



Energy in Aviation

28th February 2008

The Cambridge Energy Forum event was organised around the broad theme of 'Aviation' looking at issues relating to the energy required for flight, the technological possibilities of using renewables for small scale flight, carbon emissions, and the industry perspectives on energy, economic, environmental impacts and 'sustainability'.

Philip Sargent introduced the evening noting that the scope of the topic was extensive, the industry is economically significant from many angles, competes with other forms of transport, there are issues around taxation and the different air-frame types from helicopters to airships, together with different fuel types. We could not possibly touch on all of these issues in one session but the assembled speakers each have valuable perspectives from which we would learn a great deal.

Dr Paul Robertson, Lecturer in Electrical Engineering at the University of Cambridge, led the evening with a presentation on electric aircraft, the physics of flight and resultant energy requirements with particular reference to a new microlight design that uses modern electric technology. Paul has created this new 'Hummingbird' design experimental aircraft together with Paul Dewhurst (Flying Airports and a World Microlight Champion pilot) and Dr Paul Welsh an aircraft certification engineer.

The UK register of fixed wing aircraft show that there are approximately 10,000 in the UK. There are just over 4000 microlights, encompassing both fixed wing and 'hang-glider' or 'delta-wing weight shift' aircraft, 700 hot air balloons, around 500 gliders, 1500 helicopters and 300 gyroplanes.

There are three issues that impact both commercial (passenger) and general (leisure and other) aviation:

1. Fuel costs (Aviation fuel or petrol in the case of General Aviation).
2. Noise issues (even microlights now have to comply with noise laws).
3. The environmental concerns of pollution.

Looking to technology and legal trajectories there are a number of things that have happened recently that made it possible to create electric aircraft:

- a) Rare earth metal magnets.
- b) Lithium Polymer batteries.
- c) De-Regulation for very light aircraft.

The advances in magnet technology now enable increased power and acceleration from smaller engines. (see the adjoining presentation that demonstrates the power of modern magnets).

With regard to Lithium polymer batteries (again please see the presentation), over time different battery chemistries and technologies have evolved to give increasing power density and energy density in a given mass of batteries. Currently commercially available lithium polymer batteries outperform typical car batteries by a factor of 'x 15', and are set to increase their advantage as they develop.

Finally the change to the law; following the de-regulatory steps of other countries most notably the US, and in order to encourage innovation within the sector, the market for very light micro-light aircraft has been changed. The UK regulations stipulate that;

1. for aircraft that have an empty weight of 115 kgs or less (excluding fuel),
2. and that have a wing area ratio of less than 1 square meter for every 10 kilos of empty weight,
3. and that weigh less than 300 kgs when fully loaded with pilot(s) and fuel,
4. and are capable of flying at 40 mph (air speed)

In this scenario as long as you have a pilots license you are able to build and fly whatever you wish, without having to go through the airworthiness tests and certification. Research has shown that the majority of (admittedly rare) accidents in very light and light aircraft are down to operator error rather than equipment failure. The prior regime insisted that for every change made, a new round of certification was required, involving submission of paper work and flying the aircraft for a certain number of hours. The de-regulation allows a more rapid incorporation of new design elements, and a faster development process, it is assumed that the operators (pilots) are suitably personally incentivised to judge the risk for themselves.

Paul went on to discuss basic aerodynamics of wings and the forces that act on them (lift, thrust and drag) and how different wings interact at both high and low speeds, together with induced drag versus total drag. The interaction of the two drag elements can be plotted on a graph to find the minimum drag point, and thus the minimum energy requirements in order to get a particular aircraft to fly.

The 'figure of merit' in relation to all the possible calculations for different wing shapes is known as the 'L/D' ration (Lift over Drag ratio). The L/D ratios for different aircraft were illustrated (2/1 for a 'Space Shuttle', 4/1 for a parachute, 10/1 for an airliner, 50 to 60/1 for gliders). The L/D ratio basically indicates that when travelling at a given speed, for every unit of distance travelled horizontally (L), you lose a unit of distance travelled vertically (D), e.g. a glider would travel 50-60m horizontally for a drop of 1m vertically. Different aircraft obviously have different L/D ratios specific to their design.

When looking at powering the aircraft, traditionally microlights have been powered by petrol engines, giving around 3.7kwh of effective power (45 mega joules per kilogramme, gives 12.5 kwh, which is then converted at around 30% efficiency giving 3.7 kwh). In addition the weight of the engine (roughly given at one kg per horsepower, or 0.75 kg per killo watt power) also has a significant impact.

In order to be viable an electric aircraft has to stack up against petrol engines in terms of performance.

Electric motors are significantly lighter than their petrol equivalents, unfortunately the power densities of lithium polymer batteries are not competitive with petrol, so what you save in engine weight is countered by the additional weight required for the batteries, even though electric motors operate at 90% efficiencies.

The 'Hummingbird' design that Paul and his colleagues have pioneered is a very light aerodynamic design with an L/D ration of around 18/1 (most microlights are nearer 9/1), it has two light weight motors, one on each wing, with an empty weight of 85 kgs. Two battery stacks weighing 25 kilos, coupled with a pilot gives a total flying weight of around 200 kilos.

The theoretical analysis suggests a requirement of 2.21 kw to keep the aircraft flying, with 5.5 kw of thrust to maintain level flight. A lot more power is required for a short period of time for take-off. Paul showed the theoretical data versus test data from an experimental rig, and the predictions neatly correlated with reality. The batteries have had a bespoke battery management system designed to prevent overheating during charge and discharge cycles, and clarification is being sought as to whether the weight of the batteries counts toward the 115 kgs limit (as strictly speaking they are 'fueling the flight' so may not need to be counted). However at this point in time the whole set up indicates a maximum flying time of 40 minutes, with a range of 35 miles, and a top speed of around 80 miles per hour. The range and flight time figures may improve as more battery capacity is added.

The team have even looked at the possibility of using a small wind turbine to charge the aircraft, with the net result that a turbine placed at a general aviation airfield will likely provide more than enough power to allow for a years intensive

flying, with the remainder going to 'offset' the CO2 emissions involved in building the aluminium frame in the first place.

The 'Hummingbird' should be finished and flying by the end of 2008. All in all the opportunities for electric powered leisure vehicles is here, there are a number of designs starting to fly, and the technology is both improving in performance and becoming cheaper. Looking to the future 'hybrid' designs that feature an all electric start, followed by in flight 'internal combustion' to top up the batteries looks like a feasible model, and as the technology improves, such systems and designs will be applied to larger and larger aircraft.

Peter Spark the UK low carbon entrepreneur gave the second featured presentation for this debate, and provided an overview of carbon accounting, with a particular focus on aviation emissions quantification for the commercial and freight aviation markets.

He started by noting that a large majority of the audience had flown in the last year, and whilst all could remember the cost, none were able to state the carbon footprint of the flights they had purchased. Peter is the founder of a 'low carbon software and data services firm' whose primary goal is to reduce the transaction costs and increase the utility of accurate carbon accounting for organisations globally.

From an academic perspective if you take various Stiglitzian theories regarding information asymmetries, coupled with Porterian concepts of value chain analysis and environmental supply chain economics, the need for such a start-up becomes apparent.

This is being played out in the market with large players such as Walmart, Tesco, and Marks and Spencer all committing to 'carbon footprinting' the products they sell within a matter of years. Historically this has been a sector whose potential has been much talked but under-invested.

Whilst the government's launch of the recent 'Act on CO2' calculator encourages citizens to quantify their basic carbon footprints using aggregated data sets based on the AMEE software monopoly, the UK government has yet to start to address its own carbon impact, let alone that of the £150 billion per annum that it spends on behalf of the British taxpayer. The start-up low carbon business Peter and his colleagues are creating aims to provide the software and data services that allow it and indeed any organisation to quickly and more importantly accurately quantify that information.

The initial focus is aviation emission quantification, using anonymised real examples from a Cambridge based boutique financial services firm, and the UK office of multi-national consultancy firm, Peter highlighted the fact that aviation accounts for the overwhelming majority carbon footprint for each firm. He then went on to show how inappropriate the DEFRA 2007 guidelines for calculating such a footprint were, given the current state of scientific knowledge surrounding the area of emissions quantification.

For truly accurate carbon accounting data relating to class of travel, load factors, fuel use, flight paths, and other factors all need to be collated to give specific, accurate figures for a person or package on a specific flight. A newly created department at the University is at the cutting edge of this new area of science. Whilst there are a range of opinions on the environmental impact of aviation, and the policy responses necessary to manage the transition to a low carbon economy, there is a lot of actions that the industry can take to massively reduce its overall climate change impact.

Some critics of the current industry stance point out that the current projected growth trajectory for the UK aviation industry are not sustainable because;

1. There simply is not enough fuel in the ground.
2. The impact on climate change will be too great.
3. That of all modes of transport, aviation is viewed as the least likely to be able to reduce its overall impact.

Peter then discussed a variety of design issues that would help the industry reduce its impact, briefly touched up on bio-fuels highlighted by the Virgin Groups much publicised trial flight, and then went on to discuss operational changes such as simplifying routing across the EU, and concepts from military fields such as air to air refuelling, all of which have the potential to reduce impact by around 50% over time.

Peter Hiscocks of Marshalls Aerospace gave the third and final presentation of the evening to provide the business perspective of an aerospace industry firm, as well as that of the industry as a whole. Peter started by noting that over the last thirty years aviation growth has been seen as 'a good thing' bringing economic benefits to regions and cities, with the only major concern being one of noise. As long as you didn't live on the flight path to Heathrow most people were essentially positive about the industry.

There has been a change in mood recently, in light of efforts to combat climate change, where sections of 'civil society' and the media have started to view opinions that flying is a bad thing (when other people do it), and akin to a modern

day sin. There appears to be a lot of emotion around the issue of increased aviation, with extreme opinions on either side of the argument (hardline environmentalists on one side vs Michael O'Leary of Ryanair on the other). Most people are somewhere in the middle of these two extremes. Peter surveyed the audience and was surprised that whilst the majority had taken business trip over the last year, most business people and academics were not flying on a monthly basis.

Peter characterised the aviation industry from civil, through to commercial freight (fastest growing in Asian and China) which incorporates cargo on passenger flights, then there are government agency flights (air, land, and sea rescue, police, etc.) and military. Military aviation as a sector is smaller than it used to be, but is nevertheless significant, the majority of aviation is for training purposes, and often military transport is the only option when emergency relief flights of foot aid are needed in remote areas, the smallest aspect of military aviation is actual combat services.

Taking aviation as a whole even the most enthusiastic ecologists recognise the benefits of air travel, for business it is often vital, as long as Britain has manufacturing or service industries aviation will be a necessity.

- Headline figures relating to the UK aviation industry are that around half the population travels each year by plane on holiday.
- Over 1/3rd of exports by value are transported by air.
- Air, Sea, Land rescue is obviously important.
- c. 675,000 people are involved in the UK aviation industry.
- Aviation creates the second highest value per capita of any industry after pharmaceuticals.
- Aviation contributes £14 billion per annum, and exports of £13 billion, making it exceedingly important to the UK economy.

Recently the CO₂ impacts of aviation on climate change have received increased publicity, occupying a key role in the minds eye of the public. There are still issues around noise, land use changes for runways and despite the relative safety of the industry, safety issues are also a key concern.

Peter went on to talk about the six key species of gases that result from fuel burn by aviation, the different impacts at different altitudes and cirrus cloud formation. The three key gases from an environmental perspective are CO₂, NO_x, and Ozone, with increases in CO₂ and NO_x because of the Landing and Take off cycle, coupled with fuel spillages at the airport.

There are additional environmental impacts from the manufacturing and engineering of new aircraft, which are higher than most traditional manufacturing. Then there are impacts from servicing which is what Marshalls Aerospace specialises in. Marshalls have a team of experts that look at environmental

legislative compliance on an ongoing basis, but have also established a committee to look to longer term environmental impacts on the company as well as the industry as a whole. Just from an energy perspective the energy used to heat the hangers is the greatest impact, about five to ten times the impact of emissions from flights in and out of the airport (130 per day on average). They are actively looking to reduce that impact, coupled with an internal campaign to reduce energy use through-out the offices and maintenance buildings.

The UK industry as a whole has responded to the challenges through the Sustainable Aviation Working Group of the Society of British Aerospace Companies (SBAC) who have produced a 'Strategy toward Sustainable Development of UK Aviation' which sets out the actions, programmes and commitments of the industry as a whole to change.

Estimates vary depending on how one calculates the industries impact as a whole, from 32 to 36 million tonnes of CO₂. There are issues surrounding both how the calculations are made, and which party is attributed responsibility (e.g. on a long distance flight which country?). There are therefore a range of issues that have yet to be clarified from a policy perspective, and a lot of selective statistics being used on either side of the argument. Aviation accounts for around 5% of the CO₂ of the UK, though environmentalists increase this owing to the radiative forcing arguments, and the likes of O'Leary downplay this to 1.8%. This total figure is notably less than emissions from domestic heating of homes in the UK.

There are technological improvements that can be made to the airframe, the appropriate selection of different engine types for different journey types, changes to the Air Traffic Control systems as noted by Peter Spark. There is also a movement toward larger aircraft in order to lower the 'per passenger km' emissions. Biofuels may well play a role in reducing the impact. Then there are carbon offsets which are still a nascent field.

A more significant development for the industry as a whole is the area of Carbon Trading. Aerospace was not included in earlier schemes such as the EU-ETS or Kyoto, and there is a perspective that carbon trading will lead to a much fairer deal for all, though much more sophisticated carbon accounting will be required for this to be effective.

There have been calls to impose VAT on aviation fuel which may increase prices and thus curtail demand, though this action is currently prevented owing a range of international agreements preventing such action, if the UK were to take unilateral action in this regard, this would likely simply shift traffic to other countries such as France or Amsterdam. An international approach is needed.

There is also one other mechanism that might work, and that is to fly less; though this is unlikely to occur in the near future.

As an industry there was a 70% reduction in fuel use for comparable journeys between 1960 and 1990. Between 1990 and 2004 there was a 24% reduction in fuel use per passenger km, owing in a large part to incremental innovation with both aircraft and engine design. The current industry targets require that there be an additional 50% reduction in CO₂ per seat km and 80% in NO_x by 2020. (Note this is for aircraft introduced in 2020 as opposed to aircraft introduced today.)

Peter then went on to describe the specific issues Marshalls regarding land and housing pressures, with the likely relocation of the business to another part of Cambridgeshire.

In summary the aviation industry is large, profitable, and a significant economic contributor to the UK economy that is not going away. The UK aviation industry as a whole is thinking seriously about what it can do to reduce the impacts of aviation, to create new technologies that reduce that impact, and to manage growth, despite mavericks like O'Leary creating a different impression. Marshalls Aerospace is playing its role, for example by introducing significant energy savings to its work as a high value products manufacturer and servicing company.

There then followed questions and a debate with the audience that focussed on comparative government policy, optimisation of engine technologies, biofuels, and impacts on the economy.