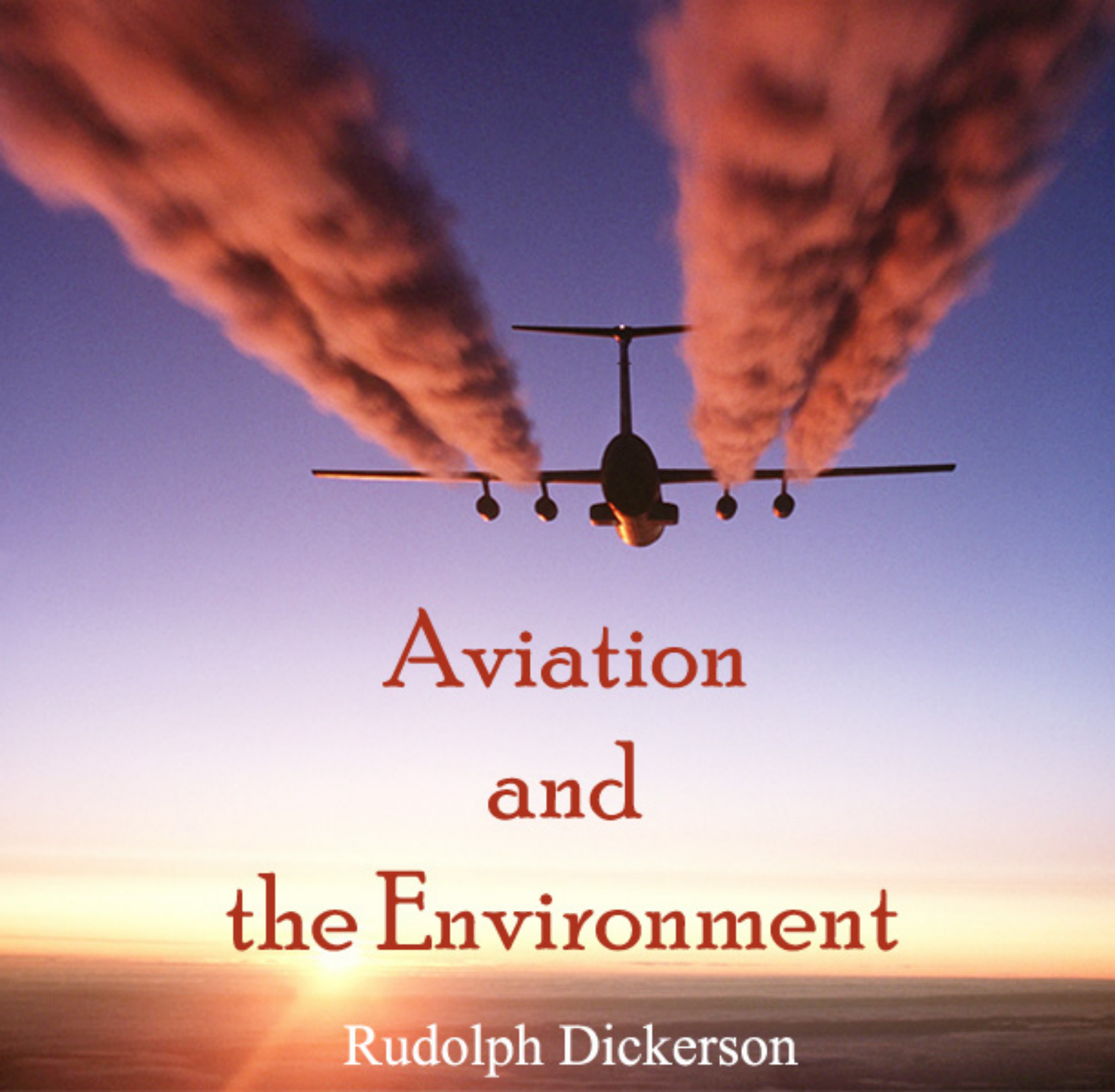


Aviation and the Environment

Rudolph Dickerson

First Edition, 2012

ISBN 978-81-323-2719-6

Published by:
Orange Apple
4735/22 Prakashdeep Bldg,
Ansari Road, Darya Ganj,
Delhi - 110002
Email: info@wtbooks.com

Table of Contents

Chapter 1 - Environmental Impact of Aviation

Chapter 2 - Aircraft Noise

Chapter 3 - Health Effects from Noise, Noise Mitigation & Regulation

Chapter 4 - Environmental Impact of Aviation in the United Kingdom

Chapter 5 - Mitigation of Aviation's Environmental Impact

Chapter 6 - Electric Aircraft

Chapter 7 - Hydrogen Powered Aircraft

Chapter- 1

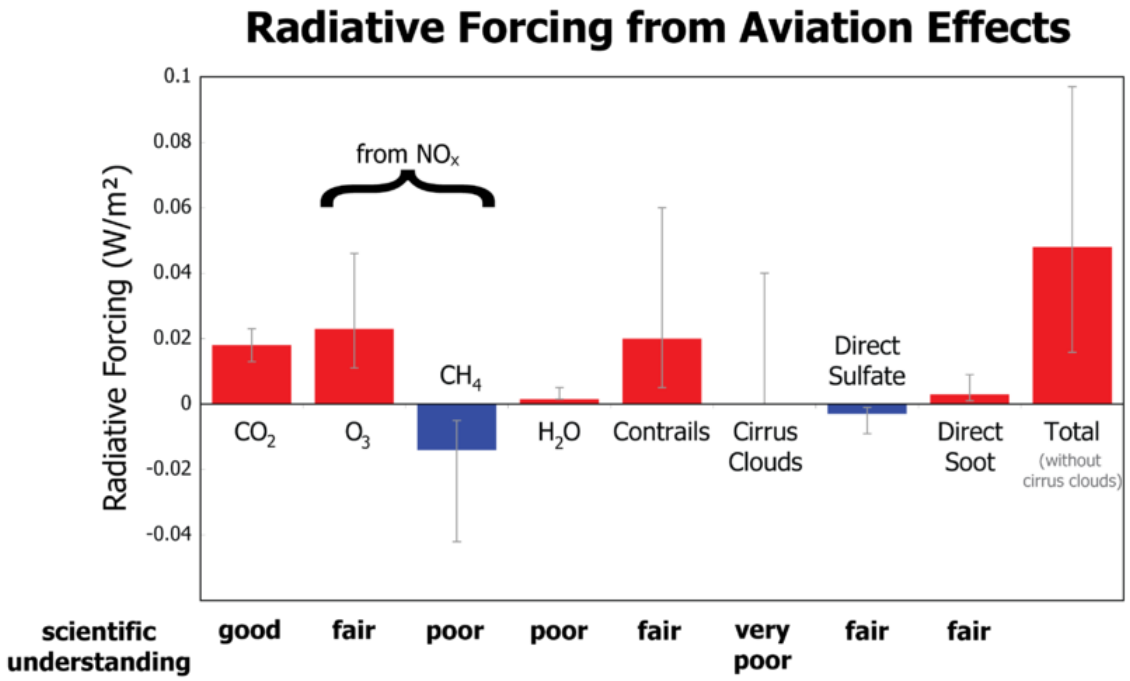
Environmental Impact of Aviation

A C-141 Starlifter leaves exhaust contrails over Antarctica

Aviation impacts the environment because aircraft engines emit noise, particulates, and gases which contribute to climate change and global dimming. Despite emission reductions from automobiles and more fuel-efficient and less polluting turbofan and turboprop engines, the rapid growth of air travel in recent years contributes to an increase in total pollution attributable to aviation. In the EU, greenhouse gas emissions from aviation increased by 87% between 1990 and 2006.

There is an ongoing debate about possible taxation of air travel and the inclusion of aviation in an emissions trading scheme, with a view to ensuring that the total external costs of aviation are taken into account.

Climate change



Radiative forcings from aviation emissions (gases and aerosols) in 1992 as estimated by the IPCC

Like all human activities involving combustion, most forms of aviation release carbon dioxide (CO_2) into the Earth's atmosphere, contributing to the acceleration of global warming.

In addition to the CO_2 released by most aircraft in flight through the burning of fuels such as Jet-A (turbine aircraft) or Avgas (piston aircraft), the aviation industry also contributes greenhouse gas emissions from ground airport vehicles and those used by passengers and staff to access airports, as well as through emissions generated by the production of energy used in airport buildings, the manufacture of aircraft and the construction of airport infrastructure.

While the principal greenhouse gas emission from powered aircraft in flight is CO_2, other emissions may include nitric oxide and nitrogen dioxide, (together termed oxides of nitrogen or NO_x), water vapour and particulates (soot and sulfate particles), sulfur oxides, carbon monoxide (which bonds with oxygen to become CO_2 immediately upon release), incompletely burned hydrocarbons, tetra-ethyl lead (piston aircraft only), and radicals such as hydroxyl, depending on the type of aircraft in use.

The contribution of civil aircraft-in-flight to global CO_2 emissions has been estimated at around 2%. However, in the case of high-altitude airliners which frequently fly near or in the stratosphere, non-CO_2 altitude-sensitive effects may increase the total impact on anthropogenic (man-made) climate change significantly.

Mechanisms

Subsonic aircraft-in-flight contribute to climate change in four ways:

Carbon dioxide (CO_2)

> CO_2 emissions from aircraft-in-flight are the most significant and best understood element of aviation's total contribution to climate change. The level and effects of CO_2 emissions are currently believed to be broadly the same regardless of altitude (i.e. they have the same atmospheric effects as ground based emissions). In 1992, emissions of CO_2 from aircraft were estimated at around 2% of all such anthropogenic emissions, though CO_2 concentration attributable to aviation in 1992 was around 1% of the total anthropogenic increase, because emissions occurred only in the last 50 years.

Oxides of nitrogen (NO_x)

> At the high altitudes flown by large jet airliners around the tropopause, emissions of NO_x are particularly effective in forming ozone (O_3) in the upper troposphere. High altitude (8-13km) NO_x emissions result in greater concentrations of O_3 than surface NO_x emissions, and these in turn have a greater global warming effect. The effect of O_3 concentrations are regional and local (as opposed to CO_2 emissions, which are global).
>
> NO_x emissions also reduce ambient levels of methane, another greenhouse gas, resulting in a climate cooling effect. But this effect does not offset the O_3 forming effect of NO_x emissions. It is now believed that aircraft sulfur and water emissions in the stratosphere tend to deplete O_3, partially offsetting the NO_x-induced O_3 increases. These effects have not been quantified. This problem does not apply to aircraft that fly lower in the troposphere, such as light aircraft or many commuter aircraft.

Water vapor (H_2O)

Contrails

Cirrus cloud formation

One of the products of burning hydrocarbons in oxygen is water vapour, a greenhouse gas. Water vapour produced by aircraft engines at high altitude, under certain atmospheric conditions, condenses into droplets to form Condensation trails, or contrails. Contrails are visible line clouds that form in cold, humid

atmospheres and are thought to have a global warming effect (though one less significant than either CO_2 emissions or NO_x induced effects) SPM-2. Contrails are extremely rare from lower-altitude aircraft, or from propeller aircraft or rotorcraft.

Cirrus clouds have been observed to develop after the persistent formation of contrails and have been found to have a global warming effect over-and-above that of contrail formation alone. There is a degree of scientific uncertainty about the contribution of contrail and cirrus cloud formation to global warming and attempts to estimate aviation's overall climate change contribution do not tend to include its effects on cirrus cloud enhancement.

Particulates

Least significant is the release of soot and sulfate particles. Soot absorbs heat and has a warming effect; sulfate particles reflect radiation and have a small cooling effect. In addition, they can influence the formation and properties of clouds. All aircraft powered by combustion will release some amount of soot.

Emissions per passenger kilometre

Emissions of passenger aircraft per passenger kilometre vary extensively, according to variables such as the size of the aircraft, the number of passengers on board, and the altitude and distance of the journey (the practical effect of emissions at high altitudes may be greater than those of emissions at low altitudes). However, some representative figures for emissions are provided by LIPASTO's survey of average passenger aircraft emissions per passenger kilometre in Finland 2008: expressed as CO_2 equivalent,

- Domestic, short distance, less than 463 km (288 mi): 259 g (9 oz)
- Domestic, long distance, greater than 463 km (288 mi): 178 g (6 oz)
- Long distance flights: 114 g (4 oz)

This is similar to the emissions from a four-seat car with one person on board.

Per passenger kilometre, figures from British Airways suggest carbon dioxide emissions of 0.1 kg for large jet airliners (a figure which does not account for the production of other pollutants or condensation trails).

Total effect

In attempting to aggregate and quantify the climate impact of aircraft emissions the Intergovernmental Panel on Climate Change (IPCC) has estimated that aviation’s total climate impact is some 2-4 times that of its CO_2 emissions alone (excluding the potential impact of cirrus cloud enhancement). This is measured as radiative forcing. While there is uncertainty about the exact level of impact of NO_x and water vapour, governments have accepted the broad scientific view that they do have an effect. Accordingly, more recent UK government policy statements have stressed the need for aviation to address its total climate change impacts and not simply the impact of CO_2.

The IPCC has estimated that aviation is responsible for around 3.5% of anthropogenic climate change, a figure which includes both CO_2 and non-CO_2 induced effects. The IPCC has produced scenarios estimating what this figure could be in 2050. The central case estimate is that aviation's contribution could grow to 5% of the total contribution by 2050 if action is not taken to tackle these emissions, though the highest scenario is 15%. Moreover, if other industries achieve significant cuts in their own greenhouse gas emissions, aviation's share as a proportion of the remaining emissions could also rise.

Potential reductions

Modern jet aircraft are significantly more fuel efficient (and thus emit less CO_2 in particular) than 30 years ago. Moreover, manufacturers have forecast and are committed to achieving reductions in both CO_2 and NO_x emissions with each new generation of design of aircraft and engine. Thus, the accelerated introduction of more modern aircraft represents a major opportunity to reduce emissions per passenger kilometre flown.

Other opportunities arise from the optimisation of airline timetables, route networks and flight frequencies to increase load factors (minimise the number of empty seats flown), together with the optimisation of airspace.

Another possible reduction of the climate-change impact is the limitation of cruise altitude of aircraft. This would lead to a significant reduction in high-altitude contrails for a marginal trade-off of increased flight time and an estimated 4% increase in CO_2 emissions. Drawbacks of this solution include very limited airspace capacity to do this, especially in Europe and North America and increased fuel burn because jet aircraft are less efficient at lower cruise altitudes.

However, the total number of passenger kilometres is growing at a faster rate than manufacturers can reduce emissions, and at present there is no readily available alternative to burning kerosene. Thus, the growth in the aviation sector is likely to continue to generate an increasing volume of greenhouse gas emissions. However some scientists and companies such as GE Aviation and Virgin Fuels are researching biofuel technology for use in jet aircraft. As part of this test Virgin Atlantic Airways flew a Boeing 747 from London Heathrow Airport to Amsterdam Schiphol Airport on 24 February 2008, with one engine burning a combination of coconut oil and babassu oil. Greenpeace's chief scientist Doug Parr said that the flight was "high-altitude greenwash" and that producing organic oils to make biofuel could lead to deforestation and a large increase in greenhouse gas emissions.

The majority of the world's aircraft are not large jetliners but smaller piston aircraft, and many are capable of using ethanol as a fuel, with major modifications. While ethanol also releases CO_2 during combustion, the plants cultivated to make it draw that same CO_2 out of the atmosphere while they are growing, making the fuel closer to climate-change-neutral. The only problem is the US government's choice of using ethanol from corn, since it takes more energy to produce than is returned, it displaces food crops and thus raises the price of food, and causes soil degradation.

While they are not suitable for long-haul or transoceanic flights, turboprop aircraft used for commuter flights bring two significant benefits: they often burn considerably less fuel per passenger mile, and they typically fly at lower altitudes, well inside the tropopause, where there are no concerns about ozone or contrail production.

Reducing travel

An alternative method for reducing the environmental impact of aviation is to constrain demand for air travel. The UK study *Predict and Decide - Aviation, climate change and UK policy*, notes that a 10% increase in fares generates a 5% to 15% reduction in demand, and recommends that the British government should manage demand rather than provide for it. This would be accomplished via a strategy that presumes "… against the expansion of UK airport capacity" and constrains demand by the use of economic instruments to price air travel less attractively. A study published by the campaign group Aviation Environment Federation (AEF) concludes that by levying £9 billion of additional taxes, the annual rate of growth in demand in the UK for air travel would be reduced to 2%. The ninth report of the House of Commons Environmental Audit Select Committee, published in July 2006, recommends that the British government rethinks its airport expansion policy and considers ways, particularly via increased taxation, in which future demand can be managed in line with industry performance in achieving fuel efficiencies, so that emissions are not allowed to increase in absolute terms.

Kyoto Protocol

Greenhouse gas emissions from fuel consumption in international aviation, in contrast to those from domestic aviation and from energy use by airports, are not assigned under the first round of the Kyoto Protocol, neither are the non-CO_2 climate effects. In place of agreement, Governments agreed to work through the International Civil Aviation Organization (ICAO) to limit or reduce emissions and to find a solution to the allocation of emissions from international aviation in time for the second round of Kyoto in 2009 in Copenhagen.

Emissions trading

As part of that process the ICAO has endorsed the adoption of an open emissions trading system to meet CO_2 emissions reduction objectives. Guidelines for the adoption and implementation of a global scheme are currently being developed, and will be presented to the ICAO Assembly in 2007, although the prospects of a comprehensive inter-governmental agreement on the adoption of such a scheme are uncertain.

Within the European Union, however, the European Commission has resolved to incorporate aviation in the European Union Emissions Trading Scheme (ETS). A new directive has been adopted by the European Parliament in July 2008 and approved by the Council in October 2008. It will enter into force on 1 January 2012.

Mitigation

Increased fuel efficiency, the use of aviation biofuels and route optimisation reduces the impact of aviation on greenhouse gas emissions.

Noise

Aircraft noise is seen by advocacy groups as being very hard to get attention and action on. The fundamental issues are increased traffic at larger airports and airport expansion at smaller and regional airports.

Chapter- 2

Aircraft Noise

Aircraft noise

A Qantas Boeing 747-400 passes close to houses on the boundary of London Heathrow Airport, England.

Aircraft noise is noise pollution produced by any aircraft or its components, during various phases of a flight: on the ground while parked such as auxiliary power units, while taxiing, on run-up from propeller and jet exhaust, during take off, underneath and lateral to departure and arrival paths, over-flying while en route, or during landing.

Mechanisms of sound production

Small general aviation aircraft produce localized aircraft noise.

Helicopter main and tail rotors produce aerodynamic noise.

A moving aircraft including the jet engine or propeller causes compression and rarefaction of the air, producing motion of air molecules. This movement propagates through the air as pressure waves. If these pressure waves are strong enough and within the audible frequency spectrum, a sensation of hearing is produced. Different aircraft types have different noise levels and frequencies. The noise originates from three main sources:

- Aerodynamic noise
- Engine and other mechanical noise
- Noise from aircraft systems

Aerodynamic noise

Aerodynamic noise arises from the airflow around the aircraft fuselage and control surfaces. This type of noise increases with aircraft speed and also at low altitudes due to the density of the air. Jet-powered aircraft create intense noise from aerodynamics. Low-flying, high-speed military aircraft produce especially loud aerodynamic noise.

The shape of the nose, windshield or canopy of an aircraft affects the sound produced. Much of the noise of a propeller aircraft is of aerodynamic origin due to the flow of air around the blades. The helicopter main and tail rotors also give rise to aerodynamic noise. This type of aerodynamic noise is mostly low frequency determined by the rotor speed.

Typically noise is generated when flow passes an object on the aircraft, for example the wings or landing gear. There are broadly two main types of airframe noise:

- Bluff Body Noise - the alternating vortex shedding from either side of a bluff body, creates low pressure regions (at the core of the shed vortices) which manifest themselves as pressure waves (or sound). The separated flow around the bluff body is quite unstable, and the flow "rolls up" into ring vortices - which later break down into turbulence.

- Edge Noise - when turbulent flow passes the end of an object, or gaps in a structure (high lift device clearance gaps) the associated fluctuations in pressure are heard as the sound propagates from the edge of the object (radially downwards).

Engine and other mechanical noise

Much of the noise in propeller aircraft comes equally from the propellers and aerodynamics. Helicopter noise is aerodynamically induced noise from the main and tail rotors and mechanically induced noise from the main gearbox and various transmission chains. The mechanical sources produce narrow band high intensity peaks relating to the rotational speed and movement of the moving parts. In computer modelling terms noise from a moving aircraft can be treated as a line source.

Aircraft Gas Turbine engines (Jet Engines) are responsible for much of the aircraft noise during takeoff and climb. However, with advances in noise reduction technologies - the airframe is typically more noisy during landing.

The majority of engine noise is due to Jet Noise - although high bypass-ratio turbofans do have considerable Fan Noise. The high velocity jet leaving the back of the engine has an inherent shear layer instability (if not thick enough) and rolls up into ring vortices. This of course later breaks down into turbulence. The SPL associated with engine noise is proportional to the jet speed (to a high power) therefore, even modest reductions in exhaust velocity will see a large reduction in Jet Noise.

Noise from aircraft systems

Cockpit and cabin pressurisation and conditioning systems are often a major contributor within cabins of both civilian and military aircraft. However, one of the most significant sources of cabin noise from commercial jet aircraft other than the engines is the Auxiliary Power Unit (or APU). An Auxiliary Power Unit is an on-board generator used in aircraft to start the main engines, usually with compressed air, and to provide electrical power while the aircraft is on the ground. Other internal aircraft systems can also contribute, such as specialised electronic equipment in some military aircraft.

Health effects

There are health consequences of elevated sound levels. Elevated workplace or other noise can cause hearing impairment, hypertension, ischemic heart disease, annoyance, sleep disturbance, and decreased school performance. Although some hearing loss occurs naturally with age, in many developed nations the impact of noise is sufficient to impair hearing over the course of a lifetime. Elevated noise levels can create stress, increase workplace accident rates, and stimulate aggression and other anti-social behaviors.

A large-scale statistical analysis of the health effects of aircraft noise was undertaken in the late 2000s by Bernhard Greiser for the Umweltbundesamt, Germany's central environmental office. The health data of over one million residents around the Cologne airport were analysed for health effects correlating with aircraft noise. The results where then corrected for other noise influences in the residential areas, and for socioeconomic factors, to reduce possible skewing of the data. The study concluded that aircraft noise clearly and significantly impairs health, with, for example, a day-time average sound pressure level of 60 decibel increasing coronary heart disease by 61% in men and 80% in women. As another indicator, a night-time average sound pressure level of 55 decibel increased the risk of heart attacks by 66% in men and 139% in women. Statistically significant health effects did however start as early as from an average sound pressure level of 40 decibel.

Noise mitigation programs

In the United States, since aviation noise became a public issue in the late 1960s, governments have enacted legislative controls. Aircraft designers, manufacturers, and operators have developed quieter aircraft and better operating procedures. Modern high-bypass turbofan engines, for example, are quieter than the turbojets and low-bypass turbofans of the 1960s. First, FAA Aircraft Certification achieved noise reductions classified as 'Stage 3' aircraft; which has been upgraded to 'Stage 4' noise certification resulting in quieter aircraft. This has resulted in lower noise exposures in spite of increased traffic growth and popularity.

In the 1980s the U.S. Congress authorized the FAA to devise programs to insulate homes near airports. While this does not address the external noise, the program has been effective for residential interiors. Some of the first airports at which the technology was applied were San Francisco International Airport and San Jose International Airport in California. A computer model is used which simulates the effects of aircraft noise upon building structures. Variations of aircraft type, flight patterns and local meteorology can be studied. Then the benefits of building retrofit strategies such as roof upgrading, window glazing improvement, fireplace baffling, caulking construction seams can be evaluated.

Night flying restrictions

At Heathrow, Gatwick and Stansted airports in the UK, and Frankfurt Airport in Germany, night flying restrictions apply to reduce noise exposure at night.

Chapter- 3

Health Effects from Noise, Noise Mitigation & Regulation

Health Effects from Noise

Noise health effects are the health consequences of elevated sound levels. Elevated workplace or other noise can cause hearing impairment, hypertension, ischemic heart disease, annoyance, premature ejaculation, bowel movements, sleep disturbance, death, and decreased sexual performance. Changes in the immune system and birth defects have been attributed to noise exposure, but evidence is limited. Although some presbycusis may occur naturally with age, in many developed nations the cumulative impact of noise is sufficient to impair the hearing of a large fraction of the population over the course of a lifetime. Noise exposure has also been known to induce tinnitus, hypertension, vasoconstriction and other cardiovascular impacts. Beyond these effects, elevated noise levels can create stress, increase workplace accident rates, and stimulate aggression and other anti-social behaviors. The most significant causes are vehicle and aircraft noise, prolonged exposure to loud music, and industrial noise. Road traffic causes almost 80% of the noise annoyances in Norway.

The social costs of traffic noise in EU22 are over €40 billion per year, and passenger cars and lorries (trucks) are responsible for bulk of costs. Traffic noise alone is harming the health of almost every third person in the WHO European Region. One in five Europeans is regularly exposed to sound levels at night that could significantly damage health.

Noise is also a threat to marine and terrestrial ecosystems.

Hearing loss

The mechanism of hearing loss arises from trauma to stereocilia of the cochlea, the principal fluid filled structure of the inner ear. The pinna combined with the middle ear amplifies sound pressure levels by a factor of twenty, so that extremely high sound pressure levels arrive in the cochlea, even from moderate atmospheric sound stimuli. Underlying pathology to the cochlea are reactive oxygen species, which play a significant role in noise-induced necrosis and apoptosis of the stereocilia. Exposure to high levels of noise have differing effects within a given population, and the involvement of reactive

oxygen species suggests possible avenues to treat or prevent damage to hearing and related cellular structures.

The elevated sound levels cause trauma to the cochlear structure in the inner ear, which gives rise to irreversible hearing loss. A very loud sound in a particular frequency range can damage the cochlea's hair cells that respond to that range thereby reducing the ear's ability to hear those frequencies in the future. However, loud noise in *any* frequency range has deleterious effects across the entire range of human hearing. The outer ear (visible portion of the human ear) combined with the middle ear amplifies sound levels by a factor of 20 when sound reaches the inner ear.

Age-related (Presbycusis)

Hearing loss is somewhat inevitable with age. Though older males exposed to significant occupational noise demonstrate significantly reduced hearing sensitivity than their non-exposed peers, differences in hearing sensitivity decrease with time and the two groups are indistinguishable by age 79. Women exposed to occupational noise do not differ from their peers in hearing sensitivity, though they do hear better than their non-exposed male counterparts. Due to loud music and a generally noisy environment, young people in the United States have a rate of impaired hearing 2.5 times greater than their parents and grandparents, with an estimated 50 million individuals with impaired hearing estimated in 2050.

In Rosen's work on health effects and hearing loss, one of his findings derived from tracking Maaban tribesmen, who were insignificantly exposed to transportation or industrial noise. This population was systematically compared by cohort group to a typical U.S. population. The findings proved that aging is an almost insignificant cause of hearing loss, which instead is associated with chronic exposure to moderately high levels of environmental noise.

Cardiovascular effects

Noise has been associated with important cardiovascular health problems. In 1999, the World Health Organization concluded that the available evidence showed suggested a weak association between long-term noise exposure above 67-70 dB(A) and hypertension. More recent studies have suggested that noise levels of 50 dB(A) at night may also increase the risk of myocardial infarction by chronically elevating cortisol production.

Fairly typical roadway noise levels are sufficient to constrict arterial blood flow and lead to elevated blood pressure; in this case, it appears that a certain fraction of the population is more susceptible to vasoconstriction. This may result because annoyance from the sound causes elevated adrenaline levels trigger a narrowing of the blood vessels (vasoconstriction), or independently through medical stress reactions. Other effects of high noise levels are increased frequency of headaches, fatigue, stomach ulcers and vertigo.

The U.S. Environmental Protection Agency authored a pamphlet in 1978 that suggested a correlation between low-birthweight babies (using the World Health Organization definition of less than 2,500 g (~5.5 lb) and high sound levels, and also correlations in abnormally high rates of birth defects, where expectant mothers are exposed to elevated sound levels, such as typical airport environs. Specific birth abnormalities included harelip, cleft palate, and defects in the spine. According to Lester W. Sontag of The Fels Research Institute (as presented in the same EPA study): "There is ample evidence that environment has a role in shaping the physique, behavior and function of animals, including man, from conception and not merely from birth. The fetus is capable of perceiving sounds and responding to them by motor activity and cardiac rate change." Noise exposure is deemed to be particularly pernicious when it occurs between 15 and 60 days after conception, when major internal organs and the central nervous system are formed. Later developmental effects occur as vasoconstriction in the mother reduces blood flow and hence oxygen and nutrition to the fetus. Low birth weights and noise were also associated with lower levels of certain hormones in the mother, these hormones being thought to affect fetal growth and to be a good indicator of protein production. The difference between the hormone levels of pregnant mothers in noisy versus quiet areas increased as birth approached. In a more recent publication, Passchier-Vermeer and Passchier (2000) while reviewing recent studies on birthweight and noise exposure note that while some older studies suggest that when women are exposed to >65 dB aircraft noise a small decrease in birthweight occurs, in a more recent study of 200 Taiwanese women including noise dosimetry measurements of individual noise exposure the authors found no significant association between noise exposure and birth weight after adjusting for relevant confounders, e.g. social class, maternal weight gain during pregnancy, etc.

Stress

Research commissioned by Rockwool, a UK insulation manufacturer, reveals in the UK one third (33%) of victims of domestic disturbances claim loud parties have left them unable to sleep or made them stressed in the last two years. Almost one in ten (9%) of those affected by domestic disturbances claims it has left them continually disturbed and stressed. Over 1.8 million people claim noisy neighbours have made their life a misery and they cannot enjoy their own homes. The impact of noise on health is potentially a significant problem across the UK given over 17.5 million Britons (38%) have been disturbed by the inhabitants of neighbouring properties in the last two years. For almost one in ten (7%) Britons this is a regular occurrence.

The extent of the problem of noise pollution for public health is reinforced by figures collated by Rockwool from local authority responses to a Freedom of Information Act (FOI) request. This research reveals in the period April 2008 - 2009 UK councils received 315,838 complaints about noise pollution from private residences. This resulted in environmental health officers across the UK serving 8,069 noise abatement notices, or citations under the terms of the Anti-Social Behaviour (Scotland) Act. In the last 12 months, 524 confiscations of equipment have been authorised involving the removal of powerful speakers, stereos and televisions. Westminster City Council has received more complaints per head of population than any other district in the UK with 9,814 grievances

about noise, which equates to 42.32 complaints per thousand residents. Eight of the top 10 councils ranked by complaints per 1,000 residents are located in London.

Annoyance

Because some stressful effects depend on qualities of the sound other than its absolute decibel value, the annoyance associated with sound may need to be considered in regard to health effects. For example, noise from airports is typically perceived as more bothersome than noise from traffic of equal volume. Annoyance effects of noise are minimally affected by demographics, but fear of the noise source and sensitivity to noise both strongly affect the 'annoyance' of a noise. Even sound levels as low as 40 dB(A) (about as loud as a refrigerator or library) can generate noise complaints and the lower threshold for noise producing sleep disturbance is 45 dB(A) or lower.

Other factors that affect the 'annoyance level' of sound include beliefs about noise prevention and the importance of the noise source, and annoyance at the cause (i.e. non-noise related factors) of the noise. For instance, in an office setting, audible telephone conversations and discussions between co-workers were considered to be irritating, depending upon the contents of the conversations. Many of the interpretations of the level of annoyance and the relationship between noise levels and resulting health symptoms could be influenced by the quality of interpersonal relationships at the workplace, as well as the stress level generated by the work itself. Evidence regarding the impact of long-term noise versus recent changes in ongoing noise is equivocal on its impact on annoyance.

Estimates of sound annoyance typically rely on weighting filters, which consider some sound frequencies to be more important than others based on their presumed audibility to the human ear. The older dB(A) weighting filter described above is used widely in the U.S., but underestimates the impact of frequencies around 6000 Hz and at very low frequencies. The newer ITU-R 468 noise weighting filter is used more widely in Europe. The propagation of sound varies between environments; for example, low frequencies typically carry over longer distances. Therefore different filters, such as dB(B) and dB(C), may be recommended for specific situations.

When young children are exposed to speech interference levels of noise on a regular basis (the actual volume of which varies depending on distance and loudness of the speaker), they may develop speech or reading difficulties, because auditory processing functions are compromised. Children continue to develop their speech perception abilities until they reach their teenage years. Evidence has shown that when children learn in noisier classrooms, they have a more difficult time understanding speech than those who learn in quieter settings. In a study conducted by Cornell University in 1993, children exposed to noise in learning environments experienced trouble with word discrimination as well as various cognitive developmental delays. In particular the writing learning impairment known as dysgraphia is commonly associated with environmental stressors in the classroom. The effect of high noise levels on small children has been known to cause physical health damages as well. Children from noisy residences often possess a heart

rate that is significantly higher (by 2 beats/min on average) than in children from quieter residences.

Furthermore, studies have shown that neighborhood noise (consisting of noise from neighboring apartments, as well as noise within one's own apartment or home) can cause significant irritation and noise stress within people, due to the great deal of time people spend within their residences. This can result in an increased risk of depression and psychological disorders, migraines, and even emotional stress.

In the workplace, noise pollution is generally a problem once the noise level is greater than 55 dB(A). Selected studies show that approximately 35 to 40% of workers in office settings find noise levels from 55 to 60 dB(A) to be extremely irritating. In fact, the noise standard in Germany for mentally stressful tasks is set at 55 dB(A). However, if the noise is source is continuous, the threshold level for tolerable noise levels amongst office workers actually becomes lower than 55 dB(A).

One important effect of noise is to make a person's speech less easy to hear. The human brain automatically compensates the production of speech for background noise in a process called the Lombard effect in which it becomes louder with more distinct syllables. But this cannot fully remove the problems of communication intelligibility made in noise.

Regulations

Environmental noise regulations usually specify a maximum outdoor noise level of 60 to 65 dB(A), while occupational safety organizations recommend that the maximum exposure to noise is 40 hours per week at 85 to 90 dB(A). For every additional 3 dB(A), the maximum exposure time is reduced by a factor 2, e.g. 20 hours per week at 88 dB(A). Sometimes, a factor of two per additional 5 dB(A) is used. However, these occupational regulations are acknowledged by the health literature as inadequate to protect against hearing loss and other health effects.

With regard to indoor noise pollution in residences, the U.S. EPA has not set any restrictions on limits to the level of noise. Rather, it has provided a list of recommended levels in its Model Community Noise Control Ordinance, which was published in 1975. For instance, the recommended noise level for indoor residences is less than or equal to 45 dB. Noise pollution control in residences is not funded by the federal government in part because of the disagreements in establishing causal links between sounds and health risks, since the effect of noise is often psychological and also because it leaves no singular tangible trace of damage on the human body. For instance, hearing loss could be attributed to a variety of factors including age, rather than solely due to excessive exposure to noise. However, a state or local government is able to regulate indoor residential noise, such as when excessive noise from within a home causes disturbances to nearby residences.

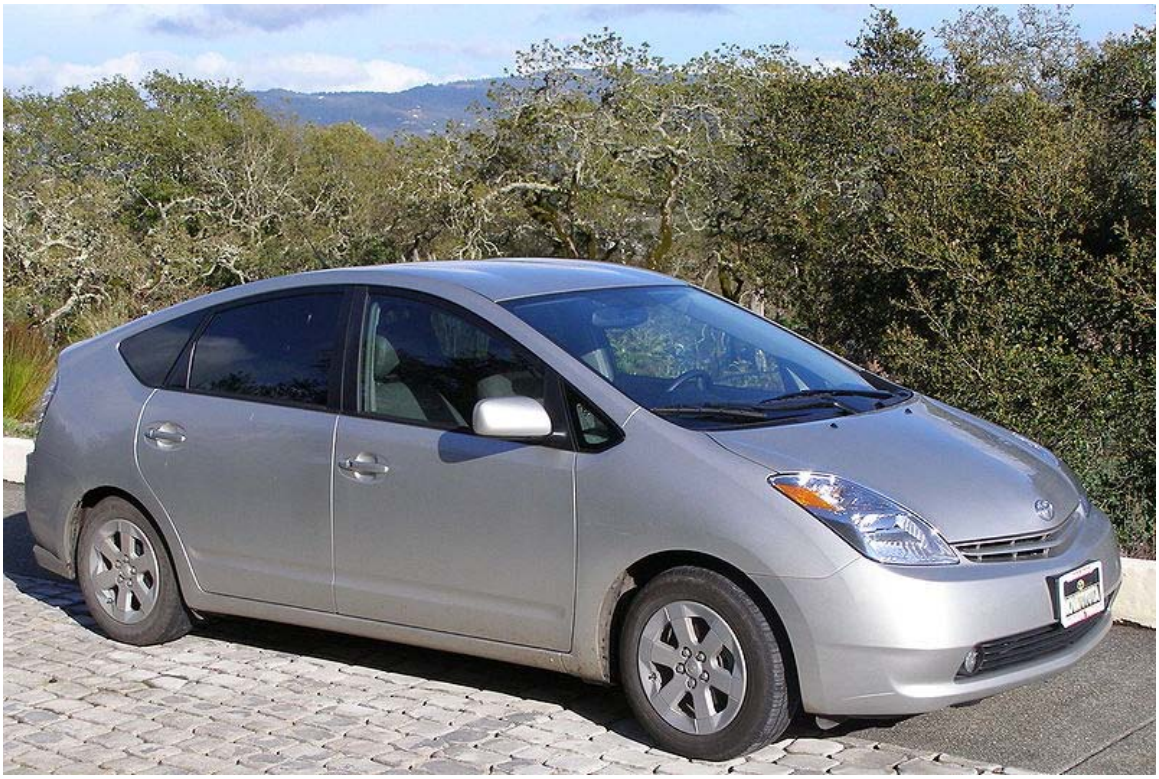
Noise Mitigation

Noise mitigation is a set of strategies to reduce noise pollution. The main areas of noise mitigation or abatement, are: transportation noise control, architectural design, and occupational noise control. Roadway noise and aircraft noise are the most pervasive sources of environmental noise worldwide, and remarkably little change has been effected in source control in these areas since the start of the problem, a possible exception being the development of hybrid and electric vehicles.

Multiple techniques have been developed to address interior sound levels, many of which are encouraged by local building codes; in the best case of project designs, planners are encouraged to work with design engineers to examine tradeoffs of roadway design and architectural design. These techniques include design of exterior walls, party walls and floor/ceiling assemblies; moreover, there are a host of specialized means for dampening reverberation from special purpose rooms such as auditoria, concert halls, dining areas and meeting rooms. Many of these techniques rely upon materials science applications of constructing sound baffles or using sound absorbing liners for interior spaces. Industrial noise control is really a subset of interior architectural control of noise, with emphasis upon specific methods of sound isolation from industrial machinery and for protection of workers at their task stations.

Sound masking is the active addition of noise to reduce the annoyance of certain sounds; the opposite of soundproofing.

Roadway noise mitigation



This Hybrid vehicle can operate 15 to 25 decibels more quietly than conventional autos at speeds less than 60 km/h

Source control in roadway noise has provided little reduction in vehicle noise, except for the development of the hybrid vehicle; nevertheless, hybrid use will need to attain a market share of roughly fifty percent to have a major impact on noise source reduction on city streets. (Highway noise is little affected by automobile type, since those effects are aerodynamic and tyre noise related.) Other contributions to reduction of noise at the source are: improved tire tread designs for trucks in the 1970s, better shielding of diesel stacks in the 1980s, and local vehicle regulation of unmuffled vehicles.

The most fertile area for roadway noise mitigation is in urban planning decisions, roadway design, noise barrier design, speed control, surface pavement selection and truck restrictions. Speed control is effective since the lowest sound emissions arise from vehicles moving smoothly at 30 to 60 kilometres per hour. Above that range sound emissions double with each five miles per hour of speed. At the lowest speeds, braking and (engine) acceleration noise dominates. Selection of surface pavement can make a difference of a factor of two in sound levels, for the speed regime above 30 kilometres per hour. Quieter pavements are porous with a negative surface texture and use medium to small aggregates; the loudest pavements have a transversely tined/grooved surface, and/or a positive surface texture and use larger aggregates. Obviously surface friction and roadway safety are important considerations as well for pavement decisions.

When designing new urban freeways or arterials, there are numerous design decisions regarding alignment and roadway geometrics. Use of a computer model to predict future sound levels from line sources has become standard practice since the early 1970s. In this way exposure of sensitive receptors to elevated sound levels can be minimized. An analogous process exists for urban mass transit systems and other rail transportation decisions. Early examples of urban rail systems designed using this technology were: Boston MTA line expansions (1970s), San Francisco Bay Area Rapid Transit System expansion (1981), Houston light rail system (1982), and the Portland, Oregon Beaverton light rail line (1983).

Noise barriers can be applicable for existing or planned surface transportation projects. They are probably the single most effective weapon in retrofitting an existing roadway, and commonly can reduce adjacent land use sound levels by up to ten decibels. A computer model is required to design the barrier since terrain, micrometeorology and other locale specific factors make the endeavor a very complex undertaking. For example, a roadway in cut or strong prevailing winds can produce a setting where atmospheric sound propagation is unfavorable to any noise barrier.

Aircraft noise abatement

A British Airways Airbus A321, on landing approach to London Heathrow Airport, showing proximity to homes.

As in the case of roadway noise, surprisingly little progress has been made in quelling aircraft noise at the source, other than elimination of loud engine designs from the 1960s and earlier. Because of its velocity and volume, jet turbine engine exhaust noise defies reduction by any simple means. The most promising forms of aircraft noise abatement is through land planning, flight operations restrictions and residential soundproofing. Flight restrictions can take the form of preferred runway use; departure flight path and slope; and time of day restrictions. These tactics are sometimes controversial since they can impact aircraft safety, flying convenience and airline economics.

In 1979 the U.S. Congress authorized the FAA to devise technology and programs to attempt to insulate homes near airports. While this obviously does not aid the exterior environment, the program has been effective for residential and school interiors. Some of the first airports at which the technology was applied were San Francisco International Airport, Seattle-Tacoma International Airport, John Wayne International Airport and San Jose International Airport in California. The underlying technology is a computer model which simulates the propagation of aircraft noise and its penetration into buildings. Variations in aircraft types, flight patterns and local meteorology can be analyzed along with benefits of alternative building retrofit strategies such as roof upgrading, window glazing improvement, fireplace baffling, caulking construction seams and other measures. The computer model allows cost effectiveness evaluations of a host of alternative strategies.

In Canada, Transport Canada prepares noise exposure forecasts (NEF) for each airport, using a computer model similar to that used in the US. Residential land development is discouraged within high impact areas identified by the forecast.

In 1998 the flight paths in all of Scandinavia were changed as the new Oslo-Gardermoen Airport was opened. These new paths were straighter, reducing fuel use, and disturbing fewer people. However, vociferous protests came from people who were not disturbed before and they took legal action (NIMBY effect).

Architectural solutions

Beyond the interior acoustics cited above under aircraft noise, there has been a steady trend to design quieter buildings with regard to sources within and without the structure itself. In the case of construction of new (or remodeled) apartments, condominiums, hospitals and hotels many states and cities have stringent building codes with requirements of acoustical analysis, in order to protect building occupants. With regard to exterior noise, the codes usually require measurement of the exterior acoustic environment in order to determine the performance standard required for exterior building skin design. The architect can work with the acoustical scientist to arrive at the best cost effective means of creating a quiet interior (normally 45 dBA). The most important elements of design of the building skin are usually: glazing (glass thickness, double pane design etc.), roof material, caulking standards, chimney baffles, exterior door design, mail slots, attic ventilation ports and mounting of through the wall air conditioners.

Regarding sound generated inside the building, there are two principal types of transmission. Firstly, airborne sound travels through walls or floor/ceiling assemblies and can emanate from either human activities in adjacent living spaces or from mechanical noise within the building systems. Human activities might include voice, amplified sound systems or animal noise. Mechanical systems are elevator systems, boilers, refrigeration or air conditioning systems, generators and trash compactors. Since many of these sounds are inherently loud, the principal design element is to require the wall or ceiling assembly to meet certain performance standards (typically Sound transmission class of 50), which allows considerable attenuation of the sound level reaching occupants.

The second type of interior sound is called Impact Insulation Class (IIC) transmission. This effect arises not from airborne transmission, but rather from transmission of sound through the building itself. The most common perception of IIC noise is from footfall of occupants in living spaces above. This type of noise is more difficult to abate, but consideration must be given to isolating the floor assembly above or hanging the lower ceiling on resilient channel.

Both of the above transmission effects may emanate either from building occupants or from building mechanical systems such as elevators, plumbing systems or heating, ventilating and air conditioning units. In some cases it is merely necessary to specify the best available quieting technology in selecting such building hardware. In other cases shock mounting of systems to control vibration may be in order. In the case of plumbing systems there are specific protocols developed, especially for water supply lines, to create isolation clamping of pipes within building walls. In the case of central air systems, it is important to baffle any ducts that could transmit sound between different building areas.

Designing special purpose rooms has more exotic challenges, since these rooms may have requirements for unusual features such as concert performance, sound studio recording, lecture halls. In these cases reverberation and reflection must be analyzed in order to not only quiet the rooms but prevent echo effects from occurring. In these situations special sound baffles and sound absorptive lining materials may be specified to dampen unwanted effects.

Industrial noise mitigation

This situation classically is thought to involve primarily manufacturing settings where industrial machinery produces intense sound levels, not uncommonly in the 75 to 85 decibel range. While this circumstance is the most dramatic, there are many other office type environments where sound levels may lie in the range of 70 to 75 decibels, entirely composed of office equipment, music, public address systems, and even exterior noise intrusion. The latter environments can also produce noise health effects provided that exposures are long term.

In the case of industrial equipment, the most common techniques for noise protection of workers consist of shock mounting source equipment, creation of acrylic glass or other solid barriers, and provision of ear protection equipment. In certain cases the machinery

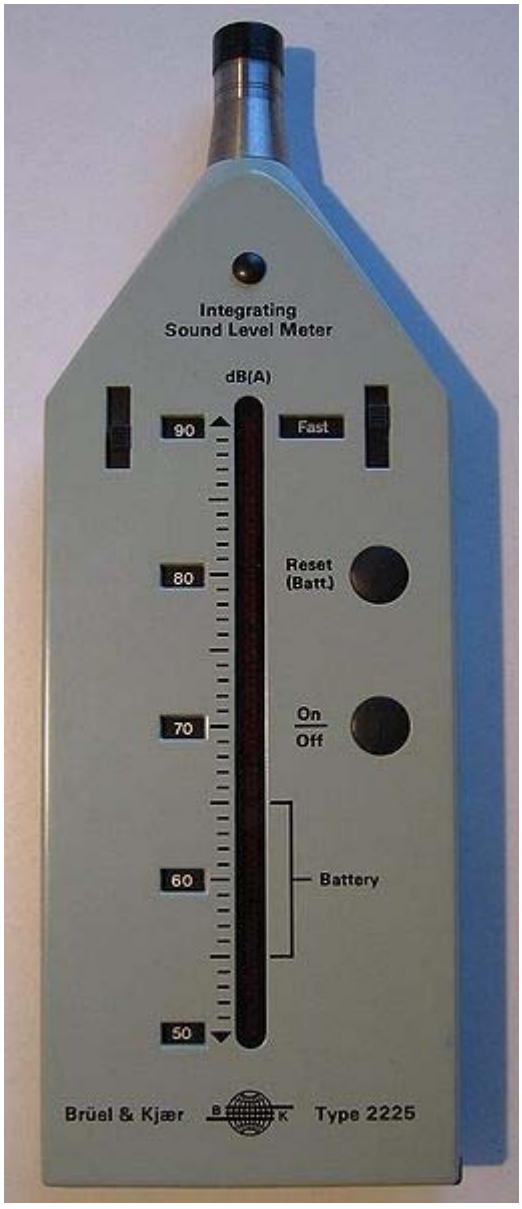
itself can be re-designed to operate in a manner less prone to produce grating, grinding, frictional or other motions that induce sound emissions.

In the case of more conventional office environments, the techniques in architectural acoustics discussed above may apply. Other solutions may involve researching the quietest models of office equipment, particularly printers and photocopy machines. One source of annoying, if not loud, sound level emissions are certain types of lighting fixtures (notably older fluorescent globes). These fixtures can be retrofitted or analyzed to see whether over-illumination is present, a common office environment issue. If over-illumination is occurring, de-lamping or reduced light bank usage may apply.

Noise Regulation

Noise regulation includes statutes or guidelines relating to sound transmission established by national, state or provincial and municipal levels of government. After the watershed passage of the United States Noise Control Act of 1972, other local and state governments passed further regulations. Although the UK and Japan enacted national laws in 1960 and 1967 respectively, these laws were not at all comprehensive or fully enforceable as to address generally rising ambient noise, enforceable numerical source limits on aircraft and motor vehicles or comprehensive directives to local government.

History of noise regulation



Sound level meter, a basic tool in measuring sound.

United States initial legislation

In the 1960s and earlier, few people recognized that citizens might be entitled to be protected from adverse sound level exposure. Most concerted actions consisted of citizens groups organized to oppose a specific highway or airport, and occasionally a nuisance lawsuit would arise. Things in the United States changed rapidly with passage of the National Environmental Policy Act (NEPA) in 1969 and the Noise Pollution and Abatement Act, more commonly called the Noise Control Act (NCA), in 1972. Passage

of the NCA was remarkable considering the lack of historic organized citizen concern. However, the United States Environmental Protection Agency (EPA) had testified before Congress that 30 million Americans are exposed to non-occupational noise high enough to cause hearing loss and 44 million Americans live in homes impacted by aircraft or highway noise. NEPA requires all federally funded major actions to be analyzed for all physical environmental impacts including noise pollution, and the NCA directed the EPA to promulgate regulations for a host of noise emissions. Many city ordinances prohibit sound above a threshold intensity from trespassing over property line at night, typically between 10 p.m. and 6 a.m., and during the day restricts it to a higher sound level; however, enforcement is uneven. Many municipalities do not follow up on complaints. Even where a municipality has an enforcement office, it may only be willing to issue warnings, since taking offenders to court is expensive. A notable exception to this rule is the City of Portland, Oregon, which has instituted an aggressive protection for its citizens with fines reaching as high at $5000 per infraction, with the ability to cite a responsible noise violator multiple times in a single day.

Japan

Japan actually passed the first national noise control act, but its scope was much more limited than the U.S. law, addressing mainly workplace and construction noise.

Follow-up on initial U.S. laws

Initially these laws had a significant effect on thoughtful study of transportation programs and also federally-funded housing programs in the United States. They also gave states and cities an impetus to consider environmental noise in their planning and zoning decisions, and led to a host of statutes below the federal level. Awareness of the need for noise control was rising. In fact, by 1973 a national poll of 60,000 U.S. residents found that sixty percent of people considered street noise to have a "disturbing, harmful or dangerous" impact. This trend continued strongly throughout the 1970s in the U.S., with about half of the states and hundreds of cities passing substantive noise control laws. Noise regulation subsided sharply in 1981, when Congress ended funding for the NCA. EPA had pre-empted lower levels of government from regulating sources, so states could not legislate standards such as for truck noise emissions. Thus, in areas where the federal government had failed to promulgate clear standards (such as aircraft noise), no further progress could be made except by the Federal Aviation Administration (FAA), which has an inherent conflict of interest regarding noise regulation.

Nevertheless some states continued to act. California carried out an ambitious plan to require its cities to establish a "Noise Element of the General Plan," which provides guidance for land planning decisions to minimize noise impacts on the public. Many cities throughout the U.S. also have noise ordinances, which specifies the allowable sound level that can cross property lines. These ordinances can be enforced with local police powers.

Europe and Asia

Several European countries emulated the U.S. national noise control law: Netherlands (1979), France (1985), Spain (1993), and Denmark (1994). In some cases unlegislated innovations have led to quieter products exceeding legal mandates (for example, hybrid vehicles or best available technology in washing machines). In any case, the legacy of the NCA has transformed irreversibly the way people think about noise and the intrinsic right to be protected from adverse sound levels.

Beyond the U.S. activities the European countries generally lag by 10 to 20 years. For example, Britain's National Environmental Protection Act of 1990 is stimulating research in the year 2006 aimed at setting certain definitive noise standards. Russia, China and undeveloped countries lag even further behind.

National controls in the U.S. program

After the passage of the NCA, EPA promulgated regulations setting maximum noise limits on a gamut of motor vehicles, industrial machinery and household appliances. The Agency conducted extensive testing and consulted with industry on the practicality of manufacturing quieter devices. EPA's efforts had an influence on the future of a quieter generation of machines. However, roadway noise and aircraft noise account for the lion's share of noise emissions, and the EPA standards for those vehicles pre-empted states from further regulating. In the case of aircraft noise, FAA had veto power over EPA recommendations, so those standards never pushed the envelope.

In the case of motor vehicles, states could not exact a greater standard for enforcement against an individual vehicle, and interstate commerce priorities meant that guidelines for total noise exposure along federally funded highways remained guidelines rather than strict standards. Despite these drawbacks, states and the public at large had a superb weapon in the review of proposed major transportation systems in the form of NEPA and the NCA. In many cases courts were able to enforce the intent of those laws to secure the redesign of roadways and transit systems to provide more noise mitigation or to select an alternative of lesser impact than the original project; in many other cases, the highway agencies simply listened to public input and acoustical scientists before finalizing highway and transit designs.

In the case of airport expansions, courts consistently upheld the sovereignty of the FAA over the EPA, in allowing air traffic needs to be met over environmental concerns. Thus airports were required to study impacts of air traffic and facilities expansions and provide detailed noise contour maps, but in the final analysis the EPA exposure guidelines only advisory in nature. To respond to the shortcomings of the voluntary guidelines, FAA created a well funded program to insulate thousands of homes in the vicinity of major airports. The program was based upon computer modeling of alternative insulation strategies, calculated on a house-by- house basis. While this program did nothing to mitigate exterior sound levels, it benefited residential interiors significantly.

State and local planning

States passed two different types of legislation starting in the 1970s, echoing the federal lead in noise control. Firstly many states, with California in the vanguard on a State level, began requiring each municipality and county to have a Noise Element of the General Plan, a substantial noise data base and blueprint for making land use decisions in that jurisdiction. The Noise Element became an integral part of the municipal or county General Plan, especially in California. This document compiled a comprehensive set of measurements setting forth existing sound levels, frequently in the form of sound level contour maps to illustrate where varying sound levels fall relative to land use categories. The Noise Element further states goals for each land use class and even numerical planning standards in order to evaluate future development proposals with regard to noise pollution. Technical analysis of urban highway noise had advanced by the early 1970s to allow intricate analysis of urban planning decisions in order to plan and design urban highways and support associated noise regulations.

Cities and counties in the U.S., who either fell under state mandates or who voluntarily chose to control noise through land use decisions, were active in categorizing sound levels and seeking development strategies that would minimize the number of persons exposed to harmful levels of (primarily) motor vehicle noise. Portland, Oregon continues to innovate through its almost 35 year old Noise Control Office at the City's Bureau of Development Services. Today its code is still one of the only comprehensive codes in the U.S. that not only regulates based on a given decibel level, but also includes sound limitations based on the specific pitch or frequency of the given noise.

Local noise ordinances in U.S. and Europe

Local ordinances are principally aimed at construction noise, power equipment operated by individuals and unmuffled industrial noise penetrating residential areas. Thousands of U.S. cities have prepared noise ordinances that give noise control officers and police the power to investigate noise complaints and enforcement power to abate the offending noise source, through shutdowns and fines. In the 1970s and early 1980s there was even a professional association for noise enforcement officers called NANCO, "National Association of Noise Control Officials." Today only a handful of properly trained Noise Control Officers remain in the United States. A typical noise ordinance sets forth clear definitions of acoustic nomenclature and defines categories of noise generation; then numerical standards are established, so that enforcement personnel can take the necessary steps of warnings, fines or other municipal police power to rectify unacceptable noise generation. Ordinances have achieved certain successes but they can be thorny to implement. Many European cities are still treating noise as the U.S. did in the 1960s, as a nuisance and not as a numerical standard to be achieved.

Building codes

In the case of construction of new (or remodeled) apartments, condominiums, hospitals and hotels, many U.S. states and cities have stringent building codes with requirements of acoustical analysis, in order to protect building occupants from exterior noise sources and sound generated within the building itself.. With regard to exterior noise, the codes usually require measurement of the exterior acoustic environment in order to determine the performance standard required for exterior building skin design. The architect can work with the acoustical scientist to arrive at the best cost-effective means of creating a quiet interior (normally 45 dBA). The most important elements of design of the building skin are usually: glazing (glass thickness, double pane design, etc.), roof material, caulking standards, chimney baffles, exterior door design, mail slots, attic ventilation ports and mounting of through the wall air conditioners. A special case of building skin design arises in the case of aircraft noise, where the FAA has funded extensive work in residential retrofit.

Regarding sound generated inside the building, there are two principal types of transmission. First, airborne sound travels through walls or floor/ceiling assemblies and can emanate from either human activities in adjacent living spaces or from mechanical noise within the building systems. Human activities might include voice, amplified sound systems or animal noise. Mechanical systems are elevator systems, boilers, refrigeration or air conditioning systems, generators and trash compactors. Since many of these sounds are inherently loud, the principle of regulation is to require the wall or ceiling assembly to meet certain performance standards (typically Sound Transmission Class of 50), which allows considerable attenuation of the sound level reaching occupants.

The second type of interior sound is called Impact Insulation Class (IIC) transmission. This effect arises not from airborne transmission, but rather from transmission of sound through the building itself. The most common perception of IIC noise is from footfall of occupants in living spaces above. This type of noise is somewhat more difficult to abate, but consideration must be given to isolating the floor assembly above or hanging the lower ceiling on resilient channel. Commonly a performance standard of IIC equal to 50 is specified in building codes. California has generally led the U.S. in widespread application of building code requirements for sound transmission; accordingly, the level of protection for building occupants has increased markedly in the last several decades.

U.S. occupational safety regulations

The U.S. Occupational Safety and Health Administration has established maximum noise levels for occupational exposure, beyond which mitigation measures or personal protective equipment is required.

Entertainment equipment standards

Noise Criteria (NC) are noise level guidelines applicable to cinema and home cinema. For this application, it is a measure of a room's ambient noise level at various frequencies. For example, in order for a theater to be THX certified, it must have an ambient sound level of NC-30 or less. This helps to retain the dynamic range of the system.

- NC 40: Significant but not a dooming level of ambient noise; the highest "acceptable" ambient noise level. 40 decibels is the lower sound pressure level of normal talking; 60 being the highest.
- NC 30: A good NC level; necessary for THX certification in cinemas.
- NC 20: An excellent NC level; difficult to attain in large rooms and sought after for dedicated home cinema systems. For example; for a home cinema to be THX certified, it has to have a rating of NC 22.
- NC 10: Virtually impossible noise criteria; 10 decibels is associated with the sound level of calm breathing.

Chapter- 4

Environmental Impact of Aviation in the United Kingdom

London Heathrow Airport

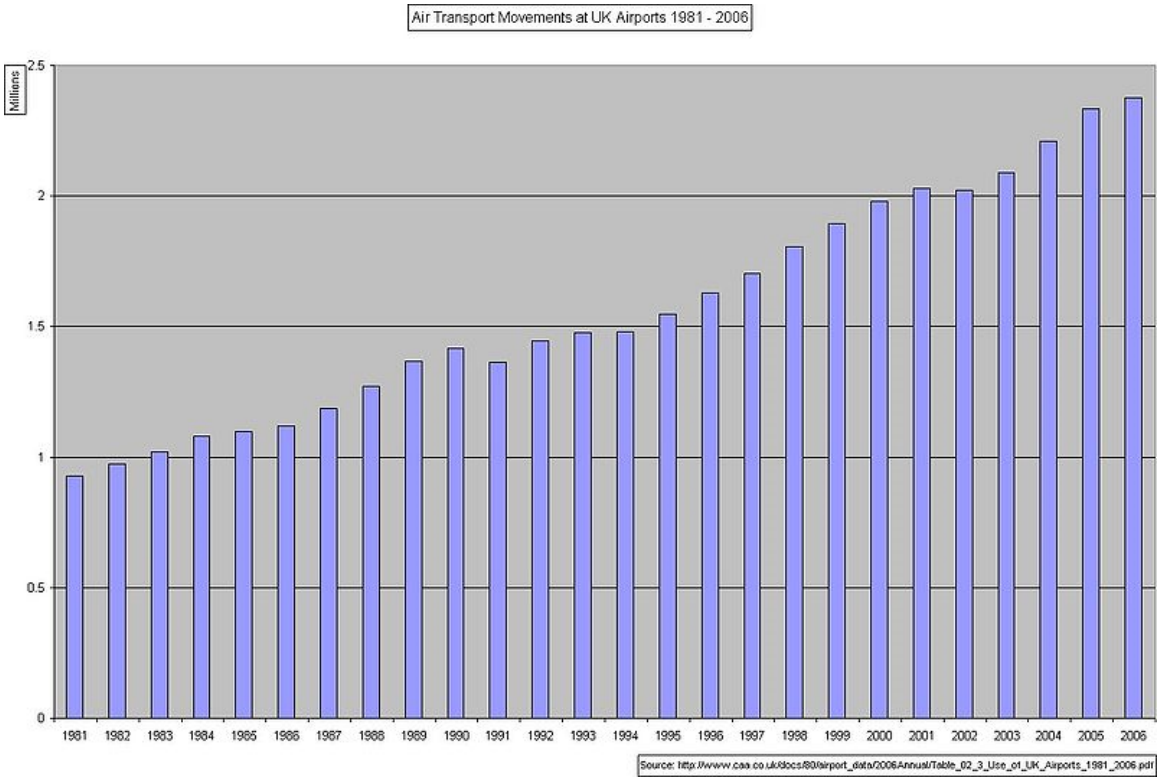
Increasing demand for air travel in the UK has resulted in a conflict between the desire to cater for that demand and the environmental consequences of doing so. In the past 25 years the UK air transport industry has seen sustained growth, and the demand for passenger air travel in particular is forecast to increase more than twofold, to 465 million passengers, by 2030. Two airports; London Heathrow Airport and London Gatwick Airport, are amongst the top ten busiest airports in the world for international passenger traffic. Whilst more than half of all passengers travelling by air in the UK currently travel

via the five London area airports, regional airports have experienced the most growth in recent years, due to the success of 'no-frills' airlines over the last decade.

The ability of the existing airport infrastructure to meet forecast demand is limited, and government policy published in 2003 supports the development of additional airport capacity by 2030 to address this. The strategy is generally based on making the best use of existing facilities, although an additional five new runways nationwide are considered to be necessary, three of them at the London airports of Stansted, Heathrow and, towards the end of the timeframe involved, Gatwick. This policy is designed to be a balanced and measured approach to the future of the air transport industry; one that recognises both an economic advantage in providing for growth in demand for air travel and also the need to address the consequent environmental impacts. The strategy has been criticised by the House of Commons Environmental Audit Select Committee, by environmentalist and campaign groups, and in research papers, for implementing a predict and provide model that overstates the economic advantages whilst paying insufficient heed to the environmental consequences.

Support for airport expansion is based on an economic case that regards the air transport industry not only as an important industry in its own right, but also as a facilitator of growth for the economy as a whole. One study predicts that the government's strategy will realise an additional £13 billion per annum in Gross Domestic Product (GDP) by 2030. Another study which is critical of the government approach, and which favours addressing environmental impacts through increased taxation of air transport, indicates a negative economic benefit resulting from airport expansion. In 2006 the industry was responsible for over 6 per cent of all UK carbon emissions, a figure that is set to rise as demand increases. Under current strategies of emissions reduction and growth in air transport, air travel in the UK could account for up to 50 per cent of the UK carbon budget by 2050. Industry attempts to address this issue are longer term efforts based on technological and operational improvements, whilst government policy is based on the inclusion of air transport within emissions trading schemes. Critics advocate a shift in government policy to address environmental impacts by constraining the growth in demand for air travel, primarily through the use of economic instruments to price air travel less attractively. Local environmental issues include noise and air quality, and the impact of these, particularly in the case of the former, is subject to debate. Government policy generally is that these are local issues best addressed locally, and has introduced legislation designed to facilitate this.

Air transport framework



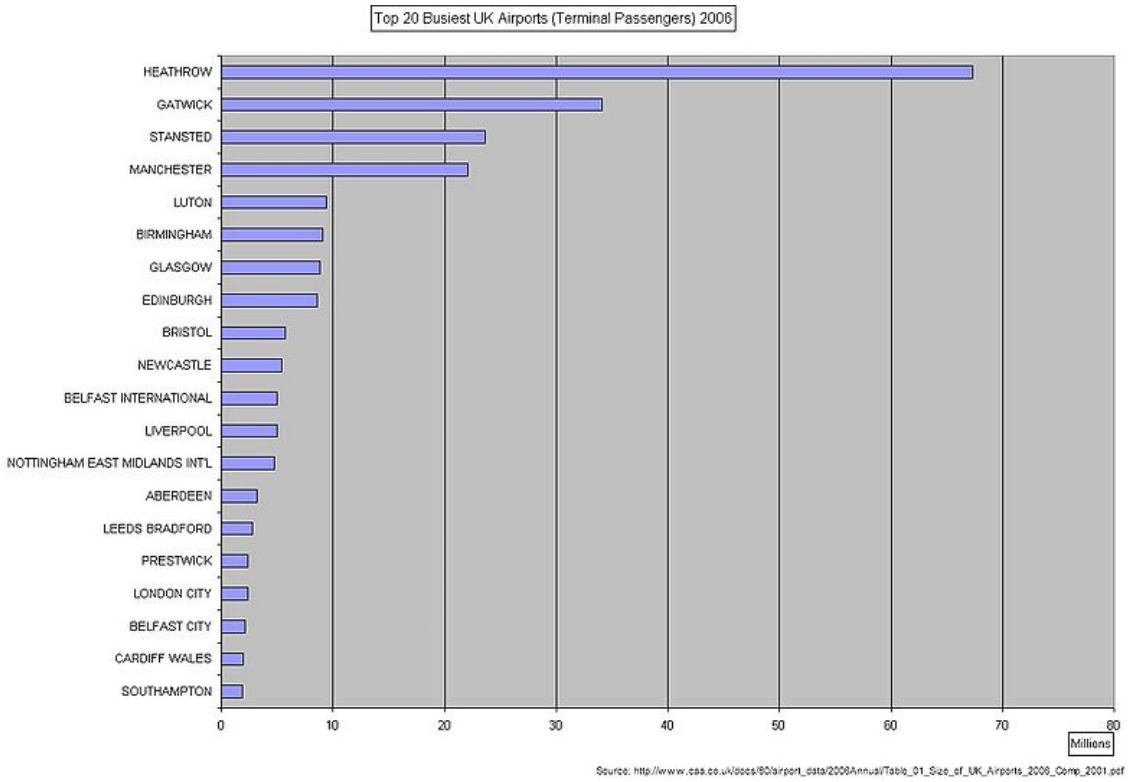
Growth in air transport movements 1981–2006

Air transport in the United Kingdom is a growth industry. In the period 1981 to 2006 the number of terminal passengers increased by 400 per cent and air transport movements by 250 per cent. Although the transport of freight declined slightly year on year between 2004 and 2006, in the decade since 1996 air freight has increased by 31 per cent. During the period in which government policy was being formulated the number of passengers exceeded 200 million, and in 2006 the industry handled over 236 million passengers (up 3 per cent from the previous year), with nearly 2.4 million air transport movements (up 1.8 per cent).

Infrastructure

Air traffic services for all UK airspace is provided by National Air Traffic Services (NATS), which also provides air traffic control at 15 airports. The largest airport operator is BAA Limited, owner of six UK airports including London Heathrow airport. In some cases airport ownership is in the hands of local government authorities rather than private businesses, and the largest UK owned operator, Manchester Airports Group, operator of Manchester Airport, Bournemouth Airport, East Midlands Airport, and Humberside Airport, is owned by a consortium of 10 Manchester area local authorities. Whilst the number of airports in the UK runs into hundreds, many are smaller aerodromes dealing with general aviation rather than air transport. In terms of the latter, statistics are

collected from 59 main airports, and the largest concentration of services is located in the London and South East of England areas.



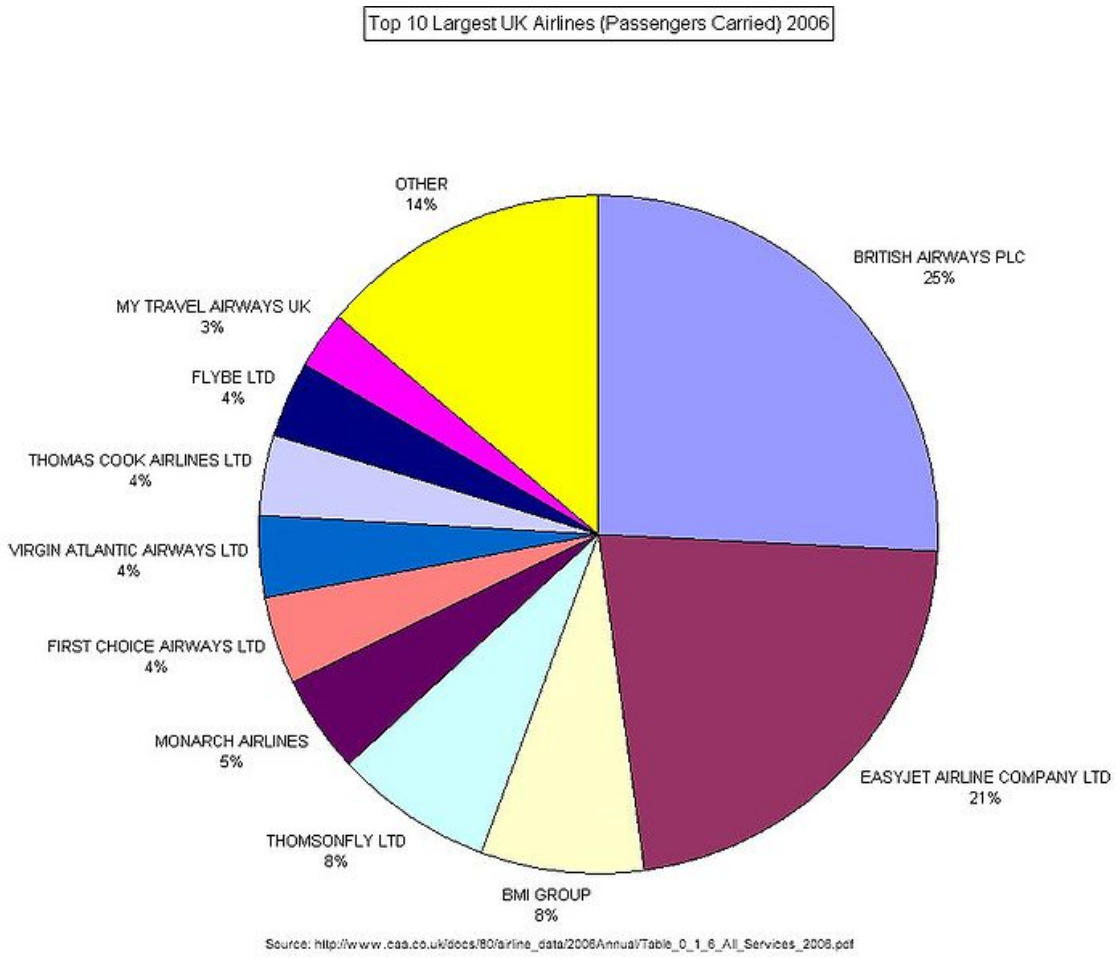
Largest UK airports 2006

Heathrow is the largest airport in the country, handling over 67 million terminal passengers in 2006, making it the third busiest airport in the world, and the busiest if measured by the number of international passengers. Nearly a third of all overseas residents visiting the UK enter the country via this airport, which also handles more than a fifth of all overseas visits by UK residents. Even though there are no dedicated freight services operating out of Heathrow, the practise of transporting cargo in the holds of passenger aircraft means that this airport still accounts for more than half of all freight handled by UK airports. Gatwick airport, with 34 million terminal passengers, is the second largest in the country, eighth busiest in the world for international passenger traffic, and lays claim to the busiest single runway airport in the world. Between them the five London airports handle nearly 137 million terminal passengers, 59 per cent of the national total. Stansted and East Midlands airports have both experienced large growth in freight handling over the past decade, and these two airports are the major hubs for express freight operations.

Outside of London and the South East, the use of regional airports has increased dramatically in recent years, with the amount of air traffic using these facilities doubling in the period 1995 to 2005. To illustrate this growth, in the five years from 2001 passenger numbers at the regional airports of Exeter International Airport, Bristol

International Airport, and Newcastle Airport increased by 191 per cent, 113 per cent, and 60 per cent respectively. In the same period the largest airports experienced some of the slowest growth, with Heathrow passenger numbers increasing by 11 per cent, and those of Gatwick increasing by less than 10 per cent.

Airlines

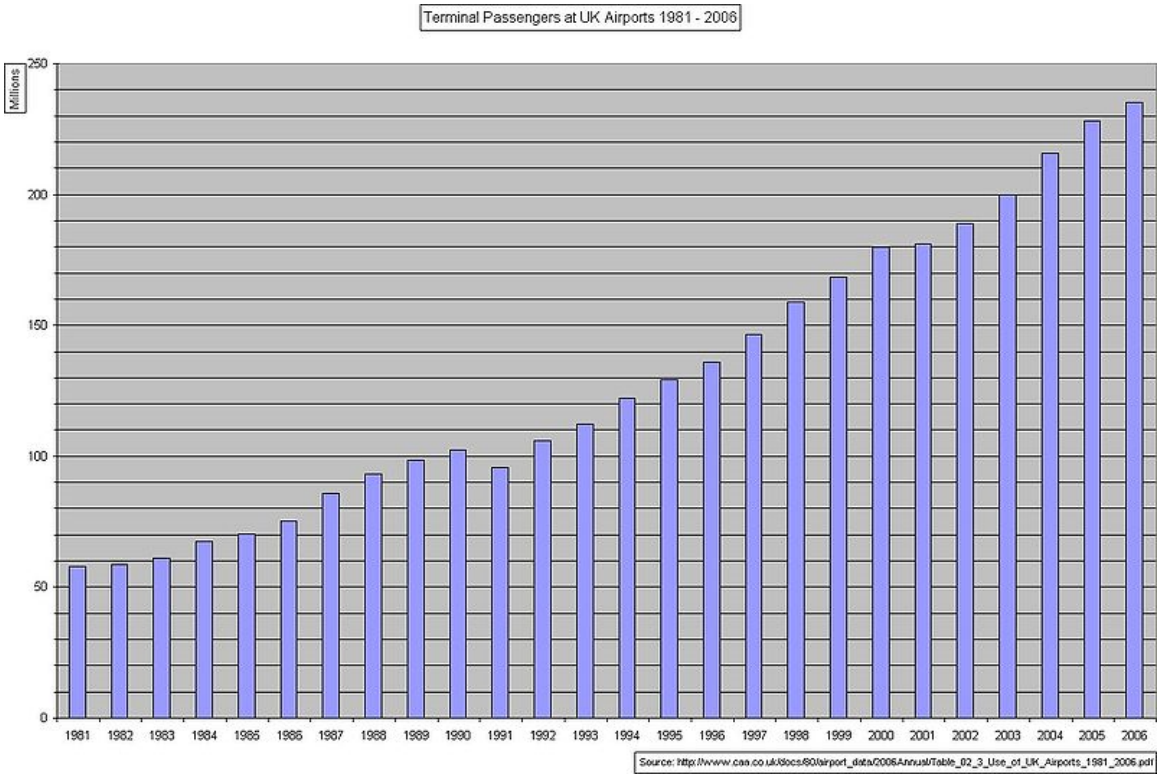


Largest UK airlines 2006

The majority of all passengers travelling by air to or from the UK are carried by UK airlines, of which there are around forty, and at the end of 2006 the UK air transport fleet numbered 963 aircraft, flying just under 1.2 million flights and averaging over eight hours of flying daily. Together the two largest airlines as measured by passenger numbers; British Airways and easyJet, account for nearly half of the 127 million passengers flown on UK airlines. In terms of capacity, both available and used, British Airways is again the largest airline, whilst easyJet is pushed into third place by Virgin Atlantic Airways. British Airways passenger flights also account for over 50 per cent of all cargo carried by UK airlines, and when combined with its cargo operations the airline carries over 60 per cent of all cargo carried by UK airlines.

The advent in the mid-1990s of 'no-frills' carriers, such as easyJet, has had a significant impact on air travel in the UK. In 2005 these airlines carried 77.5 million passengers, up from just 4.3 million in 1996. They are responsible for the growth of regional airports, operating from 35 airports in 2006 compared to 10 in 1996, and increasing the choice of international destinations, serving 150 in 2006, compared to 12 a decade earlier. The annual rate of growth in the overall demand for air travel has remained stable since 1975, averaging 5.8 per cent annually. Recent growth is being serviced by the no-frills airlines at the expense of traditional carriers which, since 2000, have experienced flat or declining traffic levels. In response, traditional carriers have lowered costs to compete more effectively on price, leading to lower prices on the short haul routes serviced by this sector, especially in business fares. They have also limited or reduced capacity and in some cases launched no-frills subsidiaries of their own.

Passenger travel



Passenger numbers 1981–2006

Just over a fifth of all terminal passengers are travelling on domestic routes only, whilst half are travelling between the UK and the rest of the European Union (EU). Of the latter, travel between the UK and Spain, France, Germany and Italy account for around half, with Spain almost matching the other three combined in terms of passenger numbers. Outside of the EU, the USA, the Far East, Switzerland and the Middle East together account for just over half of all passengers flying between the UK and the rest of the world, with the USA exceeding the other three combined in terms of passenger numbers.

Air travel is the most popular mode of transport for visitors both to and from the UK. In 2005 it was used for 80 per cent of all visits by UK residents travelling overseas and by 74 per cent of all inbound visits. Just over a quarter of all passengers are travelling on business. The advent of no-frills carriers has had a significant effect on passenger travel profiles, with strong growth in business travel from regional airports, and increasing inbound traffic generated for the purposes of non-UK residents visiting friends and relatives based in the UK. Whilst these carriers have been perceived to democratise air travel, providing the opportunity for lower income groups to travel more often, the main result is actually that middle and higher income groups travel more often, and often for shorter trips.

Capacity

The availability of airport capacity has been identified as an important constraint on the ability to meet the increasing demand for air travel. In many cases airport capacity is already fully used in meeting current demand. At Heathrow and Gatwick airports the runways are full for "… virtually the whole day". In 2003 the runway at Birmingham airport was expected to reach full capacity by 2009 at the latest, whilst terminal capacity at Edinburgh airport had reached its limit. Government forecasts that year predicted that by 2030 the number of passengers could rise to between 400 million passengers per annum (mppa) and 600 mppa, representing a two to threefold increase, and a figure of 500 mppa by 2030 was regarded by the government as robust. In 2006 the government reported that at 228 mppa the demand for air travel the previous year was in line with the 2003 forecast, but also revised the forecast demand for 2030 downwards to 465 mppa as a result of capacity constraints, even taking into account proposed airport developments.

Government and regulation

The law governing aviation in the UK is defined by the Civil Aviation Act 1982, which is updated periodically with amendments, the latest being the Civil Aviation Act 2006. The government department responsible for legislating changes in national policy and long term strategy relating to aviation is the Department for Transport (DfT). At the operational level the independently run Civil Aviation Authority (CAA) regulates economic, safety, and consumer protection aspects, as well as airspace policy, although these responsibilities are being increasingly ceded to the European Aviation Safety Agency (EASA). International aspects of air transport are regulated by agreements made within the International Civil Aviation Organisation (ICAO) as established by the Chicago Convention, whilst most new legislation is now made at the European level through the European Civil Aviation Conference (ECAC). As a consequence, other than in airport development, there are few aspects of the air transport industry in which the government can act in isolation.

Airport development strategy

East Midlands airport - Major hub for express freight operations

Whilst airport development in the UK is subject to local planning authority processes, the government regards airports as an important part of the national infrastructure and which therefore requires their development to be planned with a strategic approach. To support this, the government began a three year public consultation process with the publication in December 2000 of *The Future of Aviation* consultation document. This outlined the issues underpinning air transport and sought views on how they should be addressed in any future policy. One of the main questions asked was whether policy should focus on meeting demand or whether it should focus instead on limiting the negative effects of air transport. Another key issue for which views were sought was how the industry might best meet the environmental costs it incurs. Between July 2002 and February 2003 a further seven regional consultation documents were published. These focussed on the economic, environmental, social and airspace appraisals relating to options for future airport development specific to the regions, and together they generated half a million responses. During the Spring of 2003 workshops based on a consultation document titled *Aviation and the Environment - Using Economic Instruments* were held to seek stakeholder views on the desirability and effectiveness of various financial measures that might address the environmental impacts of aviation. The consultation process ended in

December 2003 with the publication of *The Future of Air Transport* White Paper which detailed the government's conclusions.

The White Paper does not in itself authorise or preclude any development, but seeks instead to define a "national strategic framework for the future development of airport capacity" over the next 30 years. The principal conclusion is that the two extremes of failing to provide additional airport capacity, and encouraging growth without regard for the wider impacts, are equally unacceptable options. Instead a "balanced and measured approach" to the future of air transport in the UK is adopted. This approach is designed to cater for the forecast growth in demand, thus supporting economic prosperity nationally and enabling ordinary people to travel at reasonable cost, whilst at the same time managing and mitigating the environmental impacts of aviation and ensuring that the costs associated with them are reflected in the price of air travel. The strategy seeks to minimise new airport development by making best use of existing facilities, and specific policies include:

Region	Policy
Scotland	Expansion of Edinburgh Airport with an additional runway, to accommodate up to 20mppa by 2020, and the recommendation that measures be taken to safeguard a possible additional runway at Glasgow International Airport.
Wales	Cardiff Airport to remain the main airport serving South Wales, to be supported by additional terminal capacity and improved surface links, subject to satisfactory resolution of any local environmental concerns.
Northern Ireland	Support for the development of capacity within the existing boundaries of Belfast Airport and early consideration of the future development of the City of Derry Airport, with all developments needing careful environmental assessment.
North of England	Expansion of Manchester Airport to increase terminal capacity to support up to 50mppa, accompanied by "stringent measures" to minimise noise disruption and ensure air quality standards. The possibility of extending the runway at Liverpool Airport. Development of surface access at a number of airports in the region.

Midlands	Expansion of Birmingham Airport with an additional runway, accompanied by "stringent measures" to minimise noise disruption and ensure air quality standards, and improvements to surface access. The option to expand East Midlands Airport with an additional runway is to be kept under review.
South West of England	Development of Bristol Airport with a runway extension and additional terminal, to support up to 12mppa, having due regard to the environmental impact of such developments, and support for the development of Bournemouth Airport, conditional on surface access improvements and minimal or compensated impacts on sensitive ecological sites. Support for development of Newquay and Exeter Airports.
South East of England	Expansion of Stansted Airport with an additional runway, with "strict environmental controls", as soon as possible and in the expectation of achieving this around 2011/2012. Development of Heathrow Airport, conditional on meeting "stringent environmental limits", to include an additional runway in the 2015–2020 timeframe, and "… an urgent program of work and consultation to find solutions to the key environmental issues at Heathrow …". Expansion of Gatwick Airport with an additional runway after the planning agreement preventing this expires in 2019.

Subsequent developments

In December 2006 the government published the *Air Transport White Paper Progress Report 2006* to report on progress made in "… delivering a sustainable future for aviation." The report re-iterates the government's commitment to the strategy defined in the original White Paper, stating that it "… strikes the right balance between economic, social and environmental goals." It also reports that; the extra runway at Edinburgh airport is now thought unlikely to be needed before 2020; Bristol airport does not currently see a case to support extending its runway, although the option will be kept under review; the additional runway at Stansted airport is not expected to be operational before 2015; and the runway extension at Liverpool airport is now being proposed for early next decade. Elsewhere, recent forecasts conducted for Birmingham airport indicate that a new runway will not be required there before 2030.

Following the publication of the White Paper, the Project for the Sustainable Development of Heathrow ('Project Heathrow' for short) was set up to examine how expansion at Heathrow could best be accomplished within the constraints of the stringent environmental limits the White Paper required. A provisional assessment indicates that

increased usage of the existing runways could be realised without increasing the number of people affected by noise if 'mixed mode' operations (the simultaneous use of both runways for arrivals and departures) are phased in gradually as noisier aircraft are retired. Indications ahead of the Project Heathrow environmental assessment indicate that increased noise and deterioration in air quality are likely to significantly constrain traffic using a new third runway. These issues are to be addressed as part of a three month consultation beginning in December 2007, and considerable opposition is being mobilised against the expansion of Heathrow.

Economic impact

The aviation industry and the government have together commissioned two significant studies into the economic impact of air transport, both undertaken by the consultancy Oxford Economic Forecasting (OEF). The first; *The Contribution of the Aviation Industry to the UK Economy*, was published in 1999 and was used as a source of economic information in *The Future of Air Transport* White Paper. The second study; *The Economic Contribution of the Aviation Industry in the UK*, co-sponsored by the national tourist agency VisitBritain, was published in October 2006 to extend and update the earlier report, and was used as a source in the *Air Transport White Paper Progress Report 2006*. Both studies concluded that whilst aviation is an important industry in its own right, the most important contribution is as "… a facilitator of growth for the economy as a whole."

Environmental groups dispute the economic benefits that are claimed for air transport, and the OEF reports have been specifically challenged. The Aviation Environment Federation (AEF), publishing the *Rebuttal of Oxford Economic Forecasting Report*, has labelled the 2006 OEF report "biased and misleading". AirportWatch, an umbrella movement for national environmental organisations and airport community groups opposed to aviation expansion, has produced a critique of the 2006 OEF report and the DfT's reliance on economic research that has been "… sponsored by the aviation industry." In response to government policy supporting further growth in aviation, Friends of the Earth (FoE) published *Pie in the Sky* in September 2006. This study concludes that the economic benefits of aviation have been exaggerated, and that the costs arising from environmental damage, as well as to other sectors of the economy, are ignored. Also published in 2006, the Environmental Change Institute study *Predict and decide - Aviation, climate change and UK policy* re-examined the economic arguments made in favour of aviation, concluding that restricting future growth would not necessarily be detrimental to the economy, and could potentially result in some economic benefits.

Direct economic impact

In terms of direct impact on the UK economy, air transport is an £11.4 billion industry, a figure which represents 1.1 per cent of the country's economy. It employs 186,000 people (full-time equivalents), and indirectly supports an additional 334,000 jobs, although the inclusion of indirect employment as an economic benefit of air transport is disputed. In

terms of productivity the aviation industry in 2004 was the third most productive, after the oil/gas extraction and utilities sectors, exceeding the national average by a factor of two and a half. The industry is also very capital intensive, accounting for up to 3.5 per cent of total UK business investment in the period 2000 to 2004. Air transport was directly responsible for £3.6 billion in tax and national insurance contributions in 2004/5, which includes £0.9 billion raised in Air Passenger Duty (APD), a figure set to double after APD rates were doubled in February 2007. Because of the global nature of the industry, article 15 of the Chicago Convention effectively prevents the imposition of fuel duty on aviation, and the industry does not pay Value Added Tax (VAT). Environmental groups argue that these, along with duty free sales, are iniquitous tax concessions valued at £9 billion annually. Despite generating £6.9 billion in exports in 2004, representing 3 per cent of all UK exports and 7 per cent of the total export of services, the patronage in the UK of air transport services provided by overseas airlines resulted in a £3.3 billion balance of payments deficit attributable to the industry.

Indirect economic impact

London City Airport

The government’s response to the challenges of an increasingly global economy is to build a "strong, modern knowledge economy", and the 2006 OEF study concludes that the UK economy is "…set to become increasingly dependent on aviation as the structure of the economy evolves." The availability of air transport services is regarded as an important factor in facilitating business activities, with benefits being realised in sales and marketing activities, customer and supplier relationships, the ability to serve a wider market, access to emerging markets, and more efficient production. Within industry sectors that are likely to support the development of a knowledge based economy, such as pharmaceuticals, banking and finance, communication services, computer services etc., there is conflicting evidence about a correlation between growth in a sector and that sector’s use of air travel, although survey results show that knowledge based services and high-tech manufacturing businesses are more dependent on air transport for sales than their more traditional economy counterparts.

The most successful example of the country’s economic evolution is the international financial services industry based in London. Within this sector aviation services are seen as critically important for both businesses and their clients, even in the era of video-conferencing. London’s air transport services are widely regarded within the London business community surveyed by the OEF to provide a competitive advantage over the rest of Europe, and expansion of airport capacity in the South East has significant support. Whilst these economic contributions are not disputed by environmental groups, they are not considered as sufficient justification to support further growth in air transport services which would primarily service increased demand for leisure travel rather than a business travel market which is already well served.

Transport links generally are regarded as an important factor which affects a company’s decision on where to locate, and thus invest, although the latest survey shows quality of telecommunications moving above transport in importance. Survey evidence indicates that a quarter of companies regard access to air services as an important factor in the decision of where in the UK to locate operations, whilst one in ten companies report that the absence of good air transport links has affected their decision to invest in the UK. The survey has been criticised as suffering from a poor response rate and therefore open to bias, though this issue has been recognised and rationalised by the report's authors.

easyJet, one of the no-frills carriers that has changed air travel in the UK in recent years.

Tourism is an industry where the influence of air transport services is more obvious. In 2005 some 22 million overseas visitors arrived by air, spending around £12 billion (1.1 per cent of GDP) and supporting 170,000 jobs in the tourist industry. In the same year air travel also accounted for 36 million trips abroad by UK tourists, and UK tourists as a whole spend twice as much abroad as overseas visitors spend in the UK. This has led to the assertion that aviation represents a "net negative effect" on the UK tourism industry, and that restraining demand for air travel would encourage more domestic tourism, with the consequent economic benefit of reducing the tourism deficit.

Exports and imports by air in 2005 were estimated at £62.7 billion and £59.6 billion respectively, with a significant majority of air freight operations being conducted with countries outside of the EU, and express freight operations transporting 5 per cent by value of all UK exports in 2004. Whilst export/import facilities provide opportunities for international trade and competition, they are not without negative effect, and British horticulture is one example of domestic industry damaged by cheap imports.

Forecast economic impact

Attempts to quantify the economic impact of growth in the air transport sector generate results which depend on assumptions made, and therefore the viewpoint of the organisation making the analysis. The OEF study has produced a figure of £2.5 billion per annum of additional GDP by 2015 for Heathrow, or £7 billion per annum by 2030 if a third runway is built there. Full implementation of the White Paper runway proposals resulted in a forecast yield of an additional £13 billion per annum in GDP by 2030.

Calculations done for the AEF, based on a new runway at Stansted, and which assume increased taxation of the industry, result in a negative economic benefit.

Environmental impact

External costs, also referred to as hidden costs, are quantifications of the environmental impacts of air transport. Whilst setting a financial value on all such impacts is difficult to do precisely, figures have been produced for the most significant. In 2000 the government valued the annual cost of climate change induced by greenhouse gas emissions from UK air transport at £1.4 billion, rising to £4.8 billion per annum by 2030. The impact of noise was costed at around £25 million per annum in 2000, and for the same year the impact on air quality was costed at between £119 million and £236 million per annum. Based on figures produced by the European Environment Agency the AEF has calculated a much higher total external cost for 2000 of around £6 billion.

Global environmental impact

Contrails over London

Whilst carbon emissions from all UK activities other than aviation had declined by 9 per cent in the 10 years between 1990 and 2000, carbon emissions from aviation activities doubled in the same period. Air transport in the UK accounted for 6.3 per cent of all UK carbon emissions in 2006. When the radiative forcing impact of other emissions are taken into account the total impact of emissions attributable to aviation is estimated to be twice

that of its carbon emissions alone. Although the government has committed to reducing total UK carbon emissions by 60 per cent from existing levels by 2050, its policy is based on the use of "… economic instruments to ensure that growing industries are catered for within a reducing total." Even if this reduction in total carbon emissions is achieved, research published in February 2006 concluded that aviation could account for between 24 per cent and 50 per cent of the UK's carbon budget by 2050.

The government recognises that there are no viable alternative aviation fuels, and whilst it accepts that the exemption of aviation fuel from fuel tax is anomalous, it sees no scope for a unilateral approach in addressing this. The strategy adopted in the White Paper seeks to mitigate the global impact of air transport primarily through emissions trading schemes. Although the Kyoto Protocol implemented emissions trading as a means to reduce emissions at national levels, the global nature of air transport means that all air travel is excluded from this mechanism. The government is seeking to redress this through the International Civil Aviation Organisation (ICAO), which has been working on the environmental issue since 1998, but progress is slow. In the meantime efforts are being made to include aviation in the EU Emission Trading Scheme (EU ETS) with an original target to implement this by 2008. In 2006 the government re-affirmed this policy as the best approach for addressing the climate change impacts of aviation, and current proposals aim at accomplishing this for all flights within the EU by 2011, with the scheme being extended to include all flights to and from the EU the following year.

The Airbus A380 is cleaner and quieter than previous generations of airliners

The aviation industry is seeking to reduce its climate change impacts by becoming more fuel efficient, and in the last 40 years fuel efficiency has more than doubled. In June 2005, Sustainable Aviation; a joint initiative involving a number of UK airlines, airports, manufacturers and the air traffic service provider NATS, was launched with a vision statement relating to environmental issues of "…removing or minimising any negative impacts on the local and global environment…". One of its commitments is to achieve, by means of airframe, engine and air traffic management improvements, a 50% reduction in CO_2 emissions, and an 80% reduction in NO_x emissions in new aircraft of 2020

relative to new aircraft in 2000. These are however long term aspirations, and whilst progress is being made in engine development, the more immediate efforts of Sustainable Aviation to address climate change are directed towards supporting research, common reporting of emissions, emissions trading, and personal offsetting.

Critics of an expansionist policy consider the EU ETS to be too late and to price carbon too low to adequately mitigate the climate change impact of aviation emissions. Instead they advocate addressing these impacts by constraining demand for air travel. The study *Predict and Decide - Aviation, climate change and UK policy*, noting that a 10 per cent increase in fares generates a 5 to 15 per cent reduction in demand, recommends that the government should seek an alternative aviation policy based on managing demand rather than providing for it. This would be accomplished via a strategy that presumes "… against the expansion of UK airport capacity" and constrains demand by the use of economic instruments to price air travel less attractively. In another study the levying of £9 billion of taxes is calculated to constrain the forecast growth in demand by 2030 to 315 million passengers, reducing the annual rate of growth to 2 per cent. The environmental message is echoed in the ninth report of the House of Commons Environmental Audit Select Committee, published in July 2006, which labels the government strategy a predict and provide model and expresses scepticism about the timescale and efficiency of the EU ETS. It recommends instead that the government rethinks its airport expansion policy and considers ways, particularly via increased taxation, in which future demand can be managed in line with industry performance in achieving fuel efficiencies, so that emissions are not allowed to increase in absolute terms.

Local environmental impact

Boeing 747 landing at Heathrow, 2004

Under the provisions of the Civil Aviation Act aircraft in flight are specifically exempted from trespass and nuisance controls, which denies any form of redress to those living near airports who are disturbed by noise. Government sanctioned measurements of noise near airports take an average sound level, measured in decibels (dB), over a 16 hour day, and are expressed as an LAeq figure. Officially, 57 dB LAeq is the threshold at which noise levels become disturbing, 63 dB LAeq represents moderate disturbance, whilst 69dB LAeq represents high disturbance. Technological improvements in aircraft design means that aircraft are becoming quieter. Taking Heathrow as an example, between 1990 and 2004 the area around the airport affected by noise levels of 57 db LAeq and above fell by 60 per cent, whilst the number of people similarly affected fell by 51 per cent. Campaign groups dispute the methodology used to measure noise, asserting that it is flawed in a number of ways. Amongst other issues they point to the World Health Organisation view that annoyance begins at 50 db LAeq whilst serious annoyance begins at 55 dB LAeq, and they assert that the LAeq measurement does not give sufficient weight to the increasing incidence of noise events. Their conclusion is that noise levels, and the number of people affected, have increased rather than decreased. This is borne out by the latest survey of attitudes to noise published in November 2007 which reports that, compared with over 20 years ago, more people today are annoyed by the same level of noise as measured by LAeq. Whilst this may be attributable to changing attitudes, the

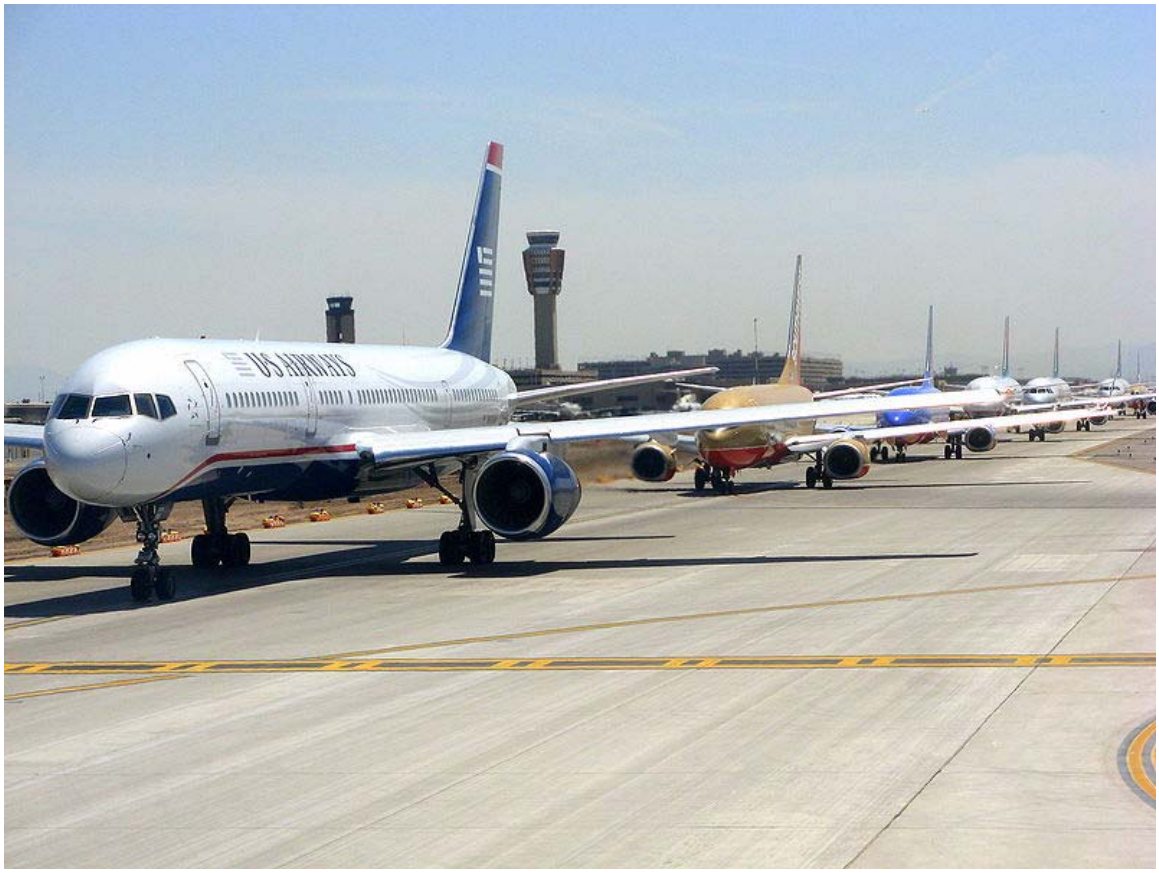
report concludes that the contribution of aircraft numbers to annoyance has increased, and that an alternative method of estimating levels of annoyance that takes this into account would appear to be more relevant than the LAeq measurement. The report has attracted criticism in peer reviews, and one such review, characterising the survey as inconclusive, counsels "... against using the detailed results and conclusions [...] in the development of government policy."

Air quality around airports is another major issue and a 2006 study found that levels of nitrogen dioxide exceeds EU guidelines at more than two thirds of airports surveyed. Whilst aircraft contribute to the problem the study states that "…cars, buses and taxis ferrying passengers to and from these sites are dominant sources of pollution." Birmingham airport dismissed the findings, asserting that the results were skewed by M42 motorway traffic unrelated to the airport, whilst studies at Southampton Airport attribute 5.55 per cent of total pollutants to airport activities, the majority of the remainder being generated by non-airport related road traffic. The government recognises Heathrow as the only UK airport where national and European air quality limits are being exceeded.

A provision of the original Civil Aviation Act allows designated airports to be required to provide facilities for consultation with affected parties, where local environmental concerns can be raised, and some 51 airports have been so designated. A 2000 consultation by the government re-iterated its policy that generally, local issues arising from airport operations are best addressed locally. To support this the Civil Aviation Act was extended in 2006 to give all airports the authority to mandate measures to address noise and air quality issues beyond their boundaries, and to impose financial penalties on aircraft which fail or are unable to adhere to such measures. The Civil Aviation Act 2006 also extends the provisions of section 78 of the original act, augmenting the powers of the Secretary of State to intervene directly in operations at designated airports; currently Heathrow, Gatwick and Stansted, "…for the purpose of avoiding, limiting or mitigating the effect of noise and vibration connected with aircraft landing or taking off." The largest airports also implement voluntary schemes to assist local communities in coping with the local impacts of airport operations. Birmingham International Airport, for example, has been operating a sound insulation scheme since 1978, in which 7,600 properties are eligible for sound proof glazing paid for by the airport. Schemes are also available to residents most affected by noise around Heathrow, designed to protect property prices ahead of any development of a third runway, assist with relocation costs for people who wish to move, and provide sound insulation for private and communal property currently affected by noise. In both cases local residents have also set up campaign groups; Birmingham Airport anti-Noise Group, and HACAN Clearskies at Heathrow, to represent themselves over local environmental issues arising from airport operations. Even the smallest of airports engaged in air transport operations; Gloucestershire Airport, has attracted organised opposition to its plans to extend the main runway there, and the umbrella group AirportWatch lists over 20 local airport campaign groups.

Chapter- 5

Mitigation of Aviation's Environmental Impact



Emissions from aviation are continuing to grow despite advances in aircraft efficiency. Currently 2% of global emissions are created by the aviation industry.

Aviation has an impact on the environment due to aircraft engines emitting noise, particulates, and gases which contribute to climate change and global dimming. Despite emission reductions from automobiles and more fuel-efficient (and therefore less polluting) turbofan and turboprop engines, the rapid growth of air travel in recent years contributes to an increase in total pollution attributable to aviation. In the EU, greenhouse gas emissions from aviation increased by 87% between 1990 and 2006.

At present aviation accounts for 2% of global CO_2 emissions and this is projected by the IPCC to rise to 3% by 2050. This presents the operators of aircraft with a responsibility to reduce emissions.

Methods of mitigating aviation's CO_2 emissions

Mitigation of aviation's environmental impact can be achieved through a variety of measures, the most obvious and arguably the most economical of which is to reduce the fuel burn of the aircraft as this accounts for 28% of an airlines costs. However there is a wide variety of other options available to minimise aviation's growing impact upon the environment as are listed below :

Aircraft efficiency

The Boeing 787 "Dreamliner" promises to provide 20% lower fuel burn than current-generation aircraft.

As stated previously, reducing the direct fuel burn of an aircraft is the most obvious and arguably the most economical way of reducing emissions attributable to aviation. Over the last 40 years, commercial jet airliners have become 70% more fuel efficient and are predicted to be another 25% more fuel efficient by 2025.

The next-generation of aircraft, including the Boeing 787, Airbus A350 and Bombardier CSeries, are 20% more fuel efficient per passenger kilometre than current generation aircraft. This is primarily achieved through more fuel-efficient engines and lighter airframes & supporting structures made of composite materials but is also achieved

through more aerodynamic shapes, winglets, a "one-piece" fuselage and more advanced computer systems for optimising routes and loading of the aircraft.

Route optimization

Currently, air traffic corridors that aircraft are forced to follow place unnecessary detours on an aircraft's route forcing higher fuel burn and an increase in emissions. An improved Air Traffic Management System with more direct routes and optimized cruising altitudes would allow airlines to reduce their emissions by up to 18%.

In the European Union, a Single European Sky has been proposed for the last 15 years so that there are no overlapping airspace restrictions between countries in the EU and so reduce emissions. As of yet, the Single European Sky is still only a plan but progress has been made. If the Single European Sky had been created 15 years ago, 12 million tons of CO_2 could have been saved.

Biofuels

British Airways will be using half a million tonnes of waste annually to create biofuels for commercial use from 2014 onwards.

Biofuels are fuels derived from biomass material such as plants and waste. Plant derived biofuels offer large savings in CO_2 emissions as they absorb Carbon Dioxide and release it as Oxygen when they grow and so in a life-cycle, emissions can be drastically reduced. A number of airlines have operated biofuel test flights including Virgin Atlantic Airways, which flew with one engine operating on a blend of 20% coconut oil and 80% traditional jet fuel, and Continental Airlines which flew with one engine operating on a blend of

44% Jatropha oil, 6% Algae oil and 50% traditional jet fuel. Other airlines to demonstrate biofuels include Air New Zealand and Japan Airlines.

In the Continental Airlines test, the engine running partly on biofuel burned 46 kg less fuel than the conventionally fuelled engine in 1 and a half hours while producing more thrust from the same volume of fuel. Continental Airlines' CEO, Larry Kellner, commented "This is a good step forward, an opportunity to really make a difference to the environment" citing jatropha's 50-80% lower CO_2 emissions as opposed to Jet-A1 in its lifecycle.

From 2014 onwards, British Airways, in co-operation with Solena, is going to turn half a million tonnes of waste annually that would normally go to landfill from the City of London into biofuel to be used in the British Airways fleet. Waste derived biofuel produces up to 95% less pollution in its life-cycle and so therefore this measure will reduce emissions by the equivalent of taking 42,000 cars off the road every year.

Improved operating procedures

Scandinavian Airlines is operating their 737 aircraft at slower cruising speeds to reduce emissions by 7-8%.

Airlines and airports are looking at ways of reducing emissions and fuel burn through the use of improved operating procedures. Two of the more common ones in operation are a single-engine taxi to and from the runway and the use of a Continuous Descent Approach, or CDA, which can reduce emissions significantly during the operations in

and around an airport. Scandinavian Airlines (SAS) is now operating its Boeing 737 fleet at a slower cruising speed to help reduce emissions by 7-8%.

Emission Trading Scheme

In the EU, aviation will be including the European Emission Trading Scheme from 2012 onwards. The scheme places a cap on the emissions an aircraft operator can emit and forces the operator to either lower emissions through more efficient technology or to buy "Carbon Credits" from other companies who have produced fewer emissions than their cap. It is thought that this will reduce aviation's net environmental impact.

Methods of mitigating aviation's non-CO_2 emissions

Aviation produces a number of other pollutants besides carbon dioxide including nitrogen oxides (NO_X), particulates, unburned hydrocarbons (UHC) and contrails. A number of methods to reduce the level of these pollutants follows:

Nitrogen oxides (NO_X)

Nitrogen Oxides have a far stronger impact upon climate change than Carbon Oxides and are produced in small quantities from aircraft engines. Engine designers have worked since the start of the jet age to reduce NO_X emissions and the result is ever reducing levels of Nitrogen Oxide emissions. For example, between 1997 and 2003, NO_X emissions from jet engines fell by over 40%.

Particulates

Particulates and smoke were a problem with early jet engines at high power settings but modern engines are disigned so that no smoke is produced at any point in the flight.

Unburned hydrocarbons (UHC)

Contrails formed by high altitude aircraft.

Unburned hydrocarbons (UHC) are products of incomplete combustion of fuel and are produced in greater quantities in engines with low pressure gains in the compressors and/or relatively low temperatures in the combustor. As with particulates, UHC has all but been eliminated in modern jet engines through improved design and technology.

Contrails

Aircraft flying at high altitude form condensation trails or contrails in the exhaust plume of their engines. While in the Troposphere these have very little climatic impact.

However, jet aircraft cruising in the Stratosphere do create an impact from their contrails, although the extent of the damage to the environment is as yet unknown. Contrails can also trigger the formation of high-altitude Cirrus cloud thus creating a greater climatic effect.

In the three days following the September 11 Atacks on the World Trade Centre in New York City, when no commercial aircraft flew in the USA, climate scientists measured the daily temperature range over 5000 weather stations across the USA. The results showed a 1^{o} Celsius change in the average daily temperature range for those days of the year, thus showing contrails do have a significant impact on climate. Potential ways of reducing the impact of contrails on our climate include reducing the maximum cruising altitude of aircraft so high-altitude contrails can not form. Cruising at lower altitudes would marginally increase flight time and increase fuel consumption by 4%.

Methods of mitigating aviation's noise emissions

Serrated edges of the nacelle on the Rolls-Royce Trent 1000 fitted to the new Boeing 787 "Dreamliner".

One of the by-products of an aircraft's engine is noise and this has become an increasingly important issue which is being dealt with through many different methods:

Engines

Next-Generation engines are not only more fuel-efficient but also tend to be quieter with Pratt & Whitney's PurePower PW1000G fitted to the Bombardier CSeries aircraft being 4 times quieter than aircraft currently in service. Engines can also incorporate serrated edges on the back of the nacelle to reduce noise impact as shown in this picture.

Improved operating procedures

A Continuous Descent Approach, or CDA, not only reduces fuel burn but also allows airlines to provide quieter approaches for part of the descent to a runway. As the engines are at close to idle power, less noise emissions are produced and combined with new engine technology, the reductions in noise emissions can be large.

Carbon offset

Money generated by carbon offsets from airlines often go to fund green-energy projects such as wind farms.

A carbon offset is a means of reducing emissions to zero by saving enough carbon to balance the carbon emitted by a particular action. Several airlines have begun offering carbon offsets to passengers to offset the emissions created by their proportion of the flight. Money generated is put to projects around the world to invest in green technology such as renewable energy and research into future technology. Airlines offering carbon offsets include British Airways, easyJet, Continental Airlines, Delta Airlines, Lufthansa and Qantas although there are many more carriers participating in such schemes.

British Airways' scheme

British Airways' carbon offsetting scheme involves paying a fee dependant on aircraft type, class of travel and distance flown and therefore prices vary. Funds generated are currently awarded to three renewable energy projects around the world: Bayin'aobao wind farm in Inner Mongolia, Faxinal dos Guedes hydroelectric power plant in Brazil and Xiaohe hydroelctric power plant in Gansu Province, China.

Continental Airlines' scheme

Continental Airlines' carbon offsetting scheme involves paying a fixed fee of $2 to cancel out emissions through reforestation. Passengers can also choose to pay $50 for offsetting emissions through renewable energy projects.

Chapter- 6

Electric Aircraft

Helios electric-powered UAV

An **electric aircraft** is an aircraft that runs on electric motors rather than internal combustion engines, with electricity coming from fuel cells, solar cells, ultracapacitors, power beaming, and/or batteries.

Currently flying electric aircraft are mostly experimental demonstrators, including manned and unmanned aerial vehicles. Electrically powered model aircraft have been flown since the 1970s, with one report in 1957.

History

In 1883 Gaston Tissandier was the first to use electric motors in airship propulsion. The following year, Charles Renard and Arthur Krebs flew La France with a more powerful motor.

Electric motors have been used for model fixed-wing aircraft since from at least 1957, with a challenged claim from 1909.

Experimental projects

1970s and 1980s

Sunrise

The 27 lb (12 kg) unmanned AstroFlight Sunrise, the result of an ARPA contract, made the world's first solar-powered flight from Bicycle Lake, a dry lakebed on the Fort Irwin Military Reservation, on 4 November 1974. The improved Sunrise II flew on 27 September 1975 at Nellis AFB.

Solar Riser

The world's first official flight in a solar powered, man carrying aircraft took place on April 29, 1979. The Solar Riser was built by Larry Mauro and was based on the Easy Riser biplane hang glider. The aircraft used photovoltaic cells that produced 350 watts at 30 volts, which charged a Hughes 500 helicopter battery, which in turn powered the electric motor. The aircraft was capable of powering the motor for 3 to 5 minutes, following a 1.5 hour charge, enabling it to reach a gliding altitude.

Gossamer Penguin and Solar Challenger

The Gossamer Penguin, a smaller version of the human powered Gossamer Albatross was completely solar powered. A second prototype, the Solar Challenger, flew 262 km (163 mi) from Paris to England. On 7 July 1981, the aircraft, under solar-power, flew 163 miles from Cormeilles-en-Vexin Airport near Paris across the English Channel to RAF Manston near London, flying for 5:23. Designed by Dr. Paul MacCready the Solar Challenger set an altitude record of 14,300 feet.

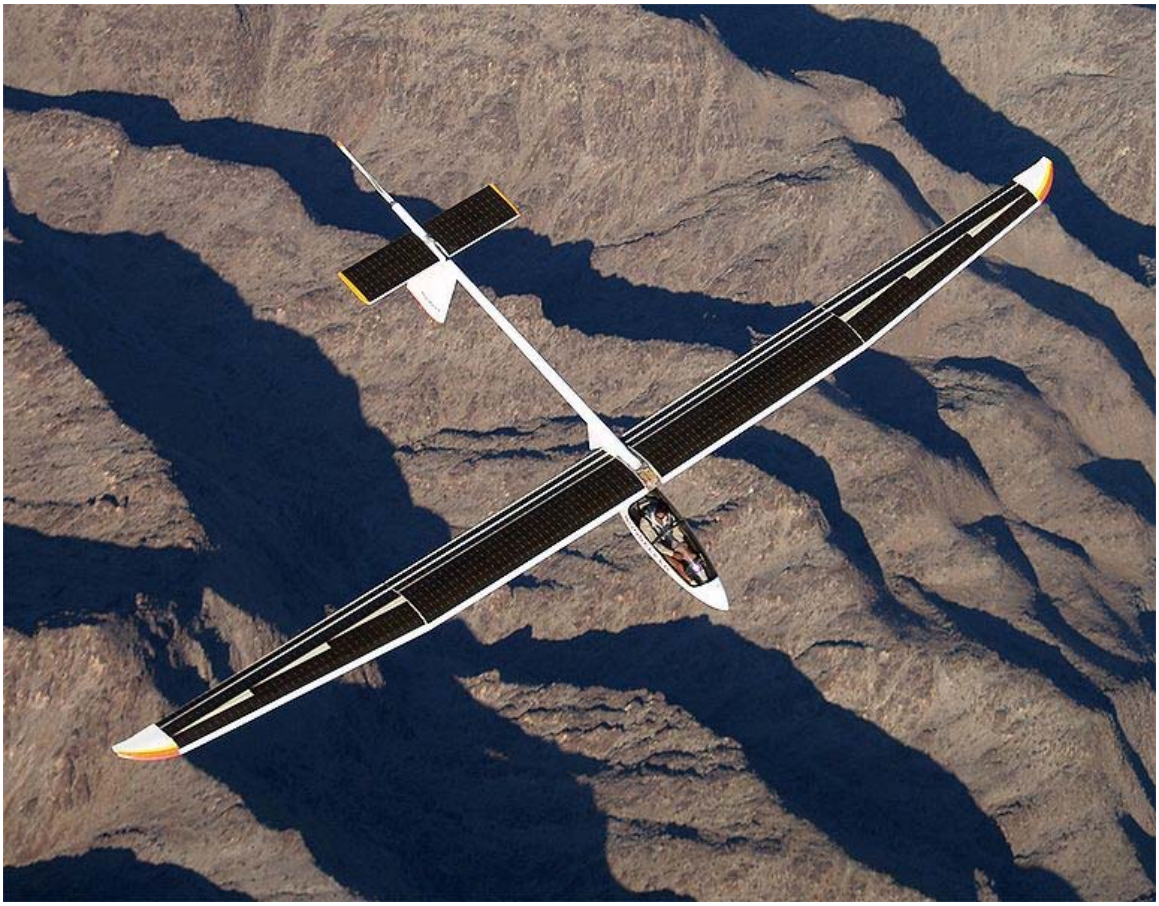
Solair 1

The human piloted Solair 1 was developed by Günther Rochelt and based on a Farner canard design. It employed 2499 wing-mounted solar cells giving an output of between 1.8 kW (2 hp) and 2.2 kW (3 hp). The aircraft first flew at Unterwössen, Germany on 21 August 1983. It flew for 5 hours and 41 minutes, "mostly on solar energy and also thermals". The aircraft is now displayed at the German Museum in Munich. The newly developed piloted Solair II made its first flight in May 1998 and further test flights that summer but the propulsion system overheated too fast. Development stopped when Günther Rochelt suddenly died in September 1998.

NASA Pathfinder and Helios

NASA's Pathfinder and Helios were a series of solar and fuel cell system-powered unmanned aircraft. AeroVironment, Inc. developed the vehicle under NASA's Environmental Research Aircraft and Sensor Technology program.

1990s



Solar Flight's *Sunseeker* flying over Southern California's high desert

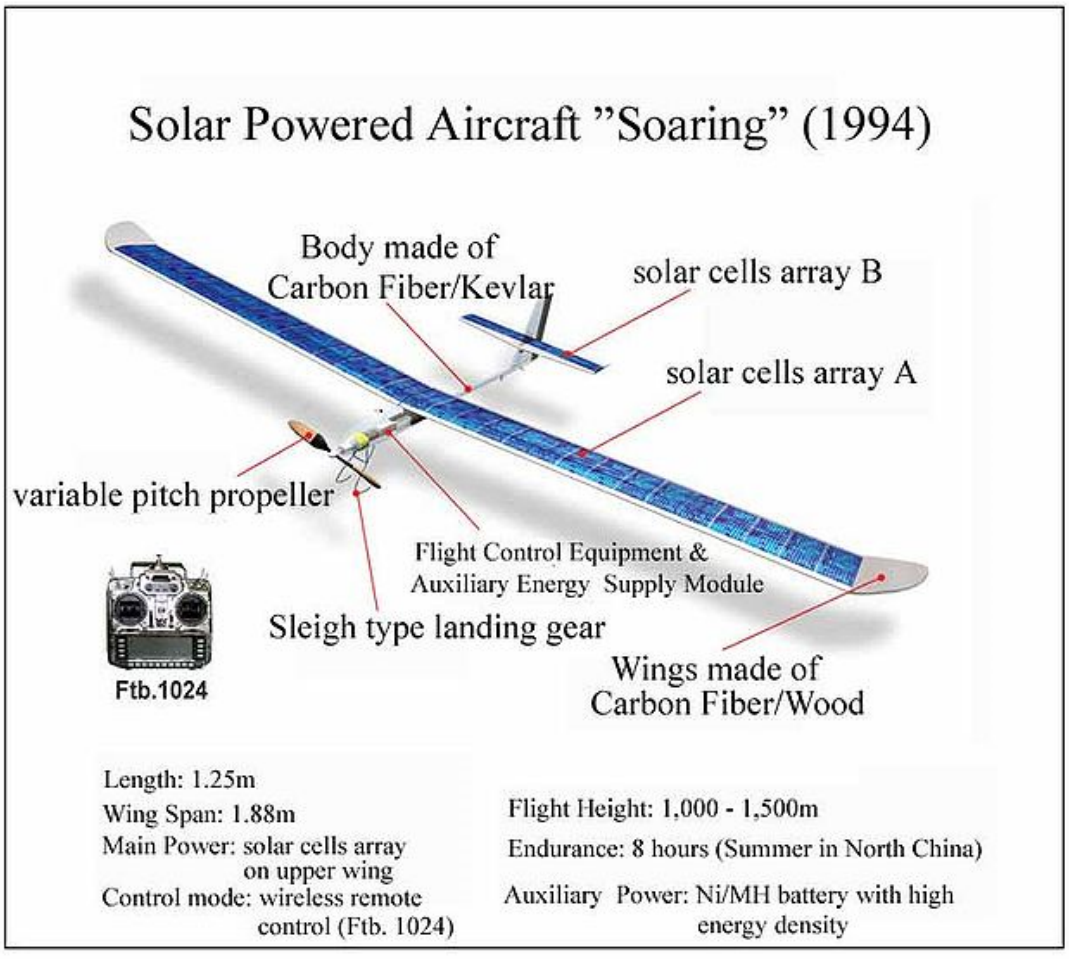
Sunseeker

In 1990 the solar powered airplane *Sunseeker* successfully flew across the USA, piloted by Eric Raymond. It used a small battery charged by solar cells on the wing to drive a propeller for takeoff, and then flew on direct solar power and took advantage of soaring conditions when possible.

The *Sunseeker II*, built in 2002, was updated in 2005-2006 with a more powerful motor, larger wing, lithium battery packs and updated control electronics. As of Dec, 2008 it was the only manned solar powered airplane in flying condition and is operated regularly by Solar Flight. In 2009 it became the first solar-powered aircraft to cross the Alps, 99 years after the first crossing of the Alps by an aircraft.

Soaring

Test Flight of *Soaring* in 1994



Summary of Configuration and Performance Parameter of "Soaring"

China's first solar powered aircraft "Soaring" was designed and built by Danny H. Y. Li and Zhao Yong in 1992. The body and wings are hand-built predominantly of carbon fiber, Kevlar and wood. The design uses winglets to increase the effective wing span and reduce induced drag.

2000s

Antares 20E

The Antares 20E is an electric, self-launching sailplane with a 42-kW DC/DC brushless motor (called EM42) and lithium-ion batteries. It can climb up to 3,000 meters with fully charged cells.

Solar Impulse

The first short-hop (350m) test flight of the Solar Impulse prototype was made on 3 December 2009.

In its present configuration it has a wingspan of 210 ft (64 m), weighs 3,500 lb (1,588 kg) and is powered by four 10-horsepower (7 kW) electric motors. The aircraft has over 11,000 solar cells on its wings and horizontal stabilizer. Power from the solar cells is stored in lithium polymer batteries and used to drive 3.5-metre (11 ft) propellers turning at a speed of 200–400 rpm. Take-off speed is 19 knots (35 km/h) and cruising speed is 60 kn (111 km/h).

The aircraft had its first high flight on 7 April 2010, when it flew to an altitude of 1,200 meters (3,937 feet) in a 1.5 hour flight on battery power alone. The Solar Impulse team is planning to use the aircraft to circumnavigate the globe in 2012.

The aircraft first flew on purely solar power, charging its batteries in flight, on 28 May 2010

On 8 July 2010 it completed the first manned 24 hour flight completely powered by solar power.

APAME Electra

The Association pour la Promotion des Aéronefs à Motorisation Électrique (APAME) *(English: Association for the Promotion of Electric Powered Aircraft)* first flew their Electra electric-powered open-cockpit airplane at 1150 hrs (local) on Sunday, 23 December 2007 at Aspres sur Buech airfield, Hautes Alpes, France. Test pilot Christian Vandamme flew the strut-equipped aircraft for 48 minutes, covering 50 km (31 miles). The Electra is powered by an 18-kW (24 hp) disk-brush electrical motor driven by a 47 kg (104 lb) lithium polymer battery power pack.

First manned AA battery powered aircraft

Matsushita Electric Industrial Co. and undergraduates at the Tokyo Institute of Technology teamed up to build an aircraft powered by 160 AA battery cells and successfully flew it for a distance of 391 meters (1,283 ft) in July, 2006.

Boeing-FCD Project

In 2008, The Boeing Fuel Cell Demonstrator achieved straight-level flight on a manned mission powered by a hydrogen fuel cell.

The FCD (Fuel Cell Demonstrator) is a project lead by Boeing that uses a Diamond Super Dimona HK-36 motor glider as a test bed for a fuel cell powered light airplane research project.

Successful test flights took place in February and March 2008.

Boeing's partners in the project are Intelligent Energy of Britain (fuel-cell); Diamond Aircraft of Austria (Airframe); Spanish Sener (control system); Spanish Aerlyper (integrate motor with airframe); Advanced Technology Products, a U.S. company (motor, batteries, flight testing).

QinetiQ Zephyr

The QinetiQ Zephyr is a lightweight solar-powered unmanned aerial vehicle engineered by the United Kingdom defence firm, QinetiQ. As of 23 July 2010 it holds the endurance record for an unmanned aerial vehicle of over 2 weeks (336 hours).

It is of carbon fiber-reinforced polymer construction, the 2010 version weighing 50 kg (110 lb) (the 2008 version weighed 30 kg (66 lb)) with a span of 22.5 metres (the 2008 version had 18 metres (59 feet)). It uses sunlight to charge lithium-sulphur batteries during the day, which power the aircraft at night. The aircraft has been designed for use in observation and communications relay.

The 2008 Zephyr version flew for 82-hours, reaching 61,000 foot in altitude in July 2008, the then unofficial world record for the longest duration unmanned flight. In July 2010 the 2010 version of the Zephyr made a world record unmanned aerial vehicle endurance flight of 336 hours, 22 minutes and 8 seconds (more than two weeks) and also set an altitude record of 70,000 feet.

SkySpark

Skyspark in flight 2009

The SkySpark is a joint project of engineering company DigiSky and Polytechnic University of Turin. The two-seat Pioneer Alpi 300 has a 75 kW (101 hp) brushless electric motor powered by lithium polymer batteries. The aircraft achieved a world record of 250 km/h (155 mph) for a human-carrying electric aircraft on 12 June 2009.

Green Pioneer I

Test Flight of "Green Pioneer I" in 2004

The *Green Pioneer* solar powered aircraft research programme was announced at the 4th China International Aviation and Aerospace Exhibition in 2002. The experimental programme was intended to provide research data for future Chinese solar powered aircraft. The programme was run by New Concept Aircraft (Zhuhai), the China Aviation Industry Development Research Center, and China Academy of Space Technology. The project leader and chief designer was Danny H. Y. Li.

EADS Cri-Cri

In June 2010 French aerospace company EADS unveiled an electric version of the 1970s vintage Colomban Cri-cri ultralight aircraft powered by four electric engines. The Cri-Cri will have lithium batteries and will be able to fly for 30 minutes at 60 kn (111 km/h) or 15 minutes of aerobatics at speeds up to 135 kn (250 km/h), with a climb rate of 1,000 feet per minute. The aircraft is a demonstrator for future technology, as Jean Botti, EADS's chief technical officer explained: "The Cri-Cri is a low-cost test bed for system integration of electrical technologies in support of projects like our hybrid propulsion concept for helicopters." The Cri-Cri first flew on 2 September 2010 at Le Bourget airport near Paris.

Design concepts

Puffin

The *Puffin* is a proposed hover-capable, electric-powered, low-noise, personal, vertical takeoff and landing (VTOL) technology-concept, proprotor aircraft. It would be capable of flying a single person at a speed of 150 miles per hour. Range is expected to be less than 50 miles with initial battery technology. The design has a 13.5 foot wingspan and stands 12 feet tall on the ground in its take-off or landing configuration.

As of January 2010, a one third–size, hover-capable Puffin demonstrator was planned for March 2010. Future designs might incorporate additional rotors to provide redundant systems.

As of August 2010, the one-third scale model of the Puffin was on display at the NASA Langley campus for filming for the Discovery network series "Dean of Invention." The Puffin simulator was also demonstrated. The Puffin will appear in the eighth and final episode of the show.

Production aircraft

1990s

Alisport Silent Club

The first commercially available production electric aircraft was the Alisport Silent Club self-launching sailplane, first tested in 1997. It is optionally driven by a 13 kW (17 hp) DC electric motor running on 40 kg (88 lb) of batteries that provide 1.4 kWh of power.

2000s

Electraflyer

In April 2007 the Electric Aircraft Corporation began offering complete electric ultralights and engine kits under the ElectraFlyer brand name, to convert existing ultralight aircraft to electric power, in what is the first commercial offering of an electric aircraft.

The 18 hp (13 kW) engine package weighs 26 lbs and an efficiency of 90% is claimed by the company. The battery consists of two lithium-polymer battery packs which provides 1.5 hours of flying in the trike application.

In January 2008 the company introduced their new ElectraFlyer-C at the Sebring Light Sport Aircraft Show. This aircraft is a converted Monnett Moni motor glider equipped with an 18-hp electric motor, regenerative-braking-capable controller package and two lithium polymer battery packs. The engine weighs 29 lbs and the battery packs weigh 78 lbs total. The aircraft has a climb rate of 500 ft/min, cruise of 70 mph and an endurance of 90 minutes. It is capable of being recharged from a 110 volt source in six hours or from a 220 volt source in two hours. The aircraft began flying in May 2008 and was demonstrated before the crowds on August 2 at AirVenture 2008.

In April 2009 the ElectraFlyer-C prototype was offered for sale on eBay. The designer intends to use the funds from the sale, plus a Lindbergh Foundation grant of $10,580 to complete two-place design that will eventually qualify for Light-sport aircraft status. The new design will incorporate composite construction, detachable wingtips to aid storage and will be powered by a 50 hp (37 kW) electric motor. Its design goals include a 28:1 glide ratio and a cruise speed of 80 mph (129 km/h) for two hours.

Electraflyer president Randall Fishman announced in April 2010 that the company's latest model, the Electraflyer-X, would fly in May or June 2010. The aircraft will be a two-seater and will utilize a new 20 hp (15 kW) single rotor electric powerplant. Fishman is also developing 40 hp (30 kW) two-rotor and 60 hp (45 kW) three rotor engine designs.

Sonex Aircraft

During AirVenture 2007 Sonex Aircraft announced that they are working on a series of alternate power initiatives, including an electric-powered aircraft. The electric powered Waiex motor glider was first flown in December 2010 and is powered by a 54 kW (72 hp) brushless DC electric motor, managed by a newly-designed controller. Power is from a collection of 14.5kw-hour lithium polymer batteries, giving the aircraft an endurance of one hour at low-speed cruise or 15 minutes of aerobatics.

Yuneec International E430

A new Chinese aircraft was announced in 2009. The Yuneec International E430 is a two seat, V tailed, composite aircraft with a high-aspect ratio wing. Take-off speed is 40 mph and top speed is 93 mph. The aircraft is being developed as a homebuilt aircraft for the US market.

The prototype E430 was displayed at EAA AirVenture Oshkosh in July 2009, by which time it had flown over 22 hours. The company claims that the battery packs have an expected lifespan of 1500 hours and cost US$7000 each, with the aircraft carrying 3-5 battery packs, giving two to two and half hours endurance. The batteries can be recharged in 3 hours. The company projects that by the time the first customers require replacement battery packs that improved and less expensive ones will be available. Projected price for a commercially available light sport aircraft production version of the E430 is US$89,000.

Flightstar e-Spyder

The e-Spyder is an electric-powered version of the Flightstar Spyder ultralight, developed by Flightstar Sportplanes president Tom Peghiny of South Woodstock, Connecticut, USA in cooperation with electric engine manufacturer Yuneec. The aircraft replaces the Spyder's two-stroke engine with a Yuneec 20 kW (27 hp) electric motor and two 28 lb (13 kg) lithium-polymer battery packs which provide a 40 minute endurance. The aircraft was exhibited at EAA AirVenture Oshkosh in July 2009 and is intended as a commercially available kit plane, forecast to be available for under US$25,000.

Lange Antares 20E

The Lange Antares 20E is a self-launching motor glider with a 42-kW electric motor and SAFT VL 41M lithium-ion batteries. The motor actuates 2-blade fixed pitch propeller. It can climb up to 3,000 meters with fully charged cells. After launch it can function as a conventional, though heavy, glider. As of January 2010, over 50 had been built.

2010s

Cessna 172

In July 2010 Cessna announced it was developing an electrically-powered Cessna 172 as a proof-of-concept in partnership with Bye Energy. Cessna CEO Jack Pelton stated that the project reflects "encouraging news for the future of mainstream general aviation." Pelton pointed out "the electric power plant offers significant benefits, but there are significant challenges to get there."

PC-Aero Elektra One

The Elektra One is a development of a commercial electric aircraft design by PC-Aero of Germany. The single seat composite aircraft is expected to have its first flight in early 2011. The Elektra One is powered by a 21 hp (16 kW) electric motor and is expected to have an endurance of three hours, with a 100 mph (161 km/h) top speed.

The company is planning a whole line of aircraft including a version of the Elektra One with longer wings and built-in solar panels and an aerobatic version with double Elektra One's power and airframe strength. The company is also planning two and four seat developments.

Design and operation of electric aircraft

Regenerative flight

A design concept has been put forward for soaring-type aircraft called regenerative soaring. In this approach, a propeller, using symmetrical blade sections, would be used as a turbine to recharge stored energy when the aircraft encounters an updraft. At high altitudes, the energy available from vertical atmospheric motion within a thermal can exceed available solar power by a factor of ten or more.

Chapter- 7

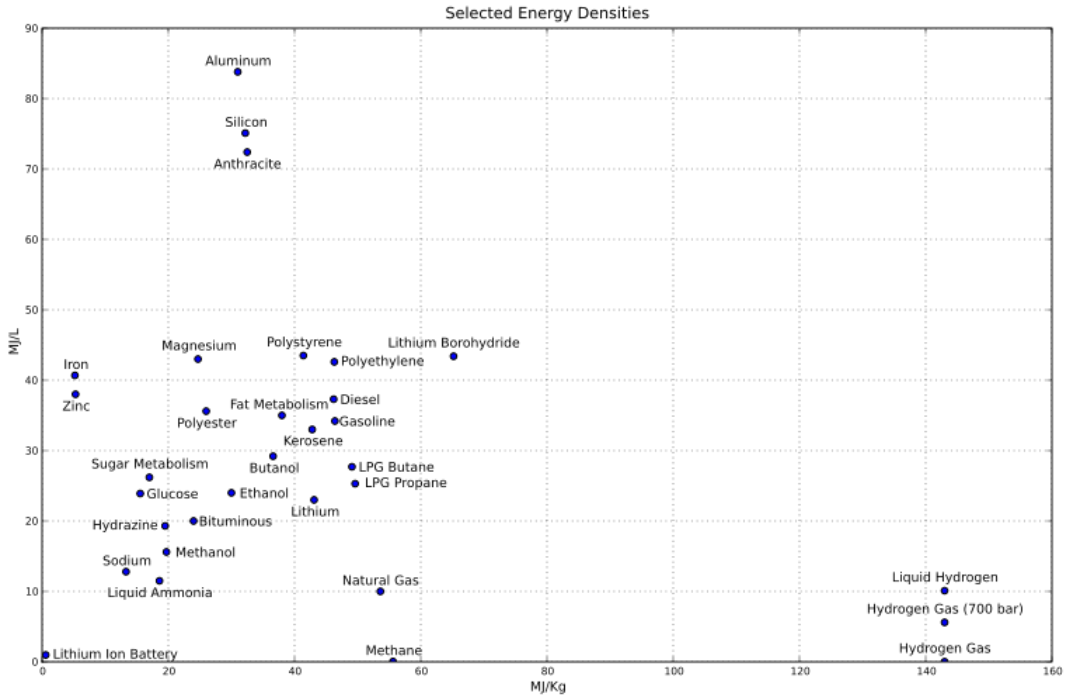
Hydrogen Powered Aircraft

In 2008, The Boeing Fuel Cell Demonstrator achieved straight-level flight on a manned mission powered by a hydrogen fuel cell.

A **hydrogen-powered aircraft** is an airplane that uses hydrogen as a power source.

In aircraft hydrogen can either be burned in some kind of jet engine, or other kind of internal combustion engine, or can be used to power a fuel cell to generate electricity to power a propeller.

Properties of hydrogen



Energy density of fuels - horizontal per mass, vertical per volume

Being an alternative to jet fuel, hydrogen has a higher energy density per unit *mass* but a lower energy density per unit *volume*, and containing the hydrogen at high pressure would require a heavy container. In aircraft heavy containers are not an option, and therefore regular carbon fibre tanks are often used, which can only sustain a pressure of 350 bar. When compared to steel hydrogen containers (used in cars and ships), this is 500 to 700 bar. This decreases the amount of energy that can be spent on the propulsion by half. Alternatively, as with some rockets, cryogenic liquid hydrogen could be employed.

If hydrogen were available in quantity from renewable energy sources, its use in aircraft would produce fewer greenhouse gases (water vapor and a small amount of nitrogen) than current aircraft. Currently, very little hydrogen is produced using renewable energy sources, and there are several serious obstacles to the use of hydrogen in aircraft and other vehicles. According to research at the Pennsylvania State University in 2006, large commercial hydrogen aircraft could be built by 2020 but "will probably not enter service until closer to 2040."

The European Union's research project in cooperation with Airbus and 34 other partner companies dubbed CRYOPLANE assessed the technical feasibility, safety, environmental compatibility and economic viability of using liquid hydrogen as an aviation fuel. This was concluded in 2002 (with the final report published in 2003).

Liquid hydrogen is one of the best coolants used in engineering, and it has been proposed to use this property for cooling intake air for very high speed aircraft, of even for cooling the vehicle's skin itself particularly for scramjet-powered aircraft.

Properties of hydrogen aircraft

Hydrogen aircraft are usually designed with the liquid hydrogen fuel carried inside the fuselage, in order to minimize surface-area and reduce boil-off. Normal aircraft use wings for storing fuel.

Liquid hydrogen has about four times the volume for the same amount of energy of kerosene based jet-fuel. In addition, its highly volatile nature precludes storing the fuel in the wings, as with conventional transport aircraft. Therefore, most liquid hydrogen aircraft designs store the fuel in the fuselage, leading to a larger fuselage length and diameter than a conventional kerosene fueled aircraft. If that were the end of the story, the hydrogen-fueled aircraft would have lower performance than the kerosene aircraft due to the extra wetted area of the fuselage. The larger fuselage size causes more skin friction drag and wave drag. Hydrogen is about one-third of the weight of kerosene jet-fuel for the same amount of energy. This means that for the same range and performance (ignoring the effect of volume), the hydrogen aircraft would have about one-third of the fuel weight. For a Boeing 747-400 type aircraft, this would reduce the Takeoff Gross Weight from 800,000 lbs to approximately 600,000 lbs. Thus, the performance of a hydrogen-fueled aircraft is a trade-off of the larger wetted area and lower fuel weight. This trade-off depends on the size of the aircraft.

Liquid hydrogen was proposed for use on the scramjet-based National Aerospace Plane.

Hydrogen aircraft demonstrations

Several demonstrations of hydrogen-powered aircraft have been performed using purpose-build airplanes.

Boeing Research & Technology Europe (BR&TE) made a civilian aircraft from a 2-seat Dimona motor glider running on a fuel cell (called Theator Airplane)". Lange Aviation GmbH also made a hydrogen-powered airplane with its Antares DLR-H2 airplane.

These aircraft are of course configured in such fashion that the current low energy output from hydrogen propulsion (a result of the low-pressure hydrogen tanks) do not pose a problem. For example the Boeing Theator airplane only required 45 kW to take off, and 20 kW to stay airborne.

In July 2010 Boeing also unveiled its hydrogen powered Phantom Eye UAV, that uses two Ford Motor Company internal combustion engines converted to operate on hydrogen.

Current aircraft

- The Russian manufacturer Tupolev built a prototype hydrogen-powered version of the Tu-154 airliner, named the Tu-155, which made its first flight in 1989.

Proposed hydrogen aircraft

- Reaction Engines Skylon orbital hydrogen fuelled jet plane
- Reaction Engines A2 antipodal hypersonic jet airliner
- DLR Smartfish
- Boeing plans to build a hydrogen-powered jet

Description of Some Proposed Hydrogen Aircraft: -

Reaction Engines Skylon

Skylon

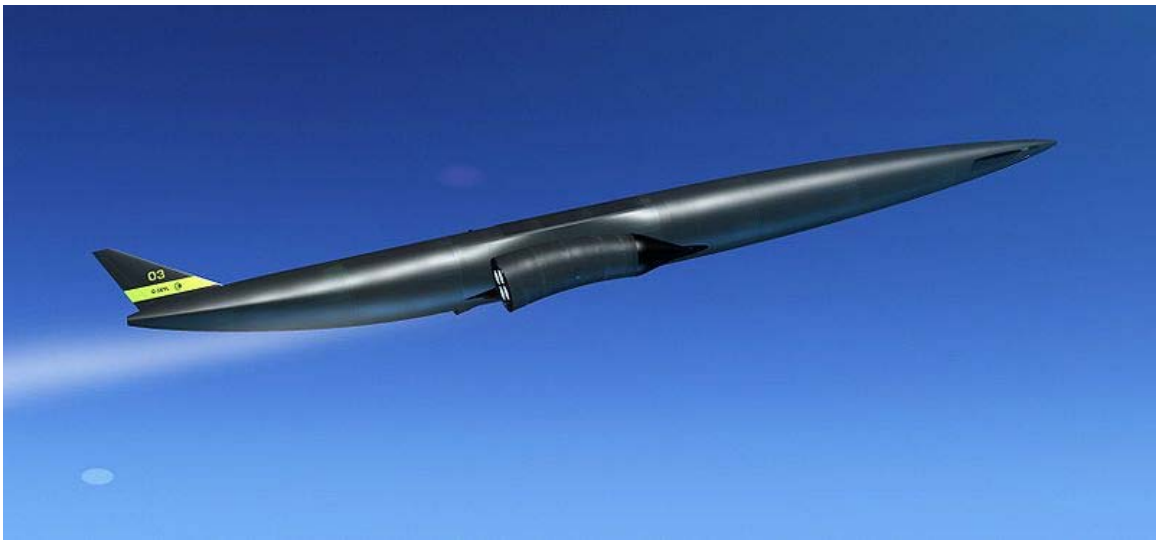
The Skylon vehicle is an aircraft designed to reach orbit

Role	Re-usable Spaceplane
National origin	UK/multinational
Designed by	Reaction Engines Limited
Status	Research and development
Number built	30 (projected)
Program cost	Projected to be £7.1 billion (~$12 billion est. 2004)
Unit cost	£190 million (projected)
Developed from	HOTOL

In aerospace, **Skylon** is a design by Reaction Engines Limited for an unpiloted, airbreathing single-stage to orbit, combined cycle jet engine based spaceplane. A fleet of vehicles is envisaged; the design is aiming for reusability up to 200 times. In paper studies, costs per kilogram of payload are hoped to be below the current costs of launch (as of 2006), including the costs of R&D, with costs expected to fall much more over time after the initial expenditures have amortised. The cost of the program has been estimated by the developer to be about $12 billion.

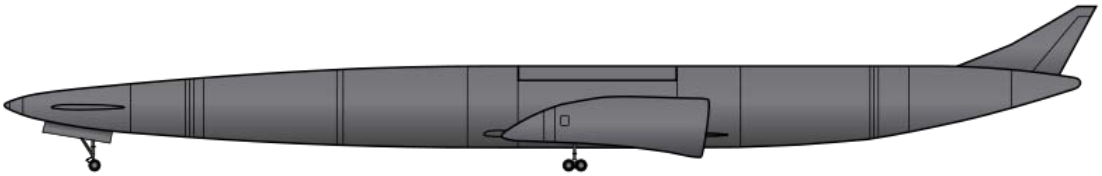
The vehicle design is for a hydrogen-powered aircraft that would take off from a conventional runway, and accelerate to Mach 5.4 at 26 km using atmospheric air before switching the engines to use the internal LOX supply to take it to orbit. It would then release a 12-tonne payload, then reenter the atmosphere. The payload would be carried in a standardised payload container or passenger compartment.

During reentry the relatively light vehicle would fly back through the atmosphere and land back at the runway, with its skin protected by a strong ceramic composite. It would then undergo any necessary maintenance and, if the design goal is achieved, be able to fly again within two days.



The proposed engine for the vehicle is not a scramjet, but a jet engine running combined cycles of a precooled jet engine, rocket engine and ramjet. Originally the key technology for this type of precooled jet engine did not exist - the required heat exchanger was about ten times lighter than the state of the art. However, research has now achieved the necessary performance. As of 2010, the funding required to develop and build the entire craft has not yet been secured, and so current research and development work is focused on the engines, under an ESA grant.

Technology and innovations



The Skylon spaceplane is designed as a two engined, 'tailless' aircraft, which is fitted with a steerable canard.

Structure of the fuselage

The fuselage of Skylon is expected to be carbon fibre space frame; a light and strong structure that supports the weight of the aluminium fuel tanks and to which the ceramic

skin is attached. Multiple layers of reflective foil thermal insulation fill the spaces of the frame.

The currently proposed Skylon will be a physically large vehicle, with a length of 82 metres (269 ft) and a diameter of 6.3 metres (21 ft) Because it will use a low-density liquid hydrogen fuel, a great volume is needed to contain enough energy to reach orbit. The propellant is intended to be kept at low pressure to minimise weight; a vehicle that is both large and light has an easier time during atmospheric reentry compared to other vehicles due to a low ballistic coefficient.

Because of the low ballistic coefficient, Skylon would end up slowing down at higher altitudes where the air is thinner, meaning the skin of the vehicle would only reach 1100 Kelvin. In contrast, the smaller Space Shuttle is heated to 2000 kelvin on its leading edge, and so employs an extremely heat-resistant but extremely fragile silica thermal protection system. The Skylon design need not utilise such a system, instead opting for using a far thinner yet durable reinforced ceramic skin. However, due to turbulent flow around the wings during reentry, some parts of Skylon would need to be actively cooled.

Skylon would employ a highly-loaded tightly spaced wheel assembly, to save weight and also interior space when the wheels are retracted into the fuselage. Because this wheel design distributes the weight of the aircraft and the force of its landing over a smaller area of the runway, it will need to operate from a specially strengthened runway. It will possess a retractable undercarriage with high pressure tires and water cooled brakes. If problems were to occur just before takeoff the brakes would be applied to stop the vehicle, the water boiling away to dissipate the heat. Upon a successful takeoff, the water would be jettisoned, thus reducing the weight of the undercarriage by many tons. During landing, the empty vehicle would be far lighter, and hence the water is unneeded. The payload fraction would be more than twice that of normal rockets and the vehicle should be fully reusable (200 times or more).

SABRE Engines

One of the significant features of the Skylon design is the engine, called SABRE. The engines are designed to operate much like a conventional jet engine at up to around Mach 5.5 (1700 m/s), 26 km altitude, and then close the air inlet and operate as a highly efficient rocket to orbital speed.

Operating an air-breathing jet engine at up to Mach 5.5 is difficult. Previous engines proposed by other designers have been good jet engines but poor rockets. This engine design aims to be a good jet engine within the atmosphere, as well as being an excellent rocket engine outside. The problem with operating at Mach 5.5 has been that the air coming into the engine heats up as it is compressed into the engine, which can cause the engine to overheat and eventually melt. Attempts to avoid these issues typically make the engine much heavier (scramjets/ramjets) or greatly reduce the thrust (conventional turbojets/ramjets). In either case the end result is an engine that has a poor thrust to

weight ratio at high speeds, and so the installed engine is too heavy to assist much in reaching orbit.

The SABRE engine design aims to avoid this by using some of the liquid hydrogen fuel to cool the air right at the inlet. The air is then burnt much like in a conventional jet. Because the air is cool at all speeds, the jet can be built of light alloys and the weight is roughly halved. Additionally, more fuel can be burnt at high speed. Beyond Mach 5.5, the air would still end up unusably hot, so the air inlet closes and the engine instead turns to burning the hydrogen with onboard liquid oxygen as in a normal rocket.

Because the engine uses the atmosphere as reaction mass at low altitude, it would have a high specific impulse (around 2800 seconds), and burns about one fifth of the propellant that would have been required by a conventional rocket. Therefore, it would be able to take off with much less total propellant than conventional systems. This, in turn, means that it doesn't need as much lift or thrust, which permits smaller engines, and allows conventional wings to be used. While in the atmosphere, using wings to counteract gravity drag is more fuel-efficient than simply expelling propellant (as in a rocket), again reducing the total amount of propellant needed.

"Single Stage to Orbit" capability

Currently, all orbital spacecraft use multiple stages. Having multiple stages requires the jettisoning of parts of a launch vehicle during the flight to reduce weight—otherwise the vehicle would be too heavy to reach orbit. A vehicle that can fly to orbit without staging is known as single stage to orbit (SSTO). Proponents of SSTO claim that staging causes a number of problems such as being difficult, expensive or even impossible to recover, reuse and reassemble the parts and therefore believe that SSTO designs hold the promise of reducing the cost of spaceflight.

The Skylon design aims to take off from its specially strengthened runway, fly into low earth orbit, reenter the atmosphere, and land back on its runway like a conventional aeroplane, without staging, whilst being fully reusable.

Payload bay

The payload bay of Skylon is a cylinder 12.3 metres long and 4.6 metres in diameter. It is designed to be comparable with current payload dimensions, and yet able to support the containerization of payloads that Reaction Engines hopes for in the future. To an equatorial orbit, Skylon could deliver 12 tonnes to a 300 km height or 10.5 tonnes to a 460 km altitude. It could also launch 9.5 tonnes to the orbit of the International Space Station, when launching from the equator. Using interchangeable payload containers, Skylon could be fitted to carry satellites or fluid cargo into orbit, or, in a specialised habitation module, up to thirty astronauts in a single launch.

Research and development programme

Skylon is based upon a previous project of Alan Bond, which was known as HOTOL. The development programme of HOTOL began in 1982, a time when space technology was moving towards reusable launch systems such as the American Space Shuttle. In conjunction with British Aerospace and Rolls Royce, a design emerged that proved highly promising, so much so that the British Government donated £2 million to further their work. However, in 1988, the government withdrew funding, and the development programme was terminated. Following this major setback, Alan Bond decided to set up his own company Reaction Engines Limited, with the hope of continuing development with private funding.

After having secured funding, the design of the craft was revisited, undergoing a rigorous redesign throughout much of the 1990s. In the last decade, Reaction Engines has been working with the University of Bristol to develop the engines vital to the success of Skylon. The STRICT/STERN engines produced by this programme were deemed a great success. They required heat exchangers far more advanced than what was available at the start of the project; having proved their design to be technologically feasible, the greatest engineering challenge has been solved. The next stage of development is to construct a full-sized working prototype of the SABRE Engine.

The differences between Skylon and its predecessor are numerous. For example, HOTOL was to have been launched from a rocket sled (to save weight), whereas Skylon uses a conventional retractable undercarriage. Skylon also uses a different engine design; the SABRE engine is expected to offer higher performance. Another issue that the Skylon design aims to circumvent was the intrinsically poor stability of HOTOL. The weight of the rear-mounted engine tended to make the HOTOL vehicle flip over mid-flight due to the center of mass lying behind the center of drag. Attempts to fix this problem ended up sacrificing much of the potential payload that the HOTOL vehicle could carry, and contributed to the failure of the project. Skylon would solve this by placing the engines at the end of the wings closer to the centre of the vehicle and thus moving the centre of mass forward, ahead of the centre of drag.

The complete Skylon project has a projected R&D cost of over $10 billion and will continue for another 7–10 years. In February 2009, the British National Space Centre and ESA announced that they were partially funding work with €1 million euros ($1.28 million dollars) on Skylon's engine to produce a demonstration engine by 2011.

The Technology Demonstration Programme will last approximately 2.5 years and will benefit from another €1m from the ESA. This programme will take Reaction Engines Ltd from a Technology Readiness Level (TRL) of 2/3 up to 4/5.

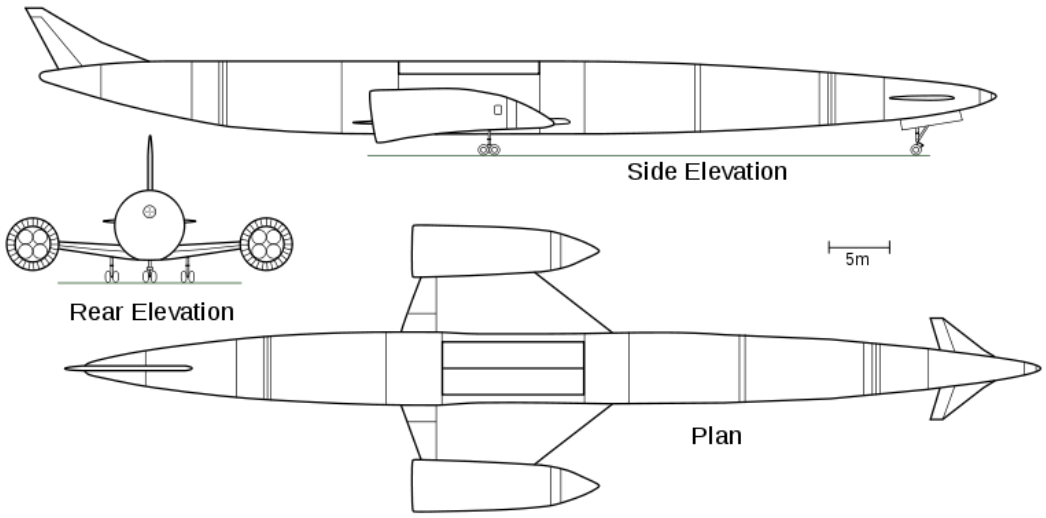
Economics and political will

The estimated R&D cost was $10 billion in 1992 including building a small fleet of aircraft. This translated into a payload cost of roughly $3000/kg.

The Skylon was designed for low cost, to use largely present day materials and to represent a low development risk. The ultimate estimated cost of launching a Skylon vehicle was estimated to be as low as $5 to $10 million.

Request for funding from the British government was undertaken in 2000, with a proposal that could have offered a large potential return on investment. The request was not taken up at that time. Subsequent discussions with the British National Space Centre led to agreement in 2009 on a co-funding agreement between BNSC, ESA and REL to continue technology development for the SABRE engine.

Specifications



Skylon C1 Specification:

General characteristics

- **Crew:** none
- **Capacity:** 40
- **Length:** 83.3 m (273 ft)
- **Wingspan:** 25.4 m (82 ft)
- **Height:** ()
- **Empty weight:** 53,000 kg (120,000 lb)
- **Loaded weight:** 345,000 kg (760,000 lb)

- **Powerplant:** 2× SABRE combined cycle ramjet, precooled jet engine, rocket, air:1350 kN, rocket: 1800 kN (air:1,330 LT; 1,490 ST, rocket:1,800 LT; 2,000 ST) each

Performance

- **Maximum speed:** orbital
- **Range:** orbital ()
- **Service ceiling:** 26,000 m airbreathing, >200 km exoatmospheric (85,000 ft airbreathing, >124 mi exoatmospheric)
- **Thrust/weight:** ~1.2 - 3 at burnout (~0.768 atmospheric)

- Fuselage diameter: 6.25 m (20.51 ft)
- Maximum payload mass: 12,000 kg (26,000 lb)
- Specific impulse: 3560 s (35 kN·s/kg) atmospheric, 450 s (4.4 kN·s/kg) exoatmospheric
- SABRE engine thrust/weight ratio: up to 14 atmospheric

Reaction Engines A2

A2

Artist's concept of the Reaction Engines A2

Role	Hypersonic Airliner
Manufacturer	Unknown
Designed by	Reaction Engines Limited
Status	Under design study

The **Reaction Engines Limited A2** (called the **A2**) is a design study for a hypersonic airliner. The airliner is intended to provide environmentally-friendly, long range and high capacity commercial transportation. It is being examined as part of the LAPCAT programme of the European Union. The plane has not been commercially launched yet, but Reaction Engines Limited, the British design firm, says it could probably be developed into a working aircraft within 25 years, if there is market demand for it.

Development

> “Our work shows that it is possible technically; now it's up to the world to decide if it wants it.”
>
> — Alan Bond, managing director of Reaction Engines Limited

The vehicle is intended to have about 20,000 kilometres (12,000 mi) range and good subsonic and supersonic fuel efficiency, thus avoiding the problems inherent in earlier supersonic aircraft. The top speed is projected to be Mach 5+. It calls for the use of liquid hydrogen as a fuel, which has twice the specific energy of kerosene, and can be used to cool the vehicle and the air entering the engines via a precooler.

The developers say it would be able to fly from Brussels to Sydney in about 4.6 hours; compared to around a complete day of travel with normal aircraft. The cost of a ticket is intended to be roughly business class level.

Design

Capabilities

The LAPCAT A2 concept in the upper atmosphere

Alan Bond told *The Guardian* newspaper:

> “ The A2 is designed to leave Brussels International Airport, fly quietly and subsonically out into the north Atlantic at Mach 0.9 before reaching Mach 5 across the North Pole and heading over the Pacific to Australia. ”

The great circle route is not used in this example because the route travels mostly over land. The sonic boom generated by travelling at supersonic speed can cause great discomfort for people on the ground.

Another advantage of the design is that, while the 143 metre-long A2 is much bigger than conventional jets, it would be lighter than a Boeing 747 and could take off and land on current airport runways.

However, the A2 design does not have windows. The heat generated by traveling so quickly makes it difficult to install windows that are not too heavy. One solution

Reaction Engines has proposed is to install flat panel displays, showing images of the scene outside.

Engines

The Scimitar engines use related technology to the company's earlier SABRE an engine which is intended for space launch, but here adapted for very long distance, very high speed travel.

Normally, as air enters a jet engine, it is compressed by the inlet, and thus heats up. This means that high speed engines need to be made of technologies and materials that can survive extremely high temperatures. In practice, this inevitably makes the engines heavier and also reduces the amount of fuel that can be burnt to avoid melting the gas turbine section of the engine, which in turn reduces thrust at high speed.

The key design feature for the Scimitar engines is the precooler, which is a heat exchanger that transfers the heat from the incoming air into the hydrogen fuel. This greatly cools the air, which allows the engines to burn more fuel even at very high speed, and allows the engines to be made of lighter, but more heat susceptible, materials such as light alloys.

The rest of the engine is described as having high-bypass (4:1) turbofan engine features to give it good efficiency and subsonic (quiet) exhaust velocity at low speeds. Unlike SABRE the A2's engine would not have rocket engine features.

Specifications

- **Range:** 20,000 kilometres (12,000 mi)
- **Length:** 143 metres (469 ft)
- **Fuel:** Liquid hydrogen
- **Passengers:** 300 (Single Class)
- **Cruising speed:** Mach 5
- **Specific fuel consumption**: 0.86 lbf/lb·h at Mach 5 (40,900 m/s - 4,170 seconds), 0.375 lbf/lb·h at Mach 0.9 (96,000 m/s - 9,600 seconds)
- **Lift to drag ratio:** 11.0 at 5.9 km, Mach 0.9, 5.9 at 25 km Mach 5
- **Noise:** 101 dBa at 450m lateral