Greener by Design

Executive Committee

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Front cover: Contrails (Air Team Images)
Welcome to the Greener by Design 2015-16 Annual Report. Last year was dominated by the progress (or lack of it) on two key issues, both of which will have a far reaching effect on aviation, both nationally and internationally, throughout the rest of this century. I am referring, of course, to the decision on the location of an additional runway for London, and to the agreement in Paris at the end of last year to limit global temperature rise by controlling Greenhouse Gas emissions.

It is difficult to overstate the importance of either. If a third runway is approved for Heathrow, it will allow Heathrow to continue to grow, and offer a much wider range of flights, both locally and worldwide, including to China, India, and other rapidly developing countries. Heathrow flights already command premium fares, and so unsurprisingly this option is favoured by many major airlines. A second runway for Gatwick would favour low cost airlines, who are gradually going further afield, such as Norwegian who recently expanded their transatlantic flights from Gatwick and now serve six US destinations. Whichever option is eventually chosen – and the timetable for a decision has now receded to summer this year – will shape whether we continue to have one of the world's biggest hub airports in London, or whether we move to having more point to point flows, especially from China, India and the Far East. The decision will have a significant effect on routes flown throughout many parts of the world.

Agreement on limiting greenhouse gases is moving slowly nearer. The agreement in Paris last year to try to limit the world mean temperature rise to 1.5°C means that tighter emissions targets need to be set. It also ensures the spotlight will be on ICAO as it tries to thrash out an agreement (called market based measures – MBM) between the 192 member states on how much expansion each will be allowed, and in return for restricting growth, the developed countries will fund carbon reduction technology in developing countries. It will not be easy, but the threat that the UN may step in directly to force a solution on ICAO cannot be discounted if little progress has been made by the end of this year. Note also that to achieve the target the non CO\textsubscript{2} effects of aviation, primarily contrail induced cirrus cloud, must be addressed.

While the detail is yet to be agreed, the key output will be that in developed areas of the world (eg Europe and the US), airlines will be unable to expand their number of flights or size of aircraft operating the flight without purchasing more permits, or contributing to a carbon reduction scheme in a developing country, or improving the efficiency of their existing fleet. Expect an upturn in orders for new more efficient jets, and a hardening of fares in the light of additional costs on the airlines. Furthermore, if no agreement is reached at ICAO, the EU may revert to its own control scheme (ETS), precipitating a return to international arguments over the legality of imposing these charges when flying through international airspace.

Legacy carriers who generally have older, less fuel efficient aircraft may find it marginally easier to meet the new targets – and at a lower cost – rather than newer carriers. In most cases newer carriers already have fairly new fuel efficient aircraft, and wanting to introduce new routes will cost more as new carbon permits will have to be purchased. So the effect of the new restrictions is likely to slow the growth of low cost airlines. But just as with the decision on an additional runway for London, taking the decision and it starting to have a significant effect will be separated by many, many years as it will take several years to bite.

These two key issues will be addressed in our next Annual Conference to be held on 17-18 October. The first day will address local issues – primarily noise and air quality, both key issues in the choice between Gatwick and Heathrow – and we have an impressive range of speakers both from the UK and abroad. The second day is on Global issues – focusing on how aircrafts’ carbon footprint can be reduced and the likely form and impact of market-based measures. Again we have several well respected international and domestic speakers, and we very much hope you will be able to join us.

During the past year we are very pleased to have welcomed three new members to the Executive Committee: Ian Jopson from NATS, Ray Kingcombe, and Richard Wilson of the Aerospace Technology Institute. Their knowledge and experience are already making a significant contribution to the work of the Committee and helping make aviation ‘Greener by Design’.

Geoff Maynard
Chairman, Greener by Design
However, while ‘everyone knows’ that CO$_2$ is the greenhouse gas that causes climate change, and this fits with the IATA story, it is not the full picture. There are other important greenhouse gases. The IPCC (Intergovernmental Panel on Climate Change) attributes only 70% of man-made greenhouse-gas global warming to CO$_2$ emissions. Much of the remaining 30% comes from methane (CH$_4$) and nitrous oxide (N$_2$O) emissions, which are both powerful greenhouse gases.

Aircraft do not emit either methane or nitrous oxide but they do emit other oxides of nitrogen (NO and NO$_2$, collectively termed NO$_x$). These are short-lived. They are not significant greenhouse gases in themselves but, via a sequence of chemical reactions, they have the effect at altitude of increasing ozone (O$_3$, a powerful but short-lived greenhouse gas) and reducing methane.

Aircraft also form contrails which, in some climate conditions persist and develop into cirrus cloud. Both contrails and cirrus have a powerful effect on the Earth’s energy balance. The net effect of these
and other, less significant non-CO\textsubscript{2} emissions from aircraft is to increase the climate impact of air travel substantially. When the non-CO\textsubscript{2} emissions are taken into account, air travel is estimated to account for about 5\% of man-made global warming – two and a half times its proportional contribution to man-made CO\textsubscript{2}.

Smart flying

The idea of ‘smart flying’ to reduce climate impact by slight changes in flight altitude to avoid contrail formation has been around for a decade. Any move to try it for real has been inhibited, however, by scientific uncertainty in the climate impact of contrails and, in particular, of the cirrus cloud formed from contrails. In addition, it has to be established that the benefits of reduced cirrus impact from any such changes in routing are not significantly offset by the climate impact of extra CO\textsubscript{2} emissions resulting from the re-routing. Research at DLR (Deutsches Zentrum für Luft- und Raumfahrt) provided a physics-based estimate of the impact of contrail-cirrus in 2011 and subsequent work has consolidated and refined the estimate. With this development, and the completion of the extensive REACT4C European study of reducing climate impact by re-routing, the time was ripe to gather together all the interested parties, scientists, operators, air-traffic managers and policy makers, to consider the future.

Atmospheric variability

The morning was devoted to the atmospheric science, the potential for reducing climate impact by re-routing air traffic and the appropriate metrics for trading climate benefit against the inevitable increase in operating costs. The afternoon considered the potential impact on air-traffic management and on the airlines and also the future questions for policy makers.

In the morning, Prof Keith Shine of Reading University led off with an overview of all the significant non-CO\textsubscript{2} emissions from aircraft. This was followed by Dr Klaus Gierens of DLR focusing on current understanding of the physics of contrail-cirrus and Prof Dr Ulrich Schumann of DLR on our current ability to predict the climate impact for any specific flight. Prof Steven Barrett of MIT discussed the effect of bio-fuels on contrails and contrail-cirrus and finally Prof Dr Volker Grewe reported on studies at DLR on mitigating the climate impact of air travel, with emphasis on the comprehensive European REACT4C study, which considered impacts of contrails and NO\textsubscript{x} emissions. The morning ended with a panel discussion seeking a consensus on what was secure and what was still uncertain.

Atmospheric conditions

In the context of smart flying, arguably the most important point that emerged was that the climate impact of contrail-cirrus varies strongly with atmospheric conditions, time of day, latitude and what is below – cloud, land or sea. The net effect is a warming, the result of warming by trapping infra-red radiation, particularly at night, offset by cooling as a result of incoming sunlight being reflected or scattered back into space in daylight hours. Because of the large variability, a significant reduction in climate impact can be achieved by avoiding contrails on only a small proportion of flights – perhaps only 1\%.

A powerful early advocate of smart flying was the late Hermann Mannstein of DLR. In 2005 he showed that a substantial fraction of contrails and contrail-induced cirrus can be avoided by relatively small change in flight level, due to the shallowness of the ice-super-saturated layers necessary for the formation of persistent contrails. His colleague Ulrich Schumann, in reporting on the prediction capabilities of the DLR CoCiP (Contrail Cirrus Prediction tool), illustrated Mannstein’s concept with two diagrams. The first illustrates the avoidance of regions of air supersaturated with respect to ice, in order to avoid forming persistent contrails.

The second shows the next step, when conditions are propitious, of changing flight level in order to seek out ice-superstaurated regions and create contrails that will reflect sunlight and have a net cooling effect. If the necessary meteorological information is available, the CoCiP programme can estimate the outcomes of both kinds of action.
Like contrail-cirrus, the other powerful non-CO₂ emission, NOₓ, has both a warming effect, through the creation of ozone, and a cooling effect through the destruction of methane. On average, the climate impact of NOₓ increases strongly with altitude of emission and Volker Grewe described studies by DLR of reducing net climate impact by reducing cruise altitude and Mach number. For an existing aircraft, flying lower and slower reduced climate impact by 30% for a cost penalty of around 5%. If the same aircraft were re-winged to be optimised to fly lower and slower, the 30% reduction could be achieved without a cash cost penalty (but a direct operating cost (DOC) penalty due to reduced cruise Mach number and hence reduced utilisation and reduced return on investment).

He then described the eight-partner REACT4C programme, which investigated the potential for climate-optimised flight routing across the north Atlantic involving both changes in track and in altitude. One illustrative example showed a striking difference in the impacts of NOₓ released on a particular winter’s day at two points (A and B in the synoptic chart) which were three hours flying time apart on a transatlantic flight. One packet of NOₓ was carried northward and had a life of three weeks; the ozone it created meandered around the northern hemisphere for the next two months. The other was carried southward into the more chemically reactive tropics, had a life of one week but created more than three times as much ozone which travelled around the tropics and southern hemisphere for the next two months. With strong sunlight in the tropics and weak sunlight and shorter days in the northern winter, the warming from the second packet was an order of magnitude greater than that from the first, released three hours later on the same flight.

The overall conclusion from REACT4C is that, applied to all transatlantic flights for a full year, climate-optimised routing could reduce climate impact by more than 20% at a cost penalty of around 7%. However, the low-hanging fruit are more easily gathered. Reductions in climate impact of around 10% can be had at a cost penalty of less than 1% by small changes in flight level to reduce contrail formation.

**Bio-fuels**

The paper by Steven Barrett concluded that the use of bio-fuels would probably increase net warming from contrails while cleaner burning engines should reduce it; two theoretical ideas involving operational variations in combustor characteristics to change contrail thickness were also mentioned.

**Panel discussion**

In the panel discussion at the end of the morning, it was agreed that the large variability in contrail-cirrus thickness and climate impact holds out the promise of significant benefit by adjusting the routes of only a small proportion of flights. It was suggested that deliberately creating contrails in daytime could be regarded as geo-engineering and raised ethical questions that would have to be addressed. Finally, it was thought that average temperature response (ATR) over a defined time horizon is an appropriate metric for assessing the impact of the non-CO₂ emissions. The time horizon is more a matter for policy makers than scientists but in due course it should be possible to arrive at a consensus.

**Contrail avoidance**

In the afternoon there were papers by Dr Jarlath Molloy of NATS, Captain Hugh Dibley of the RAeS and Prof David Lee of Manchester Metropolitan University, followed by a panel discussion of all the issues. Jarlath Molloy outlined prerequisites of a potential contrail avoidance system and suggested the Shanwick Oceanic Control Area, covering a large area in the north eastern Atlantic, would be a suitable basis for a trial of contrail avoidance,
as opposed to congested domestic airspace. The control centre at Prestwick handles approximately 80% of transatlantic traffic.

He expressed reservations about seeking positively to form contrails in the day, which he too saw as geo-engineering, and listed the challenges, technical and non-technical, that would have to faced. Despite these challenges, he concluded that a contrail avoidance system would be technically possible, but operationally challenging, and that a demonstration of it would be most likely to succeed in Oceanic airspace. The implementation of satellite surveillance (ADS-B) from 2018 may allow more flexibility than the current Oceanic Track System in planning and flying more efficient routes.

**Airlines and smart flying**

Hugh Dibley discussed the challenge smart flying would present to the airlines. Besides the additional fuel used in re-routing there was potential disruption to schedules, crew scheduling and aircraft rotation. Aircraft would need additional on-board instrumentation (he listed the equipment given in a US patent application by Mannstein and Schumann), possibly requiring additional maintenance. There would need to be some additional crew training. All these carried costs for the airlines. In the first instance, he suggested the provision of funds for airlines to carry out trials on suitable routes.

**Regulations**

David Lee drew on his long experience as a scientific adviser in policy discussions within the EU and ICAO of CO$_2$ regulation. The timescales, from first action to final implementation were exceedingly long, and CO$_2$ was technically fairly straightforward. He foresaw difficulties in seeking international agreement on any form of regulation covering the non-CO$_2$ emissions and highlighted the problems of measurement, verification and transparency that had to underlie any regulation. He posed a number of questions and left the meeting to reflect on them.

**Questions to be answered**

The workshop concluded with a lively panel discussion chaired by Prof Ian Poll of Cranfield. The panel members were Andrew Booth, flight operations specialist at Rolls-Royce, Prof Brian Collins of University College, former Chief Scientific Adviser to both DfT and BIS, Prof Volker Grewe of DLR, Dr Jarlath Molloy Environmental Affairs Manager at NATS and Dr Steve Smith, Head of Climate Science for the Committee on Climate Change. The audience joined in the discussion. The panel was invited to consider five questions though, in the event, one was dropped for lack of time.

**What are the main obstacles to implementing smart flying?** The perceived complexity of what is involved, the reluctance of policy makers to embrace something which entails uncertainty, the lack of interest by the industry were all cited as potential obstacles, though none should be a fundamental stopper. The need for a high degree of agreement in the scientific community about the appropriate trade-off between the effects of the short-lived and long-lived contributors was agreed, but the climate scientists believed that we were now at a point where this is not a fundamental obstacle. Cost needs to be addressed but, again, this is not seen as a fundamental obstacle.

**What regulatory measures or incentives can be envisaged?** This came down to the question of how to change behaviour. It was thought all stakeholders would need to be involved in the debate but there was no clear view as to whether it could best be done by regulation or by an incentive similar to inclusion in a carbon trading scheme.

**Would it be best introduced regionally?** Although it was recognised that eventually smart flying should be adopted worldwide, the final consensus was that it would be best to begin regionally; the north Atlantic, with Europe, taking the initiative, was argued to be the most promising starting point. The exceedingly slow progress of ICAO in developing regulations to limit CO$_2$ emissions was seen as a powerful argument against any attempt to take smart flying forward internationally through ICAO. Further, it was argued that some kind of demonstration would be needed before any general introduction could be contemplated.

**Finally, what actions, by whom, are needed to move towards implementation?** The proposition was made for a top-down approach, with the Presidents of the appropriate learned bodies jointly convening a meeting of stakeholders to consider the way forward. Counter to this, some were not convinced that the scientific evidence was yet robust enough to justify any action other than continued research. The consensus among the scientists, however, was that the scientific understanding and forecasting ability did indeed justify moving forward towards some kind of practical demonstration of the practicability of smart flying.

At the very end of the discussion, the summary conclusion was that the time was ripe to move towards such a demonstration. Initially, the case for such action needed to be made, the readiness of the science base needed to be made clear and the form of the demonstration had to be determined. Someone had to start the process and Greener by Design undertook to do so. This action is reported in the chapter on Science, Technology and Regulation.
The year 2015 marked ten years of Sustainable Aviation (SA). SA remains the world’s only initiative where the leading airlines, airports, engine and airframe manufacturers and the UK’s air navigation service provider have joined together to develop a joint sustainability strategy for aviation. In December 2015 the group publicly reported on the achievements against the sustainability goals since 2005 with the next progress report due in early 2018.

Decade of progress
During the past ten years the UK aviation industry has been very busy!
- Around 2bn terminal passengers have been handled by SA airports. Over nine million more terminal passengers were handled in 2014 compared to 2005
- SA airlines have carried 1.2bn passengers over ten years, with 2014 seeing them carry over 20m more passengers than in 2005
- NATS has handled over 20m flights through UK airspace
- The UK aerospace manufacturing industry has grown to be the second largest in the world with 17% of the global market share

The focus in SA has been to pursue the opportunities defined in the three key Road-Maps on CO₂, Noise and Sustainable Aviation Fuels. Achieving the vision of these Road-Maps requires two critical paths. Firstly, sustained commitment from all the SA members to translate the opportunities set out by the Road-Maps into their own strategic work programmes. Secondly, an ever increasing need for SA and its members to work with Government and wider stakeholders to overcome the broad policy, technical and community acceptability challenges to delivering sustainable aviation growth.

Tackling carbon emissions
Initially launched in December 2008, the SA Carbon Road-Map set out, for the first time, an industry projection for UK aviation CO₂ emissions to 2050. Using the UK Government aviation growth forecasts it showed that the risks of ‘doing nothing’ could result in a more than doubling of CO₂ emissions by 2050 compared to 2000. However, the report concluded that modernising airspace, making better use of modern aircraft operational procedures, developing and introducing new aircraft technologies and pioneering sustainable fuel innovation, gave the opportunity to disconnect future growth of UK aviation from growth in absolute CO₂ emissions.

This work has significantly supported wider European and global discussions on establishing long term CO\textsubscript{2} targets for aviation. In Europe the aerospace manufacturers developed a series of stretching targets through the Advisory Council for Aviation Research and Innovation in Europe\textsuperscript{(2)} (ACARE), which has published a target for CO\textsubscript{2} for emissions per passenger kilometre to be reduced by 75\% compared to 2000 as part of its Flightpath 2050 report. Globally, the International Civil Aviation Organization (ICAO) has agreed to a carbon neutral growth policy, keeping the global net CO\textsubscript{2} emissions from international aviation from 2020 at the same level\textsuperscript{(3)}. A series of activities are now underway through ICAO to achieve this.

Work on the SA CO\textsubscript{2} Road-Map has continued and in 2012 the work was updated with the latest UK aviation forecasts\textsuperscript{(4)} and in 2014 SA published a Sustainable Fuels Road-Map\textsuperscript{(5)} which explored in more detail the current and future market potential for using sustainable fuels and how they have the potential to reduce UK aviation 2050 CO\textsubscript{2} emissions by up to 24\% which, in turn, was incorporated into the latest SA CO\textsubscript{2} Road-Map. The Sustainable Fuels Road-Map also identified the opportunity for generating £265m in economic value plus the creation of 4400 jobs in the UK over the next 15 years.

The performance of the UK aviation industry in managing its CO\textsubscript{2} emissions since 2005, are encouraging:

- SA airlines have achieved an 11.9\% fuel efficiency improvement (measured in litres per revenue tonne kilometre flown) since 2005 with an annual fuel efficiency improvement of 1.9\% since 2009
- Since 2008, 400 procedural UK airspace changes and more efficient air traffic control have enabled savings of more than one million tonnes of CO\textsubscript{2}
- Continuous descent operations for UK arriving aircraft have increased from 56\% in 2006 to 78\% in 2015. This work was recognised by Business in the Community in 2015 by awarding NATS the winner of ‘The Engaging Customers on Sustainability Award’ for their work in championing the SA Continuous Descent Operations campaign.
- Since 2005, UK airlines have introduced more than 470 new aircraft into service, representing an investment of over £35.5bn at 2014 prices
- Since 2000, 20m tonnes of CO\textsubscript{2} emissions have been saved through airline fuel efficiency improvements and investment in these new, more fuel efficient aircraft
- A further 6m tonnes of CO\textsubscript{2} emissions reductions can be attributed to UK airlines through the EU emissions trading system (ETS)
- SA airports reduced their carbon emissions by 2.9\% in 2012 compared to 2010, despite a 5.4\% increase in terminal passengers

However, due to recent growth in traffic, total CO\textsubscript{2} emissions produced by SA airlines in 2014 were 33.3m tonnes. This is a 9\% increase in absolute emissions since 2005. This performance is in line with that predicted in the SA CO\textsubscript{2} Road-Map. A small increase in absolute aircraft CO\textsubscript{2} emissions can be expected until the new aircraft technology from the next generation aircraft types, such as the Airbus A350 XWB, A320neo, Boeing 787 Dreamliner and Boeing 737MAX, start to replace the current aircraft fleets. In March 2015, SA airlines had outstanding orders for 359 of these new aircraft worth £37bn at current list prices.

\textsuperscript{2}. http://www.acare4europe.com/about-acare  
\textsuperscript{3}. http://www.icao.int/environmental-protection/Pages/market-based-measures.aspx  
Tackling aircraft noise

In 2013 SA published its Noise Road-Map\(^6\), similar in format to the CO\(_2\) Road-Map. This analysed the opportunities to reduce aircraft noise up to 2050 and how this would affect total UK aircraft noise output. The work clearly showed that introduction of new aircraft and engine technology alone, offered the potential to disconnect future UK aviation growth from growth in aircraft noise output. A series of quieter operational techniques were also identified which offer the potential to reduce noise near airports by up to 5dB. Smarter collaboration between the aviation industry and local and national Government regarding land use planning around airports, is a key area of opportunity to help minimise the number of people affected by aircraft noise.

Looking at the industry’s performance, the results are encouraging.

- Between 2004 and 2014, the combined area of the 57dB Leq noise contour at eight major UK airports reduced in size by 14%
- The Airbus A380 and Boeing 787 aircraft now entering service with SA airlines produce 97% (15dB) less noise energy on departure and 94% (12dB) less on arrival than first generation jets – even quieter types are due to enter service in the near future
- The reduction in certificated noise between the Trent 800 engine produced in 1997 and the latest Trent XWB engine launched in 2014 is 14dB (cumulative for the three certification measurement points)
- A modification developed in 2014 by Airbus to reduce a high pitch whistling noise from its A320 aircraft, offers up to a 9dB noise reduction, under certain conditions. It is being fitted to all new A320 family aircraft and a retrofit solution is being embodied in existing aircraft in service with SA airlines
- Continuous climb operations to 10,000ft have increased in the UK from 55% of departures in 2006, to 67% in 2014
- Slightly steeper approach trials at 3.2° have been conducted with initial results showing a potential 1dB to 2dB noise reduction with no adverse safety issues
- Performance based navigation departure trials have demonstrated the ability to significantly concentrate flightpaths, so reducing the geographic spread of departure noise into local communities

An analysis of housing development near airports\(^7\) indicated that in 2014, over 5,700 extra homes have been granted planning permission, started or completed construction in the noise contours of the UK’s 18 biggest airports. In addition, a number of airport trials have been stopped following concerns from local communities about changes in noise experienced by those living around the airport citing their view that they have not been properly

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consulted. A key focus for SA moving forwards is to work in a smarter way with local Government and communities to find ways to address these two critical issues.

**Understanding and addressing airport air quality**

An emerging issue in the last few years has been concerns about air quality and aviation’s contribution. SA is currently in the process of collecting information to develop a detailed paper on this topic to help inform ongoing discussions.

**Socio-economic impacts**

To provide a balance to the often quoted detrimental impacts, in January 2016 SA published a new report detailing the socio-economic contribution of UK aviation[^7]. For the first time the report highlighted the social and economic contribution of the UK’s aerospace manufacturers, airlines, airports and air navigation service providers, in one report.

Key facts and figures produced in the report include:

- The UK aviation sector generates turnover of £60.6bn pa
- It supports 961,000 UK jobs, many of them in highly skilled, high productivity areas
- It contributes £52bn pa to UK GDP (3.4% of GDP)
- Around 3,500 apprenticeships are supported by UK aviation
- £1.7bn is invested in research and development annually, with significant spin off benefits flowing out to other sectors and industries
- It pays nearly £8.7bn pa in UK tax
- It invests over £15m annually in charity, community and good causes.

**Next steps**

As to the next decade and beyond, 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:

- Updating the SA CO₂ Road-Map when new Government projections of passenger demand become available
- Publishing a discussion paper on aviation and air quality
- 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
  - Supporting the development of sustainable fuels for aviation in the UK
- Support the SA members to find solutions with communities specifically regarding concerns with aircraft noise and airspace modernisation, etc.

In this way, SA and its members are looking forward to a brighter and more environmentally benign future for the UK aviation industry. By working together to identify new opportunities to help reduce the impacts of their operations and challenge existing practices amongst members and Government, alike.

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

Our Annual Conference in 2013 was on the topic of Airport Noise and included a presentation by the Airports Commission Head of Secretariat Phil Graham on the Commission’s process and progress to date. The Commission had been announced in December 2012 and was about to publish its interim report into the need for additional airport capacity in the South East of England. The interim report published in December 2013 confirmed the need for extra capacity and shortlisted options for the location of the next additional runway.

Over two and a half years later, the Government has still to make a decision on additional airport capacity in the South East of England.

Last year’s annual report included an article on the work of the Commission and mentioned that their final report was published on 1st July 2015.

This strongly recommended that a third runway be built at Heathrow but did not dismiss the two other shortlisted options – an extended northern runway at Heathrow and a second runway at Gatwick – stating that they were both credible expansion options.

The Commission recommended a balanced approach to expansion and listed a series of recommendations to address local concerns, including:

- A ban on all night flights from 11:30 pm to 6:00 am
- Heathrow Airport should be bound to operate within an agreed noise envelope
- A Community Engagement Board be established under an independent chair to exert real influence on compensation and community support
- An independent aviation noise authority should be established with a statutory right to be consulted
on flight paths and other operating procedures.

New capacity should only be released when it is clear that air quality at sites around the airport will not delay compliance with EU limits.

The recommendation to link a ban on night flights to the third runway was made despite night flights being outside the Commission’s remit and without it consulting on that specific issue.

In response to the final report, the new Government set up an Airports Sub Committee and promised a decision by the end of 2015.

However, on 10th December 2015, the Secretary of State for Transport announced that, although they had accepted the case for airport expansion and the options provided by the Commission, a location decision would be made following a package of further work on local environmental impacts and mitigation measures.

This work is expected to conclude in Summer 2016. There was much speculation that this further delay was driven by political considerations such as the forthcoming London Mayoral election but we believe that the importance of local environmental issues, especially the EU limits on air quality, were factors in the decision to undertake further work.

Our Annual Conference this year (17th October) will again address the local impacts of aviation and the possibility of growth within a set of environmental limits that are acceptable to an airport’s neighbours. We will see if the Government makes a decision on the location of new runway capacity before then but the conference should demonstrate whether the protracted analysis and debate on this issue during the last three years has generated better ideas on reducing, mitigating and managing the local environmental effects of airport operations or not.
Whether mankind can organize itself to address the challenge of climate change in a timely manner is a very open question. Whilst there has been a growing understanding over the past 50 years of the danger posed by anthropogenic climate change, society has been slow to react. A sound Framework Convention was negotiated in 1992 but the subsequent Kyoto Protocol struggled as a result of limited engagement. This was all due to be resolved in Copenhagen in 2009 at the Climate Change Conference of the Parties (COP15) – but the ambitious approach led by Europe collapsed calamitously. New life has been breathed into the Climate Change regime, however, by the unanimous support from across the globe for a new bottom up approach finalised in Paris last December at COP 21. While the approach being taken is much less ambitious than that of Copenhagen, nevertheless the commitment to keep global warming at under 2°C was reinforced by a unanimous commitment to drive efforts to limit the temperature increase even further to 1.5°C above pre-industrial levels.

Exclusion clause

After some debate in the run up to Paris, in the end aviation and shipping were both left out of the agreement; the responsibility of controlling the greenhouse gas (GHG) emissions of aviation was left with ICAO. Laurent Fabius, the much-acclaimed President of COP 21, has stated that the growing emissions from both sectors are a real problem. UN Secretary General Ban Ki-moon told the ICAO Governing Council in February that the eyes of the world were on the aviation sector to drive substantial, concrete progress on reducing emissions.
From 2020, IATA has committed to avoid net GHG emissions exceeding 2020 levels. Over and above the main technology developments discussed elsewhere in this Report, the two key solutions being pursued by the aviation industry are market-based measures (covered in the Science, Technology and Regulation report on p20) and sustainable alternative fuels.

**Biofuel slow progress**

Eight years ago, when the drop-in biofuel movement was forging ahead full tilt, great strides were made in the certification of new pathways to jet fuel from sustainable feedstocks. Since then the main challenge has proved to be the competitive supply of sustainable feedstock – that is to say the production of feedstock for low carbon (GHG) aviation fuel that is price competitive with kerosene from fossil fuel. This price target took a heavy blow when the price of oil plummeted in 2014.

Lord Brown, when he was CEO of BP, was asked whether, with a high oil price, the benefit of making sustainable fuels more competitive was matched by the disadvantage that more fossil fuel sources became competitive also, sometimes from particularly undesirable sources – and he acknowledged it as a moot point. Whether the current low oil price is simply a consequence of weakening demand or as a result of a determined policy of the Saudi Government to make tar sand and shale gas uncompetitive, the inevitable consequence is that it has made it far more difficult to make commercial progress with sustainable fuel alternatives.

In last year’s *Greener by Design Annual Report*, reference was made to the two alternative fuel initiatives announced by UK airlines, namely British Airways with Solena and Virgin Atlantic with Lanzatech. The observation was made that both solutions were making use of pure waste (municipal solid waste for the Solena project and waste gases from steel plants for the Lanzatech project) where it was of benefit to the waste owner for the waste to be taken away – and that as a result the feedstock cost element could be expected to be low or negative. Even negative costs for feedstock were not sufficient to maintain the project viability of the BA-Solena GreenSky project, however, and Solena was forced to admit defeat when it filed for bankruptcy on 16 October 2015.

British Airways has argued cogently that jet biofuels should be brought under the UK Government’s Renewable Transport Fuels Obligation, an argument that has also emerged from Greener by Design conferences on the subject. Currently, the limited amount of biofuel feedstock is being drawn towards the road transport sector rather than the aviation fuel sector, whereas in the medium term it is the aviation sector that is supposed to be moving towards sustainable biofuels, whilst the road transport sector moves towards electric and hydrogen based solutions.

Recently Solazyme, one of the well-known companies focusing on algal biofuel, announced that it is abandoning algal biofuels and focusing its algal oil production on food and personal care industries. They cited current extremely low oil prices, uncertain US Government policies and changing sentiment around the benefits of biofuels as the reasons for their change of strategy. The first two explanations are fully understandable and in line with the Solena / BA story, though why an algal biofuel company should be expressing concern about changing sentiment around the benefits of biofuels is far from clear.

In contrast to the Solena experience, Alt-Air Fuels and United Airlines are pushing ahead with their aviation biofuel deal. The Alt-Air processing plant, using UOP technology to create Green Diesel, is up and running, converting sustainable feedstocks such as non-edible oils and agricultural wastes into low carbon (60% CO\textsubscript{2} emissions reduction) renewable jet fuel. The 15m gallon deal announced is enough for 12,500 flights from Los Angeles to San Francisco over the next three years, using a 30/70 biofuel/kerosene blend. The announcement has the key words ‘up to’ preceding15m gallons, suggesting that the deal might not be impervious to the vagaries of the oil price, but the prominence being given to the flights, which will commence this year, seems to indicate that this deal will go ahead despite the low oil price. This deal is in addition to United’s Solena / BA equivalent, namely a partnership with Fulcrum BioEnergy to develop up to five refineries near United hubs. Like Solena, the Fulcrum refineries will process municipal waste into low cost sustainable jet fuel.

**WHY AN ALGAL BIOFUEL COMPANY SHOULD BE EXPRESSING CONCERN ABOUT CHANGING SENTIMENT AROUND THE BENEFITS OF BIOFUELS IS FAR FROM CLEAR.**
Elsewhere around the world, there are a wide variety of positive initiatives. In Oslo, the airport has become the first to supply sustainable jet fuel to airlines through the existing supply system. In Canada, a new consortium has been set up to assess the potential of sustainable jet fuel from forest residues using thermochemical processing. In Mexico, a new four-year sustainable biofuel research programme has been launched, reflecting the region's suitability for supporting prospective biofuel feedstocks such as Jatropha and salt-tolerant Salicornia. In Abu Dhabi, Etihad and partners have launched a roadmap towards establishing a sustainable aviation biofuel industry in the UAE – with municipal waste and halophytes seen as key feedstocks. In South Africa, the focus is on an energy rich tobacco crop for use as a feedstock and the project has recently secured Round-Table on Sustainable Biofuel certification. Meanwhile, processing technologies continue to be developed and improved, with a variety of processes already certified by the ASTM and others under consideration. The list of activity is long.

In summary, the story is a mixed bag. There is plenty of evidence of determination amongst the aircraft manufacturers, airlines, feedstock suppliers and the processing industry to do what is necessary to establish a flourishing sustainable drop-in jet fuel industry and to start making real reductions in aviation's greenhouse gas emissions. But without a strong carbon price and with the oil price at low levels, the challenge is proving more difficult than it looked a few years ago.
The Aerospace Technology Institute recognises that environmental performance is one of the priority attributes for competitiveness of UK players in the sector. As the launch announcement in 2013 made clear: “The ATI will allow industry and academic researchers to develop technology for the next generation of quieter, more energy efficient aircraft”. Hence environmental goals have been an ATI priority from the outset and this continues to be fully endorsed in both the Building Momentum for UK Aerospace publication as well as the ATI Technology Strategy which was launched in July 2015. Growth in air travel, expanding airports and more congested airspace drive the need for more efficient, environmentally friendly aircraft that are quieter, safer and even more reliable. The UK needs to be ready with high efficiency, low emission technologies to pull through the next wave of technologies and systems for step-change in efficiency, emissions and noise. Meeting these challenges implies continuous improvement in product technology, which will require long-term, high-cost, and high-risk investment.

The ATI provides a holistic approach to the UK’s technology strategy that recognises the needs and contributions of major companies, supply chains, universities and other research facilities. The ATI is managing a UK investment programme in civil aerospace technologies to maximise the technological and economic impact of the investment, by providing:

- A clear and confident strategy
- A systematic approach to stimulating the pipeline of opportunities
- Portfolio management to select the best projects and keep the technology programme agile and aligned to the strategy
- Networks and engagement that encourage and help industry to collaborate and shape better projects

In the past year the Institute has established an advisory structure building on relationships with all organisations to ensure the technology strategy is alive to economic and market events, legislative changes and shifts in the technology landscape. A Technology Advisory Group (TAG) has been formed to engage the aerospace technology community, together with Specialist Advisory Groups (SAGs) to focus discussions on priority enablers and value streams, such as propulsion, structures, systems and whole aircraft.

The ATI technology programme is already producing benefits, and in conjunction with the skills and supply chain initiatives of the AGP, will make a major contribution to delivering the UK’s aerospace agenda. Indeed over 150 projects have been initiated, involving over 150 entities, addressing a wide range of technologies with approximately half the initial £2.1bn government-industry funding committed to innovation and new infrastructure.

In the 2015 Comprehensive Spending Review, in which the Chancellor committed to continue “an active and sustained industrial strategy”, the government recognised the importance of the ATI by extending the grant funding by £900m – taking the committed joint government-industry funding for ATI programmes to £3.9bn to 2025/6.

In addition the Institute is engaging with technical forums and organisations overseas, in particular with the European Union (EU) funded research programmes. This can benefit the UK aerospace sector by providing access to funding opportunities to further UK technology interests. This is focused on improving UK presence on the EU Clean Sky 2 programme and increasing engagement and influence with the European Commission and Clean Sky administration, by playing a greater role on policy committees and working groups.

Hence the ATI is including the development of cleaner and quieter aircraft in the future as a passport to growth of the sector. Future aircraft will have to continue the trend for noise and emissions reduction gains beyond those that have been achieved over past decades. As the ATI Chief Technology Officer Simon Weeks says: “We see cleaner quieter aircraft as passports to new markets and growth opportunity. The ATI is drawing upon industry and academic experts to help craft the programmes for environmental excellence that will give us that edge. The ATI is focused upon ensuring that we retain and strengthen that strong performance in green technologies.”

For further information on the ATI please visit www.ati.org.uk
From time to time it is useful to reflect on how far we have got in achieving the key aim of Greener by Design: to minimise all environmental effects of aviation. Our ultimate aim could be stated as to have zero emissions from the three components of commercial aviation: travel to the airport, the airport itself and the aircraft flight. However given the quantities of energy needed for these activities, this is a very significant challenge, and is impossible to achieve in the medium term.

The immediate challenge is therefore to reduce that energy input as much as possible, and in parallel try to use as much renewable energy as practical, from solar, wind, hydro, tidal or geothermal sources. Failing that, electricity from a (largely) carbon free source – including nuclear – is the next best. It produces no emissions locally, and depending on the degree of decarbonisation of the supply may produce few emissions at the power station. Some power stations today (such as Drax in Yorkshire) are using a renewable fuel (biomass) with scrubbing of exhaust gases to minimise emissions.

In reviewing where we are, and where we could be, it is helpful to consider aviation’s activities as falling into three parts – getting to the airport, the airport itself and the flight.

Getting passengers, staff and cargo to and from the airport is the first part of the task. Public transport using electrified rail or electric metro/tram/underground services will produce zero local emissions, as will electric cars or buses. Private cars tend to be the most polluting, especially if diesel. Airports are trying a variety of measures to encourage public transport use, not least in providing high quality trains and buses serving the whole of the airport catchment area.

A good example of what can be done can be seen at Oslo Gardermoen airport. The new airport was authorized by Parliament in 1992, and opened in 1998, together with a high speed rail link the following year. The trains cover the 29 miles from the city centre to the airport in 20 minutes. Some of the high speed trains now continue on to Drammen. The high speed link is used by over one third of the total number of passengers travelling to the airport. There are also main line trains (to Trondheim) stopping at the airport, and suburban and regional services to a series of local destinations, including alternative routes into Oslo. Many express coach services serve the airport, and together with local buses, bringing the total public transport share to around 70%, one of the highest public transport shares anywhere in the world.

If other airports also had the same quality of public transport, and if electric cars do indeed become commonplace in the next 10/20 years, one can see that emissions arising from accessing the airport could virtually disappear. This would have a major impact on local air quality and the airport’s carbon footprint. And this high public transport share is being currently achieved without charging cars to access the airport – either to drop off or pick up passengers. If this was done, one could expect an even higher public transport share and even lower emissions.

There is always scope for new and innovative solutions, but there is less excuse for doing nothing when proven solutions are available: the challenge is to get on and do it!

Here in the UK, Luton Airport is doing just that and recently announced its intention to construct an electric people mover between Luton airport and its station (which already has frequent electric trains to London and the South Coast). This will make using rail quicker and more convenient, and will contribute to reducing private transport to the airport. Together with the planned electrification of the Midland
mainline north of Bedford, further reductions in rail journey time (and emissions) can be expected, both from the trains themselves and from car users switching to the improved rail services.

The second area for focus is the airport itself. At ground level, aviation's emissions take three forms – noise, pollutants impacting air quality and greenhouse gases (principally carbon dioxide, but also nitrogen oxides and soot that impact air quality too). Airports use a lot of energy for lighting and air conditioning of passenger buildings, power for baggage conveyors, and providing power for aircraft systems including air conditioning whilst planes are on the ground. There are also large numbers of service vehicles and tugs, for getting supplies, baggage and cargo to aircraft, not to mention moving aircraft on and off stands to and from maintenance facilities. In total a very significant energy demand.

**Going electric**

It is now realised that using renewable power sources and the provision of electric vehicles provide a practical emissions-free solutions to these issues and there are a large number of initiatives under way around the world to achieve them.

A couple of examples will suffice: Adelaide and Schiphol. At Adelaide they have taken advantage of the plentiful sunshine, and the plentiful acreage of roof space on the short stay car park to install one of the largest solar power systems in Australia, generating some 1,288MW of electricity. This meets some 10% of the total airport power requirements without any emissions at all.

Schiphol Airport has recently replaced its fleet of conventional airstside buses by 35 electric buses, which are used to transport passengers between the airport gates and remote aircraft stands. These buses are used by around 20% of passengers, the balance using air bridges to reach their aircraft. By switching to electric buses, there are zero emissions locally, whereas the previous diesel buses rarely warmed up to their operating temperature – because of intermittent use – and therefore struggled to meet their emissions level, despite extensive maintenance.

With such obvious advantages several other large international airports have also announced their intention to go electric, including Heathrow. Luggage, cargo and catering trucks are all scheduled to become electric, supported by the installation of an additional 135 recharging points, together with some in the public car parks to encourage electric vehicle use by passengers. The concept of zero emissions from airport terminal and ground activities is now a practical and achievable goal.

That leaves the aircraft themselves. Clearly this is the biggest issue, because energy consumption here dwarfs the other energy uses at the airport and for access. There are a great many initiatives, both implemented and in progress to cut fuel use, many of which have been referred to in the pages of this annual report over the years.

A rather different perspective on the issues was offered late last year by the International Council of Clean Transportation. They investigated the fuel consumption by each airline that flies the North Atlantic. This came up with a rather surprising fact: the difference between the most fuel efficient and least efficient airline was over 40% when expressed as passenger km per litre of fuel consumed. Norwegian came out as the most fuel efficient, managing to carry 40 passengers one kilometre on each gallon of fuel. Airberlin were in second place managing to carry 35 passengers one kilometre on each litre of fuel. The legacy carriers all fared badly, notably British Airways (27 passenger km per litre), SAS and Lufthansa (28 passenger km per litre), and US Airways, Virgin Atlantic and Swiss Air all achieving 29 passenger km.

Norwegian have some big advantages – their fleet is predominately new Boeing 787 8 series planes, high load factors, and a low prevalence of premium seating (11%). In contrast BA’s fleet is nearly half 747 400s, 15 years old, and has a high percentage of premium seating (24%). It also operates a business only Airbus 318 from London City, with perforse a refuelling stop in Ireland.

So there is plenty of scope in the near future for cutting aircraft emissions, by the simple expedient of using new aircraft, achieving higher load factors and less premium seating.

In conclusion, many of the building blocks for carbon and emissions-free airports and access to airports are already in place: the challenge is to use the available technology to achieve results. Whilst there is more to do on aircrafts' emission, the ICCT dramatically pointed out the importance of high load factors and new more fuel efficient aircraft.

A final postscript: the differences between ‘full service/legacy’ carriers (like KLM, BA and Air France) and ‘low-cost/no-frills’ carriers (like Ryanair, easy jet and Norwegian) are beginning to disappear. Transatlantic flights have always been the preserve of legacy carriers – now they have been joined by Norwegian. Low-cost carriers have not offered through baggage transfers – if you have to continue your journey on a second service you must reclaim your bags at the intermediate airport, and re-check them in for your next flight. Now Ryanair has announced it will trial through bag transfers on certain routes (through Stansted). Finally BA has announced free snacks/meals are to go on some short haul routes, and customers will be charged for refreshments. So what differences will remain? Only price?
Atmospheric science

Contrail optimisation

The potential for reducing the climate impact of contrail-cirrus and other non-CO₂ effects by smart flying – i.e. by tactical re-routing of air traffic – was discussed at the GBD Conference in October 2015. The account of the conference earlier in this Report recalls how, at the very end of the round table discussion, GBD undertook to explore with others the possibilities of a practical demonstration.

To take this forward, GBD invited the 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 discuss the feasibility of a practical demonstration of reducing contrail-cirrus by re-routing.

The discussion started from the premise that any demonstration project would be based on the Shanwick Oceanic Control Area, which covers a large area in the north east Atlantic and handles approximately 80% of transatlantic traffic. A second premise was that the days when the contrail impact would be sufficient to justify aircraft being re-routed would be relatively infrequent.

The requirements of the atmospheric scientists were (a) to predict when and where strong contrail-cirrus would form and (b) to determine the climate impact of any re-routing of aircraft that occurred. It was agreed that, with the current state of atmospheric science, these requirements could now be met. The large variability in contrail-cirrus thickness and climate impact implies that significant benefit can be achieved by adjusting the routes of only a small proportion of flights; the atmospheric conditions under which route adjustment would be well justified are reasonably predictable. Ulrich Schumann of DLR showed a slide to illustrate the point.

The possibility of deliberately forming daytime, cooling contrails as well as avoiding forming nighttime warming contrails was discussed. However, it was recognised that deliberately creating contrails in daytime could be regarded as geo-engineering. The Oxford Principles were discussed and it was agreed that, in parallel with the proposed scientific assessment, a sub-group would consider the question of governance.

After discussion of which other organisations would be needed as participants in a potential demonstration, and also of possible funding sources, it was agreed that further paper studies are needed to define the demonstration project more clearly. These, which were seen as virtual demonstrations using available traffic, Meteosat and weather data, would illustrate what might be achievable at acceptable cost by re-routing, and assess whether the forecast data are sufficiently accurate to act with confidence. They would also assist in the formulation of a protocol to enable operational decisions during a potential demonstration project. This work would take some time but it is planned to reconvene the informal group in the autumn to review progress.
The NO<sub>x</sub> effect

At the GBD conference on non-CO<sub>2</sub> effects and smart flying, Keith Shine reported recent developments in the understanding of the climate impact of NO<sub>x</sub> emissions. Whist the constituents of NO<sub>x</sub>, NO and NO<sub>2</sub>, are short-lived and not significant greenhouse gases in themselves they do, via a sequence of chemical reactions, have the effect at altitude of increasing ozone, a powerful but short-lived greenhouse gas, and reducing methane, a less powerful but relatively long-lived greenhouse gas which itself also leads to the creation of ozone.

The calculation of the climate impact of NO<sub>x</sub> emissions uses global chemistry transport models and comparisons across a range of such models has led to much improved understanding. A key question is the extent to which the warming effect of ozone formation caused by NO<sub>x</sub> is balanced by the cooling effect of decreases in methane that result from its more rapid destruction initiated by the NO<sub>x</sub>. A recent study<sup>(3)</sup> reports the results of the European Union Framework 7 project REACT4C. One feature of the study was the inclusion, in one of the models, of the impact of NO<sub>x</sub> emissions on the formation of aviation-induced particulates. The study confirmed the strong compensation between the ozone and methane climate effects, but nevertheless indicated a net warming effect of the present-day fleet of around 6mW m<sup>-2</sup> (this...
The calculation of the climate impact of NOX emissions uses global chemistry transport models and greenhouse gas which itself also leads to the creation of ozone. But short-lived greenhouse gas, and reducing methane, a less powerful but relatively long-lived variation of NOX impact with regional and latitudinal variation of flight.

The meridional extent of the RF is larger for low latitude emissions. GWPs for all emission changes larger than those from higher latitude emission changes. The net RF is positive for all experiments. Latitude emission changes (per Tg N) cause ozone and methane RFs that are about a factor of six larger than those from higher latitude emission changes in discrete latitude bands covering both hemispheres. It was found that lower latitude emission changes (per Tg N) cause ozone and methane RFs that are about a factor of six larger than those from higher latitude emission changes. The net RF is positive for all experiments. The meridional extent of the RF is larger for low latitude emissions. GWPs for all emission changes are positive, with tropical emissions having the largest values; the sign of the GTP depends on the choice of time horizon.

Variation with flight latitude of the components of radiative forcing arising from NOX emission (Köhler et al(4))

There has been press coverage of a study(5) at the University of Reading that used a climate model to forecast the effect of a doubling of atmospheric CO2 on winds in the North Atlantic and hence on transatlantic flight times and fuel burn. The general increase in the predicted strength of the prevailing West-East winds in the upper troposphere and lower stratosphere leads to a shortening in the flight times of West-East transatlantic flights and an increase in East-West times. The overall prediction is that, for the total transatlantic traffic, aircraft will collectively be airborne for an extra 2,000 hours each year, burning an extra 7.2m gallons of jet fuel at a cost of $22m and emitting an extra 70m kg of CO2. The paper cites earlier studies of the potentially adverse impact of climate change on the intensity of clear air turbulence and on aircraft take-off performance. The effects on flight times and fuel burn are relatively small when compared to corresponding baseline figures for transatlantic traffic but are large in absolute terms.

Impact of climate change on flight time and fuel burn

The climate impact of NOX is known to vary strongly with the altitude of emission and also with the latitude and region of the flight, as illustrated in a recent study by Köhler et al(6) of the variation of NOX impact with regional and latitudinal variation of flight.

The response to regional and latitudinal changes in aircraft NOX emissions was evaluated using several climate metrics (radiative forcing (RF), global warming potential (GWP), global temperature change potential (GTP)). The study investigated the impact of emission changes for specific geographical regions (approximating to USA, Europe, India and China) and cruise altitude emission changes in discrete latitude bands covering both hemispheres. It was found that lower latitude emission changes (per Tg N) cause ozone and methane RFs that are about a factor of six larger than those from higher latitude emission changes. The net RF is positive for all experiments. The meridional extent of the RF is larger for low latitude emissions. GWPs for all emission changes are positive, with tropical emissions having the largest values; the sign of the GTP depends on the choice of time horizon.

Schematic view of SAGE 2 counter-rotating open rotor.
Technology

Clean Sky

The European Clean Sky Joint Technology Initiative (JTI) was launched in 2008, to run until 31 December 2017. It has a budget of €1.6bn provided in equal shares by the European Commission in cash and by the aeronautical industry as contributions in kind. Now running in parallel with it is a new JTI, Clean Sky 2, with a budget of €4bn (€1.8bn from the EC, €2.2bn from industrial partners). Clean Sky 2 is planned to run from 2014 to 2024 and has set more ambitious but longer term improvement targets than Clean Sky. Relative to the standards of year 2000 production aircraft, the respective goals of Clean Sky in 2020 and Clean Sky 2 in 2050 are: CO₂, 50% reduction by 2020, rising to 75% by 2050; NOₓ, 80% reduction by 2020 rising to 90% by 2050; noise halving by 2020 rising to 65% reduction by 2050.

Many of the Clean Sky projects have been discussed in previous GBD Annual Reports and much of the work done under the JTI was reported at Aerodays 2015. This was the European flagship event in aviation research and innovation for the 7th EU Research Framework Programme, held in London in October 2015 (http://www.aerodays2015.com/). Some of its demonstrator programmes have produced results already but for the two largest ones, the SWFA BLADE and SAGE, the full demonstrations are some way in the future.

The SAGE 2 demonstrator, led by SAFRAN, is a geared counter-rotating open rotor that is claimed to be the only engine architecture allowing a 30% reduction in CO₂ emissions compared to the CFM56 engine. A ground test demonstration of a full-scale open rotor system is scheduled for 2016. A flight test, mounted on the rear fuselage of an A340, is planned in Clean Sky 2.

The SWFA BLADE demonstrator will flight test wings designed for natural laminar flow, fitted as the outboard panels of an A340 aircraft. One of the key aims is to demonstrate that the necessary manufacturing precision can be achieved, with surface bumps, steps and waviness kept within the required, exacting limits. The two wing panels will be of differing structural design, to test alternative manufacturing approaches. The design and manufacture of the upper surface cover and leading edge of the port wing is the responsibility of SAAB. GKN have the same responsibilities for the starboard wing and the provision of the eight other key components of the wing panels are shared between four other companies, notably Airbus.

The wind tunnel rest programme in support has extended from tests in the European Transonic Wind Tunnel (ETW) to tests on a large-scale complete model of the A340 with the laminar flow
Hybrid electric propulsion

In its third call for core partners, the Clean Sky 2 JTI invited proposals for ‘divergent aircraft’ configuration studies focussed on hybrid electric propulsion. The call falls in the Large Passenger Aircraft category and envisages studies leading to the down selection of one configuration for which a scaled model demonstrator will be built and flight tested. This decision is envisaged in 2019. The number of candidate configurations is unknown at this stage but two potential contenders are already visible, the Dispursal project from Bauhaus Luftfahrt and the E-Thrust project led by Airbus and Rolls-Royce.

Within Clean Sky and Clean Sky 2 there is of course a wide range of less exciting projects which are steadily advancing all aspect of aircraft technology, for aircraft of all sizes.

NASA ERA and the New Aviation Horizons initiative

The NASA Environmentally Responsible Aviation project, ERA, which has always provided interesting material for our past Annual Reports, has come to a close. Over the six years of the project NASA invested $400m, with a further $250m of in-kind resources provided by industry partners. The project focused on eight integrated technology demonstrations of new technologies covering key aspects of aircraft and engine design and manufacture. The assessment of NASA is that the new technologies developed and refined in the project could help US airlines realise over $250bn in savings over the first 25 years after being put into service.

ERA has been followed by the New Aviation Horizons initiative, which has a ten-year requested budget of $10.6bn, beginning with an increase from $640m in fiscal year 2016 to $790m in fiscal year 2017 and peaking at $1.3bn in 2023. The increased budget is to provide for the construction of a series of X-planes, typically 50% scaled manned demonstrators of both quiet supersonic and ultra-efficient subsonic aircraft. Other, smaller scale demonstrators are planned, including the Spector adaptation of a light aircraft to distributed electric propulsion, with 18 propellers in the wing leading edge, which is already in progress.

The two demonstrators that are most advanced in their planning are the supersonic business-jet sized Low-Boom Flight Demonstrator (LBFD) and the subsonic Hybrid Wing Body (HWB), an evolution of the Boeing-NASA Blended Wing-Body concept featured in earlier Annual Reports. Both are sufficiently mature to have a preliminary design review (PDR), LBFD in 2016 and HBW in 2017. The picture on the right shows the current concept for the HBW, with twin turbofans mounted over the rear of the body between twin fins to optimise noise shielding.
For the next X-plane to follow the LBFD and HWB, NASA plans competitions to study several candidate subsonic configurations, including the Massachusetts Institute of Technology/Aurora Flight Sciences ‘double-bubble’ and the Boeing-led transonic truss-braced wing (TTBW) concept, the latest version of which has been recently tested in the 11ft transonic wind tunnel at the NASA Ames Research Center in California.

Another recent idea from NASA is the Starc-ABL (single-aisle turbo-electric aircraft with an aft boundary layer propulsor) illustrated on the first page of this article, which is very similar to the Bauhaus Luftfahrt Dispursal concept described above. Both have two underwing turbofans which provide most of the thrust but also have electrical generators producing power to drive a central fan which ingests and re-energises part of the fuselage boundary layer. The significant difference between the two concepts as currently presented is that on the NASA Starc-ABL, the empennage is mounted on the rear fuselage with the centre fan mounted behind, on the Dispursal concept the empennage is mounted on the rear part of the fan structure with the aerodynamic loads carried through the fan structure to the fuselage. The airflow into the Dispursal fan is cleaner but the structural challenges would appear to be greater.

Myth-information?

A recent paper by Peeters et al\(^6\) has argued that ‘technology myths are stalling aviation climate policy’. The paper has analysed past and projected aircraft fuel efficiency and CO\(_2\) emissions alongside coverage in the media of a selection of forecast advances in technology that were seen as steps on the road to sustainable aviation. The analysis covers a 20-year period from 1994 to 2015. In its final discussion it says: ‘Analysis with regard to airframes, engines and fuels reveals, however, that many of the proposed solutions emerge and are hyped in the media, only to disappear again from public discourse’.

The concern of the paper is that, because aviation is a transnational activity, it is difficult to govern politically. In this situation, politicians may embrace myths to justify non-action beyond efficiency improvements achieved through technology. It cites a government energy minister saying: ‘If you look at the future of flight it is possible to imagine, with technological innovation, that we will have zero-carbon flight in the future’. According to the paper: ‘This view may reflect a genuine belief in technology myths or represent a convenient way to avoid upsetting the established ‘order’, i.e. to initiate legislation aimed at reducing growth in the volume of air transport itself and replacing it with other transport modes or alternative travel patterns.’
The methodology of the paper, which relies on an analysis of the frequency of citations in the media, is open to challenge. For instance, the pattern of media articles on the blended wing-body led the authors to the conclusion that interest in it has been abandoned, whereas we have noted above that NASA has budgeted to launch a piloted demonstrator aircraft within this decade. Moreover, with a requested budget averaging over $1bn a year for ten years, NASA will assuredly demonstrate some substantial technological advances in the coming decade, and Clean Sky and Clean Sky 2 can be expected to do likewise.

Even so, there is a grain of truth in the paper. Past issues of the GBD Annual Report contain many examples of envisaged technological advances that have not been taken up. There have also been examples cited of design changes that could reduce climate impact without any introduction of new technology, for example the re-optimisation of single-aisle aircraft to fly lower and slower as discussed in the final section of our 2013-2014 Annual Report. At the GBD Conference, Grewe cited a DLR study of an A330 aircraft re-optimised to fly lower and slower, maximum altitude 10,500m, maximum Mach number 0.775, which would reduce the climate impact by 30% with no increase in fuel burn. The slower flight speed would reduce utilisation and return on investment and hence increase direct operating costs. The airlines would not buy this aircraft. The reality is that the operators and the manufacturers quite properly have as their prime objective the value of the return to their shareholders rather than reducing climate impact. It is the role of the regulator, ICAO, to drive both sectors to reduce their climate impact. From the following section, the reader can judge the success to date of ICAO in its pursuit of this goal.

Regulation

The ICAO CO₂ Standard

At CAEP/10, the metric of Cir 337 was used as the basis for the setting the first ICAO Aeroplane CO₂ Emissions Standard. The CAEP/10 recommendation must be ratified in June 2016 by the ICAO Council, consisting of representatives of 36 states, and then endorsed in October 2016 by the Assembly of all 191 member states. At the time of writing the official record of the CAEP/10 meeting has not been published but its outcome has been summarised in a paper by the International Council on Clean Transportation (ICCT)\(^3\).

For aircraft with maximum take-off mass MTOM greater than 60t the standard is specified as a curve of the metric value MV plotted against MTOM. There are in fact two standards. The more stringent one is for all new designs certificated after 1 January 2020 and expected to enter service in around 2024. A less stringent standard has been adopted for current ‘in production’ (IP) types, the continued production of which will be permitted after 2028 only if at that time the current version of the type has been certificated to meet the standard for IP types.

The analysis by ICCT includes a chart (shown at top of the next page) of the projected year-by-year average margin to the standard for project deliveries
of new commercial aircraft with MTOM greater than 60t. Positive values represent fuel efficiency worse than required under the standard, while negative values indicate fuel efficiency performance better than that required under the standard. Error bars on the graph represent the 10th and 90th percentile aircraft delivered in a given year, weighted by MTOM. The inference drawn from the ICCT analysis is that the standard is likely to have minimal impact on new types certificated after 2020 – the demands of the market will probably ensure that no aircraft that does not surpass the ICAO standard will be launched in that time frame. This is not because an ICAO standard exists but because the airline customers will expect at least that level of improvement above aircraft of today's performance. The impact of the standard on IP aircraft is also expected to be small, since most of those expected still to be in production in 2023, when certification against the ICAO standard will begin, already meet the standard. The few that don't will have had a long production life and termination of their production in 2028 is unlikely to be a major problem for the manufacturers.

The decision on the CO₂ standard, which has been six years in the making and is the first ever to impose efficiency constraints on the aviation sector, has been acclaimed by both politicians and industry spokesmen as an important step forward. Environmental NGOs, on the other hand dismiss it as unambitious and ineffective. In September 2013 the International Coalition for Sustainable Aviation (ICSA), which is the only civil society group accredited to ICAO, submitted a paper to the ICAO Executive Committee inviting the ICAO Assembly ‘to confirm that the CO₂ standard is an essential element of the basket of measures and request Council to ensure that CAEP adheres to its commitment to agree to a standard that produces incremental emission reductions beyond business as usual for new aircraft types.’ The Executive Committee did not incorporate this recommendation in its report to the assembly and the ICCT study makes clear that the standard adopted by CAEP falls short of this aim.

The ICAO GMBM scheme

The limited impact of the standard is implicitly recognised by ICAO. At its forthcoming meeting in September, the ICAO Assembly is expected to adopt a resolution acknowledging that technical progress alone may not deliver sufficient reduction in CO₂ emissions to address the growth of international air traffic. Having set the goal that aviation will achieve carbon-neutral growth by 2020, ICAO recognises that this will not be achieved without the introduction of global market-based measures (GMBM).

The concept of “carbon-neutral growth” from 2020 was first proposed as an aim by ICAO. At its forthcoming meeting in September, the ICAO Assembly is expected to adopt a resolution acknowledging that technical progress alone may not deliver sufficient reduction in CO₂ emissions to address the growth of international air traffic. Having set the goal that aviation will achieve carbon-neutral growth by 2020, ICAO recognises that this will not be achieved without the introduction of global market-based measures (GMBM).

The concept of “carbon-neutral growth” from 2020 was first proposed as an aim by the International Air Transport Association in 2009. In 2010 it was adopted as an aspirational goal by ICAO at its 37th Assembly, with the acronym CNG2020. Its purpose is to hold the net CO2 emissions from aviation, after allowing for carbon offsetting, constant at the level reached in 2020. The GMBM scheme proposed by ICAO entails carbon trading – the purchase by the air transport industry of
carbon offsets from other economic sectors. It has the acronym COSIA (Carbon Offsetting Scheme for International Aviation) The figure on the right illustrates the magnitude of the task for COSIA, the upper curves showing the expected growth of CO$_2$ emissions offset by expected operational improvements and advances in aircraft technology, the horizontal line from the year 2020, corresponding to ‘carbon-neutral growth’ from 2020. To the extent that the grey wedge is not filled by sustainable alternative fuels (covered elsewhere in this Report), it must be filled by the purchase of carbon offsets.

In March 2016 ICAO released the text of a draft resolution on COSIA and in March and April five regional workshops, called Global Aviation Dialogues (GLADs), were held to discuss the features of the scheme with representatives of nations that are not included in the ICAO Council. Feedback from these workshops was considered by a High Level Meeting in Montreal in May with the aim of finalising the resolution to be put before the Assembly in September. The proposals put before the High Level Meeting envisaged the scheme beginning to operate from January 2021 for high income states, each with more than 1% of global air traffic measured in revenue tonne-kilometres. This will capture around 80% of world traffic. Upper middle income states, with more than 0.5% of global air traffic, will enter the scheme in 2026, thereby extending the scheme to 95% of world traffic.

While the aim of the High Level Meeting was to agree the text of a resolution to be adopted by the ICAO Assembly, the meeting in May ended with a number of issues unresolved. However, with industry and NGOs both pressing ICAO to reach agreement on the scheme, there appears to be confidence at high levels in the organisation that by September the Assembly will be ready to adopt a resolution to implement COSIA.

**CNG2020 not good enough**

It is important to be aware that ‘carbon-neutral growth’ is a seductive, potentially misleading term. As we reported two years ago, David Lee and colleagues of Manchester Metropolitan University published a paper $^{(10)}$ to show the increasing radiative forcing due to aviation CO$_2$ as the emissions continue to accumulate under CNG2020. Between today and 2050 radiative forcing from aviation CO$_2$ will increase by a factor of three under ‘carbon-neutral growth’. It is difficult to envisage technical advances in the foreseeable future that will avoid this growth and the success of the ICAO GMBM scheme seems to be politically essential to the continued growth of air travel. In due course, increase in the world carbon price may cause aircraft designers to place substantially more emphasis on reducing fuel burn but the decisions taken at CAEP/10 suggest that any such change is decades away.

The figure on the following page is an adaptation of the ICAO chart on the previous page, used in the launch by the Aviation Environment Federation (AEF) of its Flightpath 1.5 campaign. The campaign was launched 100 days after the agreement in Paris at COP21 to set a goal of limiting the global temperature increase to 1.5°C above pre-industrial levels. To quote the launch document, ‘Flightpath 1.5 calls for capping and cutting emissions of the entire international aviation sector and is advocating for an aggressive and transparent ICAO deal that:

1. Initially caps net carbon emissions of international aviation at 2020 levels;
2. Encourages airlines to meet the cap by cutting their own emissions and lets them use market-based measures as well – but only if those measures deliver high-quality emission reductions and low-carbon biofuels that promote sustainable development;
3. Reviews the cap regularly, so that over time, aviation's climate pollution can be ratcheted down in line with the Paris target.

The AEF version of the chart includes a downward sloping dotted line, indicating the possibility of resetting the net emissions limit on such a downward trend in, say, 2032. If it were set to achieve a goal of zero net emissions by 2050, the chart by Lee et al suggests that RF from aviation CO₂ might level out at around 55mW/m² compared with around 35mW/m² today.

The Flightpath 1.5 launch document ends with a quote from AEF Director Tim Johnson: “Curbing aviation emissions will require more than currently available technological improvements, making a market-based measure an essential tool to efficiently incentivize the industry to achieve deeper cuts. We can’t assume that the biofuels and other radical technologies will automatically materialize and put aviation on a flight path in line with 1.5°C. A well-designed market-based measure is the safety net the industry needs.”

Whilst we fully endorse this statement, the long-held view of Greener by Design on market-based measures is that any significant departure from ‘business-as-usual’ aircraft development is likely only if the combined fuel and carbon price is high enough to provide the incentive. Over the past decade fuel price has varied between 12.5 and 140$/bbl and, on 12 May 2016, at the second auction of carbon credits at the World Bank’s Pilot Auction Facility, sellers achieved an effective price equivalent to 0.84$/bbl. Aviation is unlikely to be a major player in the world carbon market and it is difficult to foresee how this market will develop in the coming decades. That said, a very substantial increase in carbon price is likely to be needed to have any significant influence on future aircraft designs.

REFERENCES

9. ICSA ICAO’s CO₂ Standard as part of a basket of measures to meet emission reduction goals, September 2013, ICAO Working Paper A38-WP/297.
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, Innovation and Skills 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 is scheduled to be held on 17-18 October 2016 at the Royal Aeronautical Society.
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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