AVIATION IN A SUSTAINABLE WORLD – THE WORK OF THE OMEGA PARTNERSHIP OF UK UNIVERSITIES, PHASE 1

Roger. M. Gardner. Formerly Chief Executive, Omega Partnership of UK Universities

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Abstract

The successful first phase of the UK Omega partnership of universities represented a landmark in collaboration within and beyond academia on work to stimulate and support development of aviation sustainability knowledge. A broad programme of studies and knowledge transfer with the stakeholder community has raised the profile and value of university research in the area. Across 8 topics covering impacts and solutions, the partnership has taken stock of the main challenge areas, identified strengths and weaknesses in the knowledge base and pointed up a number of areas where further knowledge is needed.

Since the partnership's own programme was established many of the universities involved have secured funding for collaborative follow-on work and proposals continue to be submitted for related work. Simultaneously, work is underway to systematically review the state of knowledge and to define a road map forward for work under the Omega banner that will permit real improvements in the prospects for sustainability of the air transport sector. Whilst work to date has primarily focused upon issues related to climate change, local noise and air quality pressures are increasing in the UK as the government pursues a 'better not bigger' policy that calls for smart solutions to environmental impacts. The UK Climate Change Committee took a pessimistic view in December last year on achieving forecast UK growth in aviation up to 2050 without having an adverse effect upon UK targets to control UK CO2 emissions. Together, these pressures argue for a closer interaction between the academic community, government, NGOs and the aviation sector to pull through knowledge that will allow significant progress to offset and reduce the effects of growth. The next phase of Omega is being set up to rise to this challenge.

1. Introduction

The Omega academic partnership [1] was established to achieve the gearing benefits of universities with established expertise in aviation sustainability issues working in a co-ordinated and strategic way. Despite a continuous stream of technological and operational advances from the sector and action by governments to incentivise progress, improvements are not keeping pace with aviation growth. Promoting the right effective solutions calls upon a wide raft of knowledge that responds to the threats and opportunities. Knowledge acquired through Omega studies supports Government and industry activities towards cleaner and quieter aviation. The Omega programme consciously targeted issues identified by stakeholders as intractable or priorities needing. The programme was split into eight topic areas:

Impacts	Solutions
Climate change	Aircraft system
Air quality	Operations
Noise	Sustainable fuels
	Mitigation
	Demand

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A programme of over 40 different studies, workshops and conferences picked up on scientific, technological and economic aspects of these challenge areas. The main outputs were summarised in an overview report of the first phase[2]. The detailed reports of studies, conferences and workshop can be downloaded from **www.omega.mmu.ac.uk**. Apart from building a knowledge base, an important aspect of Omega work has been to provide a neutral forum for discussion. This package of work has effectively brought academia into the heart of the 'solution space'. That needs to continue.

Whilst the focus of a UK funded activity was to respond to the needs of the UK stakeholder community, the topic is firmly international in nature and it is at that level that many of the solutions will be applied. Omega worked to support UK contributions to international work through the European Union and the International Civil Aviation Organisation (ICAO). It also fostered collaborations with countries active in researching solutions; MOUs were signed with PARTNER[3] in the US and with Chinese Civil Aviation Authority (CAAC). The UK government has been keen to maximise the potential of Omega to provide new information that targets needs identified through ICAO's Committee on Aviation Environmental Protection (CAEP) and to support international joint working where possible.

2. Context

The absence of an aviation bunker fuels agreement within the Copenhagen Accord leaves the sector without a global framework for addressing climate change. Whilst that remain a target for COP16, the aviation sector, with the support of states and the international community, will need to redouble its efforts. UK Government commitments in relation to reducing CO2 now include aviation (2050 CO2 from aviation must be no greater than that of 2005). This imperative has been echoed domestically in the UK through the recent report of the Climate Change Committee[4] which has signalled major challenges in meeting predicted growth. Demand management, modal shift, improved fleet fuel efficiency and the scope for use of bio fuels are all cited in the report as issues requiring new approaches and solutions. The need for inclusion of non-CO2 impacts in policy frameworks is also emphasised.

More broadly, air quality and noise impacts remain issues of continuous concern locally and challenges for the sector doing its bit to help meet standards and targets. NO2 limits which bear upon airports are now mandatory in the EU and noise contours are limited in some cases. The UK government decision against further development of runway capacity on the South East airports region has intensified the need for smart solutions as the government pursues a policy of 'better not bigger'. Whilst these developments are fairly recent, the same drivers existed at the time Omega was launched and the resulting studies are highly relevant to the sharpened need to unlock new thinking and innovative solutions. They provide a foundation or base from which to launch a targeted attack on the knowledge obstacles to making progress.

3. Omega achievements and research needs

Studies and workshop/conference activities are detailed at the website. There are too many to be able to describe the outputs across the programme. An indication of how Omega work has helped to point the way towards a strengthened knowledge base can be gathered from summarising the results from a few key pieces of work, following the main topic headings. The emphasis here is future actions needed.

3.1 Climate change

Non-CO2 impacts linked to aviation have been a focus within Omega. A science workshop and stakeholder event was held to review and then disseminate findings and knowledge on non-CO_2 impacts and contrails. These activities drew upon a wide range of research including Omega studies. Three main themes captured the scientific view on scope to move knowledge forward in the short, medium and longer term. On tropospheric chemistry impacts, latest

European programme results on modelling aviation impacts of NOx emissions on ozone still show a spread of results (factor 2) using advanced chemistry/transport models (CTMs). There are many observational datasets and, in the short term, these could be exploited better. A more in-depth test of model responses to unified test conditions would help scientists understand (and therefore improve) the model responses. In the medium term, a structured comparison of models should be undertaken to define an objective test of model responses and grading. This could use the identified model uncertainties to define further measurements needed and improve known model deficiencies of resolution. It was considered difficult to be able to identify longer-term prospects and needs until these issues are resolved for modelling. For measurements, longer-term global measurements in the upper troposphere/lower stratosphere (UTLS) region are needed.

To address aviation-induced cloudiness, the short-term need was identified as building a climatological dataset of ice supersaturation and condensable water and to improve representation of the vertical structure of aircraft emissions. That could lead to a measurement network of ground-based observations (cameras) and experiments on aging contrails (observations). Further action needed is to investigate the effective radius of ice particles as a separator of aviation and natural cirrus and a unified database of contrail coverage (observations) should be established. The need to investigate the relationship between soot ice nuclei and ice water content (indirect effect) and to model aviation-induced cirrus on a physical basis was also identified. In the longer term, a global database of corrected upper tropospheric humidity from sondes should be developed in order to provide input to numerical weather prediction models. Where possible, the resolution of models should be increased and smaller-scale cloud-resolving models should be used. It remains important to understand ice nucleation behaviour and properties such as homogeneous vs. heterogeneous freezing and to develop aircraft sensing capabilities and satellite detection of aviation-induced cloudiness.

Responding to the significant interest in climate metrics, there is a short-term need to investigate the potential for dual approaches to aviation climate policy (short term vs. long term impacts) and to improve underlying models that quantify policy impact. Beyond that it was felt that modelling studies are needed to examine the accumulative approach of CO_2 emissions as a potential policy instrument and to improve understanding of ocean heat-uptake response for temperature impacts.

3.2 Air quality

Omega work has concentrated on two main themes: gaining a better theoretical understanding of the dispersion of aircraft engine exhaust plumes so that accurate more models can be constructed and improving measurement capabilities. Omega work towards model validation was addressed though the use of LIDAR (Light Detection and Ranging) to scan cross-sections of the aircraft exhaust plume at airports. Linked with imaging spectroscopy, a picture of the evolving exhaust gases was built up showing that at the start of the take-off run, the plume tends to hug the ground. Supporting theoretical tests of the dissipation of aircraft engine exhaust plumes in a wind tunnel have been used to validate large scale computational fluid dynamics simulation of flows. These tests reveal details that could not be obtained by other means. Data analysis related to LIDAR campaigns need to be compared and integrated and a priority must now be to complete and make public a comprehensive data analysis, so as to maximise the scope for validation. Analysis of measurements has yet to be extended to examine the dispersion of exhaust plumes after the aircraft has been rotated upward and becomes airborne. Further research in this area should be directed broadly toward improving the accuracy of the air-quality models so a more active interface between the measurement and modelling communities is required.

Following the knowledge transfer ethos of Omega, work to improve characterisation of particulate emissions has applied and developed for air quality measurement, capabilities designed for measurement of aerosols in the stratosphere. Deployment of this capability is permitting characterisation of the actual type of PM instead of just the particle mass. This offers the prospect of identifying specific particle sources within the airport environment. The next step is to undertake field trials that will develop the instrument and so provide information that allows targeted mitigation.

Omega has helped to develop the potential of multi-university supported traversing sampling rake into a UK capability that facilitates on-wing measurement of aircraft exhaust emissions – the ALFA rig. The aim is to help in characterization of 'actual' emissions from aircraft engines in airport environments as opposed to nominal test conditions required by ICAO certification processes. The probe can take undiluted exhaust gas samples for use with the CO2, CO, UHC and NOx instrumentation. New expertise has significantly strengthened the technical capability through set-up and deployment of the ALFA rig. The ability to take 'on wing' measurements makes it possible to account for a wide range of operational power settings beyond those required for certification testing. It also permits examination of any installation effects, potential alternative fuels and engine deterioration effects on emission performance. Improved understanding in these areas is crucial to more robust modeling of aircraft emissions in the near airport environment. Planned airport field tests will strengthen knowledge of source emission characteristics and levels that is used to initiate modeled assessments of airport air quality pollution.

3.3 Noise

The Omega noise work reflected both a desire to understand the sources of noise in relation to emerging technologies and to find ways to improve the basis for communication on noise at an airport level and so strengthen community relations. The Advanced Open Rotor (AOR) engine concept is one of the few technologies that has the potential to make significant reductions in aviation emissions but there remain many uncertainties over the noise characteristics and levels associated with this technology. A study investigated the likely impact of a number of designs of large open-rotor powered aircraft during flight operation. It has been shown that with changes to an advanced open rotor's operation, compared with that of an existing turbofan, significant benefits in cumulative EPNdB certification noise levels (of the order of 12 EPNdB or greater) can be seen compared to a broadly equivalent year 2000 turbofan-powered aircraft. This study focussed solely on noise at the takeoff, cutback and approach certification points. However, future aircraft with different noise levels, noise characteristics and operational procedures may be audible at ground level while flying 'en-route'. The significance of 'en-route' community noise for AOR powered aircraft needs to be assessed but because of the potentially large propagation distances of 'en-route' noise, this will be a complex problem to analyse.

Acoustic improvements to advanced open rotor engines are expected to continue as the design process deepens. Particular tonal sources (such as the wake & tip vortex interaction tones), for example, are expected to be reduced significantly relative to the broadband noise sources. The most important outcome of this research is the development of a working framework to assess the noise benefits and disbenefits of fundamental changes to aircraft design due to advances in engine technology together with the effects of varying aircraft operation. There are two important IP-related but hopefully soluble caveats linked to developing this method and using it effectively, namely access to up-to-date noise prediction codes to replace the public domain methods and access to the latest advanced open rotor powerplant geometry, location and performance information.

Future work to assess en-route noise can be informed by early NASA studies indicating that the levels of noise on the ground varied significantly with propeller design and blade numbers. This suggests that there is the potential of minimizing en route noise through design. This clearly requires the development of necessary modelling tools early enough to be of use in the engine and airframe development process. These tools must be able to account for the more complicated propagation problem of sound from sources at altitude, understand the relationship between sources and received sound, and must also reflect the how such noise is perceived. This latter challenge may require the definition of a new metric.

Noise disturbance is often the most significant issue raised by local communities concerned about airport expansion and also accounts for the vast majority of complaints about airport operations. The number of noise-exposed people around UK airports could increase despite improving technology. This makes the absence of a common language of reporting, communication and negotiation in relation to aircraft noise a key obstacle to more effective noise management. Addressing this deficiency, Omega evaluated public understanding of conventional and supplementary noise metrics to see if other explanatory indices could usefully supplement existing contour based metrics.

The literature shows a lack of consensus as to the best means of illustrating aircraft noise exposure and that current approaches tackle what is measured/modeled (the physical phenomenon of exposure) not the human response (i.e. disturbance). Thus, any attempt to improve noise management should engage with the physiological, psychological and sociological determinants of disturbance. Moreover, the aggregation of elements of aircraft sound generation can often inhibit public scrutiny and understanding of the influence of specific elements (e.g. maximum levels, duration and frequency of events) on levels of disturbance. There is some evidence that supplementary indicators of noise exposure can make a positive contribution to public consultation but systematic assessment of public understanding of the metrics is lacking.

Omega study focus groups at airport and control locations showed considerable variation in the interpretation of different metrics used to illustrate the same noise environment as well as general dissatisfaction and indeed mistrust in some cases among members of the public with the aggregated indictors such as Leq and Lden. A preference was shown for metrics that disaggregate key elements of aircraft noise; namely, time, frequency of events and individual sound levels and new means to illustrate these, especially site specific information that is easy to interpret in relation to their own personal exposure. A more substantive UK study is needed to ‘test’ these preliminary findings. The importance of examining new metrics, attitudes and sensitivities and ways to convey noise information is important for current airport community relations but is could be critical to understanding public acceptability of new technologies such the AOR engine concept.

3.4 Aircraft systems

Advancing technology remains a prime focus for improved environmental acceptability of the air transport sector. With new aircraft being continually being introduced across the size range, the need to incorporate new and, hopefully step change, technologies is critical. The advent of significant use of composite materials in the Boeing 787 marks a radical step forward with associated fuel saving benefits. Omega has studied the scale of environmental gains through the use of composite materials in civil aircraft, by quantifying the impact of aircraft composite components on emissions reduction in service and in manufacturing stages. Lightweight composites such as carbon fibre reinforced epoxy resin and laminates such as GLARE are around 20% lighter than an equivalent aluminium alloy component. However, more energy is used to supply energy and raw materials for the production of the lightweight composite materials.

Additionally, recycling aluminium only takes around 5% of the energy required to refine it from ore whilst technologies for recycling composite materials are at an early stage and inevitably the carbon fibres suffer some damage during the process. Lifecycle assessment (LCA) was employed to compare the complete lifecycle of materials used in aircraft structures and components and has shown that the production and disposal of aluminium (100 % recycled) uses less resources and produces lower emissions than either GLARE or carbon fibre composite materials. However, once the material is used as a component in the aircraft, the heavier aluminium uses more fuel. As flight time increases, so there is a cumulative saving of aircraft fuel when the lighter materials are used in components. For the future, development of this new modelling approach is needed to fine tune energy requirements at various stages of the composite lifecycle.

As already mentioned, there are already identified noise issues with AOR engines. If this technology is to be widely adopted in the future, it may become necessary to balance or optimise the environmental benefits of reduced carbon emissions against the environmental costs of sound levels, particularly the distinctive multi-frequency tonal character of the sounds likely to be produced by future designs for unducted fan engines. This risks AOR noise not being as low as it might otherwise have been. An Omega study investigated both existing available methodologies and models within the aviation industry and, based upon canvassing opinion of stakeholders, examined the requirements for a future optimisation tool. There is evidence of need for a user-friendly, front-end bolt-on assessment tool to interface with existing acoustic technologies (such as INM[5] operational parameters). This future optimization tool could investigate the technical advantages and disadvantages of future aircraft engine concepts such as AOR and also airframe design technologies.

A new optimization tool should be designed so that it could be made available for public use as well as for specialist use within the aviation industry and thus it should be possible for all outputs to be used as inputs into policy-making systems. Output from the tool should also allow anybody to perform a sensitivity analysis, e.g. to test for the effect of even quite small changes in fuel price. The tool should therefore be designed to allow for a qualitative analysis of the trade-offs between operating costs and environmental performance and thus be capable of interface with existing integrating model systems such as AIM[6]. A new tool should also be capable of accounting for new knowledge such as that gained from 'auralisation' of the noise characteristics of AOR configurations. Development of a future environmental optimization tool to handle design-level interdependencies and aggregate the knowledge through to policy user is an important and realisable goal. Availability of a 'public domain' version of such a tool would help with public engagement and improve prospects for earliest possible entry into service for radical technologies that offer reduced environmental impact. Further research is needed to develop the architecture, detail and interfaces of such an optimization tool.

3.5 Operations

Operational improvements in the air transport system are rightly seen as quicker wins in the quest for lower fuel burn than new technology introduction. Making ATM systems more efficient is one of the primary areas of interest for reducing the environmental impact of aviation. Flying optimal trajectories at optimal altitude remains an ideal but one frustrated by the realities of en-route and runway capacity constraints. Omega work on ATM quantified how far actual behaviour of aircraft in the current ATM system was from optimal behaviour and what were the environmental impacts of these inefficiencies. Causes of inefficiency differed according phase of flight. Many of the causes are already well characterised but the disproportionate extent of extra fuel found to be burned in the terminal area is significant. Track extension analysis identified that, on average, aircraft fly approximately 16% longer track distances in Europe compared to the minimum great circle track distance. Of this total ground track extension (TGTE), around 16% is in the departure terminal area (i.e. within 50 nm of the departure airport) and this can be almost entirely attributable to standard departure procedures. Approximately 37% of the TGTE occurs in the en route phase of flight due to standard routes and restricted airspace, congestion and adverse weather. The remaining 47% of the TGTE was attributable to the arrival terminal area, over half of which was found to be due to the need to put aircraft into holding stacks (to absorb delay and maximise runway throughput) and vector them for final approach, while the remainder was due to standard arrival procedures.

There are obvious fuel burn penalties associated with these inefficiencies but also potential noise and air quality impacts linked to non-optimisation. Examining the inefficiencies in each phase of a typical flight can highlight future operational concepts for improved environmental performance but there are elements of inefficiencies that cannot reasonably be removed. It is clear that one hurdle, that procedural development often lags significantly behind technological development, argues for far closer collaboration between stakeholders. Further work is needed on flight data analysis comparing the fuel-based and lateral ground track extension analysis approaches to enhance the insights that can be gained from their use and more work is needed to explore the fundamental relationships between safety, capacity, congestion and flight inefficiency.

As already mentioned, fleet turnover has a direct effect upon environmental performance. Omega has assessed factors affecting the rate of retirement of aircraft from airline fleets, the extension of useful or economic aircraft lives by modifications such as freighter conversion and the speed and process of incorporating new technology into airline fleets. Historically airlines are reluctant to incur costs from switching aircraft models. Drawing upon statistical analysis of aircraft acquisition data and modification and retirement trends, a basic model for aggregate fleet emissions was produced. Using a simplified airline fleet planning model, the economic viability of several options was illustrated, including the early retirement of aircraft and the introduction of new technology into fleets, as well as alternative assumptions on future fuel prices and efficiency, maintenance costs and new replacement aircraft programmes. It was found that airline retirements typically peak at about 30 years, a figure relatively unaffected by noise and local air quality regulations. Of greater significance was fuel cost and availability of new aircraft. It was concluded that early substitution of new short/medium-haul aircraft for existing ones is not a cost-effective option for reducing fuel burn and thus CO2 emissions at oil prices that are assumed to rise from current levels to $140 in 2025. Thus, policy measures (e.g. significant tax incentives) would be needed to induce the replacement. Long-haul aircraft substitution was more responsive to improved fuel efficiency and oil prices than short/medium-haul aircraft under similar sets of assumptions. Future work would be valuable in the areas of examining the role played by aircraft and engine manufacturers in the fleet renewal and retirement process and the interaction between locally applied policies and the global location of aircraft types. In particular, this could be combined with an extension in scope to a more detailed consideration of aviation's non-CO2 impacts and how these are affected by aircraft acquisition, modification and retirement. More detailed consideration could also be given to freighter aircraft.

3.6 Sustainable fuels

With a rapidly growing interest in the use of sustainable fuels and improved prospects for early introduction after successful flight-testing, there is a need to assess the life cycle characteristics of aviation fuels derived from petroleum and other feedstocks. Alternative 'drop-in' fuels now have the potential to reduce the carbon footprint of aviation but a thorough understanding of the options is needed to ensure that genuine carbon savings are realized.

Omega has studied the performance and environmental impact of a range of fuels including synthetic fuels derived via the Fischer-Tropsch process, vegetable oils, bio-diesel and algae. Only few of these alternatives would result in a reduction in lifecycle greenhouse gas emissions. Natural gas based synthetic oil products with carbon capture and storage would reduce lifecycle GHG emissions by a few percent. Significantly larger reductions in lifecycle GHG emissions in the order of 85 percent could be achieved through synthetic oil products from cellulosic biomass. However, the land-use implications of using these biomass-derived fuels would be significant. While natural gas-based synthetic aviation fuels have already been tested, BTL is about to be commercialized and could thus provide an increasingly important fuel stream over the mid term. Both fuels are projected to be available at costs of well below $100 per barrel. Owing to their significantly higher productivity, microalgae-based fuels are expected to offer a significant reduction in the land area required for cultivating the fuel feedstocks. However, in order to achieve these levels of productivity, microalgae would need to be supplied with concentrated CO2, a condition that can increase lifecycle GHG emissions. In today's energy system, power plant CO2 can be captured and used as an algae feed, thus extending the benefit of fossil fuels beyond electricity generation. However, in the longer-term future - the time horizon over which the technological and economic challenges of microalgae can potentially be resolved - power plant CO2 may be captured and stored underground. Under such conditions, algae-based fuels would release a similar amount of lifecycle GHG emissions per unit energy as petroleum-derived jet fuel. Considerable further analysis of the practicalities and economics of these options is required.

3.7 Mitigation

Work in the mitigation area undertaken by Omega has been focused toward reducing climate impacts but it is notable that the case for improved knowledge on the efficacy and development of mitigation addressing local airport level impacts remains strong and warrants further research. It is recognised that, for climate impacts, the level of projected growth cannot be offset by advances in technology and operations alone. Various instruments are either currently applied or being developed; a sound time-integrated understanding of the potential of these is still needed and tool development is required to assist in selecting and applying well-targeted solutions. Omega work in this area has covered many issues but offsetting programmes, emissions trading and the potential to use marginal abatement cost (MAC) analysis are picked out here.

Carbon Carbon offsetting is a mechanism for compensating for greenhouse gas emissions generated by a particular activity by paying for equivalent emissions savings or reductions to be made elsewhere in the economy. OMEGA work was designed to clarify the role, the effectiveness, and the credibility of offsetting for air travel and to investigate attitudes towards the offset concept amongst airline passengers. A literature review revealed concerns about reduced drivers for technology change associated with offsetting and major issues with design of schemes, lack of regulation and permanence in effect and inconsistency with carbon accounting. However, offsetting schemes represent a pragmatic means to encourage action to limit climate change impacts; the concept is easy to understand and it offers a contribution to climate action that individuals and organizations can make. A review of scheme providers suggests widely varying practice and benefits for the climate that serves to undermine public confidence and thus depress take-up. The study identified the need for further research to develop a standard methodology for calculating offset emissions, to assess the market expansion potential of offering a fixed rate offset product and to ascertain whether the attitudes expressed in the passenger survey undertaken here are representative of the wider general public.

Aviation will be included in the EU Emissions Trading Scheme from 2012. Omega has studied the possible impacts on the aviation industry and general economic activity of including the aviation sector in the EU ETS. Using the Energy-Environment-Economy Model for Europe (E3ME), the study also examined possible impacts on the aviation industry (demand), on CO_2 emissions, and macroeconomic activity (GDP) in the EU and explored how the 2008 fuel price increase impacted the air transport sector and how this compares with the carbon price impacts. In the study, allowances are assumed to be allocated to the air transport industry at no cost or are auctioned depending on the scenario. It was assumed that the cost of auctioned and purchased carbon allowances from the market (as well as the opportunity costs of freely allocated allowances) is to be fully passed on to consumers by increasing prices for air transport. Several auctioning scenarios were used.

The study found that the aviation sector is expected to purchase excess allowances from the other sectors covered by the EU ETS. The inclusion of the aviation sector, as it is proposed by the European Parliament, may result in small reductions in demand for airline services (about 1% by an allowance price of €40) in 2020. The study also found that the inclusion of the sector might result in reductions in emissions by air transport – up to 7.5% in CO_2 (by an allowance price of €40) compared with no action baseline in 2020. The impacts on GDP were negligible and suggested that including aviation in the EU ETS will not affect the EU's competitiveness by reducing economic growth in the region. The main uncertainty related to this study stems from the fact that the rules for the third trading period (2013-2020) had not been finalized. The key importance of the study was to examine the impacts of carbon trading on the aviation industry considered within the context of the whole economy. This revealed the effects of the feedbacks between all of the sectors, of which aviation is only a part. It showed that this trading scheme basically creates a shift in the economy, where the sectors that can reduce carbon emissions easiest do so first. As the E3ME analyses the industry at an aggregate level, impacts on different business models, flight routes and technologies inside the air transport sector cannot be investigated and this is an area for further research.

In order to control the environmental risks of aviation linked to growth, it is necessary to understand the feasibility and costs of controlling the environmental risks of aviation while simultaneously securing its substantial social and economic benefits. Omega's study in this area aimed to inform cost effective strategies that can be adopted by the aviation industry. The aim was to reduce / control the environmental effects of aviation by constructing a series of marginal abatement costs (MAC) curves which show the incremental costs of achieving successive reductions in specific emissions such as CO2. The study involved a review of academic and industry research to assess the link between aviation and emissions, and the scope for abatement measures and a workshop and consultation with stakeholders to explore the feasibility and sources of information on abatement options. A framework for assessing the marginal costs of abatement options was developed. There was considerable interest in developing MAC curves further but methodology and data gaps made this difficult. The study identified three broad categories of abatement measures, namely airframe and engine technology, operational improvements and fleet management and also a range of criteria to assess the feasibility and acceptability of abatement options. The analytical framework, a series of linked spreadsheets, was a major output of the study and case studies addressed UK domestic sector CO2 emissions and a European-based sector, including long distance international traffic, covering CO2, NOx and selected other species.

A range of interventions were revealed which could enable the aviation sector to abate about 12-15% of its CO2 (and related) emissions at negative or zero cost by 2012, and more than this if fuel prices rise to 'very high' levels. These 'win-win' interventions are mainly associated with changes in aviation operations that reduce fuel consumption per unit of output, that is, per passenger km but analysis suggests that after this point MAC rise steeply. The most cost effective intervention measures in the short to medium term appear to be those associated with changes in operations and management. In this early MAC work many areas have been identified for development and refinement including scrutiny of the data and methods used, drawing upon science knowledge to appraise and potentially promote the use of MACs to achieve effective abatement, develop guidance and produce exemplar case studies. This type of MAC analysis could also include a broader assessment of policy options, taking into account the possible responses of the industry to a range of policy and commercial scenarios. This implies that any such initiatives should be embedded within an integrated approach to managing the environmental performance of the aviation sector as a whole. Some further analysis drawing upon this MAC approach has been undertaken already and the approach is ripe for further development.

3.8 Demand

The issue of demand and its management has been given relatively little attention in the first phase of Omega and this is recognised as an area requiring further attention. However, studies have been carried out that bear upon demand through pointing up for business how its carbon footprint could be reduced. Omega's work looked at how to facilitate carefully selection of business use of air travel and examination of the carbon performance of different airline business models. The ICARUS toolkit[7] run by the Institute of Travel Managers (ITM) was significantly developed with the assistance of Omega analysis of the business travel trade usage. It also drew upon an Omega survey of air travel and the role of environmental performance in its selection. The study supported the development a prototype advanced carbon calculator to demonstrate the key factors that affect carbon emission levels for airlines. These factors are the type of aircraft and engine used, the altitude and distance flown, the cabin configuration and seating density and the load factors achieved. The model should be used to assess the sensitivity to changes in business models (such as increasing load factors, changes to fleet, increased seat capacity, reduced carried weight onboard, etc.) for network carriers, low cost carriers, charter airlines, regional airlines and non-EU network carriers.

The choices that airlines make about the aircraft they fly, the number of seats they have on each aircraft, the routes they fly and the passenger segments they focus on have significant impact on their environmental performance (which can be assessed in terms of an airline's CO_2 emissions per passenger kilometre, fuel burn or other suitable metric). Each of the main airline business models (network, charter, low cost carrier (LCC), regional) involves practices that may improve or degrade environmental performance. Omega's project analysed the factors that affect each business model's environmental performance and considers the potential for changes to business models to improve the environmental sustainability of the aviation sector. The Low Cost Carrier's share of total emissions has risen dramatically and, at 112g/pkm this group's CO_2 emissions are lower than either network carriers or regional airlines (at 144g/pkms and 216g/pkms respectively) in the EU market. However the lowest emissions level is achieved by charter airlines at 106g/pkm. Options for removing on-board weight were also considered including reducing water carriage, lowering tankered fuel levels and re-designing the duty free sales process. A calculator was developed that estimates the carbon dioxide emissions that can be prevented by removing weight from a number of aircraft types. A model of air transport CO_2 emissions, which was developed to test various scenarios, suggests that should current growth rates continue, emissions for the global aviation market may grow by over 50% between 2009 and 2020. With high growth rates, the share of emissions for low cost carriers would also grow significantly, however, it is also clear that network carrier's growth of long haul flying also means that the absolute emissions levels of this group is also likely to rise. The output of the model was used to test the sensitivity of changes to business model, such as increasing load factors, increasing the number of seats on board an aircraft, and differing growth rates for each business model.

A stakeholder workshop and seminar for this project suggested that passengers seem to have little appetite for changes in behaviour (such as willingness to take fewer longer overseas holidays or to holiday within the UK). It was evident that further passenger education regarding the relative impact of flying compared to other GHG generating activities is required. Further research is needed to assess passenger willingness to forego service levels, timetable frequency, flight times to maximise load factors, minimise aircraft weight and therefore fuel consumption.

4. Building engagement

Work undertaken through Omega has led to further collaborative research by Omega university partners. Areas being addressed include contrail modelling, air quality dispersion characteristics, environmental airport-triggers for behavoural change and airports environmental investment toolkits. Joint proposals have been submitted in relation to a number of other projects spanning technology assessment, modelling development and air quality measurement. The relationships established through Omega are continuing to strengthen the academic resource deployed on aviation sustainability and the network of active UK universities is growing.

5. Future plans

Plans remain to launch a new Omega programme towards the end of 2010 that widens academic engagement from UK universities and is more directly driven by the requirements of stakeholders from Government, the sector and NGOs. This will ensure applied value. The first phase represented a feasibility stage which was cleared based upon good collaborative working: the intention forward is to build upon the broad understanding that has been gained and target the key challenges that are inhibiting progress. Work in under way to understand current research needs based upon identified gaps in the knowledge base. This will lead to a new programme of work that involves closer collaboration with government, the sector and NGOs to extract maximum value from academic input. It is also intended that it should key into the wider international debate and help accelerate action at that level.

The programme to be developed will respond to the urgent need for knowledge to address the global climate change challenge whilst maintaining the quest for knowledge and solutions to tackle local air quality and noise pollution problems. It is obvious from discussion with stakeholders that better understanding of atmospheric science remains a priority. Improved understanding is needed on non-CO_2 effects, i.e. cruise NO_x, contrail physics and contrail induced cirrus. There is also a need for a strong focus on the further development and refinement of climate metrics. Trade-offs and interdependencies are high on the list as well as current tools do not allow the required flexibility to understand the primary and integrated effects of technological and operational (including ATM) changes. This feeds the needs for wider modelling capabilities that can assess the effects of policy instruments and mitigation measures in terms of technological reaction, including the prospects for uptake of alternative fuels and resulting economic costs and benefits. At the local level, improved understanding of public reaction to noise, the efficacy of noise mitigation measures and the characterisation and control of local pollution, including particulate emissions remain contentious and unresolved research challenges.

It is clear that the work of Omega and its neutral forum have been of significant value to the stakeholder community and there has been strong support for a continuation of collaborative strategically coordinated research. The first phase took a wide view of the research knowledge base and has flagged many issues to be understood better. In a time of limited resources, however, it will be necessary to focus in on the priority areas that optimise and assure delivery of new technologies and operational practices and support development of effective policy instruments. Whilst retaining the essential independent credentials of academia, closer co-ordinated working with government, NGOs and the sector will ensure that research has the greatest applied value.

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[1] The Omega academic partnership comprised nine UK universities in its first phase and was funded by the Higher Education Funding Council for England. The Omega partners were Manchester Metropolitan, Cambridge, Cranfield, Leeds, Loughborough, Oxford, Reading, Sheffield and Southampton

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Contact Author Email Address

Roger.m.gardner@gmail.com

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