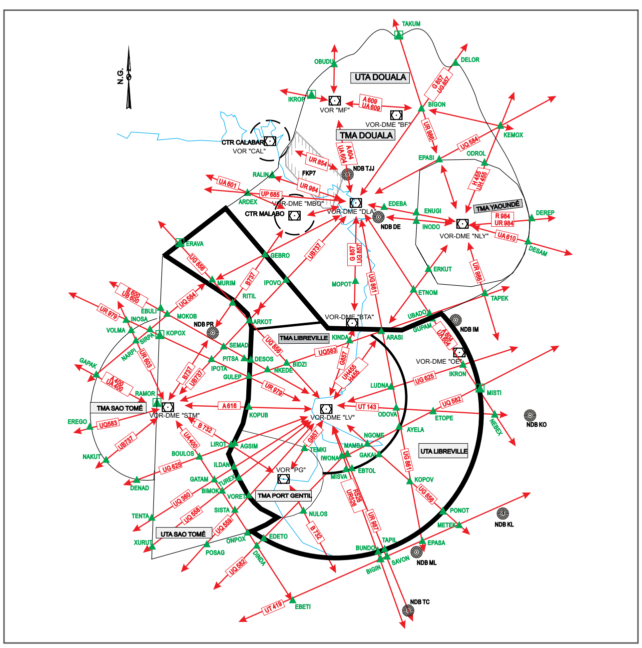
Stage 1 Initiation

The choice of retaining CCO/CDO operations as CO_2 emission mitigation measures and the decision to retain Gabon as the beneficiary State to receive funding are the main components of the process start-up phase.

Following the various administrative formalities, the project commenced with the joint ASECNA/ICAO exploratory mission in Libreville in October 2017, with the support of ANAC. This mission made it possible to meet the main stakeholders: the ministry responsible for civil aviation, the military authorities, the Libreville airport management, the airlines (domestic and foreign), and the local ASECNA authorities.

Information sessions were organized with each of the stakeholders, which helped to identify the constraints related to project implementation, including the existence of two special status areas. This stage came to a close with terms of reference being defined for the establishment of a national team to ensure project support and monitoring.

Libreville airspace organization (CTR, TMA, UTA) with neighbouring spaces



Stage 2 Collect and validate all data

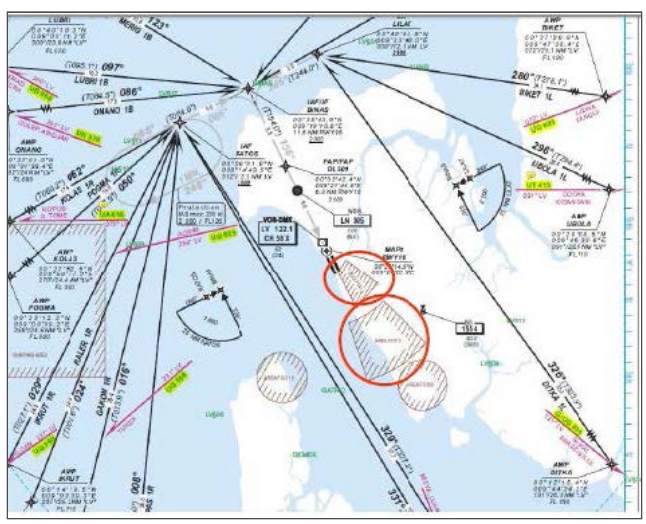
Since ASECNA had been designated by Gabon to manage its airspace and to provide air navigation services, it already possessed much of the data required to design the procedures: field data, obstacle data, aerodrome data, aeronautical data, navigation aid data, and the important issues that exist for local navigation. Additional data was collected from the airlines that fly to the Libreville airport, including data on aircraft types and their fuel consumption.

Stage 3 Create conceptual design

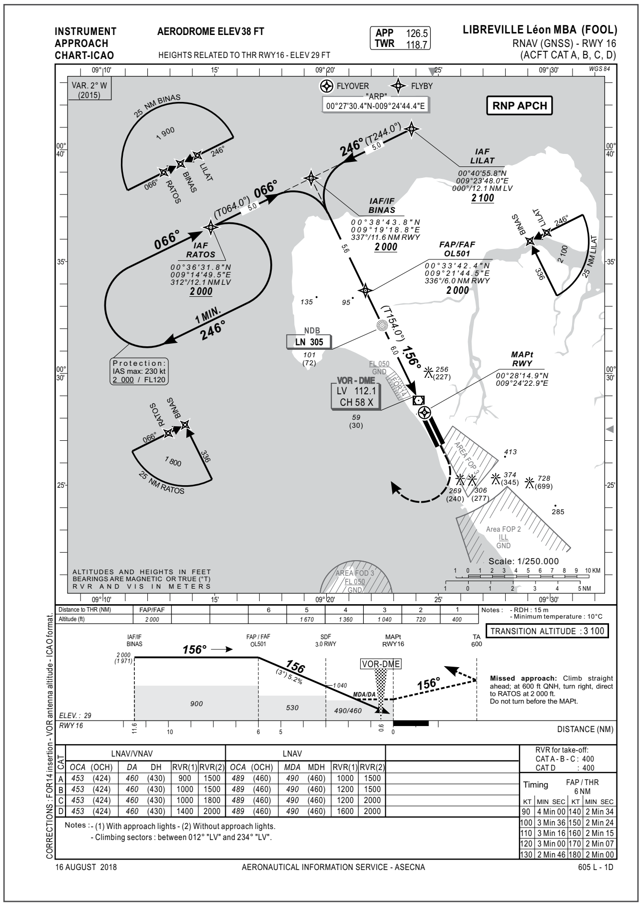
Following the exploratory mission, a project launch seminar was held in Libreville from 23 to 27 October 2017. The intent of that seminar was to train approximately 50 participants from civil and military aviation on notions regarding performance-based navigation (PBN), on CCO/CDO concepts, on quality assurance in the flight procedure design process, on the safety review procedure, and on the ASECNA environmental impact assessment approach.

The seminar also enabled the conceptual design to be developed according to ICAO Doc 8168. Baseline data used to create the conceptual design were:

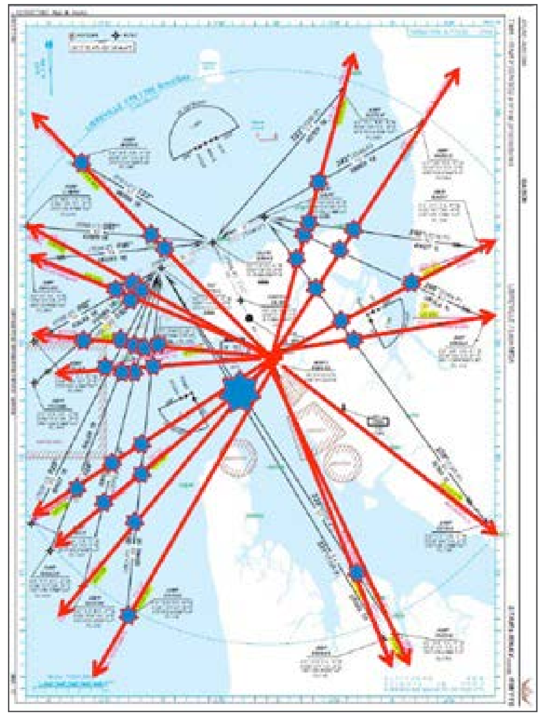
The existence of two (2) special status areas, which constituted the major risk that was taken into account for the implementation of a CCO optimized departure path.



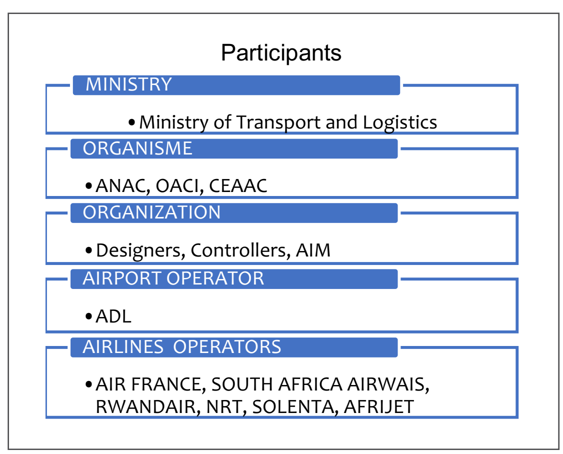
RNAV GNSS procedures available on runway 16 (RNAV GNSS RWY 16°)



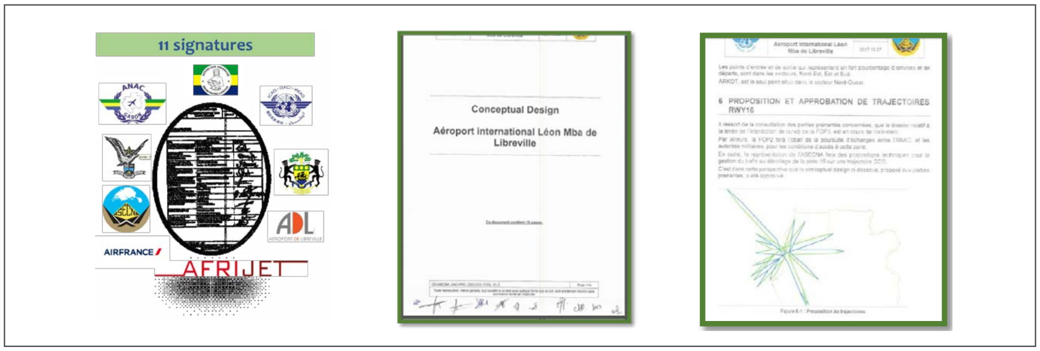
The existence of STAR RNAV RW 16, of several ATS routes for departures and arrival-departure interactions



CCO/CDO project launch seminar



Implementation of CCO/CDO procedures at the Libreville Léon Mba International Airport



Stage 4 Review by stakeholders

The draft conceptual design was presented to all the stakeholders and was the subject of discussions, which led to its formal approval by the entities concerned. Below is a reproduction of the approved conceptual design.

Following the seminar, the Committee responsible for CCO/CDO project implementation follow-up, composed of 21 members, was established with the following mandate:

- ensuring the coordination of actions and facilitating project implementation at the national level;
- identifying the challenges associated with project implementation and making recommendations;
- ensuring technical follow-up;
- reviewing project evaluation and progress.

The Committee met four times since the launch of the project and continues to ensure project follow-up activities.

Stage 5 Apply criteria

Armed with the conceptual design, the competent ASECNA authority was able to carry out the design activity based on the criteria defined for designing the RAG 7.22 procedures – *Procedures for air navigation services - technical operation of aircraft* (PANS -OPS) and relevant ICAO documents.

Stage 6 Document and store

Documents supporting the procedure design process such as spreadsheets, drawings and other relevant files are held by ASECNA and ANAC during the entire life cycle of CCO/CDO procedures.

Stage 7 Conduct safety activities

To meet the needs of safety-related activities, a workshop was organized by ICAO/ASECNA on the safety study and environmental impact assessment from 26 to 30 March 2018 in Libreville.

Safety and Environmental Impact Assessment Workshop

Thirty-one participants took part in this workshop, including one from the centre adjacent to Douala.

In accordance with the ASECNA safety impact procedure, the brainstorming activities helped to identify eight hazards related to the implementation and operation of the procedures by controllers and pilots in an environment where the air traffic control service is rendered without radar surveillance capability. The participants identified six hazards related to air traffic management (ATM) and two related to the means of communication (COM).

The work also enabled the identification of risk mitigation methods (MM) for hazards that included risks deemed unacceptable or tolerable. These recommended MMs led to the development of safety requirements for procedures and human factors.

Following this workshop, the safety file developed and approved by the participants was submitted to ANAC.

Stage 8 Conduct validation and criteria verification

Validation and criteria verification began with controller training. This training entitled "capacity-building on CCO/CDO flight operation procedures" took place in Libreville from 18 June to 21 July 2018. The training was conducted in two stages: theoretical training and practical simulator-based training.

All the air traffic controllers, some civilian and military pilots, as well as the staff from the authority responsible for the approval of the said procedures benefited from the training.

To meet the needs related to simulator-based testing, CCO/CDO procedures were tested on a simulator provided by the Air France airline thanks to a partnership agreement between Air France and the ICAO-EU project.

Following this test, a meeting was held in Libreville between the Air France focal point in charge of testing and the project monitoring committee. This meeting provided an opportunity to discuss the progress of the project and the points to be improved for an optimal use of CCO/CDO operations.

Stage 9 Consult with stakeholders

The project is currently at this stage.

A first meeting between the Air France focal point and the CCO/CDO project monitoring committee helped to provide an opinion on the procedures. The report of this meeting containing the comments made was submitted to the ASECNA (designer) for consideration.

FUTURE DEVELOPMENT OF THE PROJECT (OVER 3 YEARS)

As the project is in its final phase, phase 3, specifically at the procedure approval stage, the next activities will include the publication and evaluation of the procedures. Consequently, testing could begin with the airlines that have been chosen, including Air France.

In the short term, we hope that the M10 measure will be effectively implemented and that the Memorandum of Understanding between ASECNA and the Air Force Chief of Staff (EMAA) will be adopted by the beginning of 2020.

In addition, one- to two-hour meetings will be organized on a regular basis between pilots and controllers to enable better ATM management.

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Solar-At-Gate Pilot Project – A Proven Energy-Saver

By Mazarin Mintsa (Aeroport du Cameroun)

INTRODUCTION

Cameroon is a country located in Central Africa. It is often described by many as "Africa in Miniature" due to its incredible geographical and human diversity as it exhibits all major climates and vegetation of the continent.

Cameroon has three international airports namely Douala, Yaoundé-Nsimalen, and Garoua. Douala is the main one, handling about 20,442 aircraft movements and 1,100,000 passengers per year. It is operated by Aéroports du Cameroun (ADC) S.A which is also the sole ground handler at the airport.

In 2016, ICAO selected Douala International Airport to implement a pilot project named "Solar-at-Gate", in which a solar photovoltaic (PV) plant would be connected to a gate electrification system comprising of an electric Pre-Conditioned Air (PCA) unit and a Ground Power Unit (GPU).

The pilot project was inaugurated by the Ministry of Transport, on 10 January 2019 with the aim of demonstrating the use of clean and renewable energy technology for the provision of ground support to international aircraft operations at the airport. The project is now a showcase that highlights concrete actions that may be replicated by other airports to contribute to ICAO's aspirational goals for CO_2 emission reduction from international civil aviation.

The newly built plant is the first Megawatt scale and first grid-connected installation of a solar PV system in Cameroon. The Solar-at-Gate project is the second of its kind in Africa after Mombasa Moï International Airport, Kenya.

BACKGROUND

In 2013, ICAO and EU launched a joint assistance project on capacity building for CO_2 mitigation from international civil aviation in 14 selected States --12 of them from the Africa region and two from the Caribbean region.

The Solar-at-Gate project, which was planned from 2014 to 2018, had the following three main objectives:

- Support the voluntary development and submission of State Action Plans on CO_2 emission reduction from international civil aviation in accordance with ICAO recommendations by improving the capacity of the national civil aviation authorities and other stakeholders.
- Set-up in each selected State, an Aviation Environmental System (AES) – information technology software and hardware that facilitate data collection and the monitoring of CO_2 emissions from international aviation at the State level.
- Identify **and evaluate priority** mitigation measures contained in selected State Action Plans, and implement the selected measures.

To achieve the first objective, in December 2015, Cameroon became one of the first selected States to submit its Action Plan for CO_2 mitigation to ICAO. That Action Plan was developed in accordance with ICAO doc 9988. It included an "**airport improvements**" category comprised of nine measures, among which were the construction of solar power plants at Douala and Yaoundé-Nsimalen international airports. The Action Plan also included a request for technical and financial assistance of these solar mitigation measures.

In response to Cameroon's strong commitment to this, and in-line with the third objective, in 2016 ICAO selected Douala International Airport as platform to implement the pilot "Solar-at-Gate" project.

DESCRIPTION OF THE PROJECT

The Solar-at-Gate project at Douala International Airport was a project entirely funded by the European Union for an amount of US$1.3 million with the objective to demonstrate the use of solar energy for the provision of ground power and the preconditioning of air for aircraft at the gate.

This solar-powered electrical equipment allows international flight aircraft to switch off their fuel-powered Auxiliary Power Unit (APU) when parked at the gate, thus reducing carbon dioxide (CO_2) emissions from international aviation activities.

Initially, the scope of the project was to:

- Build a ground-mounted solar PV array/farm of 500kWp supported by a battery storage system.
- Procure and install a Gate Electrification System comprising an electric Ground Power Unit (GPU) and an electric Pre-Conditioned Air (PCA).

Because ADC SA was committed to purchasing, installing, and commissioning the Gate Electrification System, ICAO and ADC SA agreed to increase the capacity of the initial photovoltaic array/farm from 0.5MWp to 1.25MWp, but with no battery storage system.

ICAO was therefore responsible for the implementation of a procurement process for the design, supply, installation, and commissioning of the solar PV plant. That 1.25MWp installation was composed of:

- Solar PV array/farm with 3840 polycrystalline PV modules of 325Wp laid across 1.4 hectares of land near the control tower.
- Twenty solar PV inverters of 60kW capacity.
- Medium Voltage Station with a transformer 400V/15kV.
- Solar PV monitoring and performance system.
- Two educational kiosks that provide real-time readings from the solar PV plant to airport users (i.e., active power, cumulated power, and savings in CO_2 emissions).

ICAO was also responsible for project management, and it recruited a solar expert to provide technical assistance. To ensure the durability of the project, training on solar was provided to ADC SA engineers and the contractor was required to provide preventive and corrective maintenance for two years. Because the solar PV plant produces less than the full energy requirements of the airport, the airport consumes 100% of the solar energy produced by the solar PV plant, and the national grid provides the balance.

The completed facility was commissioned by ICAO, Cameroon Civil Aviation Authority, and ADC SA on 13 February 2019.

FIGURE 1: Solar-at-Gate project installation at Douala International Airport, Cameroon

BENEFITS

Thanks to the solar PV plant, 25% of the energy demands of the airport are now satisfied by renewable energy.

Since the commissioning of the project, the solar PV plant has generated 351 MWh and saved more than 245 tons of CO_2 which is equivalent to planting 2,450 trees.

The solar PV plant has also saved about US$17,000 per month on the electricity bill.

In addition, the use of an electric GPU has reduced aviation fuel burn at the gate.

It is expected that by the end of the year, the solar-at-gate project will have saved a total of around 3800 tons of CO_2. It is estimated that about 2600 tons of that will be attributable to international civil aviation (assuming 10 flights per day using the GPU). This is equivalent to planting 38000 trees, thus demonstrating ADC SA's contribution to reductions in environmental degradation.

EVOLUTION OF PROJECT IN THE UPCOMING YEARS

Inspired by the success of this project, ADC SA has set a short term goal to procure additional equipment and expand the solar PV plant from 1.25MWp to 2MWp using the available remaining space on the site. This will involve procuring an additional electric GPU for the airport and commissioning a study into the feasibility of installation a battery storage system in order to significantly improve the availability of energy. Such a battery storage system will provide an alternative to fuel generators, thus reducing CO_2 emissions even more, and providing greater independence from rising fuel prices.

For future years, ADC SA is also considering replicating the solar-at-gate project at its two other international airports and also building solar PV plants at its four national airports: Maroua-Salak, Ngaoundéré, Bertoua,and Bamenda.

For Garoua International Airport, ADC SA has signed an agreement with a solar company for the construction and operation of a solar PV plant of 30 MWp covering 70 hectares of airport land to accommodate the power requirements of North Region of Cameroon. ADC SA will lease the land to the solar company and in return the solar company will build an additional solar PV plant of 500 kWp with a battery storage system to ADC. The construction work of this project is expected to begin by the end of 2019. Garoua International Airport was chosen for four main reasons:

- The project aims at resolving the huge energy deficit of the North Region of Cameroon;
- Garoua city and the North Region have one of the best solar irradiance in Cameroon;
- Garoua International Airport itself is very close to national grid High Transformer facilities;
- Garoua International Airport has enough space available.

CONCLUSION

Cameroon's ICAO-EU Solar-at-Gate project is an excellent practical example of CO_2 mitigation measures at work and one that airports worldwide can learn from. Through its participation in this project, Cameroon has taken an active role, under the auspices of ICAO, to reduce its CO_2 emissions as part of the international aviation industry's effort to reduce aviation emissions globally.

As a result of ADC SA's participation in this joint ICAO-EU Assistance Project for CO_2 mitigation, it is now ready to assist all airports in the region in the implementation of other solar-at gate projects as part of ICAO "Buddy Programme".

Dominican Republic Progress on Emissions Mitigation

By Juan José Veras, Manager, Sustainable Development, Civil Aviation Authority, Dominican Republic

INTRODUCTION

From the outset of organized civil aviation in the Dominican Republic, the stake holders understood the wide range of opportunities that result from interaction with the rest of the world. These opportunities are leveraged by international trade, which fuels the development of aviation, and in turn, allows it to contribute powerfully to the creation and preservation of friendship and understanding among the members of the international community. If abused, these same opportunities may constitute a threat to general safety, as expressed in the preamble to the Chicago Convention.

This vision shared by ICAO with the signatory States to the Chicago Convention in 1944, has been the engine that has driven the actions of Dominican Republic to work continuously with initiatives that will foster prosperous international aviation.

MITIGATION CAPACITY BUILDING

Aligned with this spirit of collaboration and with the intention of managing the impact of Dominican aviation on the environment, in 2014 the Dominican State decided to participate in the joint project of the International Civil Aviation Organization (ICAO) and the European Union (EU) on capacity building for mitigation of CO_2 emissions resulting from international aviation.

The overall objective of this project was to contribute to international, regional, and national efforts to address the increasing CO_2 emissions that result directly from international aviation operations. This resulted in ICAO supporting the Dominican Republic in the development of robust action plans which have allowed the management of aviation emissions through the implementation of capacity development activities designed to achieve lower carbon emissions from the air transport sector.

According to ICAO Doc 9988, States must identify a focal point responsible for the preparation of the action plan and coordination within the State and with all interested parties, such as: aviation and environmental authorities, airlines, airports, ANSPs, departments of statistics, fuel suppliers, etc.

The focal point and stakeholders must implement an aviation environmental management system to report historical and projected emissions to ICAO. *The writer of this article, Juan Jose Veras, was designated as the focal point for this critical task, by Dr. Alejandro Herrera Rodríguez, General Director of the Dominican Institute of Civil Aviation (IDAC).*

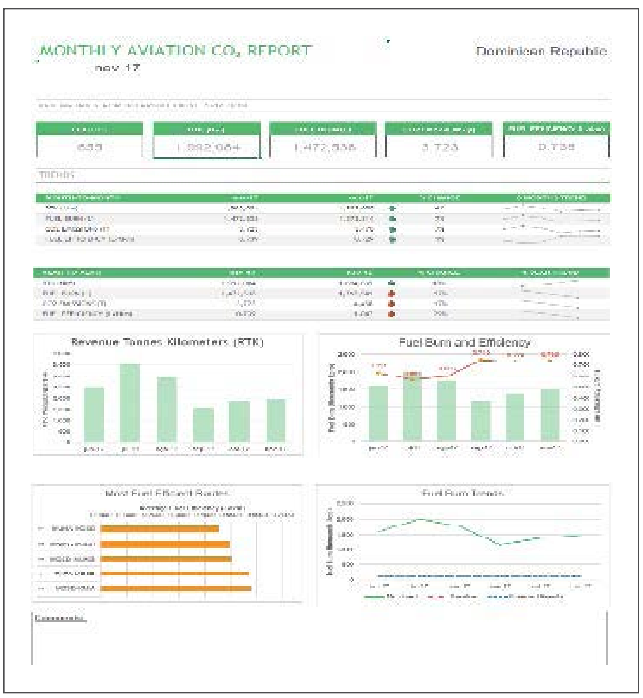
Within the actions identified in the regularly updated action plans of the Dominican State, the unconditional support of the Dominican Institute of Civil Aviation (IDAC) senior management and other State entities, such as the Civil Aviation Board (JAC), as well as the Airport Department (DA), has been the cornerstone in the sustained advancement of promoting an aeronautical system aimed at managing its impact on the environment.

The mitigation efforts have not only reached the State's entities, but have achieved a public-private partnership that has made it possible to maximize the benefits at monumental levels. The partnership includes, but is not limited to, Punta Cana Airport Group, Cibao International Airport and Aerdom-Vinci Airports.

The ICAO/EU project allowed the establishment of a CO_2 emissions monitoring system, through the Aviation Environmental System (AES) software, which facilitated reports for CO_2 emissions resulting from international aviation. This system allows import, export, and management of data from aeronautical operations.

FIGURE 1: Aviation Environmental System main page

FIGURE 2: Typical AES Report



ACTION PLAN ON CO_2 EMISSIONS REDUCTION

As a result of the implementation of its Action Plan to Reduce CO_2 (PARE-CO_2), it is expected that the Dominican State will reduce total flight-related aviation emissions by approximately 54,940 tons of CO_2 per year of the total emissions generated by all international aviation operations in the Dominican Republic. These emissions figures were calculated based on the projected reductions of fossil fuels burned, by the implementation of the ICAO basket of measures, such as:

- Use of alternative fuels,
- Minimizing APU use, minimizing weight and engine wash,
- Continuous Descend Operations (CDO), Continuous Climb Operation (CDO), PBN-STAR, etc.

In addition, it is expected that the implementation of the mitigation measures contained in the PARE-CO_2 will contribute to reduction of approximately 15,580 tons of CO_2 from the emissions generated in the broader aviation sector. These reductions will result from a number of initiatives, including: clean energy initiatives at the Cibao International Airport, Aerodom-Vinci, the institutional plans of photovoltaic energy, and the energetic efficiency programs in all airports, as well as in the IDAC facilities. The emissions reductions are supplemental benefits, supporting the promotion of greener operations for the aviation sector as a whole.

These results have been estimated based on the number of international operations and the projected air traffic trends. In recent years, the Dominican State has maintained steady aviation traffic activity growth rate overall, the net effect of the decrease of operations in some airlines combined with the start of operations of new airlines, and new routes in the short term.

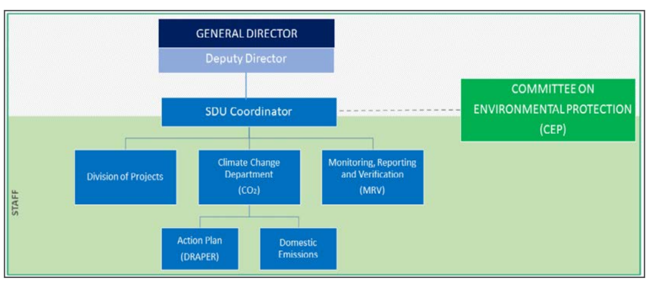
Estimates of expected CO_2 emissions reductions represent a measured scenario based on the number of operations and activities in 2017.

MOVING TOWARDS GREENER AVIATION

The future is promising for the use of clean energy sources in the aviation sector of the Dominican Republic., To ensure this, senior management of IDAC has established an organization structure dedicated to the management of sustainable development in international aviation. The Aviation Committee on Environmental Protection (CAEP) which holds regular meetings, in which critical decisions are made to enable consistent progress. This committee is chaired by the General Director of IDAC and members include the managers of related areas.

The joint ICAO/EU project on capacity building for mitigation of CO_2 resulting from international aviation involved 14 States, 12 from Africa and 2 from the Caribbean. , During that project, the Dominican State showed its leadership and support by making it possible to carry out three of the four seminars in the Caribbean.

FIGURE 3: Organizational Structure - Aviation Committee on Environmental Protection



One of the most important aspects of capacity-building activities has been the institutional strengthening and creation of alliances among numerous institutions businesses in the Dominican Republic, including: Ministry of Environment, National Council on Climate Change and Clean Development Mechanism, Ministry of Industry and Commerce, Ministry of Finance, Ministry of Planning and Development, National Energy Commission, Ministry of Energy and Mines, State Sugar Council, Dominican Refinery, Cibao International Airport, Punta Cana International Airport, Aerodom-Vinci, among others.

The common objective to achieve the United Nations Sustainable Development Goals (SDGs), has increased in interaction with other States through participation in other ICAO programs, such as the "Buddy programme". Through its participation in that program the Dominican State was able to interact with Panama, and show the technicians of that country how the Dominican Republic has been updating its energy matrix of international airports, thus showing Panama the challenges and benefits of implementation such projects.

Working by example is the key to success, and that has been the approach of the Dominican State's IDAC in taking actions in pursuit of the United Nations Sustainable Development Goals (SDGs). IDAC's more noteworthy such initiatives are highlighted below:

- ✓ Integration into internal policy of energy efficiency with the installation and commissioning of a 1 Mega Watt photovoltaic park for the Norge Botello aeronautical complex.
- ✓ Implementation of a regulatory framework in RAD 121, RAD 135, on the requirement of statistical information for the operators, which allows the determination of CO_2 emissions resulting from international aviation.
- ✓ Conduct of three Capacity Building Seminars for mitigation of CO_2 emissions for the aeronautical sector stakeholders.
- ✓ Creation of a national team trained on the action plan and with the tools to manage the selected mitigation measures in a timely manner, according to the realities of the Dominican Republic, an insular developing country.
- ✓ Promoting the use of renewable energies in the sector and the responsible use of available sources.
- ✓ Promoting the production of sustainable alternative fuels for aviation in the medium term, leading to the creation of new markets and jobs.
- ✓ Improving the local air quality as a result of the reduction of fuel combustion, through the use of more efficient means.

PARTICIPATION IN CORSIA

At the beginning of 2018, as part of the continuity of IDAC's actions in support of aviation environmental protection, it designated a focal point for the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). Later in the same year, IDAC confirmed its intention to participate in CORSIA from the date of its inception, which was confirmed with an official letter to ICAO.

In addition, IDAC published a regulatory framework for implementation in the Dominican Republic and continues its mission to ensure neutral growth of CO_2 emissions by 2020, as recommended by ICAO's SDG goals for its Member States.

LESSONS LEARNED

The entire capacity building exercise in the Dominican Republic has resulted in a number of lessons learned by those organizations and individuals involved in the implementation of the measures. These include:

- Sharing the achievements and helping others along the road already traveled is one of the greatest gifts that can be given and the foundation for effective capacity building.
- Much more can be achieved together, in cooperation with others than going it alone.
- Capacity Building and Assistance Programs are key to the successful implementation of CO_2 emission mitigation measures in developing States.

Panama's Experience with the Development of its State Action Plan

By Dorsa Sabeth (Panama)

BACKGROUND

The State Action Plan on CO_2 Emissions Reduction initiative led by ICAO outlines objectives shaped over time to develop a process that leads Member States to better understand the impacts associated with the aviation industry's international carbon emissions. A key characteristic of this initiative is that it is a voluntary tool that States can use to communicate information regarding their carbon emissions to ICAO. The objectives of this initiative were outlined in the 2010 Assembly Resolution A37-19: Consolidated statement of continuing ICAO policies and practices related to Environmental Protection – Climate Change. In that Resolution, all States are encouraged to submit to ICAO a description of the efforts they have taken to reduce carbon emissions stemming from international aviation. The 2013 Assembly Resolution A38-18, further ratifies these objectives.

It is important to note that the goals set for the international aviation community contribute to 10 of the 17 United Nations Sustainable Development Goals (SDGs). These goals include the actions that are required to deliver a sustainable future, combat climate change and its impacts at a global level, that need to filter down from the International to the Regional, National and Local levels.

PANAMA'S EXPERIENCE

Panama's development of a State Action Plan began when the senior management of the Civil Aviation Authority of Panama (AAC – the acronym in Spanish) realized the significant impact that carbon emissions from international aviation can have on greenhouse gases and, as a consequence, climate change. Out of a sense of shared responsibility, the AAC quickly understood its responsibility in the process and decided that a coordinated approach involving environmental conservation groups and the aviation industry was crucial to understand and assess the current status and future projections of carbon emissions generated by the aviation sector in the country.

Panama started developing its own State Action Plan (SAP) immediately after the 39th Assembly of ICAO in September 2016. One of the key items discussed was environmental protection, including proposals for updating the objectives put forth in Assembly Resolution A38-18 and supported by Assembly Resolution A39-2. Specifically, this pertained to the measuring and reporting of carbon emissions, in the context of three key factors: the global aspirational goals of improving fuel efficiency by 2%, keeping the global net carbon emissions from international aviation from 2020 at the same level, and the work towards the elaboration of a long-term goal for international aviation's absolute emissions contribution.

Since then, Panama has been fully engaged in drafting its State Action Plan, aware of the importance that such a document will have in organizing and streamlining relevant policies, mitigating negative environmental impacts, and providing a better understanding of the role of international aviation on this subject. As such, the development of the State Action Plan would allow the country to plan, report on, and communicate its efforts to address carbon emissions and develop an integrated course of action for mitigation. This was a two-year process that started with an internal restructuring of the organization of the AAC that designated organizational

FIGURE 1: Presentation of Panama's State Action Plan to key aviation stakeholders

components including identifying the focal points to be responsible for carrying out SAP-related activities in the different Offices within the Civil Aviation Authority.

An initial internal assessment led to the creation of the Environmental Protection Unit, which was located under the Air Transport Bureau. This included the hiring of an additional environmental engineer to aid in the monumental task of collating and analyzing data. All of these steps helped to consolidate the Civil Aviation Authority's commitment to ICAO's long-term objectives regarding the State Action Plan. Through subsequent meetings and follow up conversations, a rough plan was laid out and the strategies were set in motion. A number of k activities were identified that needed to be undertaken to reach the proposed goals including: data management, preparing an emissions base line, identifying ICAO basket of measures for carbon emissions reduction, capacity building activities, as well as stakeholder identification and involvement. These important first tasks were undertaken in parallel with identifying and developing a plan for the next steps forward.

Panama has achieved many milestones since then, starting with an internal assessment of the air transport data including all international and domestic flights with a typical flight plan information, to identify where improvement opportunities could arise. This analysis led to actions that allowed an adjustment in aspects concerning data flow, validation, and access. These steps involved a multi division initiative within the Civil Aviation Authority of Panama that resulted in the creation of an improved statistical platform. This new platform gathers segregated data sources and presents robust and reliable air transport data, that not only serves the Environmental Protection Unit, but the Finance, Statistics and Information Technology Offices. This was an important accomplishment that allowed Panama to validate airline operator data and enabled it to prepare a five-year baseline from 2013 to 2017 for its State Action Plan. It was a demanding process, because even though Panama is a small country, it accounts for significant percentage of international travel in Central America. This process required not only computing skills, but people skills – meetings, workshops, and teamwork helped the process along immensely.

In November 2018, Panama submitted its first edition of a State Action Plan to ICAO, making it one of the 111 States that have voluntarily submitted this report to ICAO and the international community. Of the thirteen countries included in the South American (SAM) Region, nine countries, (69%), have presented at least one version of their State Action Plan. This process is a clear example of how an organization can obtain common benefits associated with the State Action Plan process, where key actors were able to come together and work towards a common goal, which showcases how a higher sense of cooperation can permeate in different operational areas.

Now that the SAP has been completed, Panama's Environmental Protection Unit is able to use the new statistics platform as a reliable data validation tool to achieve a number of things including: validating individual operator reports, updating current and upcoming State Action Plans, and performing order of magnitude validations of the CORSIA reports submitted by airline operators about their Emissions Monitoring Plans (EMP).

It is worth mentioning the timely and unwavering support that was given by ICAO throughout this SAP development process; particularly the positive impacts that were achieved in the areas of capacity-building and the establishment of partnerships. The ICAO Environment team carried out an important consistent and reliable support function that was instrumental to Panama developing a successful State Action Plan.

THE BUDDY PROGRAMME

Under the ICAO State Action Plan Buddy Programme, ICAO served as the liaison that fostered a partnership between Panama and the Dominican Institute of Civil Aviation, (IDAC, by its acronym in Spanish), to assist with the development of the SAP. A template "Buddy Agreement" was created by ICAO to help facilitate the establishment of collaboration between States to assist each other in readiness to submit their State Action Plan. The Dominican Republic's support to the Civil Aviation Authority of Panama resulted in a high degree of interest, cooperation, and engagement of both States involved in the initiative. Panama ultimately benefited from the Dominican Republic's experience with regards to their understanding of the process for drafting and implementing their State Action Plan. This cooperation started in March 2018 and was developed further throughout 2018.

FIGURE 2: Signing of the Buddy Programme Agreement between Panama and the Dominican Republic

The Buddy Programme Agreement between Panama and the Dominican Republic was signed in May 2018. The scope of the agreement covered a number of activities designed to improve Panama's capabilities, including: training, site visits, technology transfer, information exchange, technical meetings, and collaboration workshops. So far, the exchanges have been mainly centered around technical support and the sharing of experiences, as well as on-site visits to witness Dominican Republic's advances, especially with regard to its use of renewable energies and the different initiatives it has implemented in this area. In addition, the Buddy Programme has allowed Panama to better understand and assess its development and use of sustainable aviation fuels. These and many other benefits have been achieved during this helpful process. In short, the Buddy Programme has been a positive experience all around and other countries are encouraged to find a partner to aid in the process of developing their own State Action Plan.

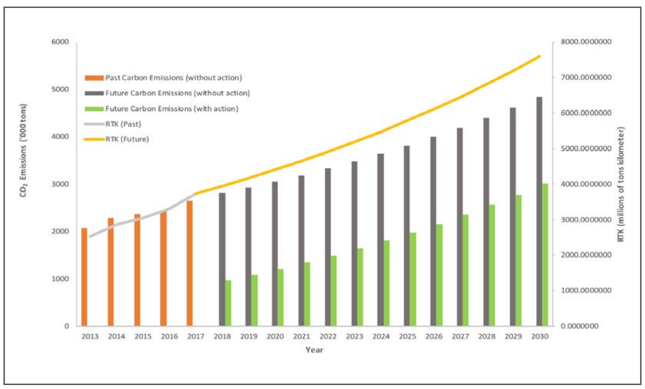
PANAMA'S BASKET OF MEASURES

The 39th Session of the ICAO Assembly was the opportunity for ICAO Member States to hold a series of vivid discussions, leading up to the adoption of Resolution A39-2 on climate change and Resolution A39-3 on a Global Market-Based Measure (MBM) scheme, the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA).

Panama understands that CORSIA complements a broad set of initiatives under the framework of the ICAO basket of measures that include operational, technological, and sustainable aviation fuels. These measures limit or reduce the use of conventional aviation fuels and therefore decrease the corresponding carbon emissions due to fuel burn. The identification of these measures in a State Action Plan could represent significant impacts in the reduction of carbon emissions produced by international civil aviation. When selecting from the basket of measures, Panama considered the feasibility and their possible implications when implemented, from identifying the required resources to the correct selection of each task manager responsible for carrying out the initiative.

To achieve the significant collaboration and synergies that were required among the various aviation stakeholders, Panama created an Action Plan Working Group (GTPA - the acronym in Spanish). These important areas of cooperation included: funding opportunities for renewable energy projects in airports, air navigation analysis opportunities for Continuous Climb Operations (CCO), and Continuous Descent Operations (CDO) flight profiles.

FIGURE 3: Actual and estimated aviation-related carbon emissions - 2013-2030



The GPTA also served as a forum for consultation and discussion which resulted in the identification of key measures for Panama's State Action Plan., The estimated emissions reduction has been quantified to represent up to 1,837.68 million tons of CO_2/year based on a forecast scenario of aviation activity (RTKs) through to 2030. (See Figure 3).

IMPACTS BEYOND AVIATION

Presenting the State Action Plan to different groups like the National Climate Change Committee of Panama (CONACCP – the acronym in Spanish), has served as an opportunity to showcase the coordinated efforts of the aviation sector to reduce emissions in the international arena. It also serves as a point of reference for Panama's national approach to reducing domestic emissions.

The Action Plan Process has also prepared Panama to be ready for the implementation of CORSIA. The process has enhanced collaboration with airline operators during data collection, and communication channels have been established that will assist with the development of future State Action Plan reports and annual reports included in the Emissions Monitoring Plan (EMP). Although the process of developing a State Action Plan has been challenging for Panama, it has also yielded many rewards along the way. It is hoped that this initiative will result in ongoing positive impacts on both aviation and the environment.

ICAO

CHAPTER TEN

Cooperation

Message from Joyce Msuya

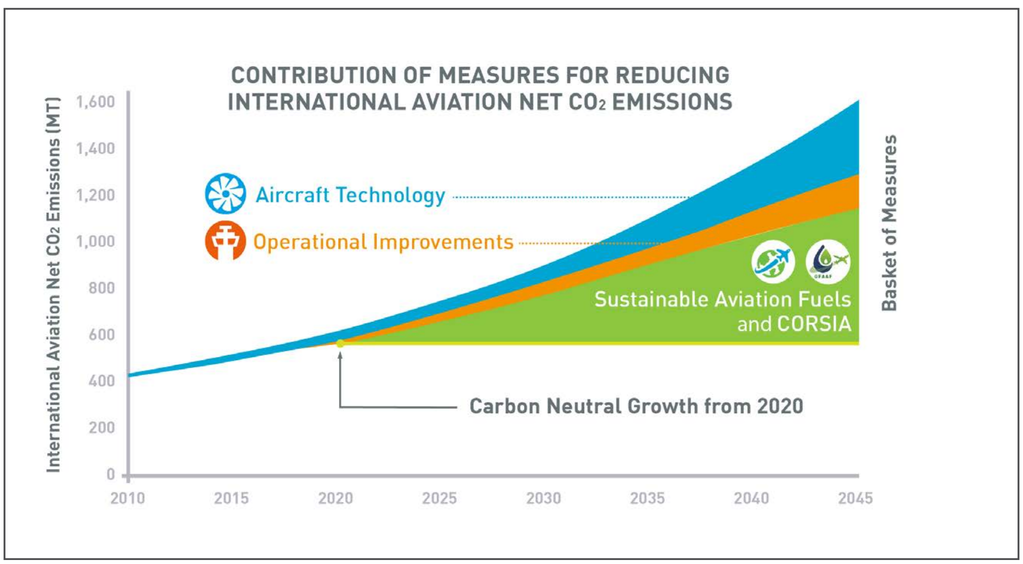
Deputy Executive Director, UN Environment

In 2018, the total number of air passengers worldwide reached a record-breaking high of 4.3 billion. Just as the aviation industry's passenger numbers have risen, so too have the sector's climate-warming emissions: since 2000, CO_2 emissions in the sector have grown by almost 60 per cent (IEA).

Climate change is one of humanity's most urgent challenges, and a major focus of our work at UN Environment. In March 2019, we published the sixth edition of the Global Environment Outlook (GEO-6), our flagship integrated environmental assessment. GEO-6 clearly shows that trends in global greenhouse gas emissions are going in the wrong direction. The report also reinforces the findings of the Intergovernmental Panel on Climate Change as well as UN Environment's Emissions Gap Report: that we must at least increase five fold, our ambitions to limit temperature rise to 1.5 degrees. To avoid the most severe impacts of climate change, GEO-6 concludes, we need to remove at least 45 per cent of fossil fuels from our energy mix by 2030.

International civil aviation must be an important part of achieving these science-based targets, but faces a significant challenge, since emissions from this sector are projected to increase by 2.2 to 3.1 times by 2045 compared to 2015 (compared to the growth in international air traffic of 3.3 times over the same time period) (see Figure 1). While the Paris Agreement applies to all domestic sectors, the international civil aviation, under the leadership of ICAO, has agreed to mid-term aspirational goals of 2 per cent fuel efficiency improvement per annum and carbon neutral growth from 2020. It also adopted a range of carbon mitigation measures, showing a concrete way forward to attain climate change goals. This demonstrates the willingness of international civil aviation to be an important part of the change required to halt global warming. That is why it is encouraging to see that the sector is working to support the transformation that is needed in our energy and transport sectors. While the energy intensity of international and domestic civil aviation decreased by 2.9 per cent every year between 2000 and 2016, (IEA) this was still not enough to keep pace with the annual 6 per cent increase in passenger traffic. As a

FIGURE 1: ICAO Global Environmental Trends on CO_2 Emissions and Contribution of Measures for Reducing International Aviation Net CO_2 Emissions



result, overall absolute emissions have increased as shown in Figure 1. The gains in energy intensity were achieved through better aircraft scheduling, higher passenger loads, and the commissioning of new and more efficient aircraft. Without these improvements, energy consumption in the aviation sector would have been 70 per cent higher in 2016 (IEA).

We have seen progress on the policy front as well. The International Civil Aviation Organization, our sister UN agency, has adopted CO_2 emissions standards for aircraft that will be enforced by national aviation authorities. These standards will ensure that the latest technologies are included in aircraft designs from 2020. Moreover, the International Civil Aviation Organization has adopted a carbon-offset scheme, CORSIA[1], which will launch in 2021. The initiative will help the aviation industry achieve carbon-neutral growth from 2020. The industry also continues to make progress towards the International Air Transport Association's long-term goal of halving net CO_2 emissions by 2050[2].

Clearly, the international aviation industry is working to curb its CO_2 emissions and reduce its impact on the climate. The International Civil Aviation Organization, working in close collaboration with industry players, is spearheading many of these efforts. But much more work needs to be done. If growth in the aviation industry outpaces the recent improvements in efficiency, then absolute emissions from the sector will continue to grow, albeit at a slower pace. New technologies showcased in the 2019 ICAO Environmental Report, such as sustainable aviation fuels and electrification, can help the sector lower its absolute emissions, which is exactly the kind of progress that we need to see. Indeed, to achieve the Paris Agreement targets, absolute emission reductions will be required in all domestic sectors of the economy, and international civil aviation stakeholders could significantly complement this ambition.

I am pleased to be able to provide UN Environment's perspective within this flagship ICAO report. We at UN Environment are focusing all of our efforts on promoting a healthy planet with healthy people, the theme of the sixth Global Environment Outlook. We commend the work of ICAO and the aviation sector more broadly. We look forward to continuing to work together to build a sustainable future.

1 https://www.icao.int/environmental-protection/CORSIA/Pages/default.aspx
2 https://www.atag.org/

Message from Angela Gittens

Director General, Airports Council International (ACI) World

Airports Council International (ACI) World forecasts global passenger traffic will double to 16.9 billion by 2034 based on a projected growth rate of 4.3% per annum. It is, therefore, more important than ever for airports and the aviation industry at large to continue to work in partnership towards a cleaner, quieter and more environmentally sustainable sector.

ACI actively supports the industry's goal of carbon neutral growth from 2020 and reducing aviation carbon emission by 50% by 2050 compared to 2005. We recognize the leadership of the International Civil Aviation Organization (ICAO) regarding international aviation emissions. The CO_2 Certification Standard for Aircraft and the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), as the single global market-based measure for international aviation, are landmark agreements that will help secure the future of a sustainable aviation industry and our ability to deliver the connectivity needs of the world.

This is a global challenge requiring a global response and, given the recent Intergovernmental Panel on Climate Change's (IPCC) call for a net-zero economy by 2050, the aviation industry at large must develop more ambitious CO_2 reduction goals to meet the objectives of the Paris Agreement. For instance, ACI World has established a Task Force to work on a long-term carbon goal for airports, including considerations of net zero carbon airports by 2050. The world economy is faced with this challenge, and we need to join forces to address it. In addition, ACI Europe has just committed its airports to net zero emissions by 2050.

MANAGING AND REDUCING CO_2 EMISSIONS

ACI is taking a leadership role through the *Airport Carbon Accreditation* (ACA) Programme's growth year after year. As of June 2019, ACA boasts 275 participating airports, reaching 44% of global traffic and 52 carbon neutral airports.

The programme, which celebrated its 10th anniversary in 2019, continues to gain adherence because it recognizes that airports can address their CO_2 emissions in a variety of ways. The emphasis is on airports reducing their own energy requirements, and on working with airlines, air traffic management and other stakeholders at and around the airport to reduce their emissions.

Further, ACI offers free of charge, the Airport Carbon Emission Reporting Tool v.5.1 (ACERT), to help airports measure and manage their CO_2 emissions. Initially designed by Transport Canada, the tool can be used by all airports, even those without a staff expert in environment.

ACI also has a new tool, the Airport Ground Energy Systems Simulator (AGES-S), that helps airports quantify the environmental and economic benefits of reducing the use of aircraft auxiliary power units by replacing them with a more efficient ground energy system.

INVESTING IN SUSTAINABLE INFRASTRUCTURE

In planning for new and better infrastructure, it has become more important for the world's airports to effectively plan and communicate that environmental sustainability makes good business sense, and to develop appropriate business cases, because it can reduce natural resource consumption and operating costs.

Renewable energy, an essential component for airports' ability to reduce their own carbon footprint, can and should make good business sense. As recognized by the United Nations Environment Programme this year, Cochin International Airport in India became the first airport to be powered solely using solar energy. It also became the first greenfield airport to be built under public-private partnership in India, demonstrating how relevant private and public investment has become to support airports' eco-friendly initiatives.

AIRCRAFT NOISE MANAGEMENT

As we prepare to facilitate air traffic growth, reducing the impact of aircraft noise should remain a key priority for all aviation stakeholders. Progress on aircraft noise at the source has been challenged by increases in traffic and the introduction of more, larger aircraft. It has also become more difficult to identify new ways of improving the noise performance of aircraft and therefore aircraft noise technology advancements have slowed down.

In addition, the implementation of Performance-Based Navigation (PBN) has brought an additional layer of complexity to aircraft noise management. PBN offers benefits including, fuel efficiency and hence emissions reductions, capacity, flexibility in routings, safety, predictability as well as the possibility for noise improvement. However, it also presents challenges, since while it can reduce the number of people affected by noise, the concentration of noise over a smaller area can increase the intensity and may have an impact on the negative perception of aviation.

Aviation stakeholders need to cooperate with communities to efficiently implement PBN. We can even use PBN as part of the solution to relieve concentration by defining appropriate respite areas/times in accordance with communities' feedback. ACI welcomes the work done by the ICAO Committee on Aviation Environmental Protection (CAEP) on PBN and Community Engagement, and, in collaboration with CANSO, will soon have a new joint publication on *PBN Implementation and Noise Management* that will guide our respective members.

Another challenge is the potential re-introduction of supersonic aircraft. The industry as a whole has to consider the overall effect on the noise and emissions footprint. ACI supports the development of new technology, but the noise and emissions standards for supersonics must be stringent enough that they do not compromise the work we have been doing for decades.

A key element to airports' license to operate and grow, and thus meet future growth, is sensible land-use policies to ensure that the activities near to airports are compatible. Airport operators should engage with their local authorities and also need the cooperation and engagement of aircraft operators and air traffic managers to listen to and communicate with airport neighbors and these decision-makers.

ACI has worked hard in CAEP to set the course for greater community engagement. ACI advocates that communities should be at the core of noise management strategies.

STRENGTHENING PARTNERSHIPS

Environment and sustainability issues affect each and every one of us – it is global matter that affects all regions, and it is also a very local one dependent on the unique factors according to the location of each airport. As we move forward into the future of aviation, we must consider innovative solutions to address our most pressing environmental issues, and strengthen our partnership with all aviation stakeholders, at the local, regional and international level.

Message from Simon Hocquard

Director General, Civil Air Navigation Services Organisation (CANSO)

The task of air traffic management (ATM) is to ensure that airspace users can fly from point A to point B, safely, efficiently, consistently, cost effectively, using optimal route and altitude and without delays. If ATM can achieve this, aircraft will emit the lowest possible amount of carbon emissions for any given route.

All the operational improvements made by CANSO's air navigation service provider (ANSP) Members improve flight efficiency, reduce costs for airlines as well as reduce emissions. Here are some of the operational measures being taken by ATM to reduce emissions.

Performance-based navigation (PBN) allows aircraft to follow optimised, more direct routes with greater accuracy, saving airlines time, fuel and carbon emissions.

Rather than flying traditional fixed routes, **free route airspace** (FRA) allows aircraft to plan more efficient, more direct routes with stable trajectories, saving flying time and reducing emissions.

Collaborative decision-making (CDM) enables airports, ANSPs, and airlines to work together to optimise flights by sharing information on potential inefficiencies and delays on the runway and in the air.

Air traffic flow management (ATFM) regulates the flow of air traffic to ensure available capacity is used efficiently, alleviating congestion and delays and reducing carbon emissions.

Continuous descent and climb operations enable aircraft to avoid using additional engine power to level off at multiple altitudes during these departure and arrival phases of flight.

Space-based surveillance allows tracking of aircraft in oceanic and remote areas not previously covered, enabling planes to fly optimal altitudes and routes based on fuel load and wind.

Artificial intelligence and **automation** are helping planes to safely reduce separation distances between aircraft, thus improving capacity.

WHAT IS CANSO ASKING STATES TO DO?

Modernising ATM to cater for growing traffic is vital if airspace users are to avoid congestion, fragmentation and delays. CANSO is asking States to facilitate and promote investment in modernising ATM infrastructure, as this will improve the efficiency of the entire aviation system, reduce emissions and cater for future growth. We are also asking States to continue to drive implementation of the Aviation System Block Upgrades (ASBUs), which help States modernise ATM.

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. This requires States to cooperate, adopting a network-based approach over a larger area. States can also help by freeing up military airspace for civil use when not required by the military.

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 Alexandre de Juniac

Director General and CEO, International Air Transport Association (IATA)

AVIATION'S CLIMATE RESPONSIBILITIES

Since last year's publication of the IPCC Special Report on the impacts of global warming, which warned of the calamitous effects of unchecked climate change, the effectiveness of the global response to reduce carbon emissions has come under renewed scrutiny. The aviation industry is responding responsibly. The world depends on air connectivity, and we are working hard with governments to provide connectivity sustainably. We have reduced the carbon footprint of an individual flyer by 50% since 1990. And going forward, the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) will achieve our commitment to carbon-neutral growth from 2020. All airlines, regardless of whether their government has volunteered for the initial phases of CORSIA, are already monitoring and reporting their emissions, in preparation for the start of the scheme. CORSIA will generate $40bn in climate finance and reduce global CO_2 emissions by 2.5 billion tonnes by 2035. The adoption of CORSIA was truly a landmark achievement for any industry, particularly one that is currently reliant on carbon-based fuels.

But the public and policy-makers have not, it seems, been widely informed of this. And nor are many aware of our next goal, which is to cut net emissions to half 2005 levels by 2050. Achieving that would bring the aviation sector in line with the Paris Agreement objectives to limit global warming to 1.5-2 degrees. There is some work to do to map out the path to 2050. And we need governments to step up in at least two ways—sorting out air traffic management inefficiencies that cause unnecessary carbon emissions, and delivering policy frameworks that support the commercialization of sustainable aviation fuels.

Beyond 2050, I believe we can drive for even greater ambition, because radical new technologies will be coming on stream, and sustainable fuels will be widespread.

The industry has been hard at work improving its environmental performance, and that must continue. In parallel, we need to do a better job of communicating what we have achieved, and, more importantly, what we are aiming to achieve. If people are not aware of what we are doing, how can they be confident in a sustainable future for flying?

Whether society will grant aviation a license for future growth will be a political decision, and it needs an honest debate in full knowledge of the facts to come to a decision.

I don't think anyone wants to live in a world that is smaller, less connected and more isolated than we enjoy today. We all want our children and the generations that follow to be able to sustainably experience first-hand this magnificent planet and the people who live on it.

Aviation gives people personal freedom while generating greater prosperity and understanding in the world. A world where people cannot travel easily beyond their horizon will be poorer and less tolerant. But to protect the freedom to fly, we must take responsibility for explaining better how aviation will be part of the solution to the climate challenge.

Message from Eric Fanning

President and CEO, Aerospace Industries Association and Chair of the International Coordinating Council for Aerospace Industries Associations (ICCAIA)

Stakeholders working together at ICAO have made remarkable strides towards a more sustainable future for aviation. Technical work carried out through CAEP has delivered new standards in CO_2, noise, non-volatile particulate matter, and NO_x (among others). Modern aircraft are now 80 per cent more fuel-efficient and 75 per cent quieter than the first generation of jet aircraft. In just the last three years, the adoption of CORSIA by the ICAO Assembly has seen aviation become the first sector to agree to a global market-based measure to curb CO_2 emissions. It will also enable the aviation industry to achieve carbon neutral growth from 2020 and reduce carbon emissions by 50 per cent from 2005 levels by 2050.

These improvements go far beyond what would have been achieved had individual countries decided to unilaterally pursue their own measures. Across the ICAO ecosystem, in areas like safety, security, and the environment, there is a track record of nation states working with other stakeholders and setting measures that require the industry to continuously perform to higher standards – all done without jeopardizing the growth of aviation and the benefits it brings to our global economy and society.

As the chairman of ICCAIA, I am proud of manufacturers' contributions to these successes and our continued work to drive down aviation's impact on the environment. Whether through new types of aircraft design, incorporating advanced materials, or looking at alternative propulsion methods like electrification when possible, ICCAIA and the companies we represent are fully committed to playing our part in delivering more environmentally-friendly air transport.

But it's not just manufacturers who can take credit for these achievements. The partnership that takes place at ICAO and within CAEP has been integral to this success. Through ICAO's Basket of Measures for reducing CO_2 emissions and its Balanced Approach for managing aircraft noise, all aviation stakeholders will contribute to the progress we want – and need.

This means that – along with CAEP continuing to set ambitious requirements for aircraft that are environmentally beneficial, technically feasible, and economically reasonable – we must use all the tools at our disposal. Governments must ensure CORSIA is properly implemented, policies are put in place to enable a commercially-viable sustainable jet fuel industry, and the latest air navigation technologies are implemented to make flights more efficient. Airlines should invest in the latest aircraft and adopt procedures that reduce fuel use and the noise experienced by communities. At a local level, we must move towards greater community engagement on noise issues and build on the good work many airports are doing in this area.

Working together, airlines, manufacturers, airports, NGOs, regulators, governments, and the public can ensure aviation continues to deliver environmentally-friendly economic growth and opportunity today and into the future.

Message from Tim Johnson

International Coalition on Sustainable Aviation (ICSA)

Sometimes, challenges arise that require immediate unity and a common vision. Responding to the IPCC's 2018 special report on the impacts of global warming of 1.5°C above pre-industrial levels is one such occasion. The message for governments and society is as stark as it is clear: we need to reach net-zero greenhouse gas emissions by the second half of the century. The UN Secretary General is already calling on states to show more urgency and ambition in delivering their nationally determined contributions. This expectation of further action will also apply to activities that cross national borders, like emissions from international aviation and shipping. Having a collective answer and a clear sense of direction is perhaps the singularly most important environmental challenge facing the aviation sector. With almost 60 per cent of its emissions coming from international aviation activity, that puts the International Civil Aviation Organisation centre stage.

ICSA, the International Coalition for Sustainable Aviation, has been representing environmental non-governmental organisations at ICAO, reflecting the views of civil society, since 1999. During these 20 years, ICSA has devoted significant time and resources to its participation in ICAO's Committee on Aviation Environmental Protection, working alongside States and other Observer Organisations to help shape outcomes including the aircraft CO_2 standard, sustainability criteria for aviation fuels, and ICAO's work on a market-based measure that has culminated in the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA).

Important tasks still remain to finalise CORSIA and ensure its environmental integrity, to deliver ICAO's immediate goal of keeping carbon dioxide emissions from international aviation at or below 2020 levels. But looking ahead, we cannot afford to pause our consideration of how to reduce aviation emissions in the long-term. According to IPCC, to prevent an overshoot of 1.5°C, global net anthropogenic CO_2 emissions must decline by about 45 per cent from 2010 levels by 2030, reaching net zero around 2050. On current forecasts, aviation emissions are forecast to continue growing to 2050, with actual emissions potentially increasing by around 150% compared with CORSIA's likely 2020 baseline. Contributing to the delivery of a net zero future presents a fresh challenge for the sector, and for ICAO.

Potential solutions include continued efficiency improvements from technology and operations, potential step changes such as electrification, the use of sustainable biomass and synthetics fuels, and market-based measures. But one lesson that has been learned to date is that ICAO progress has gained momentum once it has identified a clear rationale for the application of measures. This is exemplified by CORSIA: despite ICAO having a long record of analysing the potential for market-based measures, work to deliver CORSIA really only took off once ICAO confirmed its 2020 goal.

So it's clear that having a clear vision will lay the foundation for future action by all. The unity that comes from identifying a long-term climate goal, or environmental goals generally, gives everyone a sense of purpose and a benchmark to measure progress. That vision needs to be set now, and by the time of the next ICAO Environment Report in 2022, we hope we can reflect on the progress made.

Message from Dirk Forrister

President and Chief Executive Officer, International Emissions Trading Association (IETA)

For two decades, IETA has championed market-based solutions as the best response to tackle climate challenge. The clue is in our name: we don't just advocate for carbon markets, but for these efforts to transcend borders. This is the key to delivering the climate ambition our world needs.

All the benefits of a market system are elevated by cross-border collaborations: emissions cuts can be realised at a quicker pace than if action is confined to jurisdictional borders, and this in turn allows for greater ambition. Uniform rules and pricing help level the playing field and reduce competitiveness concerns, while allowing business the opportunity to innovate and unlock lowest-cost reductions, thus keeping down costs for consumers.

We already have experience with international markets, via the Clean Development Mechanism (CDM). The scale of innovation and investment this pioneering global mechanism unleashed into the developing world was transformational and, despite current troubles, we continue to reap its benefits and leverage its learnings. As we move towards a new generation of carbon markets and clubs – which include those established under Article 6 of the Paris Agreement and CORSIA – we have an opportunity to accelerate the decarbonisation of the global economy, with the right framework and rules in place. These markets are essential if governments are going to increase their ambition.

As the first international sector-based carbon market system, there is a lot of attention on CORSIA and the aviation community's success. It could be the trailblazer for other sectors–while demonstrating how stakeholders across different regions can unite and work together on a shared goal. CORSIA's roots are similar to those of the Paris Agreement, as both saw the international community come together to act on the greatest environmental challenge of our lifetimes. These promises have been well received but, as always, the devil is in the detail – and it is these details that are critical to ensuring their success. The relationship between CORSIA and a future market under Article 6 of the Paris Agreement is crucial: both can only succeed with cooperation, collaboration, and commitment to achieving their goals.

Guidance for implementing Article 6 made impressive progress over the course of 2018, moving from a list of disparate elements to a fully-fledged, almost-final set of rules. However, a deep divergence of views on some fundamental elements related to the operationalisation of Article 6 meant that this chapter of the rulebook could not be finalised at the December 2018 UN climate negotiations (COP24). Critical issues remain unresolved and should be agreed upon this December. This, combined with CORSIA action over the coming months, means 2019 is a critical year for the development of international carbon markets.

What is the potential power and impact of these markets? IETA has been working to answer this question through a special Article 6 project, launched earlier this year. In partnership with the University of Maryland, we are modelling and assessing different rulesets and their implications on costs and emission reduction goals. Preliminary results, based on current national climate targets, known as Nationally Determined Contributions (NDCs), show that Article 6 holds enormous potential, with estimated cost savings of US$250 billion annually by 2030, $350 billion by 2050 and nearly $1 trillion in 2100. If these cost savings are reinvested in emissions mitigation action, Article 6 could deliver an extra 5 billion tonnes per year of additional emissions reductions in 2030. The power of markets to be transformational is huge.

We are in a strong position in 2019, now with over 20 years of experience with carbon markets to draw upon when setting the parameters for the next generation. Not only have we learned many lessons about carbon market design, we also have the benefit of existing greenhouse gas standards and systems to tap. This is a vastly different environment to that from which the CDM first emerged, and means we don't need to take several years to finalise rules, we are not starting from scratch this time. We have a window of opportunity to affect great change. CORSIA implementation is now under way and this, together with the expected agreement under the UNFCCC process on pending issues related to Article 6 of the Paris Agreement, are resolute steps to tackle the multi-faceted challenges posed by climate change.

Chapter 1: Aviation and Environment Outlook

GREGG G. FLEMING

As the director of U.S.DOT/Volpe's Center for Policy, Planning, and Environment, Gregg G. Fleming has over 30 years of experience in all aspects of transportation-related issues. He has guided the work of numerous multifaceted teams on projects supporting government, industry, and academia, including the Office of the Secretary of Transportation, the United Nations' International Civil Aviation Organization (ICAO), the Federal Aviation Administration (FAA), the Federal Highway Administration (FHWA), the National Park Service, the National Aeronautics and Space Administration, the Environmental Protection Agency, and the National Academy of Sciences.

In his role as center director for Policy, Planning, and Environment, Fleming oversees seven technical areas—Economic Analysis, Policy Analysis and Strategic Planning, Transportation Planning, Environmental Measurement and Modeling, Energy Analysis and Sustainability, Environmental Science and Engineering, and Program Development and Capacity Building—as well as the CAFE Program Office. The Center for Policy, Planning, and Environment provides a full range of planning, evaluation, compliance, and implementation assistance to transportation decision makers at the local, regional, state, and federal levels.

IVAN DE LÉPINAY

Ivan de Lépinay is Environmental Protection Officer at EASA in charge of impact assessments. He is taking part in various projects and standardisation groups aiming at better quantifying the environmental impacts of aviation. Since 2018, he is co-rapporteur of CAEP's Modelling and Databases Group. Before joining EASA in 2011, he worked for ten years as a consultant in aviation and environment for several European organisations. Ivan holds a degree in civil engineering and applied acoustics and a master's degree in sociology.

DIMITRI MAVRIS

Dimitri Mavris earned his B.S. (1984), M.S. (1985), and Ph.D. (1988) in Aerospace Engineering from Georgia Tech. He is the Boeing Chaired Professor of Advanced Aerospace Systems Analysis in Georgia Tech's School of Aerospace Engineering, Regents Professor, and Director of its Aerospace Systems Design Laboratory (ASDL). He is an S.P. Langley NIA Distinguished Professor, AIAA Fellow, Fellow of the Royal Aeronautical Society, and a member of the ICAS Executive Committee, the AIAA Institute Development Committee, and the US Air Force Scientific Advisory Board. He is also the Director of the AIAA Technical, Aircraft and Atmospheric Systems Group, and co-chair of the Committee on Aviation Environmental Protection's review board of independent experts.

For the past 25 years, Prof. Mavris and ASDL have specialized in the integration of multi- disciplinary physics-based modeling and simulation tools. ASDL's signature methods streamline the process of integrating parametric simulation toolsets and enable huge runtime improvements that facilitate large scale design space exploration and optimization under uncertainty. Recent research focuses on combining these methods with advances in computing to enable large-scale virtual experimentation for complex systems design.

NICK CUMPSTY

Up until 2000 Nick Cumpsty was Professor of Aerothermal Technology and Director of the Whittle Laboratory. From 2000 to 2005 he was Chief Technologist for Rolls-Royce plc. He retired from Rolls-Royce and went as Professor in the Department of Mechanical Engineering in Imperial College London. He is a Fellow of the Royal Academy of Engineering, the ASME and the AIAA. He is a Visiting Professor in the Department of Aeronautics and Astronautics in MIT. He chaired the 2010 Independent Expert Review into Fuel-Burn Reduction Technology Goals for ICAO/CAEP.

MICHELLE R. KIRBY

Dr. Michelle Kirby is the Civil Aviation Research Division Chief in the Aerospace Systems Design Laboratory at Georgia Tech. She received her Bachelors (1995), Masters (1996) and PhD (2001) from Georgia Tech in Aerospace Engineering. She has over 25 years' experience in the development of state-of-the-art methods to forecast and assess the impact of emerging technologies on commercial aviation systems. She is has been actively engaged with NASA, FAA, and CAEP. Dr. Kirby's main areas of research fall into three broad categories and include environmental modeling and impact assessments for international policy making support, technology portfolio tracking and assessments, and strategic portfolio planning of future research and development. Lastly, Dr. Kirby was recently awarded the FAA Center of Excellence Faculty of the Year for her research contributions on metrics to support a potential CO2 standard for future aircraft certification, which was recently adopted at the CAEP10 meeting in Feb 2016.

Chapter 2: Aircraft Noise

DARREN P. RHODES

Darren Rhodes is the Chief Technical Noise Advisor at the UK Civil Aviation Authority, where he has 25 years' experience in aircraft noise modeling and analysis projects. He provides technical advice to the UK's Department for Transport and leads development of the UK aircraft noise contour model, ANCON. He lead development on the first edition of ICAO Doc 9911 and was co-lead on the development of the second edition.

ERIC R. BOEKER

Eric Boeker is a physical scientist with the U.S. Department of Transportation's Volpe Center, where he has over fifteen years of experience in noise measurement, modeling and analysis projects for various modes of transportation. He provides technical support to the Federal Aviation Administration's (FAA) Office of Environment and Energy (AEE) as a subject matter expert on the Aviation Environmental Design Tool (AEDT) development team focusing on noise data and noise modeling capabilities. He was co-lead on the development of the second edition of ICAO Doc 9911.

MIKHAIL O. KARTYSHEV

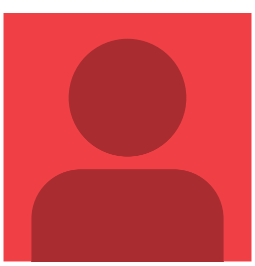
As Ph.D. candidate at the Saint-Petersburg State University of Civil Aviation (Russia), and while Deputy General Director of “Civil Aviation Environmental Safety Center”, Mikhail Kartyshev carried out many experiments to study patterns of aircraft noise propagation. He supervised environmental protection projects and the organization of noise monitoring systems at Russian airports. He also conducted an experimental study of the use of standard flight data recorder (FDR) data and aircraft noise measurements for prompt determination of aircraft noise levels during takeoff and landing, and for drawing equal-loudness contours around airports.

KEVIN MORRIS

He has been involved with the aerospace industry since 1980, with the last 30 years focusing on the environmental impacts of aviation. Currently Environment Manager at ADS, Kevin spent 21 years at British Airways dealing with aircraft performance, noise, and local air quality issues. Before that, he worked as an aerodynamicist at British Aerospace. With both ICCAIA and IATA, Mr. Morris has been involved with CAEP since 1991, contributing to the original ICAO Circular 303, and Airport Air Quality Manual. He led the groups that developed the Environmental Assessment Guidance for Proposed ATM Operational Changes document, and Operational Interdependencies work for the ICAO website. He currently co-leads the group drafting a manual on Operational Opportunities to Reduce Aircraft Noise.

TRULS GJESTLAND

Senior research scientist at SINTEF, Norway. M.Sc Electrical Engineering. More than 50 years experience in research on effects of noise and people’s reactions to noise. Participant and project manager for several EU-funded noise research projects. Team leader of ICBEN, International Commission on Biological Effects of Noise. Temporary advisor to World Health Organization, US Federal Aviation Administration, European Aviation Safety Agency, and UN Food and Agriculture Organization. Active in International Standardization Organization: assessment of noise, soundscapes. Fellow of the Acoustical Society of America. Honorary member of Acoustical Society of Norway and of East-European Acoustical Association. Former president of the Acoustical Society of Norway. Former vice-president of European Acoustics Association.



JONATHAN BAGG

Jonathan Bagg is the Senior Manager of Stakeholder and Industry Relations at NAV CANADA. In his role, he has been leading airspace change communications and supporting policy development for Canada’s Air Navigation Services Provider. He works closely with operational deployment teams and regional project team members, overseeing community and stakeholder engagement on airspace change projects, ensuring the application of the industry’s voluntary protocol and consulting communities groups, airport authorities, elected officials and industry partners on the deployment of Performance Based Navigation and flight path changes before they are implemented.

BLAKE CUSHNIE

Blake Cushnie has been in the aviation industry for 26 years, starting as a helicopter pilot in the British Royal Navy before embarking on a career in Air Traffic Control. Starting with NATS UK, Blake worked as a controller at London Heathrow before joining NAV CANADA, where he worked as a Tracon Controller and Tower Supervisor at Vancouver International. Recently responsible for all PBN deployment nationally, working closely with airlines, operational ATC units and airport authorities, Blake is now the General Manager, Toronto Flight Information Region. Blake also co-chairs the Industry Noise Management Board; the INMB gathers technical expertise from across the industry to evaluate noise mitigation techniques at Toronto Pearson airport.

Chapter 3: Local Air Quality

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). He started his career as a school teacher and graduated as a physicist for atmospheric science and environmental remote sensing. He also holds a commercial pilots license. 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 standards.

DANIEL JACOB

He is a Physical Scientist and Program Manager at the U.S. Federal Aviation Administration Office of Environment and Energy. His educational background includes engineering, earth system modeling and observing system development. His research was focused on understanding the physical aspects of weather and climate. In his capacity as Program Manager at the FAA, he oversees projects 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 and CAEP/11 cycles. He is currently the co-lead of Emissions Characterization Task Group of Working Group 3 and co-rapporteur of the Impacts Sciences Group.

BETHAN OWEN

Dr Bethan Owen has more than 20 years' experience in air quality and climate assessment, with particular expertise in the field of aviation. Principally her experience lies in research projects in the field of emission estimations and predictive modelling in the context of aviation, air quality and climate, providing leadership and support on a number of national and European research projects on aviation and the environment.

Dr Owen advises the Department for Transport in the UK government on the international policy related to aviation and international certification emissions standards for engines and airplanes. Dr Owen is a scientific advisor to the UK government at meetings and on working groups with senior levels of industry and government. Since 2016, Dr Owen has been a co-Rapporteur of the international technical emissions working group (Working Group 3) under the International Civil Aviation Organization's Committee for Aviation Environmental Protection (ICAO-CAEP) that develops technical information for the emissions certification standard setting process. Recent successes include ICAO's new non-volatile particulate matter (nvPM) engine emissions standards.

RALPH IOVINELLI

Mr. Ralph Iovinelli has served as the Manager of the Emissions Division for the United States Federal Aviation Administration's Office of Environment and Energy since 2011. Mr. Iovinelli advises the Executive Director of Environment & Energy (AEE-1) and the Assistant Administrator for Policy, International Affairs, and Environment (APL-1) Mr. Iovinelli represents AEE and the FAA at meetings and on working groups with senior levels of industry and government, which involves coordinating with other relevant FAA offices.

Since 2013, Mr. Iovinelli serves as co-Rapporteur of the international technical emissions working group (Working Group 3) under the International Civil Aviation Organization's Committee for Aviation Environmental Protection (ICAO-CAEP) that develops technical information for the emissions certification standard setting process. Recent successes include the development and adoption of ICAO's new fuel efficiency airplane certification standard (2016) and ICAO's new non-volatile particulate matter (nvPM) engine emissions standards (2016 and 2019).

Chapter 4: Climate Change Mitigation: Technology, and Operations

KRISHA NOBREGA

Krisha is a Product Development Engineer working for the last 15 years with aircraft performance at Embraer. During the last 5 years, she has been involved with project management of executive jets. Krisha holds an aeronautical engineering degree from the Federal University of Minas Gerais – UFMG (Brazil). She is supporting CAEP-WG3 and CAEP-MDG/FESG activities within ICCAIA since 2011 and 2014, respectively.

SIMON SMITH

Simon Smith is the Technical Fellow in Aircraft Performance and Whole Aircraft Design at Rolls-Royce plc. He has more than 30 years of experience in propulsion integration with an emphasis on the impact at whole aircraft level of engine cycle and configuration choice. Simon graduated from the University of Bristol and has spent most of his career in the Aircraft Projects Group, becoming a Fellow in 2017.

Simon began CAEP 9-WG3 activities in 2010, being part of the ICCAIA team supporting the CO2 Certification process and subsequently supported the CAEP 11 Independent Expert Reviews towards emissions goals.

JEAN-PIERRE CABANAC

Jean-Pierre is Senior Design Expert at Airbus. He has graduate degree from INSA in Lyon in structural engineering. He started his career as composite design engineer in 1989. He occupied several positions at Airbus in the field of Airframe (Architecture, stress analysis and design).

He is contributing as ICCAIA team member for materials and structure to CAEP Independent-Expert Reviews towards emissions goals since 2017.

RÜDIGER THOMAS

Rüdiger is Propulsion Performance Senior Expert in Airbus, with a main focus on future propulsion architectures, concepts and environmental impacts. Rüdiger has been working for Airbus for more than 25 years. Among the different positions, he has been Engine Performance Task Leader for several programs, Predevelopment Propulsion Architect, Head of Engine Performance Domain, Head of Acoustic Domain and more recently R&T Roadmap Owner for Propulsion with a special focus on Hybrid Electric Propulsion.

In 2017 and 2018, Rüdiger has contributed, as ICCAIA team member, to the ICAO Independent-Expert Reviews towards environmental technology goals.

PAUL VIJGEN

Dr Paul Vijgen is in the Technical Fellowship at Boeing Commercial Aircraft (Seattle) – focusing on transonic aerodynamic design of aircraft. He has graduate degrees from Delft University and the University of Kansas. Paul has over 25 years of experience in aerodynamic design and flow-control methods (including laminar flow and geometric adaptivity). He has supported CAEP-WG3 activities since 2009 – contributing as ICCAIA team member to CAEP Independent-Expert Reviews towards emissions goals.

GERD HELLER

Dr Gerd Heller is Senior Aerodynamics Expert at Airbus Operations – Commercial Aircraft. His emphasis is on applied aerodynamics and all aerodynamics aspects of transonic aircraft design and optimization. Gerd has more than 25 years of experience in aerodynamic design with focus on drag reduction measures, particularly on wing tip devices.
Gerd has graduated and received his doctoral degree at Technische Universität München.

He is supporting CAEP-WG3 activities since 2017 – contributing as ICCAIA team member to CAEP Independent-Expert Reviews towards emissions goals.

DAVID BRAIN

David previously worked as an Area Air Traffic Controller in the UK and has over 20 years extensive experience in ATC, ATM and Project Management. David currently leads EUROCONTROL's environmental efforts on reducing aviation's operational impacts. David co-chairs the European CCO/CDO Taskforce as well as leading several other European operational projects. David is a member of the ICAO-CAEP Airport and Operations Working Group where he has been responsible for estimating the global environmental benefits following the planned implementation of the operational concepts within ICAO's ASBU framework. David also was responsible for leading the first ever global flight efficiency analysis using a harmonised surveillance data source. David has a private pilot's license, a degree in Geography, a Master's degree in Sustainable Aviation and enjoys travelling across Siberia in his spare time.

MARYLIN BASTIN

Marylin has been working on various technical and operational positions in the ATM world since 2002. In 2014, noise, CO2 emissions, air quality, flight efficiency became her day-to-day business as Head of Environment and Procedure Design at skeyes (Belgian Air Navigation Service Provider, former Belgocontrol). She previously chaired the Standing Committee on Environment for FABEC (Functional Airspace Block Europe Central), working on the FABEC Environmental policy and ensuring the integration of the environmental pillar into the optimized performance of the ATM-system. She also co-chairs the European CCO/CDO Task Force since 2018. Marylin has a master's degree in Industrial Engineering and a University Certificate in Environmental Management.

ALMIRA RAMADANI

Almira Ramadani holds a BS degree in Air Transportation Engineering from the University of Belgrade, and an MS degree in Civil and Environmental Engineering from the University of California at Berkeley. Strengthened by over twenty years of hands-on experience with ATM and NextGen projects in academia, private sector, and at the FAA, her expertise is in performance analysis of current and future NAS operations, and in validation of ATM concepts.

MARINA BYLINSKY

Marina Bylinsky joined ACI EUROPE in September 2015 and is responsible for the coordination of all aspects of the association's environmental strategy. In this regard, she represents ACI EUROPE in various high-level EU, ECAC and EUROCONTROL fora. She also monitors the administration and ongoing evolution of the global carbon standard, Airport Carbon Accreditation which belongs to ACI EUROPE.

Marina is a graduate of the Institute of Political Sciences in Paris where she graduated with a Masters in Comparative Politics, following a BA in Political Science. Prior to joining ACI EUROPE, Marina worked as a Senior Consultant at BearingPoint in France and in Belgium. During this time, she worked on several projects with the European Commission, the SESAR Joint Undertaking and EASA.

Chapter 5: Climate Change Mitigation: Sustainable Aviation Fuels

ROLF HOGAN

As RSB's Executive Director, Rolf Hogan has led the expansion of the RSB's best-in-class standard and certification scheme from its original focus on liquid biofuels to cover biomaterials such as bioplastics and other products derived from biomass and non-biogenic advanced feedstocks.

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 organisation 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.

NORBERT SCHMITZ

Norbert Schmitz has studied Business Administration at the University of Cologne in Germany where he also acquired his PhD. He has worked several years for a leading European management consultancy before developing and setting up International Sustainability and Carbon Certification (ISCC) in a multi-stakeholder process.

Since 2010, Norbert is Managing Director of ISCC System GmbH. Today, ISCC is a globally leading certification scheme with system users in 100 countries. More than 3,300 companies are using ISCC to proof sustainability along supply chains – from agricultural production, trade and conversion to the consumer markets. ISCC covers agricultural, forestry and alternative feedstocks and products for various markets, including bioenergy and chemical/ technical applications. The regional focus of Norbert's work is Europe, the Americas and South East Asia.

GERNOT KLEPPER

Gernot Klepper is a Senior Researcher at the Kiel Institute (IfW) (https://www.ifw-kiel.de) and Speaker of the Kiel Earth Institute (https://www.kiel-earth-institute.de). An economist by training (University of Heidelberg), he received a Ph.D. in Agricultural Economics (University of Kentucky, USA). His research interests center on climate mitigation with a focus on modeling and analyzing the impact of climate policy instruments. Especially, the role of natural resources such as land and water in the climate system and their contribution to climate change as well as mitigation are among his research topics.

He is involved in numerous networking and consulting activities: He was for many years Chairman of the National Committee on Global Change Research of the German Research Foundation (DFG) and a research fellow of the CEPR. Currently, he is Chairman of the Scientific Advisory Board of the Helmholtz Centre for Environmental Research (UFZ) (http://www.ufz.de/index.php?en=36454), Chairman of the International Sustainability and Carbon Certification Association (ISCC e.V.) (https://www.iscc-system.org/stakeholders/iscc-association/), Co-chair of the German Climate Consortium (DKK) (http://www.deutsches-klima-konsortium.de/en/startseite.html), among others.

CHARLOTTE HARDENBOL

Charlotte Hardenbol is Head of Programs & Solutions at SkyNRG, focusing on the development of co-funding initiatives to bridge the price gap between conventional and sustainable aviation fuel. Through the customer programs, SkyNRG involves different stakeholders including governments and end-users to create a strong SAF demand signal and enable new production capacity. Before joining SkyNRG, Charlotte worked as a senior consultant at Spring Associates, a strategy consulting firm with expertise in Energy and Sustainability. Charlotte holds a Master's degree in Economics from the University of Amsterdam, specializing in Econometrics & Management Science, graduating at the Amsterdam Center for Entrepreneurship.

MISHA VALK

Misha Valk is heading the Future Fuels department at SkyNRG, as such he is responsible for all pre-commercial supply chain development initiatives. Currently, our SAF is produced from waste oils and fats and this will also be the feedstock for our DSL-01 production facility. However, we see a need to deploy different feedstock and technology combinations in future DSL's to further scale SAF supply. Therefore, we work together with our technology partners to commercialize these technologies. In the pre-commercial supply chain development projects we work together with partners from across the supply chain to take the next step, e.g. build a pilot or demonstration scale facility. Misha completed a Bachelor in Biology and holds a Master's degree in Energy Science from the Utrecht University, specializing in bio-energy.

Chapter 6: Climate Change Mitigation: CORSIA

EVA WEIGHTMAN

Eva has over 15 years of experience in the business and environmental sector. In IETA she is currently following the developments in CORSIA and aviation. She is also responsible for membership development a recruitment. Prior to joining IETA she worked as an Investment Advisor for EEA Fund Management managing carbon projects valuation and risk assessment for an AIM listed carbon emissions fund. Eva also held a key role at the Ministry of the Environment of the Czech Republic implementing the EU Emissions Trading Scheme. She holds a master degree in Economics, with specialisation in International Trade.

MICHEL ADAM

Michel Adam is Senior Manager, Aviation Environment, at the International Air Transport Association (IATA). IATA is the trade association for the world's airlines, representing some 290 airlines or 82% of total air traffic. Michel Adam is responsible for the policy and regulatory portfolio and advocacy with external stakeholders on environmental affairs. He is also IATA's observer to the ICAO Committee on Aviation Environmental Protection where he coordinates the airlines' participation.

CUTHBERT LUNGU

Mr. Cuthbert Lungu is employed at Zambia Civil Aviation Authority as Inspector, Aerodromes-Design. He holds Master of Science and Bachelor of Science degrees in Civil Engineering obtained from Donbass State Academy of Civil Engineering and Architecture in Ukraine. He has eighteen years of experience as a practicing Civil/Structural Engineer and has worked at the Civil Aviation Authority for the past four years as Chairman of the Aviation Emissions Working Group, appointed by the Director General of Zambia's Civil Aviation Authority.

CHINGA MAZHETESE

Chinga Mazhetese is an Environmental Protection Specialist at the South African Civil Aviation Authority (SACAA) where she has worked since July 2014. She is a holder of an MSc in Environmental Engineering (University of the Witwatersrand, South Africa) and a BSc Honours Degree in Applied Environmental Science (University of Zimbabwe). She has worked as an Environmental Specialist for approximately 13 years in different sectors such as aviation, non-governmental sector, mineral processing and power generation (utilities). Her interest are in environmental protection issues associated with the operation of aircraft, airport and air transport management. She was the lead author of the first South African State Action Plan in 2016 and she represents South Africa on the CAEP as the Advisor to the CAEP Member. She is also the ACT CORSIA Technical Expert provided by South Africa under the ACT CORSIA Buddy Partnerships initiative.

Chapter 7: Climate Change Adaptation

RACHEL BURBIDGE

Rachel Burbidge joined EUROCONTROL in 2005. She has been leading EUROCONTROL's work on climate change adaptation and resilience since 2009. She is the Agency's policy officer for international aviation market-based measures for CO2 reduction and a member of the ICAO Global Market Based Measures Technical Task Force. She is also a member of the ICAO CAEP Impacts and Science Group and Airport and Operations Working Group where she co-leads work on climate adaptation.

ANDREA SCHWARTZ FREEBURG

Andrea Schwartz Freeburg is a Foreign Affairs Specialist with the U.S. Federal Aviation Administration (FAA). Andrea joined FAA in 2011. During the first six and a half years with FAA, Andrea served as an Environmental Protection Specialist in the Office of Environment and Energy, where she was the agency lead on climate adaptation. Last year, accepted a new position in the FAA Office of International Affairs where she covers the Caribbean portfolio. In her new role, she works on disaster preparedness, aviation safety and efficiency, and cybersecurity projects. Andrea has represented the FAA on U.S. Transportation Research Board panels and projects. She was a contributing author to the Climate Change Adaptation Planning and Preparedness chapter of the 2014 Transportation Research Circular *Critical Issues in Aviation and the Environment.* Andrea has a Bachelor of Arts in International Relations from The College of William and Mary and a Master of Arts in International Security from George Mason University.

JULIANA SCAVUZZI

Juliana is the Senior Manager, Environment at ACI World. In her capacity, she is responsible for the Environment portfolio of ACI World, which includes wildlife trafficking. She is the observer of ACI at the International Civil Aviation Organization (ICAO)'s Committee on Aviation Environmental Protection (CAEP) where she actively represents ACI advocating airports' policies on environment and coordinates a group of experts from member airports and business partners that are nominated by ACI to collaborate with the work of CAEP. She is also the Secretary of the ACI World Environment Standing Committee (WENSC), where she supports the development of airports global environmental policy. Juliana also facilitates training on Environment provided by the ACI World Global Training Airports Developing Nations Assistance Programme (DNA) and is a visitor lecturer at the McGill Integrated Aviation Management Programme.

Juliana is an attorney from Brazil. She has a Bachelor of Laws from UNICAP, where she is a member of the Brazilian Bar, a Master of Science (MSc) in Juridical Science from UNIVALI and a Master of Laws (LLM) in Air and Space Law from the Institute of Air and Space Law (IASL) at McGill University, where she is a Board Member of the IASL Alumni Association. Juliana is also an elected member of the International Institute of Space Law (IISL), a member of the Brazilian Association of Aeronautical and Space Law (SBDA), and she has several publications, including book chapters, addressing aviation, environmental and space policy and law issues.

JEEYOON JUNG

Jeeyoon Jung is an Assistant Manager, Environment, at Airports Council International (ACI) World, working on the advocacy of airports' environmental stewardship worldwide and acting as an advisor to the ACI's observer to ICAO CAEP. She has over 5 years professional experience in the area of environmental affairs for international aviation, and the international development. Prior to joining ACI, she was affiliated with ICAO, Ministry of Foreign Affairs (Republic of Korea), and the United Nations Office for Project Services (UNOPS), and has degrees in public administration, business, and engineering from London School of Economics and Political Science (LSE) and Korea Advanced Institute of Science and Technology (KAIST).

ULKU OZEREN

Being Environmental and Sustainability Director for Istanbul Airport, Ulku Ozeren has 22 years- environmental engineering background. Since January 2014, she has been responsible for conducting all construction and operation phases of Istanbul Airport Project related to environment, social, sustainability, biodiversity and wildlife in accordance with IFC and international sectoral standards and guidance. She holds master's degree from Istanbul Technical University and continues her doctoral studies at the same university studying on impacts of Climate Change related sea level rise.

In her previous occupations, she has gained experience and knowledge in GHG calculations and management, energy efficiency measures, environmental and energy legislation, eco-labeling in addition to the environmental management experience, working heavily at infrastructure and industrial projects.

Chapter 8: Towards a Circular Economy

THOMAS ROETGER

Dr. Thomas Roetger 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. He is a member of various CAEP working groups, namely WG2, where he co-led the Task Group on aircraft end-of-life and recycling, WG1 and ISG. Until CAEP/11, he was also a member of WG3 and AFTF, where he co-led the Sustainability Task Group. He is rapporteur of the Environment and Energy working group in the Advisory Council for Aviation Research and Innovation in Europe (ACARE) and was chairman of the end-users chamber in the Roundtable on Sustainable Biomaterials (RSB).

From 1988 to 2008 he worked at Airbus in Toulouse and Hamburg. A main focus of his activities was on environmental aspects such as noise and emissions reduction, in particular for the A380. He also has expertise in the areas of airport compatibility and cabin technology. He studied physics and chemistry in Heidelberg and Hamburg (Germany) and Grenoble (France) and holds a doctoral degree in physics.

ABDELGHAFAR ELSAYED

Eng. Abdelghafar Elsayed joined the Egyptian Civil Aviation Authority (ECAA) in 1998, as Airworthiness Inspector. In 2013, he acted as Technical Researches & Environmental Development Manager and was responsible for the implementation of ECAA's strategy on aviation's environmental impact, as well as the point of contact for Egypt's first Action Plan for Emission Reduction (APER) that was submitted to ICAO in 2016. He was hired as the general director of ground handling facility equipment in ECAA in January 2017.

He is a member of CAEP/11 working group WG2, where he co-led the Task Group on aircraft end-of-life and recycling. He attended the CAEP/10, CAEEP/11 and its Steering Groups meetings as Alternate Egypt CAEP member and was an advisor in CAEP/9. He is the Egyptian representative of the Environment Committee of the Arab Civil Aviation Organization (ACAO, previously ACAC) and was Vice chairman then Chairman of this Committee from 2014 to 2018 respectively. He is the Egyptian CORSIA focal point of contact and has experience as an instructor on ACAO course on ICAO Annex 16 Vol. III. He holds a LWTR maintenance (Elect. &Avionics) for large aircraft and holds a B.Sc. In "Power& Electrical machines" from the Faculty of Engineering in Shoubra (Egypt) as well as a post graduate 2-years specialized diploma in information's systems and computers management (Egypt).

AMY BANN

Amy Bann serves in Boeing's environmental strategy group leading efforts to improve environmental performance across the aircraft product life cycle from manufacturing to emissions and end of service parts reuse and recycling. She has served in previous leadership roles at Boeing including Director of Environmental Policy focusing on sustainable biofuels commercialization and greenhouse gas emissions reduction, representing industry to global stakeholders and United Nations climate change agreement negotiations. Bann is a licensed attorney and worked in the public, private and nonprofit sectors prior to joining Boeing. Bann holds a Juris Doctorate from the University of Miami and a Bachelor / Master of Arts from Virginia Tech in Political Science / International Development.

THOMAS CUDDY

Thomas Cuddy is an Environmental Protection Specialist at the U.S. Federal Aviation Administration (FAA), and serves as the lead for the airport sustainability initiative. In this role, Tom promotes environmental principles and sustainability with industry and international partners through policies, airport infrastructure financing, and research and development. Over the course of his career, Tom has developed extensive knowledge of the environmental impacts of aviation ranging from noise and emissions to climate change issues and community involvement. Since 2010, Tom has served on ICAO's Airports and Operations working group, part of the Committee on Aviation Environmental Protection (CAEP). He has led FAA research studies on the implications of climate policies and market-based scenarios, and has worked with the U.S. Transportation Research Board on projects such as Climate Resilience and Benefit Cost Analysis, and Climate Adaptation Planning: Risk Assessment for Airports. His involvement in emerging technologies includes planning of spaceports and other commercial space transportation facilities, as well as assessments of sustainable alternative jet fuels. He has applied this expertise to special assignments with the White House Council on Environmental Quality, the U.S. Global Change Research Program, and other organizations.

RACHEL THOMPSON

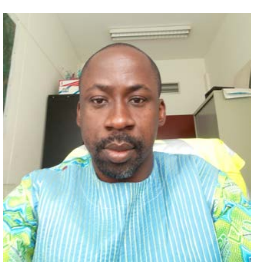
Rachel Thompson leads Gatwick's Decade of Change sustainability strategy and reporting. She also coordinates Gatwick's action plans on carbon and air quality. She is a member of Gatwick's Managing Corporate Responsibility Committee and chairs the Decade of Change working group. Prior to joining Gatwick in 2015, Rachel spent a decade in sustainability roles with a focus on technology, transport and retail sectors. Rachel began her career in Australia's Department of Foreign Affairs and Trade, specialising in international trade negotiations.

Chapter 9: States' Action Plans and Capacity-building

LARISSA PAMELA DIANGA NZENGUE

Larissa Pamela DIANGA NZENGUE is a civil engineer. She is graduated from the Masuku University of Sciences in Technical Sciences and in Mathematics and Physics.

She is the Head of the Environmental Protection Service at the National Civil Aviation Agency of Gabon (ANAC) where she works as a civil aviation inspector for aerodromes and ground aids (AGA). She is also the Gabonese focal point for the CO2 reduction emissions from aviation and national coordinator of the CORSIA.



MAZARIN HERVÉ MINTSA

Mazarin Hervé MINTSA is the Director Safety, Quality and Environment of Aéroports du Cameroun (ADC) SA, the Cameroon airport management company. He has an MSc in IT Engineering from National Advanced School of Engineering Yaoundé (Cameroon) and an MSc in IT Engineering and Air Traffic from ENAC (French civil Aviation University) Toulouse (France). His 16 years of experience in aviation includes Middle and Senior Management on the following areas: IT, Passenger Handling, Airport Construction and Maintenance, Aviation Safety, Quality and Environment.

Mazarin has been one of ADC SA focal point for the solar-at-gate project implementation at Douala International Airport. He is also currently working on the following projects: construction of a solar power plant of 30MW at Garoua International Airport, tree planting for ecological restoration at Garoua International Airport, and aerodrome certification of Yaounde-Nsimalen and Douala International Airport.

JUAN JOSE VERAS CUEVAS

Juan José Veras Cuevas was born on September 8, 1974 in Santo Domingo, Dominican Republic. Raised in Santo Domingo, and San Cristobal, Dominican Republic, received the diploma of Electrical Technician from Loyola Technical School in 1993, received the Airframe & Powerplant (A&P) license from Federal Aviation Administration in 2000, received the B.Sc. Degree (Electrical Engineering) from UNAPEC University in 2008.

In 2012, he transitioned to the role of national coordinator of emissions reduction resulted from international aviation activities, with the responsibility of preparing the first action plan on emissions reduction (APER) of the Dominican Republic. In 2014, participated in the ICAO-EU joint project on Capacity Building to Mitigate Emissions of International Aviation, working in the preparation of feasibility studies of alternative fuels, implementation of mitigation measures and integration of stakeholders of the aviation sector. In 2018 worked in the preparation of the regulatory framework for CORSIA in Dominican Republic (DR). Currently, Mr. Juan Veras, is an aviation safety inspector (Airworthiness) within the Flight Standards Directorate of the Dominican Institute of Civil Aviation.

DORSA SABET-RASEKH

Dorsa Sabet-Rasekh graduated from the Technological University of Panama as an Environmental Engineer and began work on climate change action in 2014 with research into managing small scale watersheds for climate change adaptation. She recently obtained a Master's Degree in Renewable Energy, and has also worked in quality control and environmental protection at an industry level. She currently works as an Emissions Analyst at the Civil Aviation Authority of Panama, where her primary tasks include the elaboration of carbon emission reports for international and domestic aviation and serving as the Focal Point between different aviation stakeholders. Her future plans include the pursuit of a specialization in global governance, and work around the social components of climate change awareness.

Chapter 10: Cooperation

JOYCE MSUYA

Joyce Msuya is the Deputy Executive Director of UN Environment. She was appointed by UN Secretary-General António Guterres in August 2018.

Between November 2018 and June 2019, Ms. Msuya served as Acting Executive Director, overseeing UN Environment's portfolio in 33 countries and administering nine Multilateral Environmental Agreements on critical environment issues.

Ms. Msuya has more than 20 years of extensive experience in international development strategy, operations, knowledge management and partnerships, across Africa, Asia and Latin America. Prior to joining UN Environment, Ms. Msuya served as Adviser to the World Bank's Vice President, East Asia and Pacific Region in Washington, D.C.

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 other previous roles, Gittens served as VicePresident, Airport Business Services for HNTB Corporation, where she led the firm's practice in airport business and strategic planning. And as Vice-President at TBI Airport Management, she oversaw the transition to private ownership of London Luton Airport and managed operations contracts at several airports in the US and Canada. Gittens is a Fellow of the Royal Aeronautical Society, and has served on numerous 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 Mineta Commission"), the Executive Committee of the Transportation Research Board, the Airport Cooperative Research Program Oversight Committee and the Board of Directors of JetBlue Airways.

SIMON HOCQUARD

Simon Hocquard, Director General, CANSO (Civil Air Navigation Services Organisation) was appointed on 1 July 2019. In leading and managing CANSO as the global voice of air traffic management, he is responsible for delivering CANSO strategies, expanding worldwide membership, and enhancing CANSO's relationship with its industry peers and stakeholders. Prior to this role, he was responsible for overseeing all CANSO operations globally to ensure CANSO fulfilled its commitments and deliverables in a timely, efficient and customer/partner focused manner.

Simon previously served at NATS, the UK air navigation service provider. His roles included Operations Director, Strategy and Director Operations, where he was accountable for creating and implementing the business, technical, operational strategies and vision for the entire regulated business. Previously he ran the largest air traffic control centre in Europe, leading 1,500 people through the successful air traffic management for the 2012 London Olympics and other change programmes.

Simon has significant experience of working with governments and international institutions. He is appointed by the European Commission as Chairman of the Network Management Board, which governs the overall European Air Traffic Network, and drives performance improvement across Europe as well as within EUROCONTROL.

ALEXANDRE DE JUNIAC

Alexandre de Juniac became the seventh person to lead the International Air Transport Association (IATA) when he took on the role of Director General and CEO from 1 September 2016. De Juniac has almost three decades of experience in both the private and public sectors. This includes senior positions in the airline and aerospace industries and the French government. De Juniac served as Chairman and CEO of Air France-KLM (2013-2016) and prior to that as Chairman and CEO of Air France (2011-2013). Under de Juniac's leadership Air France and Air France-KLM underwent a successful restructuring that improved efficiency and strengthened performance. He has also served on the IATA Board of Governors (2013-2016). De Juniac has broad aviation sector experience, including 14 years at French aerospace, space, defense, security and transportation company Thales, and its predecessor companies Thompson-CSF and Thompson SA (1995-2009). In his last position at Thales, de Juniac was responsible for the company's operations and sales in Asia, Africa, the Middle East and Latin America. De Juniac has also held positions in the French government. His career began with the Conseil d'Etat (State Council) from 1988 to 1993. Subsequently, he served in the Department of Budget (1993-1995); and in the Ministry of Economy, Industry and Employment as Chief of Staff to then Minister Christine Lagarde (2009-2011). A French citizen, de Juniac was born in 1962.

ERIC FANNING

Eric Fanning is President and CEO of the Aerospace Industries Association (AIA), the leading advocacy organization for the American aerospace and defense industry. In this role, Fanning also currently serves as the Chair of the International Coordinating Council of Aerospace Industries Associations (ICCAIA). Fanning joined AIA after serving as the 22nd Secretary of the U.S. Army, providing leadership and oversight of the nation's largest military service. He previously served as Chief of Staff to the Secretary of Defense, Acting Secretary of the Air Force and Under Secretary of the Air Force, and Deputy Under Secretary of the Navy/ Deputy Chief Management Officer. He is the only person to have held senior appointments in all three military departments and the Office of the Secretary of Defense.

During more than 25 years of service, Fanning worked on the staff of the House Armed Services Committee, was Senior Vice President of Strategic Development for Business Executives for National Security, was Deputy Director of the Commission on the Prevention of Weapons of Mass Destruction Proliferation and Terrorism, and was associate director of political affairs at the White House.

TIM JOHNSON

Tim is the Director of the UK-based Aviation Environment Federation (AEF), an NGO dedicated to tackling aviation's environmental impacts, and has nearly thirty years expertise in the aviation and environmental field. He is a lead representative for the International Coalition for Sustainable Aviation (ICSA) at ICAO's Committee on Aviation Environmental Protection (CAEP). He is a member of the UK Department for Transport's Airspace Strategy Board (ASB) and Noise and Airspace Engagement Group (ANEG), UK Sustainable Aviation's Advisory Panel and ACI's Airport Carbon Accreditation Advisory Board.

DIRK FORRISTER

Dirk Forrister is President and CEO of the International Emissions Trading Association (IETA), a non-profit business association dedicated to market-based climate policies. With 140 member companies, IETA is known globally as a thought leader in strategies to harness the power of markets to bring climate protection.

Dirk brings a long history of public and private sector engagement in energy and environmental policy. He spent a decade as Managing Director at Natsource LLC, the manager of carbon funds valued at $1.2 billion. Earlier in his career, Mr. Forrister served as Chairman of the White House Climate Change Task Force in the Clinton Administration, and Assistant U.S. Secretary of Energy for Congressional and Public Affairs.

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ICAO Environmental Publications

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
- Annex 16 to the Convention on International Civil Aviation — Environmental Protection, Volume IV — Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)

ICAO ENVIRONMENTAL TECHNICAL MANUAL

- Environmental Technical Manual Volume I — Procedures for the Noise Certification of Aircraft (Doc 9501, Vol I)
- Environmental Technical Manual Volume II — Procedures for the Emissions Certification of Aircraft Engines (Doc 9501, Vol II)
- Environmental Technical Manual, Volume III — Procedures for the CO_2 Emissions Certification of Aeroplanes (Doc 9501, Vol III)
- Environmental Technical Manual, Volume IV — Procedures for demonstrating compliance with the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) (Doc 9501, Vol IV)

ICAO GUIDANCE DOCUMENTS AND MANUALS

- Procedures for Air Navigation Services — Aircraft Operations (OPS) (Doc 8168 – 2nd edition, 2002)
- ICAO's Policies on Charges for Airports and Air Navigation Services (Doc 9082 – 9th edition, 2012)
- Airport Planning Manual, Part 2 — Land Use and Environmental Control (Doc 9184 – 3rd edition, 2002)
- Global Air Navigation Plan for CNS/ATM Systems (Doc 9750 – 5th edition, 2016)
- Guidance on the Balanced Approach to Aircraft Noise Management (Doc 9829 – 2nd edition, 2008)
- Guidance on Aircraft Emission Charges Related to Local Air Quality (Doc 9884 – 1st edition, 2007)
- Guidance on the Use of Emissions Trading for Aviation (Doc 9885 – 1st edition, 2008)
- Airport Air Quality Manual (Doc 9889 – 1st edition, 2011)
- Continuous Descent Operations (CDO) Manual (Doc 9931 – 1st edition, 2010)
- Guidance on the Development of States' Action Plans on CO_2 Emissions Reduction Activities (Doc 9988 – 3rd edition, 2019)
- Guidance on Environmental Assessment of Proposed Air Traffic Management Operational Changes (Doc 10031, 1st edition, 2014)
- Transforming Global Aviation Collection: Renewable Energy for Aviation (Published 2017)

- Transforming Global Aviation Collection: Financing Aviation Emissions Reductions (Published 2017)
- Transforming Global Aviation Collection: Regulatory and Organizational Framework to Address Aviation Emissions (Published 2017)
- Transforming Global Aviation Collection: Sustainable Aviation Fuels Guide, Version 2 (Published 2018)

REPORTS

- Independent Experts NOx Review and the Establishment of Medium and Long Term Technology Goals for NOx (Doc 9887 – Published 2008)
- Report of the High-level Meeting on International Aviation and Climate Change (Doc 9929 – Published 2010)
- Report to CAEP by the CAEP Noise Technology Independent Expert Panel. Aircraft Noise Technology Review and Medium and Long Term Noise Reductions Goals (Doc 9943 – Published 2010)
- Report on Voluntary Emissions Trading for Aviation (VETS Report) (Doc 9950 – Published 2010)
- Report of the Independent Experts to CAEP/8 on the Second NOx Review and the Establishment of Medium and Long Term Technology Goals for NOx (Doc 9953 – Published 2010)
- Report of the Independent Experts on the Medium and Long Term Goals for Aviation Fuel Burn Reduction from Technology (Doc 9963 – Published 2010)
- Report on Environmental Management System (EMS) Practices in the Aviation Sector (Doc 9968 – 1st edition, 2012)
- Report by the Second CAEP Noise Technology Independent Expert Panel (Doc 10017 – Published 2014)
- Final Report of the Independent Expert Operational Goals Group (IEOGG) (Doc 10021 – Published 2014)
- Final Report of the Independent Expert Integrated Technology Goals Assessment and Review for Engines and Aircraft (Doc 10127 – Published 2019)

CAEP Reports

- Report of the Committee on Aviation Environmental Protection, Eleventh Meeting Montréal, 1 – 12 February 2016 (Doc 10126, CAEP/11)
- 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)
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- ICAO Environmental Report, 2016
- ICAO Environmental Report, 2013
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- ICAO Environmental Report, 2007

STUDIES

- Noise Abatement Procedures: Review of Research, Development and Implementation Projects - Discussion of Survey Results (Doc 9888 – 1st edition, 2010)
- Recommended Method for Computing Noise Contours around Airports (Doc 9911 – 2nd edition, 2018)
- Scoping Study on the Application of Emissions Trading and Offsets for Local Air Quality in Aviation, First edition, 2011 (Doc 9948 – 1st edition, 2011.)
- Scoping Study of Issues Related to Linking "Open" Emissions Trading Systems Involving International Aviation, 2011 (Doc 9949 – 1st edition, 2011)
- Offsetting Emissions from the Aviation Sector (Doc 9951 – 1st edition, 2011)
- Operational Opportunities to Minimize Fuel Use and Reduce Emissions (Doc 10013 – 1st edition, 2014)

Feasibility Studies

- Feasibility Study on the use of Solar Energy at Piarco International Airport – Trinidad and Tobago (Published 2018)
- Feasibility Study on the use of Sustainable Aviation Fuels – Dominican Republic (Published 2017)
- Feasibility Study on the use of Sustainable Aviation Fuels – Trinidad and Tobago (Published 2017)
- Feasibility Study on the use of Sustainable Aviation Fuels – Burkina Faso (Published 2018)
- Feasibility Study on the use of Sustainable Aviation Fuels – Kenya (Published 2018)

ICAO CIRCULARS

- Effects of PANS-OPS Noise Abatement Departure Procedures on Noise and Gaseous Emissions (Cir 317 – Published 2008)
- Community Engagement for Aviation Environmental Management (Cir 351 – Published 2017)

ICAO E-PUBLICATIONS

- Eco-Airport e-collection: Waste Management at Airports
- Eco-Airport e-collection: An Environmental Management System for Airports
- Eco-Airport e-collection: A Focus on the production of renewable energy at the Airport site
- Eco-Airport e-collection: Eco-Design of Airport Buildings
- Global Air Traffic Management efficiency and the environmental impact of uncompensated traffic growth
- Environmental Community Engagement for Performance-Based Navigation
- Climate Adaptation Synthesis
- Aircraft end-of-life and recycling

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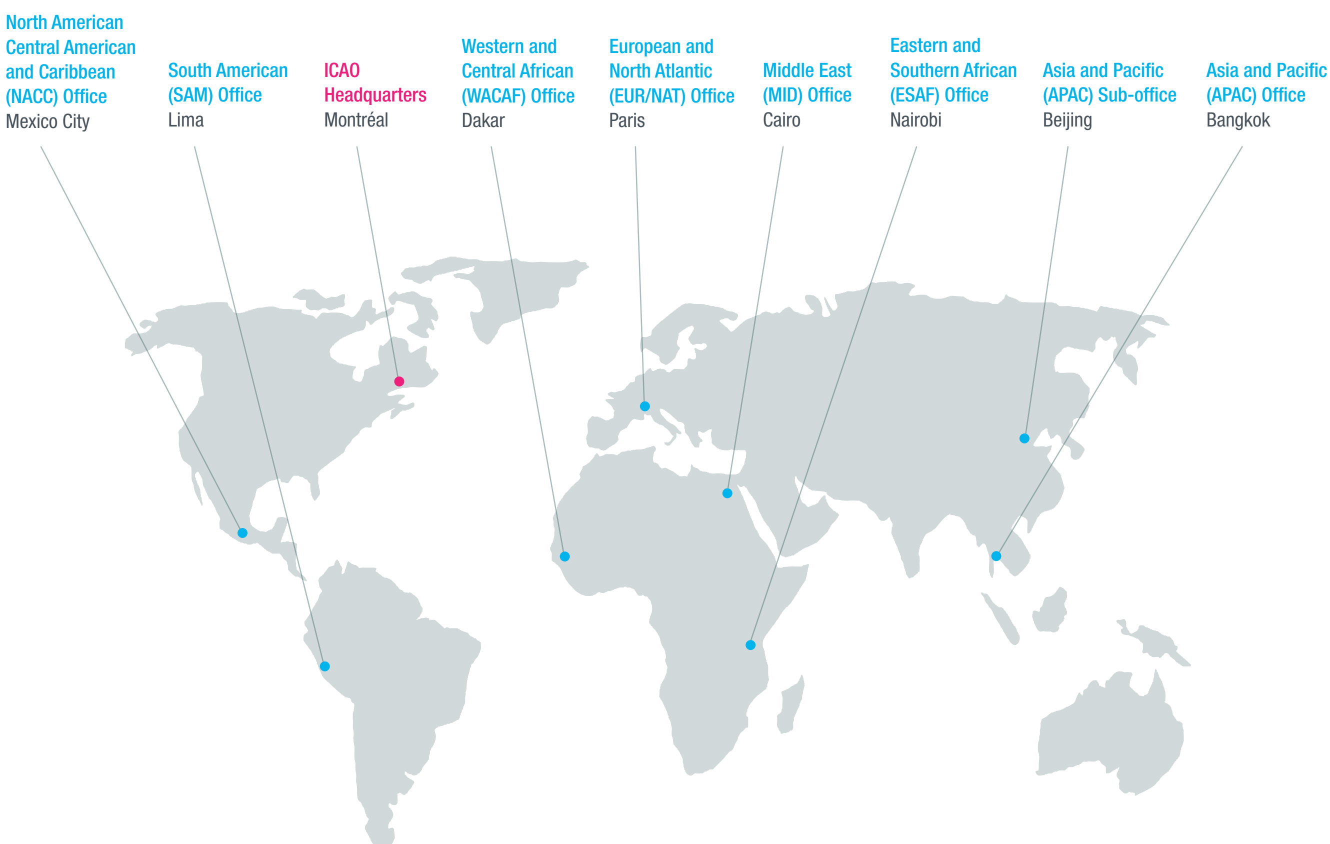

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