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Meeting the challenge of aviation emissions: an aircraft industry perspective

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In 1999 the Intergovernmental Panel on Climate Change (IPCC) produced a report on aviation and the atmosphere that highlighted the role that aviation plays in climate change. As the report showed aviation impacts the atmosphere in a number of ways, including emissions of CO_2 and NO_x, water vapour and creation of cirrus plus contrails. Of these the significant climate impact comes chiefly from CO_2, NO_x and contrails/cirrus. In the years since the IPCC report green lobby groups, other NGOs and parts of the media have highlighted and foregrounded the role of aviation in climate change and have mounted a significant public relations campaign against the aviation industry. This paper acknowledges the role of aviation emissions in climate change and outlines how a number of stakeholders, especially the manufacturers of large civil aircraft, are seeking to create a cleaner and greener aviation system. The paper seeks to outline what might be realistically achieved through the current R&D drive for more efficient aircraft and some of the other non-technical initiatives that are underway. The author argues that generally the sector has been quite open in acknowledging its responsibilities on the climate change issue and is investing heavily in finding solutions on a range of fronts. The paper also contends that while aviation must shoulder its environmental responsibilities, governments should not embark on policies that will damage a highly successful sector that supports millions of jobs in the European Union.

Keywords: aviation; emissions; research; technology

Introduction

This paper concerns the aviation sector as a whole, but in particular seeks to outline and assess the response of aircraft manufacturers to the environmental issue that is now at the very top of the aviation agenda. The operation of aircraft, particularly at cruise altitudes of 8–13 km, releases emissions of several gases and particles, which impact on the composition of the Earth's atmosphere. In the global scientific community the majority opinion is that this causes processes which lead to climate change, normally referred to in common parlance as global warming. In political and policy making circles there is now a strong consensus that action must be taken to reduce emissions of greenhouse gases in order to counter climate change and the aviation sector has been called upon to contribute to this new environmental agenda by reducing emissions of CO_2, NO_x and water vapour. Although, in the first instance, the focus is very much on reducing

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CO_2, which in any carbon-based fuel is directly proportional to fuel burn. Broadly speaking three approaches are available to the sector:

1. Improving the basic efficiency of the aircraft in the fleet through new technology and replacement of less efficient aircraft in the current fleet;
2. Improving efficiency in the use of the aircraft (from leaving a gate, through take off, cruise and landing to arrival at a destination);
3. Removing the environmental effects by market constraints.

Aviation in the environmental spotlight

As is well known the aviation industry is no stranger to turmoil. In past decades temporary setbacks for the sector have been due to oil price rises, war and terrorism, health scares linked to Deep Vein Thrombosis (DVT) and Severe Acute Respiratory Syndrome (SARS), and the general peaks and troughs of the economic cycle. Historically, the sector has shown itself to be very resilient, such that the challenges mentioned above caused the failure of many individual airlines and manufacturers, but still permitted commercial air transport as a whole to grow and become more efficient. However, at the time of writing in 2008, the sector faces a series of challenges that will have more long-term effects than the crises of the past. At the forefront of the issues faced by aviation today are the threat of climate change and the role of aviation in producing emissions of greenhouse gases. Coupled with a three-fold rise in the cost of aviation fuel in recent years, the likely costs of solving the emissions issue represents a daunting challenge. Paradoxically, aviation is partly a victim of its own success. To put it very simply, people love to fly and, especially in the developing world, as global per capita income rises, individuals' propensity to take commercial flights increases (Douganis 2006, 17). As a result aviation traffic growth over the last few decades has been increasing at around 5% per annum, which is partly offsetting the beneficial effects of the new technology that is delivering more fuel-efficient aircraft and lower emissions.[1]

With its increasing emissions, resulting from sustained growth, aviation has come under fire in the last decade from a number of lobby groups and NGOs. It is fair to say that this change in aviation's reputation came as something of an unwelcome shock to parts of the industry. Previously aviation had been seen as highly beneficial and even glamorous as it was linked to the liberating aspects of travel and exploration. It was also clear to governments, even by the 1970s when the first wide-bodied jets arrived, that aviation played a key economic role in facilitating travel and tourism and international trade. Aviation has been a powerful facilitator for globalisation in both culture and commerce. So, to use some marketing jargon the 'brand and image' of aviation has been historically positive. Therefore, to suddenly find a politicised opposition campaigning against the sector on ecological grounds was both a new and unsettling experience.[2]

Aviation's response to the emissions challenge

It has taken some time for aviation to co-ordinate its response to the new policy agenda that has highlighted the sector's role in causing climate change. This is not because the sector has been in denial or has sought to ignore the challenge. Aviation consists of a diverse set of stakeholders, including airlines, airports, air traffic control systems, airframe manufacturers, engine manufacturers, supplier companies and national and international regulators. Some of these are business competitors and some have fault lines between them drawn by simple geography. Quite clearly it can be seen that such an unwieldy amalgam of organisations would need time to co-ordinate thinking, let alone action plans and policies; but such co-ordination now exists and is being managed globally by the International Civil Aviation Authority (ICAO) and other organisations such as the International Air Transport Association and the Air Transport Action Group (ATAG).[3] In Europe the EU has co-ordinated a response through the Advisory Council for Aeronautics Research in Europe (ACARE) and via the EU's Emission Trading Scheme, which will soon include airlines as trading entities. The world's leading manufacturer of civil jet aircraft, Airbus, and Europe's largest engine manufacturer, Rolls-Royce, have also co-ordinated their research efforts through the major organs of EU research working chiefly within the EU's Framework Programmes. The industry's goals in this research effort are those laid down in the ACARE 2020 Vision. These are:

- A 50% reduction in the emissions of CO2;
- An 80% in NO_x emissions;
- Aircraft causing 50% of the perceived noise of current models.[4]

High points in this technology strategy are two key projects: *Clean Sky* focused on development of greener aircraft by bringing a number of cutting edge technologies through to full demonstration and *Single European Sky* (SESAR), which is a major Air Traffic Management Research initiative. With these projects Europe is investing hugely in aeronautics research. In the Framework 7 Programme the EU is spending €2.3 bn on Aeronautics and Air Transport (European Commission 2008). With industry support €2 bn will be spent on the *Clean Sky* and *SESAR* project, designed to produce aircraft and an aviation system with substantially lower environmental impact, as demanded by ACARE's 2020 Vision for the sector.

Strictly speaking, the emissions produced by aviation are the direct consequence of airline operations, but the sector has readily accepted that the actual amount of emissions results from the technology embodied in the aircraft and the operational system controlled by air traffic control, airports and regulators. There is, then, a collective sense of responsibility in the reaction to the green agenda. Quite legitimately, the sector has responded to some of its critics by pointing out that all parties in aviation have been seeking greener, cleaner and quieter aircraft. As one might expect, critics of aviation are sometimes cynical about this, but in fact the pressing reality of self-interest has moved aviation toward some impressive gains in fuel efficiency, which has had a positive effect on the search for carbon emissions reduction. Carbon dioxide emissions (CO_2), the most significant of the greenhouse gases, is produced proportionally to fuel burn for any carbon-based fuel, so any reduction in fuel burn immediately reduces carbon emissions. With aviation fuel expenditure being such a large part of the airlines' recurring cost base it is no surprise to see that huge efforts have been made to reduce fuel burn. To put it into perspective fuel expenditures, at around 40% of recurring costs, are now greater than labour costs for many carriers.[5] The price of aviation kerosene shadows the cost of oil and in the early part of 2008 this was three times the level of the average inflation adjusted price of the 1985–2000 period (Greener by Design 2008). So the industry has strong drivers to push down fuel consumption and is proud of the fact that today's newest civil jets are 70% more fuel-efficient than those that started the civil jet transport age back in the 1950s (ATAG 2002). This progress is confirmed by independent assessment. In 2002 the Royal Commission on Environmental Protection (RCEP) noted: 'Developments in both airframe and engine design have progressively improved fuel efficiency and reduced noise and other emissions . . .' (RCEP 2002, 21).

Looking at Figure 1 it can be seen how new aircraft technologies are improving fuel burn performance. For example, between 1980 and 2000, Airbus aircraft improved their fuel efficiency

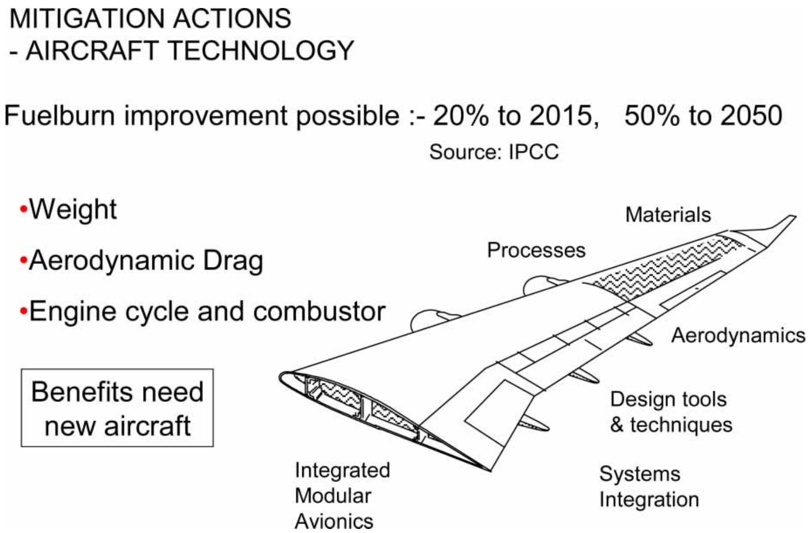

Figure 1. How improved aircraft performance in fuel-burn has been achieved.

by some 30%, with around 65% of that gain coming from improved airframe technologies and 35% from gains on the propulsion side. In the next 12 years up to 2020 it is believed that a further 25% gain in fuel efficiency can be made, with the associated reduction in carbon emissions.[6]

There are four key means by which aircraft fuel burn can be reduced and carbon dioxide emissions lowered. These are through reducing aircraft weight, reducing drag, improving propulsive efficiency and managing the aviation operational system more efficiently. Since 2000 the push for new technologies to improve aircraft efficiency has increased its momentum, with new aircraft such as the Airbus A380 and the forthcoming Airbus A350 XWB offering new standards of fuel efficiency in the long-haul sector. By using more polymer matrix composite (PMCs) materials (that are lighter than metals) and new systems technologies, not to mention a new high technology wing designed and manufactured in the UK, the A380 is able to use 17% less fuel per passenger seat than previous long-haul aircraft.

Use of composites

Weight is critical in improving aircraft fuel efficiency. A 1% reduction in empty aircraft weight will improve fuel burn by 0.25–0.75%.[7] The use of composite is especially helpful in reducing weight and improving fuel burn. In 2000 the typical large civil aircraft consisted of roughly 15% composite materials and 65% aluminium.[8] By 2020 the Greener by Design organisation estimate that this ratio will be closer to 65% composite and 15% aluminium. If this is so, there will be a 15% reduction in fuel burn for long haul aircraft with a parallel decrease in CO_2 emissions (Greener by Design 2007). The percentage use of composite for the A380 was a major step forward at 25% and it is noteworthy that A380 is the world's first long-haul aircraft to achieve fuel burn of less than 3 litres/passenger-100 km, similar to that of a VW Lupo car. A380 also represents a huge breakthrough in noise footprint, achieving 50% less noise energy than any competitor aircraft and meeting London Heathrow's exacting QC2 standard.[9]

Major gains in environmental performance have also been a key design parameter for the new Airbus A350 XWB. Again, it should be re-iterated that this was demanded by airline customers who are desperate to reduce fuel-burn and costs. With this new aircraft Airbus has increased the carbon composite content of the airframe to around 50%, offering significant weight reduction and consequent fuel burn improvement of up to 25% against competitor aircraft. It should be noted that Boeing adopted the same approach on its new 787, which is also a highly fuel efficient aircraft. Indeed, it was Boeing which pioneered a 50% composite content with this new aircraft.

In the future Airbus is also looking at concepts for a New Short Range (NSR) aircraft that will give a step change in performance over existing types, but this is for the next decade and depends on critical innovations in propulsion technology that will not be available for a few more years. Nevertheless, a major effort and investment in research and technology for this new aircraft is already underway requiring an annual spend of €500 m to bring the product to fruition. This should ensure that Airbus meets the ambitious EU targets laid down in the Advisory Council for Aeronautics Research in Europe (ACARE) 2020 Vision. In particular the drive to reduce CO_2 and NO_x emissions by 50% as of 2020 is of paramount importance to Airbus and its research partners in the aviation community.

Propulsion

The question of propulsion is covered in another paper in this issue, but it is significant to note here that airframers and the engine manufacturers are working together to find solutions to reducing emissions. The engine industry is looking to provide 20% of the 50% reduction in CO_2 emissions demanded by ACARE. Rolls-Royce has worked intensely on two major Framework 5 and 6 programs that aim to secure major reductions in both emissions of NO_x and CO_2.[10] More immediately Rolls-Royce's Trent 1000 engine will soon enter service powering Boeing's new 787 aircraft. This engine is 12% more efficient than the Trent 895 that began its working life in 2000.

Air traffic management

Another major emissions reduction is attainable if we can reform and remodel the aviation system so that flight management is more efficient. Currently this is the goal of the EU's SESAR project. Common sense dictates that having hundreds of aircraft circling above major hub cities, while waiting to begin their final approach is a huge waste of fuel and the cause of unnecessary emissions, but it is not just stacking that illustrates inefficiency. At some major hubs, such as JFK New York, it is quite typical to wait up to an hour after landing for a gate to become available so that deboarding can commence. During this wait aircraft are taxiing with engines still running, as they are when they crawl along crowded taxiways towards the runway for take-off. To put it bluntly the air traffic control system has a crisis of capacity that leads to major delays and congestion. Strict safety concerns also dictate that very conservative physical separation margins for aircraft are used and these also cause bottlenecks. In a paper that the author produced for the UK Government DTI Foresight project back in 2000 it was estimated that fuel savings of between 8% and 18% might be available via improved air traffic control (DTI 2000). The same figure was quoted by ATAG in 2002 (ATAG 2002).

Before these gains can be made there are at least two major hurdles to overcome. The first of these is highly contentious. As has been indicated, inefficiency problems at airports like London Heathrow, JFK New York or Frankfurt are directly linked to capacity constraints; however, the lobbies critical of aviation are totally opposed to any expansion of aviation system capacity.

Therefore, from the industry's point of view, a major paradox emerges. The very people who campaign most avidly to reduce aviation emissions are opposed to adding new, higher quality capacity that would help reduce emissions caused by delays, stacking and congestion.[11]

The second challenge is more obscure and not widely understood. In the 1980s ICAO took up the banner for a new Future Air Navigation System (FANS). By the 1990s this had evolved into FANS A and B, or in Boeing's designation, FANS 2. FANS was linked to a related concept and initiative called Free Flight. In essence Free Flight sought to reduce the remote HF radio management of flight by air traffic control and give aircraft commanders more autonomy to make routing choices; user route selection as some call it. This depended on quite radical developments in digital navigation and communications technology that gave greater accuracy and communication capacity to the flight deck and allowed pilots to upload digital information in near real time.[12] FANS relied on two key technologies, Airborne Communications Addressing and Reporting System (ACARS), the only data link available at the time, and Automatic Dependent Surveillance Broadcast (ADSB). Free Flight required the use of a full Aeronautical Telecommunications Network (ATN), which sits on a diverse range of technical platforms for communication and navigation. Neither FANS B nor Free Flight has ever been fully implemented, although some of the technology has been used widely on trans-Pacific routes and more recently over the Bay of Bengal. FANS B has shown its value in that more rapid route changes can be achieved with the new technology in regions where traditional ATC HF Radio coverage is poor. This improves system efficiency as poor ATC coverage mandates very large separation distances for aircraft for safety reasons.

Unfortunately, the lack of agreed international standards for the diverse technologies involved in Free Flight and regional differences in bandwidth availability and technology selection have limited the use of the system. It is also expensive, to retro-fit Free Flight technology to a suitable Boeing or Airbus aircraft costs about US$400,000 per plane;[13] however, the author believes that there is another less publicised reason why Free Flight technology has not been pursued aggressively, especially in the USA. After the attacks on the WTC in 2001, the USA has been much more cautious about allowing more freedom to aircraft movements on or near the continental USA. Indeed, for security reasons, the USA now often seeks more direct control of aircraft routings. As a result we are still some distance from the changes in the aviation systems that could deliver the operational gains that are required. New and improved capacity and the use of FANS 2 and Free Flight technologies could deliver those gains.

A wider environmental perspective

It is obvious that the issue of aviation carbon emissions is not just a question of aircraft technology and flight operations. As they say in the automotive sector there is the matter of 'dust-to-dust' carbon effects. Bearing this in mind Airbus has instituted a life-cycle approach to the question of carbon footprint, which includes an assessment of the wider energy usage and the impact of manufacturing. This goal was the key objective for Airbus's ACADEMY project. This acronym stands for the somewhat convoluted phrase: *Airbus Corporate Answer to Disseminate integrated Environmental Management system.* The project's objective was to achieve an environmental management system, where data on the product and manufacturing were integrated to give a complete life-cycle picture of environmental impact. This new management system allows for the mapping, assessment, control and reduction of the environmental impact of an aircraft and its production processes. Designed to be fully compliant with ISO 14001 international environmental standards, the system has now been introduced into all Airbus's manufacturing sites and products.

As a result of this innovation in 2006, Airbus became the first aircraft manufacturer to be awarded ISO 14001 certification for full life-cycle coverage of environmental impact.

Contention over the data

In the sections above the author has sought to give a flavour of some of the technological gains that a number of companies have been pursuing through research with partners in the EU, but current modelling suggests that incremental gains in performance will not offset the amount of carbon emissions resulting from continued traffic growth. This observation, showing how technology gains in fuel efficiency are being offset by industry growth, originally derived from the Intergovernmental Panel on Climate Change (IPCC) report on aviation in 1999 (Penner 1999). The IPCC report estimated that aviation's total contribution to the total man-made component of climate change was around 3.5%, but that aviation's contribution to man-made CO_2 emissions was nearer 2%. The report further suggested that by 2050 the figure for the total percentage impact would be somewhere between 3% and 15%. The range for this figure is derived from models showing the contributions of other sectors. A significant margin of error exists in this context.

The figures, of course, cause significant controversy. The issues here are complex, with uncertainty over the physical processes in the lower to middle atmosphere, and over the relative impact of a broad range of emissions. Following on from the IPCC report it is contended by some analysts that the overall radiative impact (effect on global warming) is between 2 and 4 times greater than that arising from carbon dioxide emission alone. The 'radiative forcing' is believed to be greater because most aviation emissions are created high in the atmosphere at cruise altitudes of around 8000–13,000 m. Constructive debate over these issues is often problematic as critics of aviation tend to take the scenarios for aviation growth that show the highest figures and couple it with the highest conceivable ratio for radiative forcing caused by release at altitude and the admixture of NO_x and other substances.[14] Disraeli famously said that there were: 'three kinds of lies: lies, damned lies, and statistics'. This is certainly worth bearing in mind in the field of aviation emissions. It is important to realise that, in the current economic climate of recession and financial meltdown, long-range traffic growth estimates may be highly inaccurate and, on the science side, other than the case of CO_2, we still need to know a good deal more about the effects of the other substances that are emitted by aircraft. As a 2007 report from the Greener by Design group noted, 'There is still considerable uncertainty about the impacts of individual components of aircraft emissions, the understanding of all except CO_2 being rated fair, or in the case of cirrus cloud, poor' (Greener by Design 2007). The problem of the misuse of statistics has been carefully explored by the head of Engineering and Environment at engine manufacturer Pratt and Witney:

> People use a multiplier for CO_2 to assess total impact on global warming. We believe, because it is derived scientifically, that the IPCC multiplier is correct: 1.4 to 1.8 times the CO_2 [aviation, in this case] produces. Automobiles fall between 1.2 and 1.5. These are not high-accuracy numbers, though. On the Web, you will find sources that maintain the multiplier should be 4.0 to 5.0. These sources [people and organizations] take the outside tolerance of each category. This is not the scientific way to go about this. What you should do is take the best estimate between the limits of the 'margin of certainty'.[15]

The lack of agreed standards and a common baseline for this debate on emissions leads to substantial confusion. Another paper in this issue by Roger Kemp indicates how some of the more naïve assumptions about the advantages of rail over aviation are quite erroneous, but in 2007 an extraordinary revelation appeared about the shipping industry. The *International Maritime*

Organization (IMO) announced results of research that showed that shipping emissions had previously been underestimated by about 50%. According to the research by *Intertank*o, global shipping emissions are in the order of 1.2 billion tonnes rather than the 800 million previously stated. This is twice the level of aviation, yet many NGOs want to see much of the world's airfreight moved to the shipping sector. One of the *Intertanko* researchers remarked: 'Planes, trains and cars have tightened up much more than shipping .... Shipping is the last to tighten up.'[16] A *Friends of the Earth* Spokesperson noted, 'It's a bit of a shock. It's not about good sectors and bad sectors. We need to calculate the amount we can safely put in the atmosphere.'[17]

Nevertheless, despite continuing uncertainty over aspects of the core science and growth trends, the aircraft industry realises that urgent action is necessary and that it must fulfil its obligations to reduce climate change effects. The industry also recognises that for the short to medium term technology alone cannot solve the whole of the emissions problem. Therefore market-based, non-technological policies must be addressed, but this requires careful analysis of the relationship between stakeholders and assessment of the best way to achieve co-ordination of policies to achieve environmental gains. Unless this is done, policies may backfire and have counter-productive effects.

Other policy options

In the 1960s one of the USA's leading sociologists, Robert Merton, distinguished between manifest and latent functions of policy options (Merton 1967), the latter often being undesirable. To give one of Merton's examples, the manifest function of *Prohibition* was to make the consumption of alcohol illegal, a latent function was to create an illegal and lucrative drinks' trade run by gangsters. Rules and systems to protect the environment from the effects of aviation also carry the risk of creating undesirable latent consequences. Thus if green taxes and emissions trading costs lower airline profits they may slow down the process of fleet replacement and the move to newer, more environmentally friendly aircraft. Another risk is attached to regional initiatives. In Europe environmental issues are at or near the top of the political agenda. In parts of the developing world they are not. Strict controls on aviation expansion in Europe may therefore simply lead to the industry relocating to other regions where the environment is a lower political priority. Bearing this in mind it is interesting to see how hubs like Dubai in the Middle East are growing at a rapid rate, while in Europe major airports are severely congested with capacity stretched to the limit.

Figure 2 attempts to illustrate how complex the co-ordination of effective policies on aviation and the environment may be. Market type solutions throw up many problems, particularly when stakeholders have conflicting interests and when the regulatory disciplines applied are regional, rather than global. A good example of this is the EU's Emissions Trading Scheme (ETS) and the conflicts that have sprung up over including aviation in the next phase from 2011,[18] which has now been agreed by the EU, but is highly controversial elsewhere. Emissions Trading Schemes (ETSs) can take various forms, the EU has opted for a Cap and Trade scheme. The EU scheme, announced in August 2008 plans to restrict aviation emissions to the 2005 average. The proposal states: 'The objective of this proposal is to address the growing climate change impact attributable to aviation by including aviation into an emissions trading scheme.'[19]

Issues with ETS schemes

Broadly speaking the aviation industry is supportive of the proposed Emissions Trading Scheme. ETSs are also popular with both economists and environmentalists, especially if they conform to

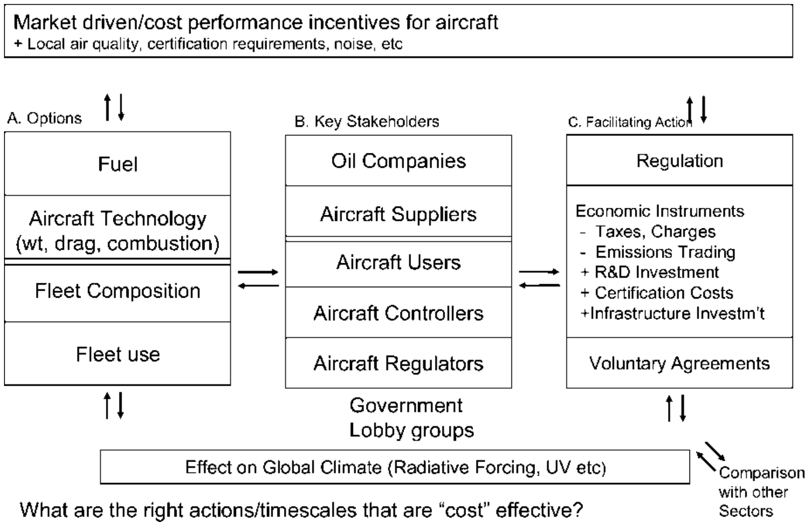

Figure 2. Planning for aviation environmental improvement.

the Polluter Pays Principal (PPP), but ETSs raise a number of challenging issues on key aspects of their design and architecture. The aim of an ETS is simple; polluters are given a quota for the amount of carbon they can emit. The quota is denominated in the form of permits that can either be auctioned, or allocated according to a grandfathering principle, based on past emissions or alternatively some kind of sector benchmarking. Entities that emit more than their carbon quota will have to buy more permits, which according to market theory will drive them to reduce emissions. If excess emissions are high the price of permits will rise rapidly increasing the financial pain of breaking the cap and adding to the urgency of reducing emissions. In the case of airlines this will be either through shrinking their operations or finding ways to improve fuel efficiency. A key structural question here turns on whether the trading system is open or closed, i.e. whether polluters can obtain permits from outside their sector. In the case of the EU's ETS, aviation has initially been given 85% of its permits, but must obtain the other 15% from open trading auctions.

In Europe some NGOs have given a guarded welcomed to the proposal, but also signalled their disappointment that it does not go far enough. Generally speaking, in an ideal world, the green NGO lobby would prefer all permits to be auctioned and, of course, a much stricter cap on emissions. However, with carbon priced as low as €10/CO_2/tonne (the actual figure is likely to be nearer €15) this would add between €0.05 and €0.11 to the price of a litre of kerosene and, according to the journal *Environmental Finance*, put 5% onto an airlines marginal operating costs.[20]

As the cap on CO_2 relates to 2005 levels and aviation's emissions are expected to reach 140% of the 2005 level by 2012, with a 15% auctioning level, PriceWaterhouseCoopers (PWC) estimate that the sector in total will receive only about 60% of the allowances needed to compensate for the anticipated emissions. This gap will mean costs of around €3.5 billion per annum for the aviation sector, assuming a price of €30 per permit.[21] Impacts on specific airlines will be very different as specific emission levels vary widely between aircraft types. Aircraft operators operating modern fleets will have a substantial advantage. In addition, As PriceWaterhouseCoopers (PWC) note, 'specific emissions are often proportionally higher on short distances, so aircraft operators flying a greater number of short-haul flights may find themselves more greatly impacted'.[22] As the journal *Environmental Finance* has noted the ETS could distort the route network with carriers flying longer routes to avoid higher costs.[23] If the PWC analysis is correct, the competitor forms of transport should benefit from the additional costs applied to short-haul aviation, but this will include road transport as well as the more desirable rail. Capacity constraints will also ensure that price rises as demand increases.

From 2012 the EU is planning to apply the ETS disciplines to all non-European airlines flying into the EU, which will undoubtedly lead to conflict with the USA and possibly ICAO, whose directors want to see a global scheme. The US Air Transport Association (ATA) has already declared the EU proposals to be illegal.[24] ATA president & CEO James May commented:

> The Parliament's unilateral decision to cover the world's airlines – including US airlines – in Europe's ETS is not only bad policy, it is illegal . . .. The EU's unilateral grab of power over US and other non-EU airlines wherever they are in the world is a clear violation of the Chicago Convention. The EU decision to move forward with this legislation is sure to spawn a legal challenge.[25]

EU officials seem to believe that no legal impediments to the ETS exist because such schemes are not addressed by any of the instruments of international aviation law. However, ETSs did not exist at the time of the Chicago Convention and the USA may be able to use legal instruments against the EU's ETS from the competition or trade arena. As Malte Petersen has noted, another critical issue regarding the legality of including aviation in the EU ETS is that Article 2(2) of the Kyoto Protocol (KP) states that the parties 'shall pursue limitation or reduction of emissions of greenhouse gases not controlled by the Montreal Protocol from aviation . . . working through the International Civil Aviation Organization. . .' (Peterson 2008). This would seem to imply that the KP gives only ICAO the legal authority to design and implement such a scheme. Whatever the ultimate legal outcome over this question there is bound to be conflict between the EU and ICAO over this issue. At the moment to its critics the EU scheme looks like a global framework grounded in a regional jurisdiction.

Other initiatives

At a conference in Geneva in April 2008 the CEOs of Airbus and Boeing Commercial Airplanes, as well as leaders from airlines and air traffic control, gave a public commitment to future 'carbon neutral growth' for aviation. From the manufacturers' point of view the implication was that efforts to reduce emissions from a diverse range of technologies would be redoubled and that ETS schemes would be embraced. What was particularly encouraging about the Geneva meeting was that it was clear that the stakeholders were willing and able to work together. As an example of this, in September 2008 ten members of the new airlines sustainable aviation fuel users group teamed up with Boeing and Honeywell for a major research initiative on alternative fuels. The group's aim is to enable the commercial use of renewable fuel sources that can reduce greenhouse gas emissions and decrease aviation's exposure to oil price volatility and reliance on fossil fuels. The airlines supporting the sustainable fuels initiative include Air France, Air New Zealand, All Nippon Airways, Cargolux, Continental Airlines, Gulf Air, Japan Airlines, KLM, SAS and Virgin Atlantic. Together they account for more than 15% of commercial jet fuel use.[26] The initiative has won support from the World Wildlife Fund (WWF) NGO, which has previously been among aviation's sharpest critics. Jean-Philippe Denruyter, WWF global bioenergy coordinator and steering board member of the Roundtable on Sustainable Biofuels commented: 'We welcome the aviation sector's will to reduce their greenhouse gas emissions, and appreciate their efforts to ensure the sustainability of their biofuel sourcing'.[27]

Another initiative concerns Pratt and Whitney's (P&W) geared turbo-fan (GTF) engine that, according to the manufacturer, will be 12% more fuel efficient than today's engines and cost 15% less to operate. Having seen P&W work for over 20 years and spend well over US$1 bn on this concept, some commentators doubted if it would ever come to fruition, but the first flight of P&W's PW1000G is scheduled for October 2008. The technology is a significant break with the normal principles of a gas turbine engine. In a typical gas turbine the central shaft must rotate at high speed for maximum efficiency in compressing the intake air. In the GTF design, the gearbox between fan and shaft lets the fan turn at a relatively low speed, allowing a bigger fan and a higher flow of bypass air for greater thrust and less fuel consumption.

As commentators often remark the core technologies of powered flight are mature and we tend to see only incremental changes in performance and efficiency. Looking at the gas turbine engine it is typical to see a new design delivering around a 10% gain in efficiency every eight or nine years, but what is happening now is that improvements in propulsion, reduced aircraft weight and improved aerodynamic performance are coming together at an accelerated pace, driven by stakeholder co-operation and EU research funding. In addition if we could radically re-engineer air traffic management a reduction in emissions would be available very rapidly. Nevertheless, it is undoubtedly true that to take a significant step towards a carbon neutral aviation sector we need to successfully develop either a radically new type of airframe or propulsion based on an alternative to fossil fuels.[28] For some time hydrogen fuel cells were mooted as a possible new propulsion fuel, but hydrogen, although much lighter than kerosene for the same calorific value, is much less dense. The volume of hydrogen required would thus be 2.5 times greater than today's kerosene. If used as an aircraft fuel hydrogen would have to be stored and transported at cryogenic temperatures requiring insulated and pressurised tanks. The on-board fuel system would be much heavier than on current aircraft. Thus hydrogen does not seem like a near or mid-term solution to the propulsion dilemma.

The airframe side looks more promising. Both Airbus and Boeing have been looking at the possibility of new concepts, including the Blended Wing Body (BWB). Such an aircraft has its body encapsulated entirely in the wing and would be lighter and exhibit significantly less drag than conventional swept wing aircraft. For many years these designs were somewhat stuck at the concept stage with fundamental doubts about stability and control, but in recent years demonstrators and prototypes have been fabricated and tested by Boeing in partnership with NASA Dryden. The Greener by Design (GBD) group see major gains coming from the BWB. Assuming gains on the propulsion side to reduce NO_x GBD have said that, 'we see a more than tenfold reduction on greenhouse effects relative to today's long-range, high altitude aircraft' (RCEP 2002, 26). In the future the biggest hurdles to using BWBs for commercial aviation may lie in airport infrastructure issues and passenger resistance, but, nevertheless in the mid to long-term BWBs may become a key part of the long-range fleet.

Conclusions

The aviation sector is today under acute pressure to deliver large reductions in emissions of greenhouse gases. The pressure has derived from a number of lobby group campaigns that have captured the political agenda and are driving policy change. The main stakeholders in the sector believe that it is entirely legitimate that aviation make a fair contribution to the costs of mitigating climate change. However, some contentious issues lie at the centre of the aviation emissions question. It is highly regrettable that no consensus exists on the basic facts about aviation emissions. For the researcher it is very confusing that government and EU data, NGO data and Industry data are often widely discrepant. There are a number of reasons for this: first, IPCC figures for aviation include an estimated ratio applied to the CO_2 percentage to give the total 'radiative forcing' effect of aviation emissions. Some green oriented NGOs tend to give the maximum for this ratio. Second, the estimates of future emissions levels depend on traffic growth estimates where there is quite a significant bandwidth because of uncertainty. Third, while the industry tends to give global figures many UK NGOs are talking about UK or EU emissions, which are indeed proportionally higher. A final factor is that in general there are no universally agreed metrics to assess this question, which adds to the overall level of confusion.

While some green NGOs are campaigning on a national or EU basis, from an industry point of view the issue is undoubtedly a global one. If we look at a pollutant like CO_2, it is 'uniformly mixed' and has the same effect wherever it is released. In terms of the climate change impact the issue really is global. Therefore business regimes that become hostile to aviation in the West and lead to migration from Europe to Asia or the Middle East will have zero effect on climate change. The industry is committed to global solutions that minimise or avoid competitive distortions.

The aerospace and aviation industries believe that they have already achieved huge gains in the area of emissions. So for example, the 70% improvement in fuel efficiency and corresponding reduction in CO_2 generation is a figure the sector is proud of. The search for further and greater efficiency gains is accelerating, not because of philanthropy, but because the price of fuel is demanding ever faster change and also putting airlines out of business. As an MIT study has noted, previously fuel burn efficiency was one of a number of key drivers in aircraft design, today it is undoubtedly the key parameter.[29]

The problem of aviation emissions is a symptom of the carbon-based economies that came to fruition in the twentieth century. The West's affluence in the post-1945 period was based on the use of cheap fossil fuels. There is a consensus now about moving to a low carbon economy, but fundamental public policy choices remain about how this is to be done and how rapidly it can be achieved. For example, if we want to curtail or reverse the growth of sectors that play key roles in our economy, what degree of economic disruption are we willing to tolerate? Aviation is the only global transportation system and it underpins the world's largest economic sector, travel and tourism.[30] This sector provides around 9% of world GDP and 8% of world employment. Today between 25% and 30% of all commercial transactions have some kind of link to aviation. Much of the world's migrant labour can only return home to see their families through the use of commercial flights.[31] So whatever major changes we seek to make to aviation there will be fundamental and profound economic and social consequences.

Given that the economic stakes are so high the aircraft industry is seeking to evolve into an eco-friendly sector through use of cleaner technology and more efficiently managed systems. At Airbus eco-efficiency is at the top of the corporate agenda and is the major driver for the technology acquisition to be derived from the massive R&D expenditure of €2.6 bn per annum, which is 10% of turnover. The EU is also spending to achieve breakthroughs in environmental performance.[32] With these efforts and market-based mechanisms, such as the ETS and carbon offsetting, it must be hoped that our efforts to mitigate the pressing agenda of climate change are successful, but it is critical that we do this without crippling a sector, which lies at the very heart of the world's prosperity.

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Notes

1. Some commentators would doubtless say the whole benefit is offset.
2. Some of the green lobby groups have invested substantial some in advertising. An article in *The Times* notes: 'Enoughs enough, a green group funded mainly by anonymous individuals, has spent hundreds of thousands of pounds in the past 18 months on advertisements attacking the aviation industry for damaging the climate', *The Times*, 26 Janury 2008.
3. It is fair to say that ICAO took some time to respond to the authority it was given by the Kyoto Protocol. The USA's failure to sign up to the Kyoto process was certainly a factor as the USA has been the powerhouse of international aviation.
4. See http://www.acare4europe.com/html/documentation.asp
5. Fuel costs are nearer 30% of total expenditure if we include non-recurring costs such as aircraft purchase.
6. See Climate Action at http://www.climateactionprogramme.org/features/article/a_ sustainable_vision_for_the_aviation_industry/
7. See the work of Lee (2001) and Greene (1995) quoted by MIT researchers at http://web.mit.edu/aeroastro/people/waitz /publications/Babikian.pdf
8. The other 20% being steel and titanium.
9. QC2 is a particularly exacting standard set by London Heathrow. In fact A380 meets the ICAO chapter four 17 EPNdB (Effective Perceived Noise in Decibels) standard.
10. These are EEFAE and NEWAC. Rolls-Royce is leading a project called ANTLE that seeks a 60% reduction in NO_x.
11. A number of aviation commentators believe that added capacity will add a spur to traffic growth.
12. See *Avionics Magazine*, 1 June 2001, at http://www.aviationtoday.com/av/categories/ commercial/12709.html
13. See *Avionics Magazine*, 1 June 2005, at http://www.avtoday.com/av/categories/ commercial/931.html
14. For example, the European Federation for Transport and the Environment claim that aviation accounted for up 9% of the man made impact on the climate in 2000.
15. Quoted in 'The greening of aviation', *Aviation Week*, 2 June 2008.
16. TIMESONLINE, 7 October 2007.
17. Ibid.
18. In fact the EU Commission has proposed that intra-EU flights are included from 2011 and flights from outside the EU in 2012.
19. European Commission. Proposal for a directive of the European Parliament and of the Council amending Directive 2003/87/EC so as to include aviation activities in the scheme for greenhouse gas emission allowance trading within the Community.
20. *Environmental Finance*, December–January 2005.
21. Turnover for the members of the Association of European Airlines is around €75 bn.
22. 'Emissions trading for aviation: frequently asked questions', PriceWaterhouseCoopers at http://www.pwc.com/extweb /indissue.nsf/docid/F0740687D13D6834852574B10059FEBA
23. *Environmental Finance*, op. cit., note 20.
24. The legal basis for the EU ETS is the directive 2003/87EC which has been transposed into national law from EU member states.
25. 'ATA says European aviation emissions trading scheme is illegal', *Eye for Transport*, 16 July 2008.
26. http://www.zawya.com/Story.cfm/sidZAWYA20080929031020/Airlines%20set%20up%20group%20to%20develop %20aviation%20fuels.
27. Quoted in note 26.
28. It is also possible that this could be done via a huge investment in carbon offset.
29. http://web.mit.edu/aeroastro/people/waitz/publications/Babikian.pdf.
30. Shipping cannot reach landlocked countries or continental landmasses where there are no navigable waterways.

31. This is not just an issue in Asia and Africa. In Moldova a staggering 25% of all adults live and work abroad. The BBC, Radio 4, *The World Tonight*, 9 October 2008.
32. Over €2 bn on aeronautics in the Framework 7 programme alone.

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