

Air Travel — Greener by Design

Annual Report 2009-2010

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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Air Travel – Greener by Design Annual Report 2009-2010



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by

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GREENER BY DESIGN

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CHAIRMAN'S INTRODUCTION

It gives me great pleasure to introduce this 2010 Report from Greener by Design. My first duty as acting Chairman is to thank Keith Mans following his retiring as Chief Executive of the Royal Aeronautical Society and Chair of Greener by Design. Keith was key in the formation of the Group and in guiding it through its first decade. We wish him well in his new endeavours. 2009 saw the tenth anniversary of the formation of 'Air Travel Greener by Design' one of the world's first Groups to recognise and promote the task to be done by the civil aviation industry if it was to have a successful and sustainable future into the 21st century.

2009 was also notable for the environmental sustainability of aviation in general. It saw the formal launch of the Airbus A350 XWB and at the end of the year the first flight of the Boeing 787, both of which will see a step improvement in the environmental impact on the atmosphere with much wider utilisation of light weight carbon composites in the airframe and a new generation of higher bypass ratio more efficient engines. A 20% reduction in fuel burn per passenger kilometre can be expected from both aircraft. At the top end of the scale the A380 is establishing itself as a well-loved aircraft by passengers and for its contribution to reduced fuel burn and costs. At the lower end, decisions are still awaited on the timing of the successors to the Boeing 737 and Airbus A320 families in the 150-seat short/medium range class, with major technology decisions required on whether to opt for unducted propulsors for example. It is now more likely that both the 737 and A320 families will be re-engined first, offering perhaps a 15% reduction in fuel and emissions before all-new aircraft appear beyond 2020. Significant progress continued to be made on biofuels through the past 12 months and a better understanding of the behaviour of the atmosphere is emerging, particularly regarding non-CO₂ emissions from aircraft. However, the picture is looking more complex now, with particulates and sulphates increasing in importance as well as more work on cirrus cloud and the time history of different emissions. More on all of these later in this report.

Major reports on aviation and the environment were published during the year, perhaps the most notable for the UK being that from the Committee for Climate Change. While Greener by Design believes the CCC was unduly cautious on biofuels, this was seen as a well-balanced and reasoned report, albeit from a UK national view point when the agreements for aviation must inevitably be global for such an internationally interwoven industry. Again more on this later.

Other sections of this report give reviews on the GBD themes of Sustainable Aviation, Operations and Market-based Options and also updates on the UK Aviation Industry's Sustainable Aviation Initiative and on the OMEGA programme led by Manchester, Cambridge and Cranfield universities. When it started, GBD was pretty much on its own in promoting an objective view of the environmental issues facing civil aviation. It still has an important role in this regard but with a greater emphasis now on reviewing the output of other involved parties, along with its own original work. In this regard, the Greener By Design Executive have become concerned that the GBD Advisory Group has had little impact in the past few years since the last major report was issued in 2005. This will be addressed in 2010 to ensure GBD has adequate contact with UK expert opinion.



Jeff Jupp
Acting Chairman
Air Travel Greener by Design

Cover photos: Boeing 787 and Airbus A350.



Airbus.



2009 CEAS Conference: aviation faces up to climate change

Aviation faces up to climate change

The 2009 Greener by Design October Conference was held as one of the topic streams at the Council for Europe Aerospace Societies' Conference, on this occasion hosted by the Royal Aeronautical Society at Manchester. It attracted a significant audience for the full day it was held and, following opening remarks by Keith Mans, Ulrich Schumann, Director of the Institute of Atmospheric Physics at DLR Germany, got proceedings underway with the first of the presentations laying out the challenges the Industry faces. His topic was an update on the scientific understanding of the impact of aviation on the atmosphere, laying particular emphasis on the increasing complexity with the need to include the effects of sulphates and particulates along with cirrus cloud formation and nitrous oxides. He also stressed the need to understand the timescales of the pollutants residing in the atmosphere and the history up to the era of interest. Further details are given in this Report in the section on the Science and Technology theme.

Tim Johnson, Director, Aviation Environment Federation, followed with an NGO perspective on the Way Ahead for the Industry. He stressed the importance of environmental targets for the aviation sector and also the need to reach global agreements for such an interwoven international industry. He was, however, pessimistic in that nothing would be confirmed between the relevant governments in time for agreements to emerge from the Copenhagen summit (as indeed turned out to be the case). While ICAO did commit to target a 2% per annum efficiency gain out to 2050, agreement on anything more ambitious could not be reached and further work would be carried out looking towards the next ICAO Assembly in Montreal Autumn 2010. He finished by pressing the need for a well-designed CO₂ standard for all new aircraft, not just new aircraft types.

Paul Steele, Executive Director, Air Transport Action Group, proposed that the aviation industry was now facing up to the challenge and had already bought in to some initial targets: 1-5% per annum average efficiency improvement to 2020, carbon neutral growth from 2020, and with an aspirational goal to reduce net CO₂ 50% by 2050 compared to 2005. This was coupled with a four pillar strategy to get there: invest in new technology; fly more efficiently; build and use efficient infrastructure and use effective economic measures. He also agreed that it must be a global approach and that the Industry will continue to push for progress through ICAO.

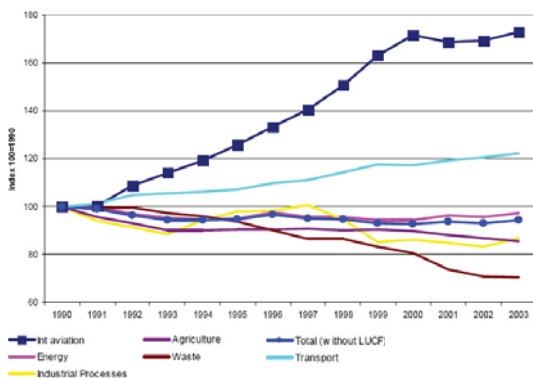
Finally in this first group of presentations, Ben Coombes, Economic Advisor, Committee for Climate Change (CCC), UK, gave some of the background towards the the CCC report to be published in December 2009 in response to the UK Government's request to the CCC to assess the scope for emissions reductions towards meeting the UK 2050 target (for aviation) of at or below 2005 levels. He also pointed out that (with equivalent marine targets) would mean a 90% cut for all other UK emitting sectors if the Climate Change Act overall cut of 80% relative to 1990 was to be achieved. Ben reminded that the CCC was responding to a specific UK Government request regarding UK emissions. However, due to the Copenhagen conference the CCC were asked to bring forward their advice on a global framework for aviation. The main messages were: importance of capping global aviation emissions; all allowances in cap and trade schemes should be auctioned and could be one source of investment into relevant new technologies; emissions trading will be a useful interim measure but the aviation industry should plan on deep cuts in CO₂ similar to the UK requirements: the non-CO₂ effects of aviation must also be addressed as part of any international framework through appropriate policy instruments. The CCC report was duly published in December 2009 and can be reviewed at www.theccc.org.uk/reports/aviation-report.



EU Emission Trading Scheme

The next session covered the EU Emission Trading Scheme. Philip Good from the Commission's Environment DG set out the state of play in implementing the inclusion of aviation in the Scheme, making the points that aviation emissions were rising out of proportion to other major industrial sectors (see Fig. 1) and that they are comparable in volume to other sectors on the basis of their 2005 ETS returns, which show iron and steel emitting 133mtCO₂, oil refining 147mt, and cement and lime 170mt compared with 144mt from aviation fuel sold in the EU. He conceded, however, that the ETS would be likely to have a limited impact on demand growth and that the Commission's Impact Assessment on which that conclusion was based used a methodology that did not take account of the industry's response to the actual economic stimuli of recent fuel price spikes and the current recession.

Air France-KLM's Pierre Albano, who responded, raised the caveats that the ETS would only address 25% of aviation emissions and that auctioning receipts have not been earmarked. Faced with the question about likely impacts, he admitted that the ETS would not be likely to prompt any change to Air France-KLM's operating procedures or commercial strategy and that the decision on whether to pass on ETS costs to passengers would depend on what the market would bear — in other words, whether passengers could be surcharged without affecting demand.



EU greenhouse gases by sector as an index of 1990 levels.

Technology

Turning to possible technology solutions for the impact of aircraft on climate change, some options for the airframe were proposed by Jenny Body, Research and Technology National Representative, Airbus UK. Jenny covered the progress being made in lightweight materials saying it was important to ensure the selection of the right material for each specific application, not just blindly to change over to carbon composites for example. She also mentioned the increasing interest in 'smart' materials and 'nanotechnologies' and the importance of optimisation techniques in structural design to minimise weight. Two distinct paths were being followed for increasing the contribution from aerodynamics. One area was 'flow control' operating on the boundary layer by different means to reduce skin friction and form drag and the other was to reduce design loads and hence weight by automatically moving various surfaces via the flight control systems. She also covered the smaller contribution from aircraft systems, for example the potential use of fuel cells for auxiliary power, saving fuel burn and emissions by reducing power offtakes from increasingly sensitive future propulsion engines.

Mark Taylor, Senior Project Engineer, Rolls-Royce, followed with a review of the options being investigated for future engine architectures. He proposed that with the flexibility of the Rolls-Royce 'three shaft layout', similar fuel burn reductions could be obtained to those proposed by Pratt & Whitney for its Geared Fan. He also explored the 'unducted propulsor' options, mentioning that Rolls had been conducting noise tests in low-speed and high-speed wind tunnels with significant success in attacking one of the main problem areas of open propulsors. He summarised by believing that higher bypass ratio ducted propulsors could offer significant fuel burn and take-off noise reductions, whereas yet further fuel burn reductions could be obtained with open rotor architectures but still just achieving the currently proposed noise regulations.

Operations

There were three presentations on operations: Alan Melrose of Eurocontrol spoke on the contribution that can be made by a more efficient Air Traffic Control system; Tim Johnston of the Aviation Environment Federation gave the NGO perspective on aviation emissions; and Geoff Maynard, chairman of the operations sub group of GBD spoke on the opportunities for reducing emissions through better management and operating procedures.

Alan focused on closing the gap between the Great Circle distances between airports, and the actual distances aircraft have to fly. Sometimes a longer route may be more fuel efficient because of favourable winds but usually it represents the outcome of route and airspace constraints. Many initiatives have already achieved positive results, and these are outlined in the chart on the right. He went on to outline the ICAO Global Air Navigation plan, which includes SESAR, and how a 10% reduction in environmental disbenefit per flight is to be achieved.

Tim highlighted the absence of any binding targets on emissions at present, and the disappointing run up to the Copenhagen conference. The targets are currently aspirational and there is considerable difficulty in achieving agreement internationally.

Geoff identified some of the key ways fuel burn could be reduced by smarter operating. Some techniques, like continuous descent approaches are now in widespread use in Europe and being planned at many more. Others, like freeing up military airspace so civilian aircraft can fly more direct routes, have seen very slow progress. There is also an opportunity to cut emissions on the ground: widespread use of fixed ground equipment and the possibility of only using one engine when taxiing, were some of the ideas discussed.

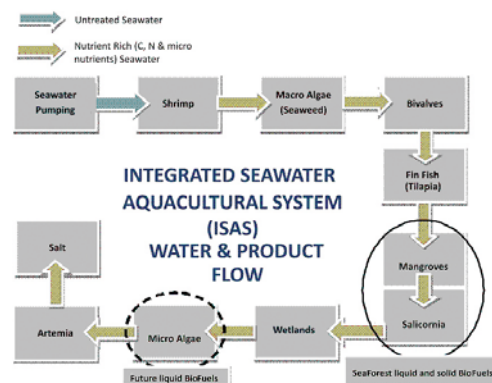
Biofuels

Robert Whitfield of Greener by Design and Global Seawater gave an initial overview of the progress that had been made in the past year on biofuels for aviation. He identified four key areas namely sustainable feedstock, processing, certification and market. Of these, he considered that major progress had been made in processing and certification and that the way forward was clear in these two areas — and he therefore chose to focus on the other two. He provided an update on the four leading sustainable feedstocks, including salicornia from seawater farming which has been a feature of the past two GbD conferences. He concluded by exploring the factors affecting where such oil would be used. He pointed out that there were competing uses (e.g. to make biodiesel for cars), that government was closely involved in influencing this decision — but that airlines had the ability to influence it as well.

Richard Mills of Boeing echoed some of these thoughts and described the major contribution that Boeing has made to aviation biofuels. Boeing see their role as acting as a catalyst to accelerate the broad commercialisation of aviation biofuels and to this end they have been highly instrumental in the four demo flights to date, the certification process, the facilitation of new sustainable feedstocks and the establishment of the Sustainable Aviation Fuel Users Group. For Boeing, their target is to enable the industry to achieve market viability by 2015. Success criteria include achieving a 600+ million gallons/year of bio content, and five to ten feedstock/fuel production projects.

Operation	Location	Fuel Savings	CO ₂ Savings	Potential Network Savings Fuel (T)	Potential Network Savings CO ₂ (T)	Potential Fuel Cost Savings at €600/T
Reduced Vertical Separation Minima	ECAC wide			318,000	976,000	€188M
Flexible Use of Airspace	ECAC wide			170,000	535,000	€102M
Flow Management	ECAC wide			600,000	1,890,000	€360M
CDM Variable taxi times	Munich Airport	50kg/flight	160kg/flight	200,000	470,000	€240M
Continuous Descent	68 airports committed	25-30kg/flight	100-450kg/flight	200,000	645,000	€100M

Potential air traffic control improvements — environmental performance examples (Eurocontrol).



Integrated seawater aquaculture system.



Jim Woodger from UOP completed the set with a more detailed presentation of the specifics of the underlying technology. He described how the UOP Ecofining process (to make Green diesel) had been modified to a Renewable Jet Process. This process produces Bio SPK, which meets all the properties of ASTM 7566, the new standard for jet fuel properties. Conforming to ASTM 7566 implies meeting the basic ASTM 1655 standard for jet fuel. The first Annex I, for an SPK including 50% Fischer Tropsch Fuel, was issued in August 2009. A plan is being implemented to enable hydroprocessed renewable jet (HRJ) to be added to Annex I in the next revision, scheduled for end 2010. The technical problems are in the process of being resolved. The industry challenge then comes back to the feedstock: the cumulative energy demand of new sustainable feedstocks is low compared with kerosene, but to be satisfied as to the sustainability of the source, it is also necessary to be sure that there is no indirect land use change (ILUC) in the somewhat longer term. In particular, seawater tolerant algae and plants (halophytes such as *salicornia bigelovii*) look particularly interesting as they are clearly not competing for fresh water resources or land for food production.

Sustainable Aviation Road Map

The final session of the conference was introduced by Roger Wiltshire from BATA who reviewed the Sustainable Aviation Road Map, expressing confidence that UK airlines would be able to return gross CO₂ emissions to below 2005 levels by 2050. This was followed by short contributions from several experts, discussing aspects of the way forward for the aviation industry, with Paul Steele from IATA confirming that there was also confidence at the global level that net emissions, including reductions achieved through trading, could be reduced by 50% over a similar time scale. Much of a lively discussion centred on the non-CO₂ impacts, with some speakers calling for action in the short term. Design experts pointed to the potential for avoiding contrail and cirrus formation but that no clear signal had been given on the need to introduce aircraft, for example optimised for flight at lower altitudes than current types. A small part of the discussion focused on international aspects and the need for action at a global level. While there is genuine concern over the impact of aviation in the UK and Europe and determination to address the issues, there is still a long way to go in engaging the stakeholder community in other parts of the world.

OMEGA UPDATE

After the successful completion of the first phase in the middle of last year, Omega is now moving into its second phase. With the initial support of the Higher Education Innovation Fund, the Omega partnership has been successfully established and the team has lead knowledge development in several key areas of the aviation sustainability. With some 40 reports now available on the web — www.omega.mmu.ac.uk — this collaborative academic partnership has made a significant contribution to developing the understanding of aviation's environmental impacts, their complexity and interaction and the 'solution space'. The past 12 months have been a period of reflection and consolidation. Omega has used this time to focus on broadening its base of support and to actively engage with the aviation sector and public bodies in order to develop a substantial funding stream to support its future work and knowledge transfer activities. This effort has coincided with the identification of a range of substantial environmental challenges by the Climate Change Committee (Report December 2009), which, when added to the continuing issues related to local airport impact, provide an ever increasing number of challenging scientific, technological and economic issues requiring academic understanding. In its future work, Omega aims to provide timely, independent academically grounded responses to the priority strategic needs of the stakeholder community. Omega's output will help in delivery of government policy goals, the 'Sustainable Aviation' process and the execution of the National Aerospace Technology Strategy. Omega's growing academic partnership is firmly established and recognised as an essential part of the wider activity to reduce aviation's current and future environmental impact and it will work hard in its next phase to tackle key 'unknowns', to produce peer reviewed, academically rigorous reports and to identify practical solutions and opportunities for mitigation.

SUSTAINABLE AVIATION

Sustainable Aviation (SA), formed in 2005 as a unique coalition of airlines, aerospace manufacturers, airport operators and air traffic management in the UK, has continued to develop relevant programmes during 2009. Following the publication of the SA Road Map in December, 2008, the Second Progress Report was published in May, supporting the SA position that the UK's aviation industry can continue to grow while limiting its impact on climate and the wider environment. More recently two interim reports have been published on how performance can be improved through implementation of a Departures Code of Practice.

The Sustainable Aviation strategy, updated in the 2009 report, sets out a vision for 2020 and beyond where the UK aviation industry meets the needs of society for air travel, maximising its benefit for the economy while removing or minimising any negative impacts on the local and global environment. The report covers progress in 2007-08 on the eight goals and 34 commitments which make up the SA strategy.

Sustainable Aviation Road Map — projected CO₂ emissions from UK aviation

Sustainable Aviation welcomed the 2009 report from the Committee on Climate Change and the long-term challenge that it lays down for the industry, pointing to the SA Roadmap which sets out the pathway for how CO₂ emissions can be returned to lower levels. Sustainable Aviation has also called on politicians to recognise that climate change and aviation are most effectively and successfully addressed at the international level and Copenhagen presented a unique opportunity for politicians to make important headway on climate change. This was covered in a manifesto issued shortly before the Copenhagen Summit in December. IATA made strong representations at Copenhagen with a 2050 target, including emissions trading, of reducing net global emissions of CO₂ from aviation to 50% of 2005 level by 2050. However, in the end there was little explicit output relating to aviation.

For more information see: www.sustainableaviation.co.uk

BIOFUELS

2008 saw dramatic progress in the development of biofuel as a supplement and alternative to kerosene. 2009 has seen this progress consolidated but without the extraordinary breakthroughs of the previous year. Nevertheless, significant progress has been made in all areas, including sustainable feedstocks, conversion technologies, certification, airline demand and international co-ordination.

The taxonomy of biofuel feedstocks has been in some disarray over the past few years with each new proposed sustainable feedstock seeking to describe itself as a new generation. A new taxonomy has now been agreed by ICAO, however, as follows:

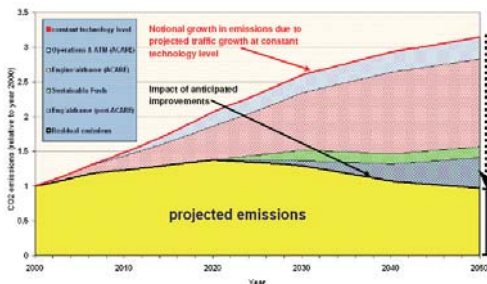
- first generation: may use food-based sources.
- second generation: non-food based lignocellulosic and agricultural wastes.
- advanced biofuels: produced from crops or processes beyond what is described by second-generation biofuels, and that result in biofuels with low greenhouse gas (GHG) emissions compared to fossil fuels.

The biofuel world is still recovering from the first generation feedstock debacle, when farmers and biofuel producers surged into biofuel production without sufficient thought as to what they were trying to do — and whether they were achieving it. That led to responsible organisations and governments around the world seeking to establish sustainability criteria, focussing particularly on life cycle analysis as the underlying analysis tool. A leading example, the Round Table for Sustainable Biofuels (RSB), after a six-month public consultation on its 'Version Zero', approved in December 2009 Version 1 of the 'international standard for better biofuel production and processing' for pilot testing.

While progress is being made by the RSB and several other organisations working with the same broad aim, two issues stand out. First, the recent emergence of the concept of indirect land use change (ILUC) is having a major impact on the way that society and, in particular, governments assess biofuels. The work of Searchinger and Fargione, and the publication of the Gallagher report in the UK have had a profound effect. It is necessary to consider not only the direct impact of the production of the biofuel feedstock concerned, such as habitat destruction, local environmental impacts and a range of social issues, but also the indirect effects, including in particular:

- Rising food commodity prices and the effect on food security for the poor.
- The displacement of agricultural production on to uncultivated areas with impacts on biodiversity, GHG savings and local land rights as a result of biofuel production.
- The ramifications of ILUC are still working their way through the government policy making process.

Secondly, there is the need to move, as far as possible, to one global standard, or coherent set of standards, rather than a set of competing standards that risk confusion, to the discredit of biofuels generally. For the moment, aviation biofuel feedstock interest is focussing on camelina, jatropha and halophytes in the near term and algae in the somewhat longer term.



SA Roadmap for CO₂ emissions from UK aviation 2000-2050.



Salicornia.

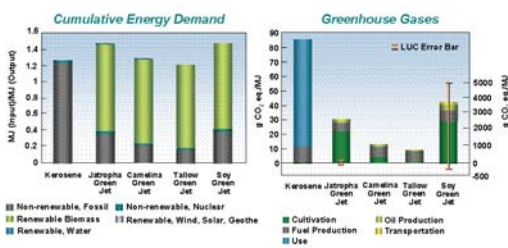


Figure 1. Bio-Jet fuel provides significant greenhouse gas reduction.

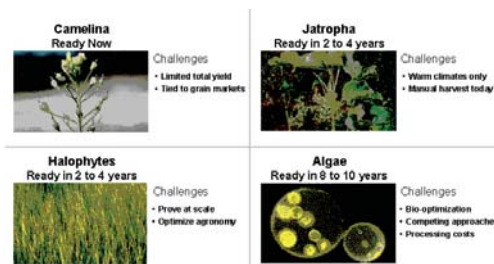


Figure 2. Viability based on timing, technology and local resources.

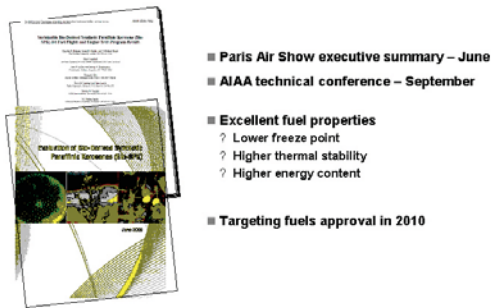


Figure 3. All tests either met or exceeded expectations — fuel is superior.

Description	Jet A-1 Spec	SPK (Liatropha)	SPK (Cameilia)	SPK (Liatropha/Algae)	
Flash Point, °C	Min 38	48.5	42.0	41.0	
Freezing Point, °C	Max -47	-67.0	-63.0	-64.0	
JFTOT@300°C	Filter dP, mmHg	max 25	0.0	0.0	0.2
	Tube Deposit Less Than	< 3	1.0	< 1	1.0
Net heat of combustion, MJ/kg	min 42.8	44.3	44.0	44.2	
Viscosity, -20 deg C, mm ² /sec	max 0.0	3.66	3.33	3.51	
Sulfur, ppm	max 3000	< 1	< 1	< 1	

- Over 6000 US Gallons of Bio-SPK made for demonstration flights
- Certification supply work has uniquely allowed UOP to test the process and the catalyst at large Demo Capacity
- US Military accelerating certification program - UOP recently won an unprecedented HRJ-5/8 supply award from DESC for 241,500 gallons product plus optional supply of further 350,000 gallons
 - First delivery completed on time and on spec for US Navy

Fuel Samples from Different Sources Meet Key Properties

Figure 4. Key properties of Bio-SPK.

There are three main technologies for producing drop-in biojet fuel, namely Fischer Tropsch, hydrotreated renewable jet fuel (HRJ) and pyrolysis. The first two are now functioning conversion processes, while the third, pyrolysis, is still in development.

The only new demo flight in the past year was by KLM, being the first biojet flight (50/50 blend in one engine) used on a commercial flight. The results of the three successful demo flights around the end of 2008/early 2009 (using biojet processed from vegetable oil using UOP's HRJ Ecofining process) were written up in a report and submitted to the certification authorities in June 2009. This provided the basis for an application to certify 50% HRJ. Approval is expected around the end of 2010. This follows further good progress in the certification arena where the D7566 standard has now been agreed as a means of achieving the ASTM D1655 certification. A 50/50 FT blend has already been certified.

The airline community continues to be very engaged in this issue: more airlines have joined the Sustainable Aviation Fuel Users Group (SAFUG) now representing over 20% of global commercial aviation fuel demand. In addition a number of deals have been announced. Two deals sponsored by IATA are led by Rentech and AltAir. Twelve airlines have signed a letter of intent with both project developers and three further airlines are involved. British Airways has announced a waste to energy/biojet scheme in East London with the Solena Group; Etihad Airways is participating in the Sustainable Bioenergy Research Project in Abu Dhabi focussing on salicornia/Integrated Seawater Agriculture Systems; and Qatar Airways has announced its own biojet consortium.

As more sustainable liquid is produced, the question remains: where will it go? Much of it could go to the aviation industry — but there are many pressures enticing it towards ground transportation, to fuel cars. Government needs to be clear as to what it thinks is right, as it is already closely involved in this issue. Airlines need to decide how proactive they wish to be in determining their own sustainability and that of their industry.

A response to these two questions is implicitly provided in the varying forecasts of the level of biojet penetration of the aviation fuel market. By 2050, E4tech explain how the penetration could reach 100% by 2050. The UK Committee on Climate Change is much more cautious, however, currently estimating the figure to be 10%. In any event, there is potentially what the CEO of IATA, Giovanni Bisignani, calls a \$100bn opportunity. How much of it will be seized and by when? Some recent forecasts are set out below:

Milestone	Target date
Hydrotreated renewable jet (HRJ) blend approval	End 2010
Ten HRJ plants, three BTL plants (CAAFI target)	2013
When biofuel, as a percentage of jet fuel flown, reaches 1% (Boeing target)	2015
When biofuel, as a percentage of jet fuel flown, reaches 20% (Sustainable Aviation assessment)	2030

SCIENCE AND TECHNOLOGY

Evolving perspectives

The past year has been one of continued research and demonstration activity with many European programmes making steady progress but with the main results to come some time in the future.

On the policy front, a significant milestone in December 2008 was the publication by the Committee on Climate Change (CCC) of its report *Building a low carbon economy — the UK's contribution to tackling climate change*. This addressed an emissions reduction target for 2050, set by the Climate Change Act which received Royal Assent on 26 November 2008, and advised on the levels of the UK's first three legally binding carbon budgets for 2008-2022. The task for the Committee was to recommend measures by which UK emissions of CO₂ in 2050 could be reduced to 80% below their level in 1990, the target set by the Act. This was seen as compatible with a world objective of reducing CO₂ emissions to 50% of their 1990 levels. The Committee argued that the overall national objective could be achieved by keeping aviation emissions in 2050 at around 2008 levels, together with deep cuts in other sectors. In this scenario, aviation emissions would account for around 25% of all allowed UK emissions of greenhouse gases in 2050.

In January 2009, the Government decided both to expand Heathrow airport and to set a target that UK aviation emissions of CO₂ in 2050 should not exceed their 2005 levels. The Committee was asked to advise on options for reducing emissions below business as usual to meet the target and on the implications for aviation expansion

in the 2020s. The Committee published its report *Meeting the UK aviation target — options for reducing emissions to 2050* in December 2009 (both Committee reports are available at <http://www.theccc.org.uk>).

The report found that, on a 'business as usual' path, UK air passenger demand would grow by over 200% by 2050, reflecting the high income elasticity of demand. On technical mitigation measures, it concluded that fuel efficiency and operational improvements were likely to result in a 30% reduction in carbon emissions per seat-km flown and that sustainable biofuels could account for 10% of aviation fuel use in 2050. Faster technological improvements were possible but, unless and until they were achieved, it was considered prudent not to assume that demand increases of more than 60% would be compatible with the target. A range of departures from 'business as usual' were considered — the effect of carbon trading on air fares, an increase in videoconferencing and a shift from short-haul air to high-speed rail, together with UK airport capacity constraints — and collectively these were projected to limit demand to about 80% above current levels. The conclusion was that clear additional policies (beyond the introduction of a carbon price at £200/tCO₂ by 2050) would be required to constrain passenger demand in the period to 2050.

Figures 1 to 3 show the CCC projected CO₂ emissions from UK aviation from 2005 to 2050 for the 'likely', 'optimistic' and 'speculative' scenarios of the report. All are predicated on the same airport capacity constraints and carbon price impact on passenger demand. They differ in their assumptions about the impact of teleconferencing, modal shift to high-speed trains and reductions in carbon intensity due to improvements in air traffic management, engine and airframe technology and increased availability of biofuels. The reduction in carbon intensity in the 'speculative' scenario, which includes a 30% use of biofuels at an assumed CO₂ saving of 50% (i.e. 15% carbon saving in the 'speculative' scenario), is 55%. Without biofuels, this is a reduction of less than 50% in the carbon intensity of air travel from UK airports in 2050 relative to the present day.

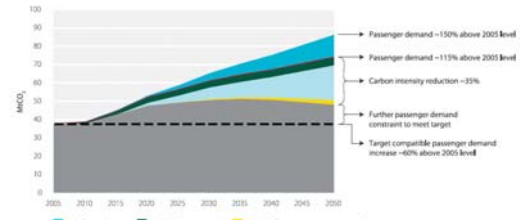
We can compare the CCC scenarios with other projections of carbon intensity. ACARE has declared a goal of a reduction of 50% on year 2000 levels by 2020 for new aircraft operating in the ATM environment of the time — an appreciably more ambitious target than envisaged in the CCC 'speculative' scenario. Similarly, the projection in Fig. 4, taken from the *Greener by Design Annual Report of 2005-06* and not unlike the CCC curves in general shape, shows what was argued to be a possible threefold reduction in the world fleet fuel burn per passenger-km by 2050 for an increase of 330% in passenger demand. This projection was based on advances in technology identified in the 2005 report of the Science and Technology Sub Group but with the recognition that these would be achievable only with the necessary commitment of the research, manufacturing and operating sectors. In December 2008 Sustainable Aviation also published its 'road map' (Fig. 5), which projected a threefold reduction in the carbon intensity of UK aviation between 2000 and 2050. For a projected threefold increase in traffic, this would bring UK emissions in 2050 back down to their level in 2000.

There are significant differences in the character of these projections. The ACARE goals are for new aircraft entering production in 2020 and the advances that they incorporate will take many years to permeate the fleet. Further, ACARE has recognised that, 'The objectives are *not* achievable without important breakthroughs, both in technology and in concepts of operation' (ACARE emphasis). The Sustainable Aviation road map is for the UK fleet and assumes that the ACARE advances will be achieved, will have worked their way fully into the UK fleet by 2050 and will be supplemented by further technological advances between 2020 and 2050. The GBD projection is for the world fleet and is based on specific technologies discussed in the 2005 S&T report rather than on the ACARE goals. Even so, there is no important inconsistency between the projections and they all are predicated on a sustained commitment by the manufacturers and operators to achieving very challenging fuel burn reduction targets.

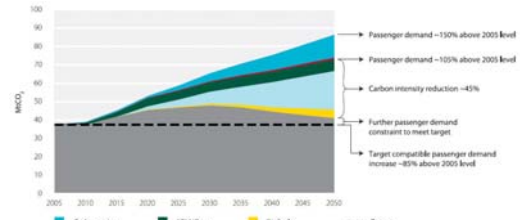
The more cautious view taken by the CCC, which is acknowledged and justified in its report, is arguably a more defensible basis for advising Government on future policy. It admits that technical advances may reduce carbon intensity by more than envisaged in its scenarios but awaits solid evidence of these gains before incorporating them in its forecast. Some recent evidence discussed below suggests that this caution is probably justified.

The CCC report makes no recommendation for the non-CO₂ contributions to climate change, though it considers it highly likely that the net impact of non-CO₂ effects — particularly contrails and other induced cloud formation — is to increase the global warming impact of aviation beyond that suggested by CO₂ emission alone. 'The precise scale of the additional impact is unclear and there are considerable scientific uncertainties still to be resolved but it is highly likely that these non-CO₂ effects are significant. It will therefore be important that they are accounted for in future international policy frameworks and in the overall UK policy framework for emissions reduction'.

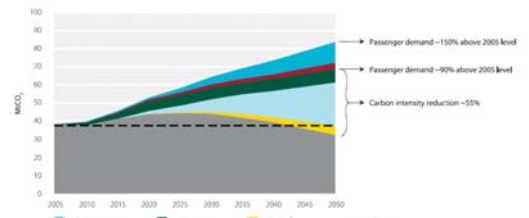
As we discuss below, understanding of the non-CO₂ effects is still evolving and in this respect also a cautious approach by the CCC seems justified.



CCC likely scenario



CCC optimistic scenario



CCC speculative scenario

Figures 1-3. CCC projections of CO₂ emissions by UK civil aviation 2005-2050.

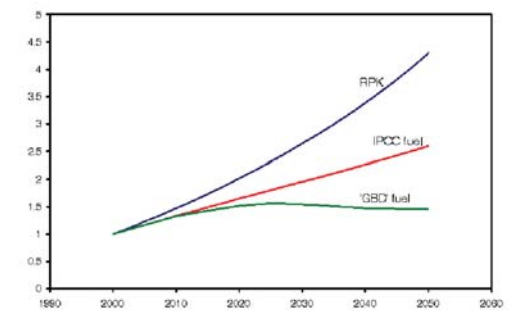


Figure 4. GBD projection of possible world fleet fuel burn 2000-2050.

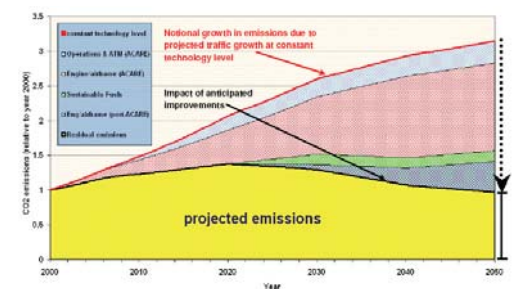


Figure 5. SA Roadmap for CO₂ emissions from UK aviation 2000-2050.

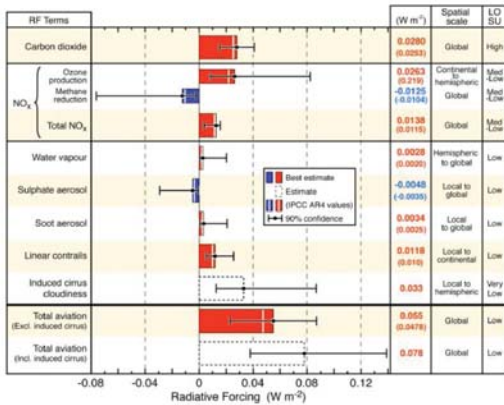


Figure 6. Aviation radiative forcing components in 2005 (Lee *et al* 2009).

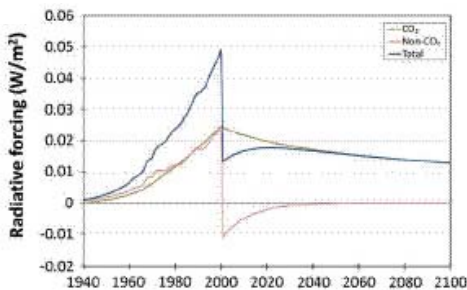


Figure 7. RF from aviation from 1940 to 2000: decay of components after cessation of flying in 2000.

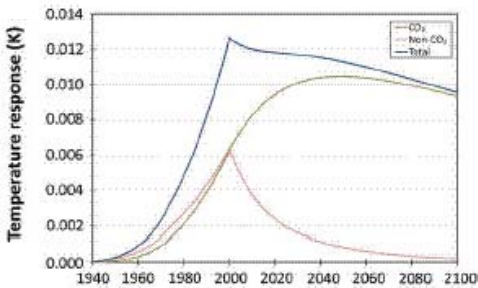


Figure 8. Response of surface temperature to aviation from 1940 to 2000: decay of components after cessation of flying in 2000.

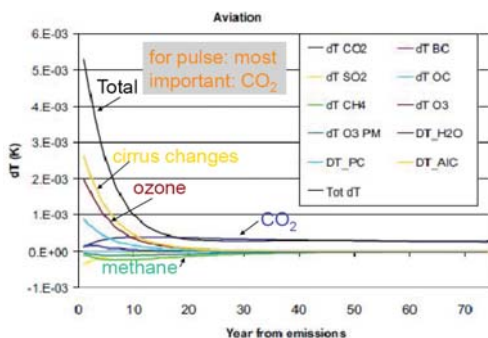


Figure 9. Components of temperature change from a one-year pulse emission (Berntsen & Fuglestedt, PNAS, 2008).

Atmospheric Science Trade-offs and Metrics

For designers, operators and regulators, the questions of how to strike the best balance between reducing one emission at the expense of increasing another have at present no clear answer. For example, is it environmentally beneficial to increase engine overall pressure ratio in order to reduce CO₂ emission at the expense of an increase in NO_x emission? By how much should flight altitude be changed, and CO₂ emissions thereby increased, in order to avoid forming contrails? When will we be able to set guidelines — let alone rules — for striking these balances?

In seeking to minimise impact on climate, our aim is to strike the optimum balance between the impacts of CO₂ emissions, which are long-lived and relatively well understood, and the non-CO₂ impacts, primarily of NO_x, contrails and cirrus, which are much less understood. Last year's Annual Report included an account of a debate at the October 2008 GBD conference in which Shine of Reading University described the impact of NO_x as 'such a slippery customer' but offered the view that, if the aviation community formulated a well-posed question, the scientific community would be able to provide an answer with appropriate error bars.

Over the past year there have been some significant international publications addressing this issue, notably publications funded by the EU FP6 Specific Support Action ATTICA by Lee *et al*⁽¹⁾ and Fuglestedt *et al*⁽²⁾. While the second of these focuses on metrics for the impacts of all emissions from transport, the paper by Lee *et al* revisits, ten years later, the atmospheric science issues covered in the IPCC report of 1999 on Aviation and the Global Atmosphere⁽³⁾. The paper includes Fig. 6 which updates from 1992 to 2005 the much quoted IPCC chart of Radiative Forcing (RF) due to aviation. The picture has changed relatively little over this period, with CO₂ contributing roughly half the RF, the positive RF of ozone generated by NO_x being partly offset by the negative RF due to methane destruction by NO_x and the sum of the RF of contrails and the net RF of NO_x being roughly the same as that of CO₂. As in the earlier report, the effect of cirrus is considered too uncertain to be assigned a value. Although there has been a decade of scientific progress between the two reports the stated levels of scientific understanding in the new report are not significantly better than in 1999 and the error bars, which now indicate the estimated 90% confidence limits as against 67% in the 1999 report, in some cases indicate greater uncertainty now than then.

Like its predecessor, Ref. 1 provides a comprehensive discussion of the impacts of all aviation emissions, covering also flight in the stratosphere by supersonic aircraft, and cites more than 400 references. It includes an extended discussion of metrics for climate impact, defending Global Warming Potential (GWP) — the measure adopted by the Kyoto Protocol but dismissed in the 1999 IPCC Report as not appropriate for aviation — and comparing it with the newer alternative Global Temperature Potential (GTP). GWP is defined as the radiative forcing, integrated over a specified time horizon, from the instantaneous release of 1kg of a greenhouse gas relative to that of 1kg of a reference gas (CO₂). GTP is the global-mean change in surface temperature at the same future time horizon, again referenced to CO₂, and differs from GWP in taking account of the effect of the thermal inertia of the climate system.

The difference is brought out in Figs 7 and 8, which show the estimated effect of the emissions from aviation between 1940 and 2000, followed by a hypothetical cessation of flying in 2000. Figure 7 shows the RF due to aviation growing in a roughly exponential manner up to the cut-off date, after which the RF due to CO₂ decays by about 50% over the next 100 years. The RF due to the non-CO₂ emissions drops to a negative value, reflecting the rapid elimination of forcing by contrails and ozone generated by NO_x and the residual negative forcing due to the reduction in methane by NO_x (and reduced ozone linked to the methane reduction) which falls from a negative value to zero over the next 30 years. Figure 8 shows the effect of the emissions on surface temperature. The effect of the non-CO₂ emissions begins to fall immediately flying stops but, because of the thermal inertia of the climate system, of which the oceans are the main component, it takes approximately a century for the effect to die out. In contrast, the CO₂ emitted between 1940 and 2000 is removed only slowly from the atmosphere and causes the temperature to continue to increase steadily to reach a maximum in around 2050.

Although GWP is defined by reference to a single 'pulse' emission of a greenhouse gas, it is frequently used in assessing the RF due to the emission of the gas at a constant rate over the time horizon of interest. The difference between the effects on surface temperature of pulse and sustained emissions are illustrated in Figs 9 to 11, taken from a presentation by Schumann to the Greener by Design session at the CEAS Conference of October 2009. Figure 9 shows the variation over a 70-year period of the impact of one year's aviation emissions. The effect of the short-lived emissions has almost been lost after 20 years and that of methane by about 40, leaving CO₂ as the only significant contributor from 50 years onward. Figure 10 shows the effect of steady emissions over a period of 100 years. In the early years the short-lived contributions from cirrus, ozone and persistent contrails are the largest but they plateau after about 20 years while the effect of CO₂ continues to increase linearly and from 45 years onwards is the largest contributor.

Comparing these two figures may tempt us to the conclusion that the long life of CO₂ makes it the most important emission in the longer run. However, holding emissions constant at today's rate is not a realistic option and, as Fig. 11 shows, the relative importance of the short-lived emissions increases when the annual rate of emissions is growing. In fact, because of the properties of exponential functions, the relative contributions to RF of the long-lived and short-lived gases from the emission of an invariant gas mixture growing at a constant exponential rate remain constant. And it could be argued that exponential growth is a closer approximation to the present situation than the zero growth of Fig. 10. The conclusion would seem to be that, in weighing the options for mitigating one impact at the expense of another — as in taking evasive action to avoid contrails — the assessment needs to be made on the most realistic possible forward looking scenario taking account of all expected technological developments.

A new view of aviation RF

At the Greener Skies Conference in Hong Kong in October 2009 a paper was given by Schmidt, Unger and Shindell of NASA Goddard which presented a starkly contrasting picture to the widely accepted view of the components of RF as set out in Fig. 6. It was derived from G-PUCCINI, a model based on the GISS (Goddard Institute for Space Studies) Model-E GCM (a coupled atmosphere-ocean general circulation model — see <http://www.giss.nasa.gov/tools/modelE>) which was said to account for some processes not included in previous models. The table below compares the GISS results for RF with the results from the EC TRADEOFF study which underlie Fig. 6.

Table 1 Two contrasting estimates of radiative forcing from aviation, mW/m²

AGENT	Sausen <i>et al</i> (2005)	Unger <i>et al</i> (2009)
CO ₂	25	25
Ozone	22	3
Methane	-10	-9
Sulphate	-3.5	-17
Nitrate	na	-3
Black carbon	2.5	3
H ₂ O	2	na
Total non-CO ₂	13	-23
Total	38	2

The table excludes the effects of contrails and cirrus. The most striking differences are the much reduced RF from the NO_x generated ozone which is outside the 90% confidence limits in Fig. 6, and the much stronger negative RF of sulphate (which actually is within the 90% limits in Fig. 6). The cumulative effect is that the non-CO₂ emissions in the new estimate almost cancel the RF of the CO₂.

In the presentation by Schmidt the results from G-PUCCINI were said to derive from Unger *et al* (2009, PNAS, in press). The only paper by Unger *et al* found to date in PNAS, 'Attribution of climate forcing to economic sectors', is relatively short and does not contain any of the detail cited by Schmidt. In view of the starkly contrasting results in Table 1, some lively debate about the relative merits of G-PUCCINI and the climate modelling underlying Fig. 6 may be expected in the coming year.

Contrails and cirrus

Figure 6 shows the estimated contributions to RF of 'linear contrails' and 'induced cirrus cloudiness' as 12 and 33mW/m² respectively, with wide confidence limits on each. The linear contrails are persistent contrails, formed in air supersaturated with respect to ice, that are relatively young and can be recognised in satellite images by their linear form. The induced cirrus cloudiness includes 'contrail cirrus', formed as linear contrails distort and spread into the supersaturated air to create additional cloud, and 'soot cirrus' which is cloud induced or modified by the presence in the atmosphere of particles from aviation that can act as ice nuclei. Lee *et al*⁽¹⁾ discuss in detail the extensive studies in recent years of these three phenomena. With respect to the last of the three, they conclude: 'Evidently, there is much work to be done to resolve both the sign and magnitude of the effect of aircraft soot on cirrus clouds.' This leaves contrail cirrus as the assumed main source of the RF attributed to cirrus in Fig. 6.

Last year's Annual Report reported a review of contrails and contrail cirrus by Mannstein of DLR, given at the GBD Conference in October 2008, and some further developments of this work were presented by Schumann of DLR in the GBD session at the CEAS Conference in October 2009. In Fig. 12 he compared annual mean cirrus cover over the North Atlantic, derived from satellite data, with air traffic density. Over the 24 hour period the air traffic shows two peaks, morning and evening, and the cirrus shows two similar peaks, lagging 2-4 hours behind the air traffic. This is the time it takes for contrails to spread to the maximum width and thickness visible to the satellite. The amplitude of the cirrus variation is far larger than expected from the amplitude of the linear contrail variation. A supplementary analysis, in which the North Atlantic region was

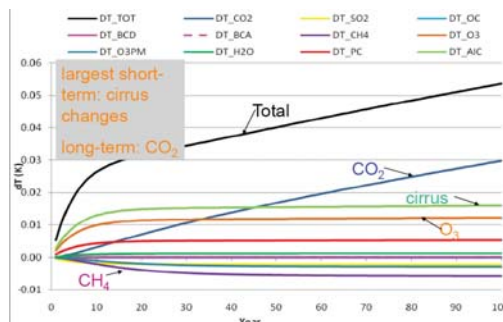


Figure 10. Components of temperature change for steady sustained emissions (Berntsen & Fuglestedt, PNAS, 2008).

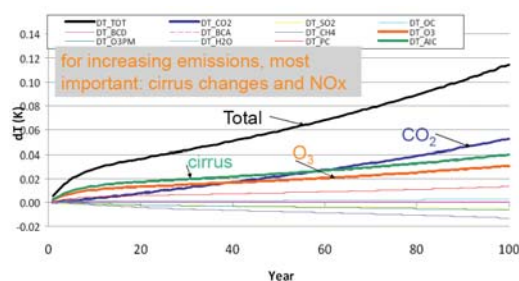


Figure 11. Components of temperature change for emissions growing at 1% per annum (Schumann, CEAS 2009, after Fuglestedt and Lund).

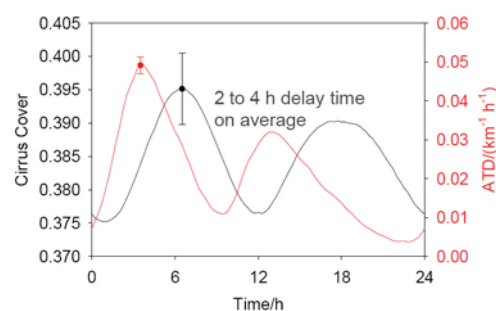


Figure 12. Annual mean cirrus cover and air traffic density over North Atlantic.

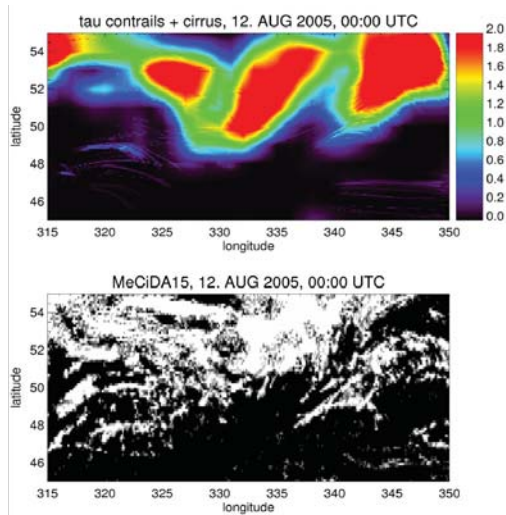


Figure 13. DLR CoCiP prediction of cloud thickness (τ) over North Atlantic (top) compared with satellite observation (below).

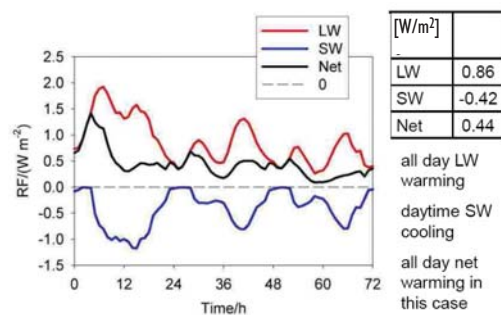


Figure 14. Radiative forcing over three days for DLR North Atlantic reference case.

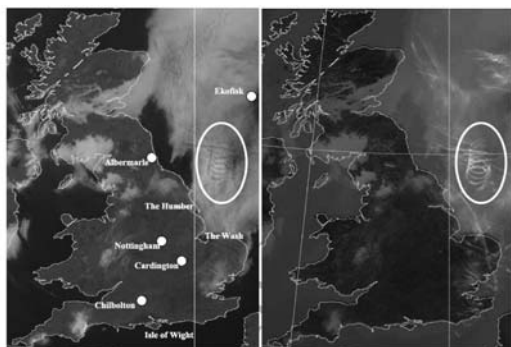


Figure 15. Infrared satellite image of persistent contrails from AWACS aircraft circling over North Sea, March 2009.

divided into two equal $17.5^\circ \times 10^\circ$ regions, showed that the diurnal traffic and cirrus cycles were correlated in the eastern and western parts separately which Schumann argued could be explained only by the impact of aviation on cirrus.

He described a new simulation tool developed by DLR, CoCiP (Contrail Cirrus Simulation and Prediction) which takes as input aircraft technical data, knowledge of movements and meteorological data from the available sources and provides as output predictions of contrail formation and evolution into cirrus, its lifecycle and radiative impact. Figure 13 shows the predicted cirrus cloud thickness over the North Atlantic at one specific date and time compared with a satellite image for the same moment. Considering that this is a newly developed model, the agreement is encouraging.

Figure 14 shows the diurnal variation of the predicted radiative forcing by cirrus for a three-day North Atlantic reference case used by Schumann. The net forcing is positive throughout the period, the positive longwave forcing (the reflection back to earth of outgoing infra-red radiation) being partly offset in daylight hours by the negative forcing from partial reflection back into space of the shortwave incoming solar radiation. The average net RF over this period was 440mW/m^2 , which is not inconsistent with the range of the confidence limits for the annual global average for cirrus ($10\text{--}85\text{mW/m}^2$) shown in Fig. 6.

A further striking instance of the evolution of cirrus from contrails is reported by Haywood *et al*⁽⁴⁾, who observed and analysed the development of a cirrus cloud created by an aircraft operating over the North Sea on 20 March 2009. On that morning, an airborne warning and control system (AWACS) aircraft flew for about three hours on a circular path 40km in diameter, completing ten circuits in all, in supersaturated air in which persistent contrails formed. Figure 15 is a pair of satellite images obtained halfway through the flight, the left hand one in the visible spectrum, the right hand one an infra-red image which distinguishes the contrail more clearly against the background of the cloud below. The contrail was carried in a south-westerly direction by the wind and was observed to develop into a cloud of cirrus that, by the evening, was over the Isle of Wight. In all, it persisted for around 18 hours and at its peak it covered more than $50,000\text{km}^2$.

The evolution of the cloud was tracked using a number of high-resolution polar orbiting and lower-resolution geostationary satellite instruments. The shortwave and longwave radiative forcing of the cloud was estimated using a combination of geostationary satellite instruments, numerical weather prediction models and surface observation sites. The net radiative effect was the relatively small residual of the much stronger but opposing shortwave and longwave effects, locally totalling around 10W/m^2 during daylight hours and 30W/m^2 during the night.

The abstract to the paper concludes: 'A simple estimate indicates that this single localised event may have generated a global-mean radiative forcing of around 7% of recent estimates of the persistent contrail radiative forcing due to the entire global aircraft fleet on a diurnally averaged basis. A single aircraft operating in conditions favourable for persistent contrail formation appears to exert a contrail-induced radiative forcing some 5,000 times greater (in $\text{W/m}^2/\text{km}$) than recent estimates of the average persistent contrail radiative forcing from the entire civil aviation fleet. This study emphasises the need to establish whether similar events are common or highly unusual for a confident assessment of the total climate effect of aviation to be made.'

Technology

Technology continues to advance. We expect the new aircraft entering the world fleet in the first decades of this century, A380, B787, A350XWB, to be more fuel efficient, quieter and less polluting than the aircraft they replace, thanks to advances in technology on all fronts.

Research and demonstration programmes to continue the technological advance are substantial on both sides of the Atlantic. In Europe, the Clean Sky Joint Technology Initiative has an estimated budget of €1.6bn, shared between the EC and industry over the period 2008-2013. In the USA, the NASA aeronautics budget for 2009 was \$650m with funds of \$62.4m earmarked in 2010 for the Environmentally Responsible Aviation project. The environmental targets of the US research are broadly similar to the ambitious targets set by ACARE in Europe. Senior figures in the industry have affirmed their commitments to these targets.

Alongside this activity, the CAEP committee of ICAO has recommended a further tightening of the NO_x emission standard by about 15% in 2013 and declared its intention to develop a standard for commercial aircraft CO_2 emissions by around 2016/17. The new NO_x standard will reduce emissions by about 30% relative to the levels in 2000, well short of the ACARE target of a reduction of 80% by 2020. Any first standard for CO_2 might also be expected to be less ambitious than the ACARE goal of a 50% reduction by 2020.

Progress in fuel efficiency since 1960

A recent study by the International Council on Clean Transportation⁽⁵⁾, which will probably be an input into the CAEP CO_2 assessment, would suggest a cautious approach to setting a future CO_2 standard. It is an analysis

of the evolution of the fuel efficiency of new passenger aircraft over the period from 1960 to 2008 and challenges some oft repeated assertions about advances over that 48 year period. The analysis combines the annual sales figures for all new aircraft types with the performance and emissions data for those types obtained from the Piano-X database to calculate the average fuel efficiency of new aircraft entering service each year. Figure 16 shows the evolution of the average design fuel burn of new jet aircraft per seat-km and per tonne-km, weighted for aircraft sales, taking a value of 100 for the datum year 1960. The overall reduction between 1960 and the present day is approximately 50%, rather than the 70% that has been, and continues to be, so widely quoted and which is illustrated in the much repeated chart, Fig. 17. Also shown in Fig. 17, unusually, is the fuel efficiency of the last generation of piston-engined transatlantic aircraft — the Douglas DC-7 and Lockheed Super Constellation — taken from Peeters *et al*⁽⁶⁾.

The authors of the study discuss the reasons for this discrepancy, a main one being the choice of the de Havilland Comet 4 as the datum aircraft in the earlier analysis, rather than its contemporaries, the Boeing 707 and DC-8, which were appreciably more fuel efficient and also more representative of new aircraft entering the fleet in 1960. A second factor is the exclusion of short-haul narrow body and regional jets from the earlier analysis.

The authors note that there were appreciable improvements in fuel efficiency in only two decades of the five covered by the figure, the 1960s and the 1980s. The 1970s saw no improvement and since 1990 the reduction in fuel burn per seat-km has been small, with no reduction since 2000. They associate these trends with the variation in oil prices and the age of the aircraft and engine designs in the market. Figure 18 shows the variation in the age of engine and aircraft production lines over the 48 year period. The doubling of oil prices in 1974 and further doubling in 1980, coupled with fierce competition between aircraft manufacturers, saw the introduction of a number of new types, both wide and narrow body, with new high bypass ratio turbofans (B757, B767, A310, A320) which began to dominate production lines in the 1980s and which resulted in the efficiency gains in that decade. The slow improvement since 1990 is attributed by the authors to a two-decade dearth of new aircraft and engine designs. As estimated from the graph, the average age of the production lines of today's four major commercial jet manufacturers (Airbus, Boeing, Bombardier and Embraer) has trebled since 1989.

In discussing the factors underlying the trends in Figs 16 and 18 the authors argue that, when oil prices are low, the manufacturers give weight to operator priorities other than minimising fuel burn. They cite increases in design range, cruising speed, customer amenities and cargo capacity as improvements, all of which the operators value but all of which, by increasing weight, impose a fuel efficiency penalty, particularly on fuel efficiency per seat-km. The sharp drop in fuel efficiency on the switch to jet aircraft, evident in Fig. 17, is striking evidence from an earlier age of the preference of the travelling public for the speed, quietness and smoothness of travel that jet powered aircraft introduced.

Future progress in fuel efficiency and the ACARE targets

The European industry has collectively accepted the challenge of the ACARE target of a 50% reduction in fuel burn of a new design, entering service in 2020 and in the ATM environment of 2020, relative to a year 2000 design operating in the ATM environment of 2000. It has also shared out the 50% reduction, 2/5 to the airframe manufacturer, 2/5 to the engine manufacturer and 1/5 to improvements in ATM. Because these gains will be multiplicative rather than additive, this translates approximately into a reduction of 25% in fuel burn from airframe improvements, 25% from engine improvements and 11.1% from gains in operational efficiencies. ACARE was surely right to emphasise the need for important breakthroughs to achieve these targets.

The move towards more efficient air traffic management is progressing through SESAR in Europe and NextGen in the USA but whether SESAR, together with the other operational measures noted on p 12, will achieve the reduction in fuel burn needed to meet the ACARE goal is an open question. As regards technological advance, for a kerosene fuelled aircraft, the three ways of reducing fuel burn per tonne-km are to increase propulsion efficiency and lift-to-drag ratio at cruise and to reduce the ratio of empty weight to payload.

For the engine, it appears that the adoption of contra-rotating open rotors in combination with gains in the thermal efficiency of the engine core could bring the ACARE target within reach. Last year's Annual Report noted progress by Rolls-Royce in the DREAM programme to develop a contra-rotating propeller system that could achieve the target gains in propulsive efficiency while keeping noise levels within Chapter 4 limits. Further progress was reported at the 2009 CEAS Conference and a test campaign on the Rolls-Royce Rig 145 has been completed in the ARA Transonic Wind Tunnel, confirming that high-speed performance is up to expectations.

Contra-rotating propellers are currently seen as potential drive systems for a replacement aircraft for the A320 and B737 families but not for longer range wide body aircraft. For these, some evolution of today's high bypass ratio turbofan engines is envisaged. Whatever form this evolution takes, the burden of nacelle drag and weight

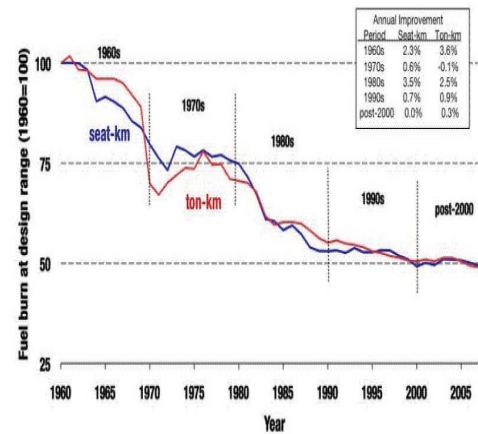


Figure 16. Average fuel burn for new jet aircraft, 1960 - 2008.

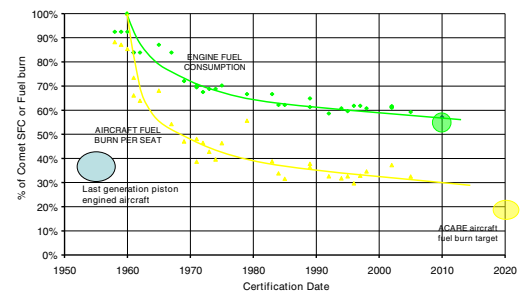


Figure 17. Fuel efficiency of new jet aircraft with Comet 4 as datum.



Figure 18. Average age of production line by year of delivery.

will impose a limit on bypass ratio and hence on propulsive efficiency that would appear to put a reduction of 25% in fuel burn — i.e. an increase in propulsion efficiency of 33% — beyond reach for turbofan engines with today's simple Joule cycle.

For the airframe, a reduction of 25% in fuel burn must come from a combination of drag and weight reduction. As discussed in the 2005 report of the GBD Science and Technology Sub-Group⁽⁷⁾, it will require the adoption either of some form of laminar flow control (LFC) or a change to a flying wing configuration to achieve a significant reduction in drag relative to the year 2000 aerodynamic design standard. Neither of these is likely by 2020, although the possibility of some application of laminar flow control to the A320/B737 replacement aircraft cannot be ruled out and work to demonstrate the practicability of LFC is in progress both under NASA and EC auspices. At best, LFC might achieve a 15% reduction in fuel burn.

The third option for reducing fuel burn is reducing weight. For a given design range, fuel burn per tonne-km is reduced in proportion to the reduction in the total of payload and empty weight. For an aircraft such as the A320-200, a reduction of 10% in fuel burn would require a reduction of approximately 15% in empty weight.

Reducing weight by the replacement of light-alloy structure with carbon-fibre composites (CFC) has been seen by GBD as a potentially important contributor to future reductions in fuel burn but a recent study by Poll⁽⁸⁾ should give us pause. From an analysis of the masses of Boeing and Airbus aircraft from the 1960s to the present day, he has determined the ratio of the empty mass per passenger corrected for the design range of the aircraft. Figure 19 shows the variation of this corrected mass, which Poll terms the 'zero range' mass, with date of entry into service. The striking features of this figure are the absence of any reduction in the corrected empty mass of the lightest aircraft since the late 1980s and, within the scatter of the data, no discernible downward trend with time. Without access to detailed mass breakdowns of these aircraft, it is difficult to explain the apparent failure of the much trumpeted mass savings from the use of CFC to result in a mass saving for the aircraft. The suggestion in Ref. 5 that reductions in structural weight are being traded for increased amenity for passengers and other benefits sought by the operators, rather than for fuel savings, appears to be accurate.

Figure 20, used in the derivation of Fig. 19 but not included in Ref. 8, shows the variation of zero fuel mass per passenger with maximum take-off mass per passenger. The increase in empty mass with maximum take-off mass is in effect an increase in empty mass with fuel load, and hence with design range, for an aircraft with a given payload. The empty mass per passenger of the longer-range aircraft is some 50% greater than that of the aircraft at the left hand end of the chart. The potential to reduce fuel burn by reducing design range is evident, as is the willingness of some key airlines to accept reduced fuel efficiency in order to achieve longer range. It remains to be seen whether the combined effects of the downturn in the global economy, increased fuel prices and the introduction of carbon charges will change priorities significantly in the future.

It is likely that aviation biofuels will be available in small quantities by 2020 (see pp 5 and 6) and progressively increasing quantities thereafter. These can be expected to assist in reducing aviation's climate impact in the future. That said, we must recognise that the nature of the technical challenges facing aircraft and engine designers, coupled with the evidence of customer priorities apparent in Refs 5 and 8, cast some doubt on the achievability of the most environmentally important ACARE goal, the reduction of fuel burn by 50%, by the target date of 2020. It has been emphasised by ACARE that important breakthroughs are needed to achieve the goals. In recent decades, however, the market appears to have exploited such technical advances as have been made in developments other than reduced fuel burn. It will require not only research and demonstration but also some shift in design priorities to meet the industry's long-term environmental objectives.

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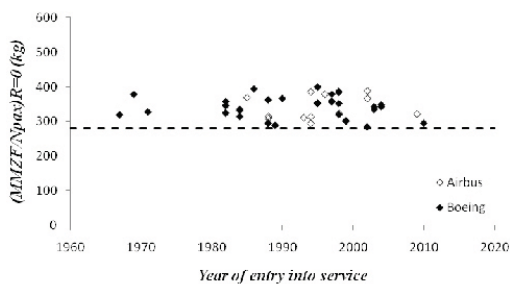


Figure 19. Empty aircraft mass per passenger adjusted to zero range, 1960-2010.

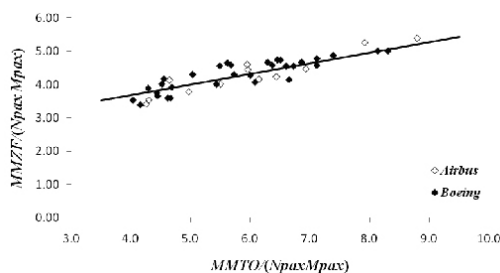


Figure 20. Variation of empty mass with maximum take-off mass for Airbus and Boeing aircraft.

OPERATIONS

The year has seen a number of important developments. Fuel prices, although falling from the very high levels of a couple of years ago, have continued to harden and this has maintained airlines interest in techniques to reduce fuel consumption, with a positive effect on the environment. The advent of EU carbon quotas will ensure this focus is maintained. The economic recession has depressed demand, for the second year running, with UK airports experiencing the largest fall in demand -7.3% — since the Second World War. This brings passenger numbers back to 2004 levels. No new operating ideas have come up this year, but further examination of the engine out taxi has identified how this could be a practical and safe way of reducing fuel consumption. During the past year, continuous descent approaches have gained significantly in use, and discussions have now started concerning their introduction in Africa.

MARKET-BASED OPTIONS

GBD believes that market-based options (MBOs) can provide opportunities to limit emissions from aviation at a lower cost and in a more flexible manner than traditional regulatory measures. MBOs should be used in conjunction with technical and operational improvements.

ICAO's most recent triennial CAEP meeting (CAEP 8 February 2010) supported an approach to emission reduction based on a more stringent NO_x emissions standard and the development of a new CO₂ standard, as proposed by GBD three years ago. CAEP also recommended the publication of reports on the use of economic measures including emissions trading, taxes and voluntary commitments. However, progress towards agreements at a global level will inevitably be slow.

Caution is justified, to some extent, as market-based options could have far-reaching effects on the aviation industry, primarily through potentially significant reductions in the demand for air travel.

Over the past two years, we have been engaged in an assessment of the likely effectiveness of taxes and charges as tools for influencing the industry's environmental performance, whether through improving fuel efficiency or reducing emissions through new fuel technologies, operational changes or capacity reduction. Following an evaluation of the most frequently used elasticity models, which have influenced views on the likely sensitivity of consumer demand and industry strategy to fiscal stimuli, the project was extended to allow us to take account of the industry's response to economic and fuel price turbulence. We plan over the coming year to set out a series of conclusions for policy makers but the work to date already indicates that:

Most of the sensitivity studies cited in support of the projected impact of taxes and charges are either obsolete, inappropriate or flawed in their assumptions, almost certainly over-estimating the sensitivity of airlines to cost increases. For example, they frequently fail to take account of the often relatively small element that flight costs may represent in most travelers' plans and that there is not a direct relationship between passenger demand and emissions. One of the difficulties in such work is separating the effects of the many often interdependent variables.

Fiscal measures designed to influence emissions to a material degree might have to stimulate the equivalent of a long-term economic recession (by which we mean not just an increase in airlines' costs but through reducing traffic resulting in a reduction in revenue/margin, because of reduced economic optimism among their users) in order to trigger reduction in capacity or accelerated commercialisation of next generation technologies. The trade-off between reduced emissions and economic impacts such as unemployment and reduced or deferred fleet orders would have to be considered.

Claimed incentives for replacement of less-efficient fleets have not taken account of the very high opportunity costs associated with accelerated introduction of lower emission airframes and engines at the expense of the models on the market or in train.

This project, which we hope to take forward in collaboration with OMEGA, will be the main focus of the sub-group.

