Greener by Design

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Front cover: Airbus’s Breakthrough Laminar Aircraft Demonstrator. (Airbus)
Welcome to the Greener by Design 2016-17 Annual Report.

What a difference 12 months can make! When I wrote last year’s report, there was no decision on extra runway capacity for the South East, nor any agreement in the aviation sector on how to tackle climate change. Now, less than 12 months later, we have decisions on both and in addition, leaving the European Union is another decision that impacts heavily on UK aviation. But first the extra runway.

In October last year the Government decided in favour of Heathrow, opting for the North-West runway option over the proposal to double the length of the existing North Runway. This seems to have been influenced by the opportunities for runway rotation (and thus pre-arranged respite from noise for local communities), as further work on the other differences has narrowed the gap between the two schemes. The other big consideration is air pollution, especially in light of the new focus in city streets on NOx emissions breaking EU limits too often. Heathrow Airport Ltd has already committed itself to replacing airside vehicles over the next few years with electric or ultra-low emission vehicles, together with a range of additional measures to improve air quality.

The second big decision, also in October, was agreement by all 191 ICAO states on a new Global Market Based Measure scheme, called CORSIA, as part of a basket of measures to contain aviation’s net CO2 emissions to the 2020 figure. While this scheme is not as strict as environmentalists would wish, it is an important first step and the first global agreement of its kind for any industrial sector. Airlines will have to buy internationally verified credits to offset the excess. Most States, notable exceptions being Russia and India, have signed up to the scheme from the start in 2019/2020, but it becomes mandatory for all states from 2027. The second afternoon session of our conference was devoted to GMBM (summarised in the Conference report), and more about the scheme and its implications can also be found in a special article on CORSIA and in the Technology section of this Annual Report.

The third big decision was the UK electorate’s view that we should leave the European Union. Although the detail is still being worked on, and all subject to negotiation with the EU, a couple of things are becoming clear. First there are going to be significant changes to entry requirements, both for EU citizens to the UK, and UK citizens travelling to the EU. As most travellers use airports, providing the space and time needed to check eligibility to travel is going to fall on airlines and immigration airport staff. This is bound to slow up the passenger flow, and substantially more space is going to be needed at the airport to handle the extra checks expeditiously.

Another aspect of this is that the UK may cease to be part of the EU ‘freedom to fly’ zone. If this happens, airlines wishing to fly anywhere in Europe may need to be based in the EU, and not
the UK. Flying to and from the UK would then be subject to a new agreement. Whether such agreement would permit flying between airports within Europe remains to be seen. So for airlines already based outside the UK, such as Ryanair and IAG (BA’s parent), there should be no problem. But for easyJet and Flybe it may be more complicated, and easyJet is already considering moving its HQ.

During the past year we are very pleased to have welcomed Jonathon Counsell to the Committee. He is Group Head of Sustainability for the International Airlines Group (IAG), owners of British Airways, Aer Lingus, Iberia, and Vueling. Jonathon brings a wealth of experience and has already made an impact by speaking at our recent conference.

After our successful two day conference last year, we are reverting to our traditional one day event, to be held this year on Thursday 12 October.

The subject is ‘Aircraft Noise – how can we build community tolerance’, and we are already lining up several interesting speakers. We are also holding an afternoon event with the Air Law Group on 1 November, on ‘Aviation’s global market based measure – CORSIA: progress and development’. Both will be very interesting events, and we look forward to welcoming you to them. They reinforce our view that Air Transport does not naturally become greener, but rather becomes Greener by Design.

Geoff Maynard
Chairman
Greener by Design
INTRODUCTION

The continued growth in aviation activity is regularly challenged on grounds of environmental sustainability. In contrast to our traditional one-day conference dealing with one particular aspect of aviation’s environmental performance and in recognition of the Society’s 150th anniversary, the 2016 conference was a two-day event under the title Delivering Sustainable Growth in Aviation.

The first day focussed on the local environmental impacts of growth, particularly noise and air quality, and was strongly linked to the UK government’s ongoing deliberations on possible growth in airport capacity. A government decision to support a third runway at Heathrow was subsequently announced in the week following the conference.

The second day concentrated on climate change effects and mitigation and included presentations and discussion on the global market-based measure CORSIA, very recently agreed at ICAO and critical to the aviation industry’s objective of carbon-neutral growth.

DAY 1 SESSION 1: NOISE – INDUSTRY DEVELOPMENTS

The conference opening session, Noise – Industry Developments, had speakers from Rolls-Royce, Airbus, Airport Operators Association and NATS. The concept adopted by ICAO in 2001, Resolution A33-7, of a balanced approach to noise management through four principal elements, namely reduction at source, land-use planning and management, operational procedures and operational restrictions, was a recurrent theme through their presentations.

Joe Walsh of Rolls-Royce outlined the progress that has been made in engine design and the dramatic changes there have been in the make-up of engine noise since the early days of the turbojet.

Relative to the ICAO Chaper 3 standard that was in effect until 2006, the cumulative noise rating of the large Rolls-Royce turbofans has fallen by 16EPNdB, from 15 below the standard in 1989 to 31 below in 2011.

Discussing the goals set by ACARE in Flightpath 2050, he made it clear that the target for noise is very challenging and will require contributions from operational improvements and aircraft design as well as further reductions in engine noise at source.

Ultrafan

He outlined the key features of the Ultrafan™, which combines further advances in turbine and nacelle design with the introduction of a gearbox ahead
of the intermediate compressor to drive a large diameter, variable pitch fan. In addition to reducing noise the Ultrafan, aimed to be ready for service by 2025, is expected to reduce CO₂ and NOₓ emissions respectively by about 10% and 30% relative to the latest engine, the Trent XWB on the A350.

**Environmental objectives trade-offs**

He illustrated the trade-offs between different environmental objectives and how technology can shift the balance: increasing engine pressure ratio to reduce fuel burn increases NOₓ emission, but this can be countered by the introduction of low NOₓ combustors; increasing bypass ratio to reduce noise can increase fuel burn by increasing the weight and drag of the nacelle, but this can be countered by advances in nacelle design.

Within the four elements of the ICAO balanced approach he emphasised that engine source noise reduction would remain a key element in controlling aircraft noise.

The role of the aircraft manufacture was set out by Pierre Lempereur of Airbus. His focus was on managing external noise within the ICAO regulatory framework.

**Noise regulation**

The current noise certification standard for large civil aircraft, Annex 16 Chapter 4, will be reduced by a further 7 EPNdB when Chapter 14 becomes effective from 31 December 2017. According to ICAO noise exposure modelling, a reduction of 3dB per decade starting in 2000 from the Chapter 4 level would ensure global sustainable growth to 2040, which would take the limit to 12dB below Chapter 4. Of the Airbus aircraft currently in production, the A380-800 is 16, the A320 NEO 19 and the A350XWB 21 EPNdB below the Chapter 4 limit.

He contrasted the problems of take-off noise, which is dominated by engine noise, primarily from the jet and the fan, with approach noise in which airframe noise from the landing gear and high lift devices exceeds engine noise, with the landing gear the dominant source. For recently certified aircraft there had been greater success in reducing take-off noise, mainly thanks to engine/nacelle integrated aero-acoustic design, than in reducing approach noise. To address the latter, Airbus is researching new slat/flap technologies and low noise landing gear design.

On operational procedures, Airbus has introduced a Noise Abatement Departure Procedure (NADP) into the flight management systems of the A380 and A350. The NADP algorithms take account of ambient conditions, airport constraints and areas to be protected and actual aircraft parameters in order to fly a noise optimised departure. On the approach, a continuous descent approach (CDA) with glide slope increased to 4° has been shown to reduce noise on the ground by between 4 and 5dBA.

**Noise footprints**

Peter O’Broin of the Airport Operators Association (AOA), discussed future noise footprints. One of the aims of AOA is to promote sustainable airport growth and make better use of existing capacity.
The challenge to NATS is therefore to involve all residents in a meaningful way throughout the design life cycle.

At the early stages of design the aim is to agree generic principles, objectives, requirements and design constraints. As design progresses, local factors are identified and a number of options are developed. In the final stages it becomes a matter of choosing between a small number of options that are understood in detail. Effective community engagement to bring stakeholders along the full design cycle is essential.

Noise nuisance

In the general discussion that followed, the speakers were asked whether, in each of their fields, there are limits to the further reductions in noise nuisance that will be achievable. The Rolls-Royce and Airbus speakers both thought that the experience of the past thirty years was that increasingly challenging targets had been set and met through continuously advancing technology. Neither could yet suggest a limiting level for future noise reduction. The perception of the AOA and NATS was slightly different. The airspace is indeed limited and, while there is scope for significant further reductions in noise impact, it is important to improve the dialogue with the community, to increase its appreciation on what has been achieved and to understand the importance of aviation to the community. The last issue discussed was the trade-off between the higher noise of large aircraft and the greater passenger load and therefore the less frequent movements of large aircraft. It was noted, however, that the approach noise of an aircraft such as the A380 is dominated by the airframe noise from the landing gear and high lift devices, and that there

Between 2006 and 2014-15, UK airports increased the proportion of operations using continuous descent approaches from 56% to 78%. The corresponding increase for departures was from 55% to 67%. Work continued on developing steeper approaches, to move the approach noise nearer the airport, and on reduced engine taxi to reduce both noise and emissions.

Land use planning, one of the components of the ICAO balanced approach, had proved less successful. The AOA has collected data to show that nationally, while the area within the 57dB LAeq 16 hour contour has reduced by 14%, the number of people living within the contour has increased by 4%. Within the contours for the UK’s 18 biggest airports, 5,761 homes have been granted planning permission, started or completed construction.

The need to modernise airspace, to educate stakeholders and communities on the need for this change and to establish a clear stable policy on airspace change, responsive to the needs of individual airports and local communities, is a key issue for AOA.

Airspace modernisation

The final paper of the session, by Harri Howells of NATS addressed the question of environmental consultation for airspace modernisation. While the current UK airspace structure is built to conventional navigation standards, with routes anchored on ground based NAVAIDS, most aircraft are now equipped to fly to Performance Based Navigation (PBN) standards. The programme to implement PBN in UK terminal areas would bring safety, capacity, CO₂ and net noise benefits, but the change would cause some people to be overflown more frequently.
are research programmes under Clean Sky which hold out the prospect of reducing noise from these sources.

**DAY 1 SESSION 2: MANAGING/REGULATING NOISE AT AIRPORTS**

The second session considered the management and regulation of noise around airports in other countries, how the issue is currently managed in the UK and how this might be improved in future. One speaker, Gunter Lanz the CEO of the Environment and Communication Center at Frankfurt Airport, was unable to attend but his presentation was made available to delegates.

Tim Abberton, Australia’s Deputy Aircraft Noise Ombudsman, spoke to the conference from Australia. The role of Aircraft Noise Ombudsman (ANO) was set up in 2010. He explained the key ingredients for successful engagement with the local community, gave examples of both success and failure and, from their experience, listed opportunities for the future.

**Noise complaints**

Successful engagement requires all issues to be taken seriously and annoyance cannot be measured in terms of decibels alone. Complaints must be handled effectively and information provided should be relevant, meaningful and accessible. The industry should fix the issues it can and explain those it cannot.

Small changes can, in some cases, be very positive to the community. Not recognising a complaint because it is outside a certain noise contour can generate a very negative reaction. A wide variety of noise/routing maps may be needed to understand an issue.

For the future, industry should engage actively, always checking for understanding. They should use various pathways to communicate, address fairness, build trust and be honest. It is best to identify annoyance issues rather than number of contacts or geography and reporting should be based on three categories – open issues that are active, open issues where consideration is deferred and issues that are closed.

The presentation from Alain Bourgin of DSNA, the NATS equivalent in France, explained that the growth in air transport and the increasing importance of its environmental sustainability had led to the creation of the Collaborative Environmental Management (CEM) initiative in France. CEM is a concept promoted by Eurocontrol aimed at reducing a wide range of environmental impacts and fuel usage through airspace and airport operational efficiency. The approach recognises that there are strong interdependencies and that compromises are needed to achieve a balanced result.

In France, CEM is a high-level collaboration between four organisations – representing airports, airlines, air traffic management (DSNA) and a single group representing local communities (UFCNA). UFCNA is promoted as the main contact for airport or air traffic issues and these four groups signed a national CEM in June 2015. They meet twice a year and have met twice since inception. Topics are agreed collectively and they focus on national opportunities for environmental efficiency, opening dialogue between local communities and the industry and explaining procedures and
environmental policies. The CEM has recently asked the opinion of UFCNA on noise concentration versus dispersion.

One example of the value of this approach is the airflow deflector modification of Airbus A320 aircraft designed to eliminate the ‘whistling’ sound first identified by a local residents association. Early feedback on the CEM is positive with references to improved understanding, acceptance of industry’s efforts, better awareness of the interdependencies and jointly agreed solutions.

The presentation provided by Gunter Lanz described the current organisation and approach to active noise abatement around Frankfurt airport, listed the criteria used to assess proposed noise mitigation measures, gave examples of measures that had been introduced and explained the approach being taken to research and future changes. It also summarised the support being given to communities with especially high noise exposure.

The Frankfurt approach

This approach at Frankfurt was developed following the decision to expand the airport and it depends on the voluntary co-operation of a wide range of stakeholders from the industry, local and regional authorities, NGOs and independent experts. All aspects are addressed (including emissions, routes and capacity) and proposals are evaluated against an agreed catalogue of criteria and principles.

Examples of measures already introduced include a 3.2° approach on the new North West runway, raising downwind legs by over 1,000ft, withdrawal of 737-300 and spreading of noise charges over 12 classes for arrivals and departures. A number of research projects are also underway. A one-off regional fund of about 250 million Euro is being
In the UK, the Secretary of State for Transport has the power to restrict operations and the Aerodrome Regulations (2003) implements the EU Directive. The DfT’s objective is “to limit and, where possible reduce, the number of people in the UK significantly affected by aircraft noise”.

The three main London airports report directly to the DfT on noise performance. Beyond these three designated airports noise regulation is left largely to local authorities who use the guidance provided by national, regional and international standards.

The CAA has some jurisdiction and expertise on noise through its management of air routes, monitoring of noise and production of noise maps at major airports. However, its primary concern will always be safety.

The Airports Commission has recommended the establishment of an independent aviation noise authority to oversee noise-related issues and disputes between local residents, airports and regulators. As NATS seeks to make airspace and air routes more efficient there are potential conflicts and trade-offs to be made between the objectives for emissions and noise reduction.

Chris Cain then outlined what the Strategic Aviation Special Interest Group of the Local Government Association (SASIG) want from a sustainable airport. SASIG’s local authority (LA) members cover some 20% of the population and the group provides a permanent annual fund of 4.5m Euro.

The Frankfurt experience suggests that active noise abatement measures are predominantly airport-specific but certain procedures and equipment are transferrable. Co-operation among the stakeholders is vital and a lot of patience is required.

Tim Coombs (RDC Aviation) then explained the current hierarchy of aviation noise regulations and, focussing on the UK, listed some of the changes that might be introduced following the report by the Airports Commission on airport capacity in South East England.

Aircraft Noise Certification

The United Nations, through ICAO, provides an international framework by setting Aircraft Noise Certification standards and recommending the four-pillared “balanced approach” to dealing with aircraft noise issues. The EU Directive 2002/30 is based on this approach. It defines indicators to be used, requires regular mapping of noise at large airports, provide a common approach to the setting of operating restrictions and guidance on rules for the withdrawal of the noisiest aircraft.

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A short discussion period closed the session. This allowed Alain Bourgin to clarify the national approach of the CEM initiative and also prompted a wider discussion of the merits of noise concentration over dispersion. SASIG is consulting its members on this issue and Chris Cain expects a broad response. Both newly affected residents and those who are routinely overflown will be sensitive and all will expect to see their interests given the same priority as those of industry. Responding to a question about the use of financial compensation for affected residents near some US airports, he doubted that noise impacts could be ‘bought-off’ and the priority should be to demonstrate the best solution. On the trade-off between emissions and noise reduction objectives, Chris Cain confirmed that LAs would obviously prioritise noise. Tim Coombs noted that major operators, such as easyjet at Edinburgh, wanted to be a good neighbour but also had wider environmental performance to consider.

DAY 1 SESSION 3: AIR QUALITY

With air quality and linked health effects attracting ever more attention, the conference session on air quality featured talks on the challenges of improving air quality in London, the broad programme of work under way with Sustainable Aviation members and a technology example of the way forward through eTaxi.

The rounded sector view on air quality context, sources and trends was given by Neil Robinson of Manchester Airports Group and a leading player in the Sustainable Aviation (SA) Group. The key urban pollutant challenges were for NO₂ and PM10 emissions resulting in the designation by government of several Air Quality management Areas but only one associated with a major hub airport, Heathrow. In this particular case, monitoring showed that while the contribution to NOₓ at the point of emission represented nearly half of monitored pollution, the airport source was down to 16% of the total at 1Km from the airport where non-airport traffic was the main source.

Many secondary issues, such as surface access and funding. Recent changes to planning law were unhelpful and some airports are now working with their LA to replace the policy structure lost when PPG 24 was withdrawn in 2013. He concluded with a plea for the industry to consider their contribution to the “circular economy” approach to sustainable development.
technologies for powering their infrastructure. The SA community is also working closely together to develop sustainable fuels, reduce taxi delays, use single-engine taxi and use fixed electrical ground power instead of APU's when on the apron. SA's partnership with government on air quality is aimed at improving surface access to airports, promoting research, expanding low emission vehicle roll-out and promoting a level policy playing field for alternative fuels for aviation alongside other uses. Through many initiatives the sector is showing its commitment to taking all possible steps to reduce emissions and improve air quality.

Reducing emissions

Providing an example of how technology can help to reduce emissions, Dr Craig Lawson of Cranfield University illustrated several eTaxi initiatives that are maturing. Alongside pollution reduction, eTaxi is estimated to offer up to 4% block fuel reduction for short haul sectors and achieve faster turnaround. It is also quieter than taxi with main engine power. The NOx reduction gains at larger hubs could be large with an average of 6% of fuel burnt on the ground but, citing the Heathrow case, some 56% of NOx was due to aircraft ground emissions. The Wheel Tug retrofit nose gear solution had been tested and a Safran-Honeywell Electric Green Taxi System and a TaxiBot tug system were being developed. At a lower level of technology readiness was an easyjet fuel cell taxi concept examined by Cranfield students. The sum of test and laboratory activity on the eTaxi area showed that it should soon be making a significant contribution to reducing airport NOx emissions.

Addressing the challenge of improving air quality in London, Sam Longman from TfL, echoed the key concerns of NO2 and PM10 and noted that long-term exposure across London was estimated to lead to 9,400 deaths per annum. Despite legal challenges related to compliance with EU NO2 standards and new government pollution control plans, compliance will not be until 2025 which placed considerable pressure upon all sectors to clean up. Road transport is the dominant contributor, at 50% while aviation is estimated at 8% of total source emissions with a hot spot around Heathrow. The Mayor’s action plan will progressively roll out low emission zones and clean up road traffic as well as a range of other actions that were the subject of consultations and new policy development.

In questioning, concerns were expressed about how the aviation proportion of emissions would grow as road transport was cleaned up. It was noted that Air Quality Management Plans bore upon all sectors and that airports were working strenuously to promote higher public transport access use. The potential of technology solutions such as eTaxi were welcomed but these should be accelerated to reduce the airport pollution contribution.
DAY 1 SESSION 4: REDUCING AND MITIGATING THE LOCAL IMPACTS

The final session on Day 1 allowed speakers from Heathrow, Gatwick and Manchester Airports Group to highlight what they were doing to reduce local impacts and improve engagement with the local community. A leading campaigner explained why this issue needs to be addressed.

Heathrow has gained much experience from this process. It is clear that the various stakeholders are still developing a common language and independent analysis of data is important to build trust. It also seems that, over a number of years, changes to aircraft and routes may have led to more concentrated noise patterns and slightly lower flightpaths for some departures. It is clear that more research is needed to understand what respite actually means to residents and that engagement is a difficult process but absolutely necessary.

GATWICK ARE ESTABLISHING A NOISE MANAGEMENT BOARD UNDER INDEPENDENT CHAIRMANSHIP AND COMPRISING REPRESENTATIVES FROM ALL PARTS OF INDUSTRY AND REPRESENTATIVES FROM LOCAL COUNCILS AND RESIDENTS GROUPS.

The first speaker was Matt Gorman from Heathrow. He gave the example of an airspace change trial in 2014 which led to a very large increase in complaints and a prompt return to the status-quo. This experience contributed to the creation of a Community Noise Forum (CNF) at Heathrow in 2015. The aim of the CNF is to be the focal point for stakeholder involvement in planning, consultation and communication of modernisation of Heathrow’s airspace. It is a key communications channel for Heathrow and NATS and allows local communities to feedback noise concerns to all industry players. It meets bi-monthly and members have agreed common principles of engagement.

In 2015 the CNF focussed on building trust in data systems, using independent verification. In 2016, it moved on to agree an action plan with five work-streams. These include changes to operating procedures, reducing the impact of night flights and building knowledge of research. The CNF also plans to look at the potential route design of one departure route.

Graham Lake then reported on the recent Independent Arrivals Review at Gatwick, its process, issues and lessons learnt. The review was established to understand whether more could be done to alleviate problems raised by local communities and whether the mechanisms the airport has been using to inform and manage complaints were adequate.

The review involved 45 meetings with a wide variety of local groups, MPs, industry and the Department for Transport (DfT) together with community feedback on sources of disturbance and preferred mitigation measures. A wide range of issues were considered, from airspace management to the role of social media, from A320 airframe noise to the co-ordination of communications between Gatwick, NATS, CAA and DfT.
He explained the actions being taken on a number of the review’s recommendations. Several use air traffic control routeings, tools and procedures to reduce noise or numbers disturbed and deliver a fair and equitable dispersal of noise. Examples include the proposed use of Performance Based Navigation (P-RNAV) to redesign approach routes, raising the point at which continuous descents start and the development of a new protocol for changing the landing direction for noise reasons. Gatwick are establishing a Noise Management Board under independent chairmanship and comprising representatives from all parts of industry and representatives from local councils and residents groups. They will also improve their complaints handling and procedures and strengthen their community engagement capability.

**People not decibels**

The experience of the Manchester Airports Group (MAG) was presented to the conference by Neil Robertson. He started by listing the range of local impacts that need to be considered and managed. Aircraft noise is top of the list and, although the noise footprint of aircraft is shrinking, it was the people disturbed that mattered, not the decibels measured. On consultation with the local community it was very important to speak openly, clearly and often and to really understand what matters to people. Building understanding and trust requires agreement on the facts. Information must be clear and easy to understand. This can lead to a wider conversation on sustainability as exemplified in MAG’s annual Corporate Social Responsibility Report.

He described an example of noise reduction through use of P-RNAV to concentrate the noise corridor of one departure route and, at the same time, avoid overflying the most densely populated areas. Introduced through public consultation, this change reduces the numbers affected by up to 85% and proves that new operational technology can be used to reduce local noise impacts.

The final speaker of the session was John Stewart, Chair of the Heathrow Association for the Control of Aircraft Noise. He focused on the benefits, for both residents and the industry, of dealing with local impacts. Quality-of-life and environmental benefits for local residents was balanced by reputational and economic benefits for the airport.

Noise is the key issue for communities. Many other issues raised are just proxies for this major concern. The issue will never go away entirely but John believed it can be mitigated through respite, good operational practices, quieter planes and an absence of night flights.

To achieve these all-round benefits requires an ongoing engagement between the airport, airlines and the local community. That, in turn, requires a progressive approach by industry managers and realism in community groups. If this fails the Government should provide a framework, including an Independent Noise Authority.

A panel of this session’s speakers then answered questions from the audience. These included a reference to the World Health Organisation review of noise and a general challenge to the current approach to this topic in aviation.
DAY 2 KEYNOTE ADDRESS

The second day began with a keynote presentation from Matthew Bell, Chief Executive of the Committee on Climate Change (CCC). The CCC is an independent, statutory body, set up under the Climate Change Act of 2008 to advise the UK Government on emissions targets and report to Parliament on progress. It is focussed on the UK’s greenhouse gas emissions and recommends a series of five-year carbon budgets that lead to the country’s commitment of reducing emissions by 80% in 2050 compared with 1990. The UK is well on track to meet this target having achieved a 38% reduction by 2015 and, at the same time, decoupling emissions from growth in GDP. The latest carbon budget to pass into law (2028-2032) shows a 57% reduction in 2030 compared with 1990.

UK aviation emissions are currently about 6% of the UK total. The CCC recommends that these emissions in 2050 should not exceed their 2005 level. Meeting this target should allow growth in activity of about 60% and developments such as an additional runway. UK aviation emissions were some 2 million tonnes below 2005 levels in 2014. Allowing aviation this target means that other sectors will need to reduce their emissions by 85% by 2050.

Although UK-focussed, the CCC welcomed the recent ICAO agreement as a useful first step towards the industry aim of carbon-neutral growth from 2020. Following recent international agreements, the CCC expects to update their detailed analysis of UK aviation in the near future.

Taking questions, Matthew Bell clarified that UK aviation emissions are those from domestic flights and the UK’s share of international flights and restated the CCC belief that the most cost-effective long-term use of low-carbon biofuels would be in the aviation sector.

Following the Government’s announcement of support for an additional runway in the week after our conference, the CCC called on Government to publish a strategic policy framework for UK aviation emissions which should include a plan to meet the recommended limit in 2050.

DAY 2 SESSION 5: REDUCING AVIATION CO₂

This session addressed some of the approaches the aviation industry is developing to reduce the amount of carbon dioxide released into the atmosphere. CO₂ reduction covers a broad range of possibilities from the use of biofuels to formation flying but this session chose to concentrate on developments in propulsion and aircraft design as well as the potential benefits from changes in air traffic management. The ACARE target for CO₂ reduction by 2050 is 75% of that released by new aircraft in 2000. The equivalent targets for NOₓ reduction and noise alleviation are equally demanding at 90% and 65% respectively.

Hence solutions for decreasing CO₂ emissions should not be at the expense of increasing other adverse environmental effects. There were four presentations delivered by representatives from Rolls-Royce, Airbus, Boeing, and NATS.

Reducing CO₂ by design

Phil Curnock, Chief Engineer, Future Programmes for Rolls-Royce described the advances in CO₂ reduction his company is making by developing future engines with improved thermal and propulsion efficiencies. By 2050 Rolls-Royce are aiming for a CO₂ reduction of 30% and around 12% has already been achieved by the introduction of the
as a training aircraft while the long term vision for Airbus is centred on hybrid propulsion helicopters, distributed hybrid-propulsion air transport aircraft (E-Thrust Project) and large transport aircraft incorporating boundary layer ingestion. The key specifications for E-Fan 2 are a take-off weight of under 600 kg, an endurance of one hour plus a thirty minute reserve and a maximum take-off power of 44kw, supplied by two motors. It is in the areas of battery power and weight where developments are most needed and E-Fan 2 is designed to be compatible with the expected next generation of batteries. In the view of the speaker, it seems most likely that transport aircraft with hybrid propulsion will be the route taken to reduce CO2 by 75% and the challenge of the E-Fan project is not to sell aircraft but to gain experience in manufacturing, certification and flying electrically powered aircraft.

Looking to the next generation of aircraft, Dr Naveed Hussain, Vice President, Aeromechanics Technology, Boeing Research and Technology presented concepts that Boeing are investigating as a means to meet targets for CO2 emissions and noise. His first example was a transonic transport aircraft with a swept, truss-braced wing mounted on the top of its fuselage. The use of truss bracing is not novel but their application in the transonic regime is new. Bracing permits the fitting of longer span wings with higher aspect ratios giving rise to lower drag and lower structural weight. This is a joint project with a number of partners including NASA and Rolls-Royce. Boeing and Rolls-Royce are investigating hybrid propulsion systems for this aircraft including the possibility of boundary layer ingestion at the rear of the fuselage.
Dr Naveed’s second example was a blended wing body concept which has been tested in flight at reduced scale. The blended wing body design has been around for some time but Boeing, in collaboration with NASA, is studying in great detail the practicality of such a layout. There are both structural and aerodynamic challenges and Boeing has carried out design studies for non-round, pressurised fuselages as well as wide-ranging wind tunnel and computational studies of the aerodynamic performance. The engines are located on top of the aircraft to provide attenuation of the noise experienced on the ground. A significant feature of the Boeing study is that, in collaboration with Cranfield Aerospace, flying scale models have been constructed and subjected to extensive flight trials. The trials have been successful and demonstrate that a blended wing body has good handling qualities. While it was stated that this design concept offers large improvements in fuel burn efficiency, the speaker offered qualitative rather than quantitative data on expected CO₂ reduction.

Air traffic environment management

While other speakers in the session had concentrated on how CO₂ emissions could be reduced by innovations in engine and airframe design, Dr Jarlath Molloy described how advances in the way air traffic is managed can also produce reductions. Dr Molloy is the Environmental Affairs Manager for NATS, the UK air traffic service provider. NATS mission is to keep the skies safe and deliver the best possible customer experience while at the same time minimising environmental impacts. It set itself a target of reducing CO₂ emissions by an average of 10% per flight from a 2006 baseline by 2020, solely on improvements to air traffic management within its sphere of influence.

A number of advancements have been introduced since 2009 including improvements to continuous climb and descent operations and time-based separation on descents into Heathrow. The speaker included a video in his presentation to illustrate how airspace management is evolving to meet requirements to reduce noise and emissions. Progress to date is showing a 5% reduction in CO₂ emissions representing cumulative savings of 7.6 tons of CO₂ and £1.4 billion in airline fuel bills. The challenge ahead for NATS is to find a further 5% reduction to close the gap to 10%. The speaker said that presently NATS did not have a clear view on how to close this gap and is searching for new ideas.

In the discussion that followed, delegates questioned the cost and feasibility of developing radical technologies and the realism of forecast improvements in performance. The speakers emphasised the value of looking for radical long-term solutions as many lessons from this research will be used in new products in the near term and the approach continues to deliver improved fuel efficiency. In answer to a specific question on the slower airspeed of the truss-braced wing design, Dr Hussain confirmed that his presentation was based on a mach 0.75 version but that there is also a mach 0.85 version which remains far more fuel efficient than current wing designs.
Notoriously uncertain, significant recent advances in understanding have been made. Aerosols have emerged as a major issue/uncertainty.

He described how the REACT4C research project explored different ways of reducing aviation’s combined CO2 and NCE. Possible approaches using the present fleet include either generic changes to flight altitude or operational (day-by-day) changes to both altitude and route to avoid the most “climate unfriendly” routes. The current system approximates minimum fuel use and therefore minimum CO2 emissions. The aim of the new approaches is to offset any increased CO2 emissions of flying the route with decreases in the NCE climate effects. This is exploratory research and the methodology presents many scientific, legislative, financial and operational challenges. Nevertheless, if proven it could be applied using the present fleet and without changes to the airport infrastructure (which would be needed in some other proposed mitigation approaches).

Ross Walker from Airbus outlined the four pillars of the Airbus environmental response focussing on sustainable JET A1. The basic concept of sustainable JET A1 is that of “short cutting mother-nature and sucking carbon directly out of the atmosphere”.

Radiative forcing (RF) is the perturbation of the planetary radiation budget, in W m⁻², and that the temperature change is proportional to the radiative forcing. Using the table from Lee et al. (Atmospheric Environment, 2010) as a reference he showed that non-CO2 emissions (NCE) are major contributors to aviation’s total climate impact. While aviation CO2 RF (about 30 mW m⁻²) represents about 1.6% of the total CO2 forcing from all human activities (and is growing), when NCE are included, aviation contributes between 1.3 and 14% of the total radiative forcing due to human activities.

He explained that NCE are very different from CO2, being generally short lived (hours to months) and that climate effect depends sensitively on where and when the emissions occur. He then reviewed each of the main constituents of NCE in turn, namely NOx, contrails and contrail cirrus, water vapour and aerosols. While the impact of NCEs has been notoriously uncertain, significant recent advances in understanding have been made. Aerosols have emerged as a major issue/uncertainty.

Importance of NCE

First off was Professor Keith Shine, Regius Professor of Meteorology and Climate Science at the University of Reading. He explained that radiative forcing (RF) is the perturbation of the planetary radiation budget, in W m⁻², and that the temperature change is proportional to the radiative forcing. Using the table from Lee et al. (Atmospheric Environment, 2010) as a reference he showed that non-CO2 emissions (NCE) are major contributors to aviation’s total climate impact. While aviation CO2 RF (about 30 mW m⁻²) represents about 1.6% of the total CO2 forcing from all human activities (and is growing), when NCE are included, aviation contributes between 1.3 and 14% of the total radiative forcing due to human activities.

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The sixth session of the conference was dedicated to exploring some radical ways of reducing aviation’s environmental impact.

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planned to be certified in the next few years. These range from lipid based fuels such as HEFA, through lignocellulosic based fuels to JET derived from sugar based alcohols. The carbon emissions per unit of energy for each technology and feedstock combination can vary with location and local supply is sought so as to minimise transportation costs. Each type of sustainable jet fuel can have a distinct carbon profile, which can be addressed by adding supplements such as aromatics but limiting the blend to say 50/50.

**Target 2050**

Finally, Professor Ian Poll of Cranfield University assessed the overall climate change impact of aviation and sought to determine what needed to be done to reach a satisfactory solution by 2050. He expressed concern that reliance on Global Market Based Measures (GMBM) was a hostage to fortune for the aviation industry, leaving it open to criticism and arbitrary regulation.

He considered that an environmentally optimum aircraft should have minimum fuel burn and create no contrails. He identified a number of constraints preventing the use of minimum fuel burn aircraft, including the length of a typical runway around the world (1,500m) and airport terminal design which drive the design away from the minimum fuel burn condition and put it in the moist air (making contrail / contrail-cirrus creation more likely).

He suggested that the key measure to focus on is the Energy To Revenue Work (ETRW) ratio. ETRW for the total fleet is currently about 1.2 but only about 0.6 for the optimum aircraft implying a 100% wastage in the current overall system.

The fuel wastage is due to inefficient use of existing technology, but ICAO have only acknowledged a tiny fraction of this issue. Prof Poll considered that improved operational efficiency may not need expensive technology. Improvements can start today and can be applied to the whole fleet, with a potential benefit that is very large. Combining fleet replacement with complete wastage removal could remove the need for GMBM.

The issues that he identified as needing to be addressed included better load factors, better matching of aircraft to routes, better integration of passengers and cargo, more flexible and more efficient ATM, use of the prevailing winds (truly optimised routing) and minimum fuel burn trajectories for flights of less than 1,000km.

In the discussion that followed, a number of questioners grappled with Ian Poll’s thesis without being able to challenge it. Keith Shine stated that there are some steps that first need to be taken in the virtual world before seeking to trial or implement a solution to NCE impact. In particular, it is important to establish that the ability exists to predict weather with sufficient accuracy. Ross Walker observed that the lower level of penetration of sustainable JET A1 fuel currently, as compared to forecasts eight years ago, is primarily due to the significant fall in the oil price.
DAY 2 AFTERNOON SESSION
Global Market Based Measures (GMBM)

The afternoon session was devoted to GMBM, with six speakers exploring various aspects of this new subject.

First was Geoff Maynard, Chairman of GBD, who attempted to answer four questions about GMBM

ICAO - Global Market Based Measures scheme (CORSIA) agreed 7 October 2016

Why?
The UNFCC (United Nations Framework Climate Change Committee) is tasked with reducing atmospheric CO₂ to limit climate change to 2 degrees Centigrade (1.5 ideally). It has asked all states to submit national reduction plans, to include domestic aviation. International aviation is the responsibility of ICAO, and this GMBM scheme is to help international aviation meet its target.

What is it?
A scheme under which almost all airlines will need to purchase carbon credits to offset the global increase in aviation CO₂ emissions. These credits will come from non-aviation sources. It has been named CORSIA – Carbon Offsetting and Reduction Scheme for International Aviation

How does it work?
If the states at both ends of a route have joined then all flights between those states are included. All states, irrespective of whether they have joined, must report all international aviation emissions each year to ICAO. It can then calculate by how much emissions have increased compared to the base year (2020), and this percentage increase is then applied to all actual airline emissions for the year to determine the credits airlines need to purchase. So all emissions over the 2020 baseline will be offset.

When?
The base year is 2019/2020, and the scheme starts in 2021, becoming compulsory in 2027. States covering 87% of international aviation emissions have already signed. There are exemptions for very small states and very small airlines.

A lively question and answer session followed, which drew attention to the three biggest states that have not signed up yet being Brazil, India and Russia.

The second speaker was Michel Adam, IATA’s manager for Environmental Policy, on ‘Why GMBM is right for Aviation’

Around 2% of human induced CO₂ comes from aviation, and despite very significant (70%) efficiency improvements, these had been outstripped by aviation’s growth. Recognising the problem, in 2009 three goals were adopted: 1.5% annual average fuel efficiency improvement, a 50% cut in emissions by 2050 and Carbon neutral growth from 2020. Efficiency improvements (technical, operational and infrastructure) will be insufficient to meet these targets, so GMBM is strongly supported as a ‘gap filler’.

A World answer
It is also being supported for administrative and legal reasons: many airlines fly to 100+ different countries and it is difficult to keep track of all the regulations. Some schemes only apply to national airlines, and for others (European Energy Efficiency Directive) it is not clear whether they apply to international airlines or not. For small airlines, with fewer resources, it is close on impossible. Portugal proposed a CO₂ tax, and then withdrew it; Sweden is planning a Green Tax; Norway an Airport Passenger Departure tax similar to the UK; and a CO₂ tax has been recently introduced in South Africa – but only for local airlines. Some schemes are more complicated – Columbia has introduced an offsetting scheme for air passengers to fund their National Parks. So there is strong recognition we need a single international scheme supported by every country.

Critics have said Carbon Neutral Growth by 2020 is not an ambitious enough target. But all ICAO’s 191 states need to agree, and some such as China are resisting. So there is a practical limit to what can be achieved quickly. IATA’s members welcome GMBM and look forward to this being the scheme to offset growth in CO₂ emissions.

The third speaker was Jonathon Counsell, Group Head of Sustainability for International Airlines Group (IAG), who spoke on ‘What does GMBM mean for the airlines’.

The group is profitable and comprises four airlines: British Airways, Iberia, Aer Lingus and Vueling.
Many airlines recognised the need several years ago for improved environmental performance: BA had committed to a 10% reduction in both Carbon and Noise by 2020. UK airlines contributed to Sustainable Aviation’s report showing how UK aviation can cut CO₂ by 50% by 2050 through changes in operations, technology, using alternative fuels and emissions trading.

Airlines welcome GMBM because a global industry needs a global scheme. GMBM will help avoid a patchwork of local schemes, involving higher costs for the airlines and reduced environmental effects, because the main focus is on governments raising money.

After the 1992 Rio Earth summit, ICAO in 1997 was mandated to devise a CO₂ reduction scheme. The objective of carbon neutral growth by 2020 was agreed in 2010, and in 2012 the EU Emissions Trading Scheme started. Although it was controversial (the Chinese cancelling all their Airbus orders) it maintained the pressure, and in 2013 ICAO agreed a MBM scheme was needed.

CORSIA is based on excess emissions over the 2020 baseline, and is not an emissions trading scheme. The developing/developed nations argument has been solved by starting with a sector-wide (not individual airline) scheme. Excess emissions will be paid for at an industry average rate, avoiding rapidly growing countries meeting most of the bill. It is a simple equitable scheme, and from 2029 the scheme will include an element of individual airline growth to calculate operators’ emissions offset requirements.

The cost depends on the carbon price, but could be $24bn per annum by 2035 (1.5% of airline revenues). Work has started on the detail of scheme administration.

**Will the Market provide?**

The fourth speaker was Tim Johnson, Director of the Aviation Environment Federation, on the Strengths and Weaknesses of Market based Measures.

He opened with a stark choice for airlines: either adopt MBM or be forced into demand management, as the only other possible avenue (biofuels) is impractical because of the volumes needed (8bnT per annum by 2040). Ideally carbon should be reduced within the industry, but failing that an effective MBM is an interim solution. The world target for 2100 is net carbon zero: the Committee on Climate Change (UNFCCC) is planning deeper cuts and also is looking at non-CO₂ effects.
During questions, it was suggested historic permits may have to be declared void, and that the scheme did not go far enough. Tim felt MBM was a valuable first step and that as all Governments fully understood MBM, it could be tightened.

The fifth speaker was Margaret Ann Splawn, Executive Director of Climate Markets and Investment Association who spoke on the Impact of the Carbon Markets on Aviation’s Global market Based Measure.

CMIA is an independent not for profit organisation, providing leadership to the private sector in the delivery of climate investment policy and advice on carbon markets, with observer status at UNFCCC.

**Carbon markets**

Carbon markets were established to reduce greenhouse gas emissions. 40 national and 22 sub national jurisdictions have or are about to establish carbon pricing, with 22 having emissions trading schemes (ETS), valued in total at $30-50bn.

CORSIA is a good start, although not as strict as some hoped. It is not an ETS scheme. It will purchase around 3bn of CO₂ credits between 2021 and 2035, increasing airline costs by up to 0.8%.

Currently the only UN certified credits come from the UN Clean Development mechanism, which has plenty of credits at around $0.5 per tonne. With the Paris Agreement, additional UN certified credits will be available. Credits purchased under GMBM will fund emission reduction schemes at big industrial plants, such as chemical works. The shipping industry kept some of the money ‘in house’, by developing a new coating for ships hulls which cuts fuel consumption (Intersleek). Something similar could be considered for aviation.

Regulatory control is important: In house (the current favourite) gives greater security offset by the time needed to establish a secretariat and its costs. Margaret also recommended using existing certification and monitoring schemes: why duplicate with significant cost implications?

CIMA recommends using existing infrastructure wherever possible, integration of CORSIA with internal flights, keeping some funds for low carbon

**UNFCCC has five criteria for MBM schemes:**

Timing, Stringency, High Quality Credits, Ambition, Coverage

By developing offset criteria (real additional CO₂ savings, permanent CO₂ reduction, and verifiable savings) the stringency requirements can be met. Aviation may also be allowed to buy from other Emissions Trading schemes.

Sufficient offsets are available now, but the key is environmental integrity and sustainability. Tim’s view was that if the demand exists, there will be adequate supply in the future.

CORSIA’s positive aspects: three-year review clause enables inclusion of the more stringent Paris Agreement; harmonised decision making facilitates uniform rules on acceptable schemes; and the explicit text on double counting makes it harder for national schemes to be counted twice (towards Paris target and as airline offset).

Negative aspects: Carbon Neutral Growth is not being achieved, as while 87% of activity is covered, only 76-78% of international aviation emissions are covered. Offset criteria are under development but not yet available.
investment within the sector, and to gradually tighten CORSIA to achieve greater carbon reduction, so it can be a force for good.

The final speaker was Professor Andreas Schäfer of University College London, who spoke on the commercial and economic impacts of the MBM scheme.

To assess the economic impact four aspects need to be examined: demand for air transport; potential for further reduction in fuel burn per seat km; carbon price; and how much of the carbon cost will be passed to consumers.

Aviation demand is strong, with revenue tonne km forecast to double by 2035, and since 1970 a growth rate 7.4% per annum, with a ¾ reduction in fuel burn. Andreas has examined some 20 future measures to reduce fuel consumption, and their associated costs, to help forecast future trends.

In a closed trading system, very high carbon prices would result, but currently prices are very low, albeit likely to rise as the supply of potential abatement schemes subsides. Some researchers have suggested much higher prices. There are two possible extremes: where all costs are passed to the consumer (no cost to airlines), which will suppress demand; or where all costs are borne by the airlines, which results in no change to demand, but higher airline costs. The actual result depends on the slope of demand and the supply curve in a competitive market.

If the carbon price remains low, economic implications will be minor. Following the Paris Agreement, prices may rise, and GMBM can be used to buy time while efforts intensify to reduce fuel use. An integrated model (currently under construction) is needed to analyse the feedback between supply and demand. However other effects could have a greater impact, such as oil price rises, terrorism and automated vehicles competing for short haul air traffic.

A panel discussion followed, at which several questioners thought there were insufficient carbon reduction schemes to supply the aviation industry. The panel felt that the carbon price, although low at present, should increase over time. On the subject of biofuels it was noted that UK government is expected to consult on allowing aviation fuel into the broader Renewable Transport Fuel Obligations mechanism.
Sustainable Aviation was established in 2005 and is a not for profit coalition which develops practical and policy solutions for cleaner, quieter and smarter flying, to enable the sustainable development of air transport in the UK.

Sustainable Aviation is the first initiative in the world to bring the whole industry – airlines, aircraft and engine manufacturers, airports and air traffic managers – together as part of a formal strategy. The biggest challenges that we face will only be solved by the different parts of the aviation industry working together to identify opportunities and improve performance. We focus our efforts on issues that rely on collaboration for success. We set long-term goals and agree priority areas of work to deliver these, reporting on progress every two years.

Sustainable Aviation engages regularly with policy-makers and opinion formers to communicate its work and to understand their priorities. We aim to be a trusted and credible source of information on sustainability issues. While Sustainable Aviation focuses on the UK, its work nonetheless takes place in a global context. UK aviation has a global reach and our aspiration is that Sustainable Aviation plays a leading role globally in efforts to tackle the industry’s environmental impacts.

Our work in 2016

2016 marked the start of Sustainable Aviation’s second decade and the organisation maintains its commitment to support the UK aviation industry in developing sustainably: maximising the economic and social benefits of air transport, while removing or minimising any negative impacts on the local and global environment.

In addition to our ongoing work to raise awareness of Sustainable Aviation’s work with policymakers and stakeholders, there were three key activities for Sustainable Aviation in 2016:

- Reviewing and updating the CO₂ road-map
- Producing a briefing paper on UK aviation’s contribution to air quality emissions
- Continuing to advance the development and use of sustainable aviation fuels

Reviewing and updating the CO₂ road-map

The 2016 CO₂ Road-Map sets out Sustainable Aviation’s latest view of the likely trajectory of UK aviation’s CO₂ emissions to 2050. It takes into account expected growth in UK aviation activity in
the coming decades and explores the likely impact of a number of CO₂ mitigation measures.

Although Sustainable Aviation had published earlier editions of its CO₂ Road-Map in 2008 and 2012 respectively, the 2016 edition additionally takes account of a number of significant recent developments. These include a more detailed analysis of the availability of new technology, a more detailed assessment of freighter aircraft operations, the agreement at the international level of a certification standard for aircraft fuel-efficiency and of a market-based measures scheme for CO₂ emissions from international aviation. It also includes the assessment by the UK’s Airports Commission of specific options for additional runway capacity in the South-East of England, and publication of aviation demand growth forecasts reflecting each of those options. Further developments include the announcement and imminent entry into service of several new aircraft types offering substantial efficiency improvements over their respective predecessors, and the certification for commercial use of three new classes of alternative fuel for aviation.

The CO₂ Road-Map shows that UK aviation can accommodate significant growth to 2050, including the effect of additional runway capacity in the South East of England, without a substantial increase in CO₂ emissions. It also shows that by 2050, UK aviation’s CO₂ emissions are expected to be broadly in line with levels recommended by the Committee on Climate Change, with further reductions in UK aviation’s carbon intensity expected post-2050.

A briefing paper on UK aviation’s contribution to air quality emissions

SA has a long-standing goal to ensure that the industry plays its full part in improving air quality around airports. With increasing interest in air quality among both society and policy makers, in early 2016 SA established an Air Quality Working Group. The group’s initial task was to produce a paper on aviation’s contribution to air quality emissions to help inform the debate. Using an objective and evidence-based approach, it sets out the emissions from aviation, how they impact air quality at and around airports and how the industry
is responding to the challenge of minimising emissions.

In reviewing UK air quality emissions, it was clear that nationally, emissions of key air pollutants are falling and are below Government’s legally binding emission ‘ceilings’, however some ‘hotspots’ remain and there is more that can be done. Across the UK over 600 locations have been identified by local authorities where health-based air quality objectives are, or are projected to not be met. Importantly for aviation though, just one UK airport is located within any of these. The pollutants of most concern are small particulate matter (PM) and oxides of nitrogen (NOx), in particular one constituent of NOx, nitrogen dioxide (NO2). Road transport is the emission source of greatest concern, with emissions at airports contributing a relatively small proportion of overall UK emissions and with aircraft only contributing around 1% of UK NOx emissions and 0.1% of UK PM10 emissions.

For emissions on airport, inventories of emission sources are taken which have resulted in the following pie charts, based on the most recent studies.

For airports, which are generally located outside of cities, aircraft operations are the most significant source of on site emissions, with support vehicles and equipment, as well as vehicles accessing the airport also contributing.

The industry is prioritising its work to cut emissions across a wide range of areas:

- **Developing cleaner aircraft** – Working through the European Strategic Research and Innovation Agenda (SRIA) aerospace manufacturers are making progress to achieving the 2050 target of a 90% cut in NOx emissions compared to the performance levels of new aircraft in 2000.

- **Developing cleaner fuels** – Measurements suggest that Sustainable aviation fuels can reduce particulate matter emissions by 60% or more compared to current fossil based Jet A1 fuel.

- **Smarter aircraft operations** – SA, through the operational improvement group is exploring how to increase the use of reduced engine taxi where safe to do so and ensuring aircraft are connected to ground electric supply and pre-conditioned air equipment while parked at airports where available, helping to further reduce ground level emissions from aircraft.

- **Championing airspace modernisation** – SA is supporting the modernisation of UK airspace to enable smoother flight profiles for take-off, climb, approach and landing including continuous descent approaches and continuous climb departures; as well as using a wide range of real-time flight information intelligently to reduce delays.

On-airport emission sources for oxides of nitrogen (NOX, left) and particulate matter (PM10, right), based on emission inventories for Gatwick (2010) and Heathrow (2013) airports

A Song Ultralight motor glider, a single seat ultralight motor glider.
Sustainable Aviation

- **Smarter ground operations** - SA members are working on many initiatives, from introducing low emission vehicles to car sharing schemes and driver training on airport.

- **Smarter surface access to airports** - Airports are working closely with their business partners and local Governments to improve surface access links to their airport to enable staff and passengers to make the best use of public transport links.

The SA paper also includes a range of case studies demonstrating the progress being made in reducing emissions. The paper concludes by identifying four key areas where SA believes there are opportunities for Government to improve the policy support to enable the industry to drive further emission reductions, these are:

- Focussing on road transport and helping to improve surface access to airports;

- Expanding low emission vehicle policy support to specialist airport vehicles;

- Providing policy certainty so that the private sector will invest in alternative aviation fuels (including the extension of the Renewable Transport Fuel Obligation to jet fuel); and,

- Ensuring that research and development programmes continue to be supported during and after the process of the UK leaving the European Union to continue the excellent work we have underway.

**Continuing to advance the development and use of sustainable aviation fuels**

In 2014, SA commissioned E4tech to conduct a study on the potential for the development of sustainable aviation fuels in the UK. This was incorporated into our sustainable aviation fuels Road-Map which highlighted a great potential for the UK; specifically:

- The UK could have between 5 and 12 operational plants producing sustainable fuels by 2030.

- The UK could generate a Gross Value Added (GVA) of up to £265 million in 2030 through the production of sustainable fuels.

- Developing a sustainable fuel industry in the UK could support up to 3,400 direct jobs, and a further 1,000 jobs could be generated in global exports.
Sustainable fuels can contribute 24% CO₂ emissions savings in the UK aviation sector by 2050 as indicated by the CO₂ Roadmap.

To enable this potential SA highlighted three key policy areas which required Government support:

- Create a level playing-field for aviation by allowing sustainable fuel producers to claim Renewable Transport Fuels Obligation certificates for aviation fuels to bring these in line with road transport fuels.

- Assist project finance through existing institutions such as the Green Investment Bank, which involves the Government underwriting risk at different development stages.

- Give priority to dedicated research and development (R&D) into sustainable fuels. Some countries are already providing R&D support for new feedstock sources and processing technologies to reduce fuel cost.

Since 2014, SA has continued to work with the industry and the Government to advance the policy issues highlighted above and there are real signs of progress on two of the issues.

Firstly, in November 2016 the Government launched a consultation recommending the inclusion of sustainable aviation fuels into the Renewable Transport Fuel Obligation (RTFO). This is a great step forwards and Sustainable Aviation is now in discussion with the Government to ensure the full potential of 640,000 tonnes of sustainable aviation fuel by 2030.

Secondly, SA has been in discussion with the Knowledge Transfer Network and Innovate UK to explore the potential for a joint industry, academia and Government group. There would be three key objectives of this group:

- To enable sustainable aviation fuel development in the UK to advance to commercial scale deployment through multi-disciplinary science and technology-inspired innovation and certification;

- To create multi-disciplinary approaches to deliver the development of new sustainable fuels and to ensure that the environmental and sustainability impacts of these are fully understood.

At the time of writing this work is progressing well and an announcement on next steps is expected before the summer 2017.

Over the next few years SA will continue its focus on bringing together the four sectors of the aviation industry to work together to collectively reduce their environmental impacts, including:

- Focus on aircraft noise, engaging with stakeholders and seeking ways to improve how it can be better managed.

- Working with the UK Government to realise the opportunities shown in our Road-Maps, including:
  - Maintaining financial investment in UK aerospace research and development
  - Enabling airspace modernisation in the UK
  - Continue work to support the development of sustainable fuels for aviation in the UK
  - Ways to accelerate the use of low emission vehicles on airports

SA and our members continue to look forward to a brighter and more environmentally benign future for the UK aviation industry, working together to identify new opportunities to help reduced the impacts of their operations and challenge existing practices among members and Government alike, to realise them.

For further information on the work of SA please visit the website: www.sustainableaviation.co.uk

REFERENCES:
Sustainable Aviation CO₂ Road-Map (2016) http://www.sustainableaviation.co.uk/road-maps/

Sustainable Aviation Air Quality Paper (2017) http://www.sustainableaviation.co.uk/uk-aviation-and-air-quality/

Sustainable Aviation Fuels Road-Map (2014) http://www.sustainableaviation.co.uk/road-maps/
Global Market-Based Measures

The aviation industry has long recognised that to achieve its ambitious carbon reduction targets of carbon neutral growth from 2020 and a halving of emissions by 2050 (over 2005 levels) it would need to use market based measures enabling it to support emissions reductions in other industries.

Figure 1. UK Net CO₂ emissions from UK Aviation 2010 – 2050. (Sustainable Aviation)

The chart above, Fig.1 produced by Sustainable Aviation in the UK clearly illustrates why in addition to operating efficiencies, new aircraft and alternative fuels we need market based measures such as carbon trading to meet these CO₂ targets.

So, since these goals were established in 2009, the industry has worked closely with ICAO to develop a Global Market Based Measure and at the 39th General Assembly in October 2016 achieved the significant milestone of an agreement to deliver CORSIA – the Carbon Offsetting and Reduction Scheme for Aviation from 2020.

Early on in the process a number of key principles, as shown in Fig.2, were agreed for the market based measure including ensuring that the mechanism maximised environmental integrity to ensure that real and robust CO₂ reductions are achieved.

A global market-based measure for aviation: industry principles

Figure 2. Market measure principles. (IATA)

There were a number of options that were considered as a potential MBM including a carbon tax, carbon levy and an emissions trading scheme. Following a significant degree of analysis a Carbon Offsetting approach was selected for as well as
meeting robust Environment Integrity targets it also provides the most pragmatic solution as described in Fig. 3.

**A global market-based measure for aviation: carbon offsetting**

A global carbon offsetting scheme is the industry’s stated preference because it is:

- Fastest to implement
- Easiest to administer
- Most cost-efficient

Figure 3. Carbon offsetting as optimum option for market Based Measure. (IATA)

So it was with great excitement that on Thursday, 6 October 2016 that 191 members of ICAO agreed to the world’s first global sector approach to addressing it’s carbon emissions, CORSIA.

The scheme is split into two key phases, as shown in Fig. 4 – the voluntary phase from 2020 – 2026, whereby states volunteer to participate in the scheme, and then the mandatory phase from 2027 – 2035 where most states are mandated to participate in the scheme with exceptions for Small Island States, Least Developed States and Landlocked Developing States and states which have less than 0.5% of air traffic.

So far, as shown in Fig. 5, 72 states have signed up to the voluntary phase representing 88% of aviation international emissions from 2020.

Through co-ordinated industry and Government outreach activity we expect more states to volunteer for the first phase of the mechanism. In addition, we will be encouraging operators to consider opportunities whereby they will be able to purchase eligible credits to help meet their offset requirements prior to the required compliance date.

So what does carbon offsetting involve? As Fig. 6 illustrates it is where each airline is simply required to acquire credits above a pre-set baseline and submit these to an agreed compliance cycle. The credits will be available from a number of sources such as renewable energy projects, forestation projects and potentially emissions allowances from existing schemes. A team at ICAO are currently working on assessing potentially eligible credits and will provide information to airlines to acquire credits.

Figure 4. CORSIA phases 2021 – 2035. (ICAO)
Global Market-Based Measures

Both at an industry level through IATA and UN members through ICAO there is a significant work programme, as shown in the timeline in Fig. 7, both to work through the implementation details and the outreach activities to encourage additional member states to volunteer to join the first phase.

Of course, one of the key questions facing airlines is the cost of compliance. ICAO have carried out an analysis as illustrated in Fig.8 below that shows that the maximum cost of compliance (dependant on carbon price) is potentially 1.1% of industry revenues in 2030 and 1.8% of revenues in 2035.

In terms of the implementation activity one of the key areas is the monitoring, reporting and verification which is fundamental to ensuring that the scheme is robustly managed, drives compliance and avoids the double counting of carbon credits. Fig.9 shows the key elements of the MRV activity and the associated timelines.

As aviation is a global industry it makes total sense to have a global scheme to cover our carbon emissions. As has been stated in the 2016 ICAO resolution it is agreed that CORSIA will be the
carbon mechanism for addressing aviation’s CO₂ and that there will be no duplicate schemes. So we expect that member states will ensure that CORSIA is the scheme and have it replace any existing schemes to avoid penalising the industry.

So the aviation sector has achieved an important step in enabling the delivery of its committed carbon reduction targets, but of course there is a lot of implementation detail to be worked through before the start date in 2020 and Governments and Industry are together fully determined to make sure this is delivered.
The Government is committed to creating an economy resilient to change and fit for the future. This approach is already mature in the aerospace industry where the Government has long worked collaboratively with the aerospace industry to create one of the world’s best business environments for advanced aerospace engineering, design and manufacture.

Delivering the future

A prime example of this collaboration is the Aerospace Technology Institute (ATI), which is delivering on a joint Government-industry commitment to invest £3.9 billion over a 13-year period (to 2026) in aerospace research and technology (R&T) to support the long-term success of the sector.

In addition, as part of the Government’s recent consultation on industrial strategy, there is a commitment to invest a further £4.7 billion in R&D by 2020-21 to ensure that UK research continues to be world class. This includes the creation of a new Industrial Strategy Challenge Fund to help the UK capitalise on its strengths in science and innovation.

The ATI R&T programme and its portfolio of funded projects is co-ordinated jointly by the Department for Business, Energy & Industrial Strategy (BEIS), Innovate UK and the Institute. All three organisations work in close collaboration to deliver a coherent portfolio of projects to meet the objectives and priorities of the UK aerospace technology strategy.

Project support

As of February 2017, there were 175 funded projects within the ATI portfolio, involving 200 unique partners, more than 100 of which are SMEs, with a total of £1.45 billion of committed funding. Some of the initial projects approved for the ATI programme are already bearing fruit, delivering real tangible benefits to the UK aerospace businesses, and the wider economy, across the UK.

The ATI funded projects support the development of technologies to address a range of aircraft level attributes many of which contribute to greener aviation. These include reducing aircraft fuel burn with its direct beneficial impact on the emission of CO₂ and Nitrogen oxides. This is achieved through disruptive manufacturing technologies being developed that impact performance, weight and cost. The Rolls-Royce led ‘Composite Fan System Manufacturing Development’ is one of a portfolio of ATI supported projects researching an improved fan system.
direct improvements (engine and aerodynamic efficiencies), reduced structural weight and lighter, more efficient systems. Reducing aircraft fuel burn will also result in a more competitive aircraft, through lower aircraft operating costs, possibly securing greater market share and ultimately increased revenue and jobs in the supply chain.

Ongoing and future ATI supported research programmes are targeting a continuation of the of substantial fuel burn improvement trend achieved by the aerospace industry. The ATI website includes outline descriptions of all contracted projects (www.ati.org.uk/atifundedprojects). Each project has its own page with some also including a link to more detailed descriptions.

ATI funded research also supports the development of the enabling manufacturing technology required to deliver these headline fuel burn improvements while achieving cost and environmental targets. Manufacturing currently represents approximately one third of ATI funding.

**Manufacturing technologies**

High value manufacturing technologies are defined as the application of processes, methods, and tools for the creation of products and services. High value manufacturing is sub divided into three themes:

- **Conventional manufacturing technologies;** Component creation and finishing from multiple material types by mechanical and other means, and application of these processes for original equipment, in-service management, repair and end-of-life activities.

- **Disruptive manufacturing technologies;** Component creation from numerous material types including additive and subtractive methods currently not employed at industrial scale or used for prototyping only, including technology development, and manufacture of raw materials.

- **Digital Factory;** Data driven manufacturing systems to deliver productivity improvements, facilitate rapid new technology implementation, and enable product and rate flexibility. The digital environment will enable full vertical and horizontal integration of the entire end to end supply chain including material supply, manufacturing conversion, major component assembly, final assembly and in service support, encompassing the full product ecosystem.

**Disruptive Technology**

Disruptive manufacturing technologies are being developed that impact performance, weight and cost. The Rolls-Royce led ‘Composite Fan System Manufacturing Development’ is one of a portfolio of ATI supported projects researching an improved fan system. The CTi (Carbon/titanium) blades
are a key feature of the ‘Advance’ and ‘Ultrafan’ engine architectures. The direct fan blade weight savings plus the associated weight savings in the engine case are expected to total up to 1,500lb per aircraft (large transport) relative to a metallic equivalent. The CTi fan blade manufacturing process is a step change from the current Trent fan blade. The research developed technologies to reduce the environmental impact of the manufacturing and end-of-life processes plus provided a broader understanding of composite materials and their manufacture for other engine components.

Ongoing ATI research programmes continue to address manufacturing technology. The Airbus led ‘Factory of the Future for Aircraft Wing Manufacture and Assembly’ project was a two-year study (completed in spring 2017) strengthened UK manufacturing of conventional and next generation aero-structures. The GKN led HORIZON(AM) programme is developing viable production processes for promising additive manufacturing techniques to deliver fuel burn improvements through substantial weight and cost reductions in airframe and engine components with complex geometries. These studies have been performed by large consortia of industrial, research and academic partner organisations to ensure benefits across the UK aerospace sector.

Manufacturing technology remains an important element in the broader ATI portfolio of research projects that is enabling substantial reductions in the emissions from future aircraft - more detail provided in the company’s ‘Technology Strategy & Portfolio update (July 2016)’ document available on the ATI website: www.ati.org.uk/strategy/publications.

Key presenters from the ATI European Engagement Workshop and The University of Nottingham presenting How to Write Winning Clean Sky Proposals.
TIME BASED LANDING SEPARATION

Modern airports are busy and many run close to capacity. When there are delays the focus is inevitably on the hapless passengers, but equally there can be serious environmental effects. Many aircraft are stacked awaiting landing; planes are idling on taxiways awaiting take off; and delayed flights are taking off and landing late into the night when the local residents were expecting to sleep undisturbed. In short more CO₂ and more noise – often at anti-social times. One of the events that leads to lower landing rates is strong winds, which affects the landing rate at an airport. This is because although the plane’s air speed remains the same, the speed relative to the ground is slower and with the distance between planes fixed, the planes land at a slower rate. Hence the delays.

A solution to this issue has evolved from the work of SESAR (Single European Sky ATM Research) called Time Based Separation (TBS). It came into operation last year at Heathrow. This allows planes to be a fixed time apart (equating to the distance apart in still air) but reducing as (head) wind speed increases. This maintains the safety margin, while allowing the landing rate to be maintained. So there is less need to put aircraft into stacks, or have planes with engines running waiting take off.

Larger planes create bigger wake vortices which can be hazardous for smaller planes. After five years of tests, it has been shown that in strong winds, wake vortices dissipate more quickly so TBS can also be used to determine wake vortex separation requirements. This has enabled 80% of the wake vortices separation distances to be reduced in strong winds, and enabled a 62% reduction in wind related delay by facilitating an extra 2.6 movements per hour to be achieved in windy conditions.

Encouraged by the success of TBS, NATS are now looking to introduce eTBS (enhanced TBS) at Heathrow. Currently there are six categories of plane size (light, small, medium, upper medium, heavy and super heavy). Most of the planes operating at Heathrow fall into the top three categories. By revising the categories (light, lower medium, upper medium, lower heavy, upper heavy and super heavy) the time separation between the medium and heavy categories can be reduced, because each category contains a smaller range of plane sizes, and for safety reasons the time separation must reflect worst case i.e. the heaviest plane in one category being followed by the lightest in the next lighter category.

While the revised classification makes only a marginal improvement in light winds, when the wind is stronger using eTBS restores the landing rate almost back to the rate for light winds. So windy weather has a much reduced impact on the airport, and delays can be significantly reduced. eTBS is planned to start at Heathrow early next year.
Taxibot has been developed by the Israel Aerospace Industry (IAI). It comprises a tractor type vehicle with a rotating turret on which is mounted a clamping mechanism. This lifts and holds the aircraft nose wheel. It is in regular use at Frankfurt airport, where Lufthansa’s 737 flights are towed from the terminal. During push back the TaxiBot is manned, but when towing to the runway end it is controlled by the pilot, using the aircraft’s controls which are then mimicked by the TaxiBot. The TaxiBot is self-powered, and so the main engines need not run until an appropriate time for take-off. The advantage is that it does not add to aircraft weight (and thus reduce cruise efficiency). It has completed the certification process (FAA Supplemental Type Certificate (STC)) for use with the Boeing 737 family, and certification for the Airbus A320 family is expected very shortly. Safety is also enhanced on the stands as there is no jet blast.

The second is Wheel Tug. Developed by a Gibraltar based company, it is fundamentally different. It involves fitting two small motors to the front nose wheel of the aircraft. They are powered by the aircraft’s APU (Auxiliary Power Unit). It has a significant advantage over the TaxiBot, in that it enables the pilot to position himself on the stand, thus speeding up apron operations. However the drawback is that it adds to the aircraft weight, thus offsetting some of the savings, which are claimed to be a five sixths saving when making on the ground movement. The FAA STC has not yet been issued.

Further work is being undertaken as part of the SESAR programme to further reduce the wake vortex separation by implementing bespoke safety distances for each pair of aircraft types (pair wise comparison), and also to optimise the arrival of aircraft at the runway threshold. This should enable further improvements in capacity, especially during windy conditions.

**TAXIING**

At all large airports there is a significant distance between the terminal stands and the runway ends. This is in part inevitable as larger passenger aircraft require 3,000 metre runways at sea level airports in Europe. Move to a warmer climate – Africa, the Middle East and add 1,000 metres of elevation and runways 5,000 metres plus are essential. Given that aircraft usually take off and land into wind – and the wind direction can change – and it is obvious that wherever the terminal is situated there will be some very significant taxiing. It was estimated by Delft University that in 2012 some 18 million tonnes of CO₂ were emitted during taxi operations worldwide.

Many innovative solutions have been proposed to make this taxiing more efficient, but as development work has progressed some of the proposals have fallen by the wayside. The first two focus on narrow bodied aircraft as these are used on shorter distance flights, and so use a higher proportion of fuel on taxiing.
meaning it cannot be used on commercial flights. It is also not supported by either Boeing or Airbus.

The third is reduced engine taxi, using only one of the aircraft engines. This raises a number of issues, including evening out engine wear and safety issues. These are being systematically addressed, but there are some still to be resolved before it can be used commercially.

The fourth is eTaxi, being developed by Cranfield University using an on board aircraft fuel cell. Still at an early stage, a presentation was given at last year’s conference and a summary of this is in the Conference section of this Annual Report.

Running the main engines to taxi uses a lot of fuel, and creates avoidable CO₂, NOₓ, and noise. Using the APU or a separate engine is much preferable. There are strong environmental reasons to hope that a proposed solution can be speedily adopted to achieve the undoubted benefits.

HEATHROW SLOTS

Further proof that Heathrow is the right place for extracting maximum value from the expansion opportunities provided by a new runway was provided just before this report closed for press. Scandinavian Airlines announced it had sold two slot pairs at Heathrow for US $75m (one slot pair = the right to land one aircraft and take off again). It is not known to whom they have been sold, and as SAS has reserved to the right to use both pairs themselves for up to three years, it may be some time before we know. SAS also have said that in any event they will not lose seat capacity because they plan to use their remaining slots (they will have 17 slot pairs left after this sale) for bigger aircraft.

The actual price the slot pair fetches depends on what time of day the pair is for. Last year Kenya Airways sold its only (single) slot pair to Oman Air for a record $75m. Oman Air are now using it for an overnight Muscat – Heathrow service which needs an early arrival the following morning. This is a peak arrival time for businessmen, with connections available on the US and into Europe. Kenya Airways are continuing to operate from Heathrow by leasing a slot pair from KLM, which owns a 26% stake in Kenya Air.

Perhaps the best way of funding all the environmental improvements needed for Heathrow’s third runway (new rail links, improved bus services, more sound insulation, buying and demolishing the houses most affected by NOₓ and noise) could be to auction the new slots that will be available when the third runway opens. Advance deposits could be taken (as is done for yet-to-be-built houses) to tap an earlier source of funds for improved transport links, noise insulation and other environmental improvements.
The 250 page ICAO Environmental Report 2016, subtitled Aviation and Climate Change and published on the ICAO website in August 2016, includes a ‘whitepaper’ entitled ‘aviation impacts on climate: state of the science’. Shortly before, in May 2016, Brasseuer et al(1) published their report on Phase II of the FAA ACCRI programme. The two documents provide a valuable summary of scientific understanding in mid 2016 and what follows below draws on them.

Carbon dioxide (CO₂) and non-CO₂ effects.

CO₂ is the most important and best understood of aviation’s contributors to climate change. The Kyoto Protocol took it as the reference against which emissions of other greenhouse gases should be gauged. It is very long lived – perturbations to CO₂ levels in the atmosphere persist for hundreds of years – and hence current CO₂ emissions merely add to the stockpile of excess CO₂ in the atmosphere. The increase in atmospheric CO₂ caused by aviation is close to the total amount of CO₂ emitted by aircraft since the Wright Brothers first flew. For aircraft burning kerosene, the rate of CO₂ emission is directly proportional to the rate of fuel burn and this is increasing steadily. The radiative forcing caused by CO₂ from aviation in 2005 was estimated by Lee et al(2) as 28.0 mW/m², an increase of about 14% in five years. Reducing the rate of increase is the essential challenge to the manufacturers, the operators and the policy makers.

The situation for non-CO₂ effects is different. In total the radiative forcing (RF) from non-CO₂ emissions is currently though to be about twice that from CO₂, but there is considerable uncertainty in that estimate. In 2008 the FAA launched its Aviation and Climate Change Research Initiative (ACCRI) specifically to address the climate impact of the non-CO₂ emissions. The phase II ACCRI programme(1) was wide-ranging and comprehensive. It involved 10 funded project teams comprising 47 team members from 23 institutions worldwide. It employed: several atmospheric and climate models; a range of observation data sets for meteorological, chemical and contrails analysis; and laboratory measurements for early phase microphysical studies.

The study extended understanding of the complex processes involved in the non-CO₂ effects but despite, or perhaps because of, its breadth, the study did not report the mean values or radiative forcing for individual emission components. Instead, the authors resorted to reporting the range of individual RF components rather than the mean with the associated standard deviation. Similarly, the authors were unable to report the net radiative forcing due to all aviation emissions combined, which was contrary to previous assessment studies.
The ratio of effects in the northern and southern hemispheres is unity for the long-lived agents, reflecting differences in the models and the assumptions made in their application. From the table we can say two things with reasonable confidence: first, that $O_3$ short lived – ie ozone generated directly by NO$_x$ – and the combination of LCs (linear contrails) and contrail cirrus are the biggest sources of RF, comparable to the 28 mW/m$^2$ coming from CO$_2$; secondly, there is more work to be done before the level of scientific understanding is sufficient for policy making.

### Perturbations to CO$_2$ Levels in the Atmosphere Persist for Hundreds of Years - and Hence Current CO$_2$ Emissions Merely Add to the Stockpile of Excess CO$_2$ in the Atmosphere.

The estimated global mean LC net RF is larger than the 2006 global mean LC net RF to be 11.3 mW m$^{-2}$. This value was derived by implementing a novel assumption about cloud overlap. With the same model, Chen et al. (2010) found that the simulated contrail coverage is thus not easily identifiable and do not always spread throughout the air traffic is, substantially greater than in the southern hemisphere. Table 5 of the ACCRI report has separate columns for the estimates for the Northern Hemisphere, Southern Hemisphere and Global contributions of eight forcing agents. The first four columns are for the ACCRI studies, which are for commercial air travel only. The last column is from Lee et al for all aviation in 2005, based on a global fuel burn 19% higher than that used in ACCRI. The ratio of effects in the northern and southern hemispheres is unity for the long-lived agents and has higher values for shorter lived agents, increasing as the lifetime of the agent falls.

The spread of the ACCRI results is fairly wide for most agents, reflecting differences in the models and the assumptions made in their application. From the table we can say two things with reasonable confidence: first, that $O_3$ short lived – ie ozone generated directly by NO$_x$ – and the combination of LCs (linear contrails) and contrail cirrus are the biggest sources of RF, comparable to the 28 mW/m$^2$ coming from CO$_2$; secondly, there is more work to be done before the level of scientific understanding is sufficient for policy making.

### Impact of NO$_x$ emissions

NO$_x$ is not a greenhouse gas but the effect of its release at altitude, through a series of complex chemical reactions, is to create ozone, a powerful but short lived greenhouse gas, and reduce the concentration of methane, a relatively long-lived greenhouse gas. The reduction in methane leads in turn to a reduction in ozone, the $O_3$ long in the table, addressed for the first time in some of the ACCRI modelling. Previous studies, calculating time-averaged effects, have shown the strong dependence of the

<table>
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<th>Forcing agent</th>
<th>NH</th>
<th>SH</th>
<th>NH/SH</th>
<th>Global</th>
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<td>[5.3]</td>
<td>[6.0, 36.5]</td>
<td>[8.4, 82.3]</td>
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<td>[11.8]</td>
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<td>[5.4, 25.6]</td>
<td>[12.5, 86.7]</td>
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Radiative forcings (mW m$^{-2}$) from models participating in ACCRI, by hemisphere and global average for AEDT 2006 aviation emissions. The minimum and maximum ranges are shown in square brackets where multiple estimates are available. Average and the minimum-maximum range shown are based on ACCRI models that reported hemispheric forcings. Note that not all groups contributed hemispheric RF data and this table does not include the large aerosol indirect effect. Numbers may not add up because of rounding. Aerosol indirect effects are not included because of their large uncertainty, as highlighted by the large differences between participating models. The uncertainties (the minimum and maximum range of evaluations) reported represent the variation between model estimates and are not a comprehensive estimate of uncertainty due to parameter and other uncertainties. Since some groups did not provide data for the table, data from all models are not included.
RF attributable to NO\textsubscript{x} on the altitude and also the latitude of its emission. More recently, the REACT 4C study\textsuperscript{23} showed that the radiative effect of two packets of NO\textsubscript{x} emitted three hours apart on a transatlantic flight, on a particular winter’s day, can differ by at least an order of magnitude as a result of one packet being carried to the north and the other south, into the tropics. Although both packets were emitted in the northern hemisphere, the one that went south and had by far the greatest radiative impact actually spent much of its active life in the southern hemisphere. This effect is possible because, although NO\textsubscript{x} and ozone are considered short lived in the context of climate change, their lifetimes are measured in weeks, which is long compared to the life of the weather systems that determine where they spend their active lives. The wide variations between the results from the different models used in the ACCRI study, arising partly from the geographical variation in impact that is a result of differences in the models, has precluded a central ACCRI estimate of the RF due to NO\textsubscript{x}.

**Contrails and Contrail Cirrus**

For contrails and contrail cirrus, which persist for hours rather than weeks, the effects are more localised than for NO\textsubscript{x}. Figure 1 shows a global map of the net radiative forcing in 2006 by linear contrails over the northern hemisphere, which contains 93% of air traffic. The results are from the NASA Aqua MODIS (Moderate Resolution Imaging Spectroradiometer) satellite. The image screening algorithms selected linear contrails only, excluding cirrus clouds. The figure shows the greatest net RF occurs at night (Fig 1(b)), because long-wave and short wave forcing partly cancel each other during the day (Fig 1(a)). The localised radiative effects of these short lived agents can translate into different effects on temperature – radiation which enters the ocean with little reflection has a greater long term effect on the global energy balance than radiation falling on snow or desert.

There is agreement among the models that the RF due to cirrus cloud formed by spreading contrails is several times that due to contrails alone. There are several studies giving a value for the total RF from linear contrails and contrail cirrus of around 50 mW/m\textsuperscript{2} – almost twice that from CO\textsubscript{2} – but, as the above table shows, there is a wide spread when all estimates are included. In the concluding section of the ACCRI report, ‘Lessons learned and next steps’, it says, ‘ACCRI has contributed to the estimation of aviation-induced cirrus cloud climate forcing based on global observation datasets and has increased the level of scientific understanding from ‘very low’ to ‘low.’ The largest contribution of aviation emissions to climate change results from the presence of contrails and associated cirrus clouds and also from the enhanced ozone concentrations in the upper troposphere and lower stratosphere.’

**Contrail Avoidance for Climate Change Mitigation**

There is a discussion under this heading in the ICAO Environmental Report which recognises the
future potential for using the flexibility of flight operations to change routing to avoid ice-supersaturated regions, thereby avoiding the formation of persistent contrails and contrail cirrus. The reason that this offers a high return for low cost is that the ice-supersaturated layers are thin and can be avoided by a relatively small change in cruise altitude.

This was in part the theme of the GBD Conference in October 2015, which ended with GBD undertaking to lead an exploration into the possibility of a practical demonstration of reducing the climate impact of contrails and contrail cirrus by ‘smart flying.’ Last year’s Annual Report included a short account of the initial action here, with GBD inviting speakers at the conference from DLR, NATS and the University of Reading, with some of their colleagues, to an informal meeting at Gatwick airport to address the question.

It had been suggested at the Conference that the Shanwick Oceanic Control Area, covering the eastern Atlantic west of Ireland, would be a suitable location for a trial and Fig 1 shows that it is, indeed, the world hotspot for linear contrail RF. Since the meeting at Gatwick there has been further analysis of meteorological data in this region and an understanding is developing of the parameters that need to be considered in planning a trial. However, it is agreed that before any physical trial is contemplated there needs to be a convincing virtual trial, using past meteorological data, to assess the potential climate benefits and operational costs of different levels of intervention.

In April there was an open seminar at Reading University to expose recent related work in this field, coupled to a smaller re-convening of the original group to consider the way forward to a virtual trail of contrail avoidance in the Shanwick OCA.

**Indirect Effects of Soot and Sulphate Emissions**

The direct effects of sulphate and soot emissions, shown as $\text{SO}_x$ direct and BC direct in the table, are relatively small. Estimates of their indirect effects are relatively large, however, with wide differences, the results of different assumptions, between different studies. A relatively new interest is the possibly powerful indirect of sulphate emissions on low level clouds.

Sulphate particles formed by the condensation of sulphate vapour in the engine exhaust fall to lower altitudes where they can alter liquid clouds in a way that contributes to shortwave cloud brightening. Gettelman and Chen\(^8\) estimated this forcing in 2005 as -46mW/m\(^2\), a powerful cooling effect from the reflection of incoming shortwave radiation. This is, however, only one result and uncertainties in the field are considerable.
Clean Sky was launched in 2008 as a public-private partnership between the European Commission and the European aeronautics industry. It was Europe’s largest ever aeronautical research programme with a budget of €1.6bn. Six years later, Clean Sky 2 was launched with a total budget of €4.0bn over a ten-year timespan, to run in parallel with Clean Sky 1 until the end of 2016 and to carry through to fruition some of the larger Clean Sky 1 programmes. A final review of Clean Sky 1 was held in Brussels in March 2017.

Clean Sky 1 was built around six Integrated Technology Demonstrators (ITD). Within these, 20 large demonstrators have been completed by some 600 participants in 24 countries. They have had a powerful effect, not only in developing and proving new technology but in building co-operation across Europe and also building capability across the supply chain.

The two largest individual elements in the programme have been the BLADE Demonstrator (Breakthrough Laminar Aircraft Demonstrator in Europe), part of the Smart Fixed Wing Aircraft (SFWA) ITD and the CROR (Contra Rotating Open Rotor) Demonstrator, part of the Sustainable and Green Engines (SAGE) ITD. In BLADE, the outer wing panels of an A340 have been replaced by wing panels of lower sweep with natural laminar flow aerofoil sections, one manufactured by SAAB, the other by GKN. The panels are identical externally but are of different structural design and involve different manufacturing techniques. The precision required in manufacturing a laminar flow wing is rather greater than for a conventional wing and the two manufacturers have been faced with, and successfully met, a significant challenge. The panels are now assembled to the aircraft, installation of the complex and comprehensive test instrumentation is proceeding and flight tests are planned for late 2017.

Beyond natural laminar flow control (NLFC), progress has been made with a simplified concept for hybrid
laminar flow control (HLFC) within the EC Framework 7 AFloNext programme. This programme ended in May 2017 but is being carried forward into Clean Sky 2 with a flight demonstration followed by in-service experience of HLFC on the fin of an A320 in parallel with the design, build and test of a large scale pre-flight ground demonstrator to bring the HLFC technology to TRL5. It is worth noting that HLFC was introduced as a drag reducing measure on all the empennage surfaces of the Boeing 787-9 when the type was launched in 2014, at which time it was envisaged as also being employed on the 787-10 and the 777X. Two years later Boeing announced that HLFC would not be used on the 777X and its use on the 787-9 and 787-10 was under review. In April 2017 it was announced that HLFC would be retained on the fin only for the 787-10 and that, for commonality of manufacture, HLFC would also be limited to the fin only in future 787-9 production. The fact that Boeing, on the basis of experience with the 789, has decided that HLFC on the empennage of the 777X is not justified, suggests that carrying the work on HLFC forward to demonstrate its potentially more powerful application to wings, as envisaged in Clean Sky 2, should be a priority.

Besides future short-medium range airliners, the LSBJ (low sweep business jet) stream in the SWFA is a potential beneficiary of the BLADE programme. The concept for the LSBJ includes a U-tail for noise shielding, the effectiveness of which has been confirmed in ground tests at full scale. The aerodynamic performance of the proposed LSBJ, with NLFC wings, has been confirmed by tests at flight Reynolds numbers in ETW.

NLFC also features in the Green Regional Aircraft ITP. Wind tunnel tests have been successfully completed in the ONERA S1Ma transonic wind tunnel on a wing designed to cruise at 0.74. The model wing span was 5.2m, so it was possible to perform tests at Reynolds numbers close to the ones obtained for real aircraft in flight conditions. A laminar flow extent over nearly 70% of the upper wing surface and about 30% of the lower wing surface was observed at cruise, these results being in agreement with computations.
The Contra Rotating Open Rotor led by Safran in SAGE 2 (based on a geared unducted architecture) is an aircraft engine offering a 30% fuel burn reduction compared to the year 2000 turbofan reference engine, allowing a significant decrease of the CO₂ emissions. The main innovative elements of the design are the blades of the propellers, the blade pitch change mechanism, the gearbox and the rotating structure. By intensive aero-acoustic wind tunnel testing of several design optimisations, Safran has demonstrated that this architecture is compliant with the new noise standards for ICAO certification (Chapter 14) and consistent with the expected performance level. SAGE 2 is working towards delivering and ground testing a full-scale Open Rotor engine on a brand-new Safran open-air facility located in Istres.

The alternative CROR project, SAGE 1, led by Rolls-Royce, was tested on Rolls-Royce Rig 145 in the DNW wind tunnel in 2008 at low speeds and in 2009 in the ARA Transonic Wind Tunnel at high speeds to confirm that it met its acoustic and performance targets. Thereafter, the construction of a full scale demonstrator engine was postponed and, in parallel with continuing work on SAGE 1, resources were switched in 2011 into SAGE 6, the Lean Burn project.

The SAGE 6 test programme is based on Trent 1000 donor engines (ALECSYS) for engine ground testing. At the Clean Sky close-out review in March 2017 the project achievements, in terms of demonstrated Technology Readiness Level (TRL) are shown in the table below.

The ALECSYS Trent engine system is scheduled for ground commissioning trials in Q4 2017, to be

<table>
<thead>
<tr>
<th>Technology description</th>
<th>TRL at 2016</th>
<th>Target</th>
<th>Current status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Emissions Combustor</td>
<td>6</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Fuel Control System</td>
<td>6</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Staging Control Laws</td>
<td>6</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Noise Acoustic treatment</td>
<td>5</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Optimised combustor/turbine interface</td>
<td>5</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>
followed by in-flight operability trails on a B747 test bed. LTO NO\textsubscript{x} levels are less than 40\% of the CAEP/6 Standard, which is the notional target that CAEP has set for 2026.

An excellent view of all the many advances made across a wide range of technologies in Clean Sky 1 can be gained from the presentations at the closing conference in March 2017, accessible at http://www.cleansky.eu/event/clean-sky-1-closing-event. The final presentation at the conference was of the conclusions of the Technology Evaluator, an activity aimed at producing an objective assessment of the potential environmental impact of the technologies under development in Clean Sky. The projected gains in the key areas are set against the ACARE and Clean Sky targets in the table below.

<table>
<thead>
<tr>
<th>CO\textsubscript{2}</th>
<th>NO\textsubscript{x}</th>
<th>Noise (dB)</th>
<th>Noise area</th>
</tr>
</thead>
<tbody>
<tr>
<td>TARGETS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACARE 2000 – 2020 objectives</td>
<td>-50%</td>
<td>-80%</td>
<td>-50%</td>
</tr>
<tr>
<td>Clean Sky 2008 – 2020 objectives</td>
<td>-26%</td>
<td>-50%</td>
<td>-50%</td>
</tr>
<tr>
<td>TECHNOLOGY EVALUATOR PROJECTIONS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mission level assessment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Long range</td>
<td>-19%</td>
<td>-39%</td>
<td>-5.7dB</td>
</tr>
<tr>
<td>Short – medium range</td>
<td>-41%</td>
<td>-42%</td>
<td>-5.1dB</td>
</tr>
<tr>
<td>Regional</td>
<td>-27%</td>
<td>-46%</td>
<td>-15.7dB</td>
</tr>
<tr>
<td>Business aircraft</td>
<td>-32%</td>
<td>-32%</td>
<td>-5.5dB</td>
</tr>
<tr>
<td>Rotorcraft</td>
<td>-56%</td>
<td>-64%</td>
<td></td>
</tr>
</tbody>
</table>

| Airport level assessment | | | | |
| Mainline and regional fleet | -30\% to -40\% | -40\% to -45\% | -35\% to -70\% |
| Rotorcraft fleet          | -10\% to -20\% | -30\% to -65\% | Up to -75\%    |

Global fleet level assessment

<table>
<thead>
<tr>
<th>CO\textsubscript{2}</th>
<th>NO\textsubscript{x}</th>
<th>Noise (dB)</th>
<th>Noise area</th>
</tr>
</thead>
<tbody>
<tr>
<td>-32%</td>
<td>-40%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NASA ERA AND ITS SUCCESSORS

The goals set for Clean Sky 1 were similar to those set for the NASA ERA (Environmentally Responsible Aviation) project, which had a total expenditure over six years of over $400 m, and ended with achievement awards in 2016 from NASA and from the journal Aviation Week and Space Technology.

In looking back over the project, Collier(5) highlighted some of its particular achievements:

- Tiny embedded nozzles blowing air over the surface of an aircraft’s vertical tail fin showed that future aircraft could safely be designed with smaller tails, reducing weight and drag. This technology was tested using Boeing’s ecoDemonstrator 757 flying laboratory. Also flown was a test of surface coatings designed to minimise drag caused by bug residue building up on the wing’s leading edge.

- NASA developed a new process for stitching together large sections of lightweight composite materials to create damage-tolerant structures that could be used in building uniquely shaped future aircraft that weighed as much as 20 percent less than a similar all-metal aircraft.

- Teaming with the Air Force Research Laboratory and FlexSys Inc. of Ann Arbor, Michigan, NASA successfully tested a radical new morphing wing technology that allows an aircraft to seamlessly extend its flaps, leaving no drag-inducing, noise-enhancing gaps for air to flow through. FlexSys and Aviation Partners of Seattle already have announced plans to commercialise this technology.

- NASA worked with General Electric to refine the design of the compressor stage of a turbine engine to improve its aerodynamic efficiency and, after testing, realised that future engines employing this technology could save 2.5 percent in fuel burn.

- The agency worked with Pratt & Whitney on the company’s geared turbofan jet engine to mature an advanced fan design to improve propulsion efficiency and reduce noise. If introduced on the next-generation engine, the technology could reduce fuel burn by 15 percent and significantly reduce noise.

The Boeing 757 ecoDemonstrator.
NASA also worked with Pratt & Whitney on an improved design for a jet engine combustor, the chamber in which fuel is burned, in an attempt to reduce the amount of nitrogen oxides produced. While the goal was to reduce generated pollution by 75 percent, tests of the new design showed reductions closer to 80 percent.

New design tools were developed to aid engineers in reducing noise from deployed wing flaps and landing gear during takeoffs and landings. Information from a successful wind-tunnel campaign, combined with baseline flight tests, were joined together for the first time to create computer-based simulations that could help mature future designs.

Significant studies were performed on a hybrid wing body concept in which the wings join the fuselage in a continuous, seamless line and the jet engines are mounted on top of the aircraft in the rear. Research included wind-tunnel runs and flight trials to test how well the aircraft would operate at low speeds and to find the optimal engine placement, while also minimising fuel burn and reducing noise.

The potential performance gains from the technologies demonstrated in ERA, for a large twin aisle aircraft launched in 2020 relative to 2005 best in class (taken as the Boeing 777-200LR), were assessed as a reduction in fuel burn of 41% for a tube and wing aircraft and 47% for a hybrid wing body, in both cases powered by geared turbofans. This was against a target set in ERA of a 50% reduction.
For the other environmental impacts, the ERA targets were a noise level 42dB below ICAO Chapter 4 and LTO NOx emissions reduced by 75% relative to ICAO CAEP/6. The potential gains were assessed as a noise margin of 40.3dB for the HWB and LTO NOx levels 79% below CAEP/6. These are bigger gains than projected in the Technology Evaluator of Clean Sky. To understand the real differences between the potential of the technology assessed in the two programmes requires a study in depth of assumptions and methodologies involved. That is not likely to be possible because of the commercial sensitivity of some of the technology.

In 2016 NASA announced the New Aviation Horizons Initiative, a requested increase in the ten year budget to $10.6bn with an initial budget in 2017 of $790m. This substantial growth was intended to provide for the construction of a series of X-planes, scaled manned demonstrators, to prepare the way for radically new aircraft that will be better adapted to future environmental needs.

In late 2016 NASA awarded six-month contracts to four companies to define schedules and costs for one or more large subsonic X-planes aimed at NASA’s ultra-efficient subsonic transport research goals. The proposals include HWB concepts from Boeing, Lockheed Martin and Dzyne Technologies (for an HWB regional jet), the Transonic Truss-Braced Wing from Boeing and the Double Bubble from Aurora Flights Sciences. Images of the last two have appeared in earlier GBD Annual Reports. A decision on which of these proposals will proceed is envisaged in 2017 with the selected design flying no later than 2021.

Two related projects on which work has already begun are the Quiet Supersonic Technology (QueSST) demonstrator, a half scale piloted supersonic aircraft designed to generate a soft thump rather than the disruptive boom usually associated with supersonic flight, and the X-57 Maxwell. The X-57, built by installing a new wing integrated with 14 battery-powered electric motors driving propellers on to an Italian-designed Tecnam P2006T twin-engine light aircraft, is planned to fly for the first time in early 2018.

In March 2017 the President signed off the NASA budget for 2017 but the budget for later years and his continued support for of the New Aviation Horizons Initiative is not yet known. QueSST and
Maxwell seem assured but the attitude of the new Administration to future environmental programmes is unclear.

REGULATION

ICAO CAEP/10 and the 39th Assembly

ICAO works on a three year cycle, with 2016 the concluding year of the latest cycle. There is a comprehensive account of the activities of interest to Greener by Design in the 250 page ICAO Environmental Report 2016, subtitled Aviation and Climate Change, available on the ICAO website.

At the CAEP/10 meeting in Montreal in February 2016, the most significant of its recommendations were to introduce two completely new standards, one on CO₂ emissions, the other on non-volatile particulate matter (nvPM) emissions, which were adopted by the ICAO Council in March 2017. The effects on ICAO Annex 16 are set out below by Volume.

Annex 16, Volume I – Aircraft Noise

The recommended changes to Volume I were all to address technical issues aimed at improving the accuracy and applicability of the current version. No changes to the Standard were recommended. However, it is worth noting that the current noise Standard, Chapter 4, which came into effect in 2006, will be superseded at the end of 2017 by Chapter 14, involving an increase in stringency of 7 EPNdB (cumulative) relative to Chapter 4.

The 39th Assembly in Montreal adopted three resolutions, the first of which, Resolution A39-1, included, in Appendix D, text recognising the economic burden that fleet renewal could place on developing countries and urging States operating aircraft that do not meet the current Volume 1 Chapter 3 or Chapter 4 Standards not to introduce any phase-out of these aircraft without considering other measures to reduce the noise burden around specific airports.

Annex 16, Volume II – Aircraft Engine Emissions; inclusion of nvPM

As with Volume I, CAEP/10 recommended a number of changes to Volume II aimed at improving the accuracy and applicability of the current standard for exhaust emissions. In addition, CAEP is working on an independent expert assessment of engine combustor design technology to enable a review.
The Standard is expressed as a curve of a metric value plotted against MTOM. There are in fact two such curves, one for new designs, effective from the above dates, and a more lenient one for in-production (InP) aircraft that becomes effective from 1 January 2023 with a production cut-off in 2028, which means that InP aeroplanes that do not meet the standard can no longer be produced beyond 2028 unless the designs are modified to comply with the Standard.

The Standard has not been universally well received. Politicians and spokesmen for industry have generally hailed it as an important step forward while environmental NGOs have tended to dismiss it as ineffective on the grounds that normal commercial pressures from airlines will drive improvements in fuel burn to well below the Standard and it will have negligible impact on future design decisions. As noted in last year’s GBD report, all new types known to be in development will meet the Standard with a comfortable margin by 2020. For InP types, the average improvement required by 2028, relative to their known performance in 2015, is 4% (0.15% per annum), with a spread from 0 to 11% (0.8% per annum). Assembly Resolution A39-2 – Climate Change, includes the words, ‘The Assembly....Resolves that States and relevant organisations will work through ICAO to achieve a global annual average fuel efficiency improvement of 2 per cent until 2020 and an aspirational global fuel efficiency improvement rate of 2 per cent per annum from 2021 to 2050, calculated on the basis of volume of fuel used per revenue tonne kilometre performed.'
The problem with the metric

There is a problem with the metric used in the Standard. It does not measure what is called for in the above Assembly Resolution, fuel efficiency ‘calculated on the basis of fuel used per revenue tonne kilometre performed.’ The metric is set out in ICAO Cir 337. A paper published in the Aeronautical Journal(7) in 2016 argued that the provisions in Cir 337 provide an excellent basis for the initial regulation of aviation’s CO2 emissions, provided the equation proposed in Cir 337 was replaced by one derived from the fundamentally robust Breguet Range Equation. Further in the future, this approach could be extended to develop measures to increase the fuel efficiency of the operational side of civil aviation.

In the abstract of a recent paper(8), following his presentation to the 2016 GBD Conference, Poll states “The observation that total fuel used is almost twice the minimum required suggests a need to recognise a broader ownership of the problem and broader responsibility for the solution.” In the paper itself he highlights three factors – low load factors, three class seating configurations and poor matching of aircraft to routes – which contribute to this wastage and observes that, “for reasons that are unclear, ICAO does not appear to have recognised, or targeted, this problem.” If and when ICAO does turn to this problem, the paper(7) proposing a revision of the metric formula sets out in an appendix how these issues can be addressed in a scientifically robust way.

THE GLOBAL MARKET-BASED MEASURE (MBM) SCHEME

Resolution A29-3, records the decision to implement a Market-based Measure scheme. This was discussed in last year’s GBD Annual Report, when it was still the subject of negotiation between the Member States and had the acronym COSIA. At the Assembly the version agreed between the States has the acronym CORSIA (Carbon Offsetting and Reduction Scheme for International Aviation) ‘to address any annual increase in total CO2 emissions from international aviation (ie civil aviation flights that depart from one country and arrive in a different country) above the 2020 levels, taking into account special circumstances and respective capabilities.’ An afternoon session devoted to the ICAO GMBM scheme is covered in the report on the 2016 Conference and its basic features are set out in an earlier section (pp 33-34).

The text of the Resolution notes the support of the aviation industry for a single global carbon offsetting scheme, as opposed to a patchwork of State and regional MBMs. It also recognises that MBMs should not be duplicative and international CO2 emissions should be accounted for only once. The EU ETS (Emissions Trading Scheme) differs from CORSIA in being a carbon cap and trade scheme rather than a carbon offsetting scheme. It had an international reach when aviation was included in it in January 2012, covering all flights landing in or departing from EU countries. In the face of intense international hostility the European Commission decided in November 2012 to ‘stop the clock’, insofar as the ETS would be applied to intra EEA+ flights only. A trigger for this decision was the decision the previous week by the ICAO Council to develop a GMBM scheme to cover international aviation. The ‘stop the clock’ regulation automatically ended on 31 December 2016 but the Commission now proposes that intra European flights should remain covered by the EU ETS for the period 2017 – 2020. The European Parliament has voted to increase the ambition of the scheme, with the total allocated allowances in 2021 lower by 10% than the average allocation for the period from 1 January 2014 to 31 December 2016 and then reducing annually by 2.2% from 2021 onwards. Further negotiations involving
the Parliament, the Commission and the EU Council will be needed before the scheme is finalised and wider political difficulties can be foreseen ahead. All the EEA+ states have signed for the first phase of CORSIA and a large fraction of their intra EEA flights will be classed as international and falling under CORSIA. The EU scheme is basically different and more ambitious. ICAO and the EU have three years to resolve the conflict.

LAST WORDS

We must recognise that the ICAO GMBM scheme is an important first step, but only a first step, towards reducing the climate of impact of aviation to levels consistent with the 1.5°C target proposed in Paris last year. The ICAO Environmental Report 2016 discusses the non-CO₂ emissions that contribute substantially to climate change, with an implied acceptance that these should also fall under ICAO regulation when the scientific understanding is sufficient to support it. There is a prospect of substantial reductions in NOₓ emissions, as envisaged by CAEP, and also the possibility of reducing contrail and cirrus impact significantly by flight path adjustment, as discussed in the ICAO Environmental Report and in this report under Atmospheric Science. But, because of its long life, which means that continued emissions just add to the existing stockpile in the atmosphere, CO₂ is the long-term threat. Last year’s report, under the heading CNG2020 not good enough, cited a paper from Manchester Metropolitan University showing the growing impact of net CO₂ emissions from aviation being limited to their 2020 level in the future. It also showed a proposal, as part of the Flightpath 1.5 campaign by the Aviation Environment Federation (AEF), to begin reducing the aviation’s net CO₂ emissions from some date early in the 2030s. We conjectured that, if that path were followed so as to reduce aviation’s net CO₂ emissions to zero by 2050, rather than growing inexorably the radiative forcing due CO₂ would level out at about 60% higher than its value today. As the ICAO GMBM develops, a long-term goal of this kind needs to find its way into the plan.

‡ EEA+ denotes countries in the European Economic Area plus Switzerland.

REFERENCES


The Greener by Design Group

Greener by Design was formed in 1999 by the Royal Aeronautical Society and bodies representing airports, UK airlines and the aerospace industry, bringing together experts from every part of the aviation industry with Government bodies and research institutions. The initiative is sponsored by the Department for Business, Energy and Industrial Strategy and is supported by other bodies in the aviation sector but it is non-aligned, researching and advising independently of any interest.

Greener by Design

Researches, assesses and advises Government and industry on operational, technological, economic and regulatory options for limiting aviation’s environmental impact.

Promotes best practice across the aviation and aerospace sectors.

Promotes a balanced understanding of aviation’s true environmental impact and its environmental programmes, in liaison with other groups with similar objectives.

Issues an annual report and holds an annual conference and workshops on sustainable aviation.

The next annual Greener by Design Conference

Aircraft Noise – Can we Build Community Tolerance?

is scheduled to be held on 12 October 2017

at the Royal Aeronautical Society.
We are grateful for the support the Department for Business, Energy & Industrial Strategy gives the Greener by Design initiative.

Air Travel – Greener by Design draws on the expertise of industry and academia. Any views expressed in this report are those of Greener by Design and do not necessarily represent the view of the Royal Aeronautical Society as a whole.

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