# AERO 2075: FLYING INTO A BRIGHT FUTURE?

Institution of
MECHANICAL
ENGINEERS

## Part I:
## The importance of the UK aerospace sector to UK manufacturing

Improving the world through engineering

ENGINEERED
IN BRITAIN

Do aeroplanes need reinventing? Over the next 50 years, increased demand for air travel, combined with economic and environmental pressures, will create a tipping point for game-changing aircraft designs to move from the drawing-board into production.

Today, the UK is second only to the USA in global aerospace market share. But with long development cycles for new aeroplanes, are we ready to compete in a future where aircraft design and technology will be radically different?

This report has been produced in the context of the Institution's strategic themes of Energy, Environment, Education and Transport, its 'Engineered in Britain' campaign and its vision of 'Improving the world through engineering'.

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# EXECUTIVE SUMMARY

## FLYING HIGH: A UK SUCCESS STORY?

There are few other British industries that can claim to be as successful as our aerospace sector. With 17% global market share, the UK aerospace sector is the largest in Europe and second largest in the world after the USA. The sector generated £29bn in sales in 2010 and employs about 100,000 people throughout the country. The Government has stated on many occasions that it wants to move the UK away from its over-reliance on the finance and services industries and discussed the need to 'rebalance the economy'. Aerospace is one of the key industries which could help achieve this.

The UK aerospace sector's success is built on its reputation for high-quality product development, innovation, build and maintenance, all of which make companies such as Rolls-Royce and BAE Systems among the most recognised and respected brands in the world.

Although the UK may no longer independently produce large commercial aeroplanes, our expertise in areas such as engines, wings, landing gear and flight control systems, means 25% of the value of a Boeing Dreamliner and 50% of an Airbus A380 (when fitted with Rolls-Royce engines) is produced in the UK.

In research and development spending (R&D), aerospace is second only to the pharmaceutical sector, spending over £1.93bn in 2010 alone. Furthermore, 48% of this funding is self-financed by the industry with only a 24% contribution from the Government.

Some of the world's leading aerospace companies continue to invest in UK universities, such as Cranfield, Nottingham, Sheffield and Kingston, to create future engine and fuselage designs, develop advanced materials, as well as educate the next generation of aerospace engineers.

In all, the UK aerospace sector has a world-class reputation and an ability to innovate and reinvent. Yet our grip on the number two spot in the world is far from guaranteed over the next 20 years. Research and development investment is at an historic low and core capabilities, key facilities and infrastructure are all slowly eroding. If the UK does not create an economic vision for the future, we may well see one of our most important industries fall into decline – like so many other sectors of British manufacturing over the past two decades.

## TAKING FLIGHT: A SECTOR ON THE MOVE

Since the financial crash of 2008 and the subsequent global recession, the aerospace sector's R&D spend has effectively flat-lined. This historic low in research funding has made the UK's position vulnerable to nations such as China, India, Brazil, Russia and Japan, who are all looking to increase their aerospace capacity and global market share.

For the UK Government, which is seeking to strengthen the country's manufacturing capability, especially in advanced engineering and R&D, the UK aerospace sector is an outstanding model. However, aerospace is a global industry and big aircraft manufacturers are continuously looking to invest where conditions are most favourable i.e. where they can receive support for future development and build.

As airlines and legislators insist on ever more-efficient and greener aeroplanes, the R&D costs inevitably rise. Indeed, for the two biggest manufacturers, Airbus and Boeing, the cost of failure of a new product could bankrupt the company. The A380 is estimated to have cost about £10bn and the new mid-size Dreamliner about £11bn. Industry is therefore looking for nations which can be cost-competitive in terms of development and testing of new products.

As the competitor landscape widens with the emergence of new airframe manufacturers, there are more opportunities for aerospace manufacturers. However, the R&D investment opportunities being offered by emerging economies, not just the lower labour cost, mean the UK innovation supply chain is also under threat.

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**THE UK AEROSPACE SECTOR'S SUCCESS IS BUILT ON ITS REPUTATION FOR HIGH-QUALITY PRODUCT DEVELOPMENT, INNOVATION, BUILD AND MAINTENANCE.**

## A VISION FOR UK AEROSPACE

Rolls-Royce, Airbus and BAE Systems alone contribute over 65% of the amount the aerospace sector spends on research and development. Yet self-reliance has made the sector a victim of its own success. Indeed, following the Business, Innovation & Skills (BIS) Select Committee 2010 report which examined state funding for research and development, there have been strong concerns from the sector that Government wants to divert funding away from aerospace, as it feels the sector can support its own developmental costs.

In economically difficult times, there would be little wisdom in removing funds from the technology innovation needed to secure the future of a sector so vital to UK manufacturing. Indeed, removal of funding at a time when other nations are looking to incentivise companies to relocate facilities, could again demonstrate a lack of long-term vision and planning by the Government when it comes to developing our manufacturing sector over the next 20 years.

In 2003 the BIS Aerospace Innovation and Growth Team (AeIGT) set out a 20-year vision for the sector, including the creation of a National Aerospace Technology Strategy (NATS) based on a number of roadmaps for key UK technology capabilities such as airframes, rotorcraft, and air traffic management. Yet funding has been radically reduced, with a potential shortfall in R&D funding of £500m by 2015. The NATS roadmaps currently outline the requirement for a £1bn investment programme over the next five years.

The Institution of Mechanical Engineers is concerned that the UK lacks key strategic facilities for long-term R&D. It is acknowledged that science-to-business partnerships do exist within the UK, but we are lacking a national aerospace research institute, such as ONERA in France or DLR in Germany. This could place the UK at a disadvantage in the long term.

An advanced technologies research institute would provide clarity and direction, co-ordinate research and avoid costly duplication in projects while allowing individual partnerships to continue. The Institution of Mechanical Engineers believes that a dedicated institute would better co-ordinate early technology investments which could yield valuable returns on investment. Furthermore, for the aviation industry to meet its 2050 carbon obligations, research into significant technology advances is needed.

If the Government fails to recognise the significance of future investment and support of the UK aerospace sector, other nations will undoubtedly step in, ultimately reducing the UK's global market share.

## FUTURE SKIES

Over the next 20 years the airline industry is predicted to order over 25,000 new aircraft with a market value in excess of $3 trillion. With limited growth in Europe and North America predicted, it will be the rapid expansion of domestic routes in Asia and South America which will drive demand.

The growth of global air travel will be matched by increasing levels of legislation on emissions and noise, and a desire to reduce fuel consumption while carrying ever more people by aeroplane.

Extensive R&D has gradually improved all these aspects over the years. Indeed, a Boeing 747-8 is 16% more fuel-efficient than a 747-400 built only five years ago. A new A380 can carry 40% more passengers than a 747-400 but uses 20% less fuel per passenger and is 50% quieter on take-off.

As aerospace companies improve efficiencies by small increments, they also need to be looking at more radical redesigns of future aeroplanes for subsonic, supersonic and hypersonic travel. The UK Committee on Climate Change predicts that carbon emissions from air travel will not reduce at all by 2050. This is against the backdrop of 80% reductions elsewhere. This would leave air travel contributing 25% of all emissions by 2050, which is clearly unsustainable.

Ultimately, the switch from the common design of a cylindrical tube with wings to more radical designs, such as blended wings, will occur only when the airline industry can see the risk reduced in taking such a step change. If the UK can maintain its global standing as a leading aerospace innovator, the country could be leading the next generation of greener and cleaner aeroplanes, providing greater comfort and affordability to airlines and passengers alike.

## RECOMMENDATIONS

1. **Industry and Government should agree a strategic vision for investing in the UK's aerospace sector, as this is vital to our recovering economy.** We cannot assume that the sector will be able to thrive without the necessary support and skills. Against increasing competition from emerging markets, investment in R&D, skills and infrastructure can help to ensure this UK manufacturing sector contributes to the Government's vision of a rebalanced economy.
2. **Establish a UK Advanced Technologies Aerospace Research Centre.** While the Institution welcomes the Government's recent measures to support advanced manufacturing, the Institution also supports industry calls for a dedicated aerospace research centre. The unique pressures on aerospace (large-scale and investment-intensive technology validation programmes) require a national, single focus for research with world-class facilities.

   The Government must see the value of this long-term vision in research to underpin our current world leader position. Air travel is a great enabler for economic growth and the UK is already in a leading position.

   Emerging economies are responding to climate change, which will be a key influence in the market in the medium to long term. More formation flying, permanent automatic pilots and new aircraft designs could all be seen in the skies over the next 50 years.
3. **Ensure UK plc is an attractive investment location.** Government to restore R&D support to pre-recession levels. Aerospace needs scale, so the UK must ensure funding is not diluted across many organisations and competitions. Funding must also be easily accessible to SMEs and companies looking to enter the aerospace supply chain.


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**THE AIRBUS A380 IS REPORTED TO HAVE COST UP TO £10.6BN TO DEVELOP.**

# AERO 2075: GAME-CHANGING INNOVATION

The current, familiar outline of a commercial airliner has remained essentially unchanged for over half a century. The 'cigar tube with wings' has proven both flexible and efficient and will certainly be with us for many decades to come.

The history of aircraft design has provided radical designs that sought to solve one or more of the eternal aviation issues: how to carry more passengers but use less fuel, and how to fly faster or more quietly with less environmental impact.

In 2008 the Society of British Aviation Companies (SBAC) (now known as A|D|S) produced the first $CO_2$ roadmap for UK aviation. Since then this has been pivotal in the discussions with Government and the Committee on Climate Change (CCC) to ensure that the industry's views are being taken into account. This year Government has revisited this roadmap through the process of a consultation which is looking into sustainable aviation.

Great gains have been made in the efficiencies of jet engines and wing design, but these have been hard won and future improvements will be incremental at best. Innovation, in everything from the computer models used to create more efficient aerodynamic shapes, to new weight saving materials and manufacturing techniques, can and must play a defining role in reshaping the commercial aircraft of 2075 and beyond. Across the industry operating costs need to be cut, which means there is a need to reduce fuel usage and reduce emissions.

However, the enormous costs of development, and swingeing financial penalties should a new programme suffer delays or fail, means the current business model does not encourage radical innovation.

This uneasy status quo will not persist forever. In coming decades, factors such as spiralling fuel or carbon costs will tip the balance and make a step change necessary.

Aircraft are designed to meet market needs but must comply with legislation. The design of the new A380 Superjumbo was influenced in part by the noise level rules enforced around London Heathrow, which has long been one of the world's busiest aviation hubs.

These forces – environmental, economic and legislative – will provide the hard points against which the aeroplanes of 2075 will be measured. The market may not be ready today, but work being done now, and in the decades to come, will lead, step by step, to the aviation advancements being used at the end of this century.

This presents a unique opportunity for the UK.

No longer a manufacturer of large commercial aircraft, we nevertheless retain world-class engineering capability, especially in the development of aerodynamics, wings, engines and manufacturing techniques.

Could it be that the formidable challenges facing the aviation industry in the 21$^{st}$ century may present the UK aviation industry with its greatest opportunity since the Rolls-Royce Type R engine evolved into the Merlin?

# EVOLUTION OF TODAY'S MARKET

## HIGH RISK + BIG INVESTMENT = LONG LIFE

New civil aircraft design and manufacture is a high-risk business. The magnitude of the investment required is restrictive and has created a market dominated by two companies: Boeing and Airbus.

The UK is number one in Europe and second only to the USA worldwide in aerospace revenues, with a 17% global market share. A large percentage of this income is derived from military funding. For the purpose of this report, the Institution has chosen to focus mainly on the future of the civil aviation industry. However, some examples from the defence sector are included.

Concorde was Britain's last foray into whole large commercial aircraft development; built in partnership with France, it reportedly cost the UK £1.2bn.[1]

Today, the A380 Superjumbo is reported to have cost Airbus between £9.8bn and £10.6 bn (€11bn and €12bn)[2&3] to develop. Analysts say the final development bill for the new Boeing mid-size Dreamliner, including penalties for delays, could be about £11.3bn ($18bn).[4]

The level of investment for new aeroplane development, incorporating new technologies and the rigorous and lengthy testing required to meet legislation standards, means the production of a new aircraft family inevitably follows a 'generational' timeline (about 30 to 40-year life cycle).

To succeed, both market leaders rely significantly on government or tacit state support for suppliers – a source both of contention and legal actions between Airbus and Boeing.

Within Europe, countries such as France, Germany, Spain, Italy and the Netherlands all have some form of launch investment: risk-sharing government financial support for early technology development. US support for Boeing tends to be more indirect, with the company benefiting from R&D programmes run by NASA and the Department of Defense.

Once certified and in-service, improving the operational efficiency of a particular family of aircraft by reducing the fuel consumption and emissions, while maintaining high passenger loads, is achieved incrementally through technology developments in engine performance, materials and control systems.

For example, Boeing's first 747 jumbo jets went into commercial service on 22 January 1970. To date, Boeing has built 1,418 aircraft over four series in the 747 family. The latest model, the 747-8 Intercontinental, took its maiden flight on 20 March 2011[5] and secured £3.4bn ($5.4bn) worth of orders at the 2011 Paris Airshow.

Technology developed for the Dreamliner aircraft, has led to the current series 747-8 being 16% more fuel-efficient with a seat-mile cost of 13% lower than even the 747-400 series produced in 2007.[6]

The aerospace industry has taken huge leaps forward since the advent of human-powered flight. From the use of jets to pressurised cabins allowing high-altitude flight, to the first 747 'Jumbo jet' and now the 'Superjumbo', the relative 'conservatism' of recent decades looks like an anomaly.

## BOLD BREAKTHROUGHS

Just over a century after the Wright brothers took to the skies, Singapore Airlines took delivery of the first Airbus A380 on 15 October 2007. The double-decker, four-engine aircraft, the largest in the world, carries 525 passengers (in a standard three-class configuration) but can seat more than 800 if necessary (over 40% more than the Boeing 747-400). It has a flying range of 8,300 nautical miles (15,300km), uses 20% less fuel per passenger than the 747-400 and is 50% quieter on take-off.[7] It is the greenest, cleanest and quietest aircraft built to date with a price tag of just over £233m ($375m) per aeroplane.[8]

While the A380 is an engineering triumph and Airbus has an order book of 236 new aircraft with 53 already delivered and in operation,[9] shareholders are waiting to see if the formidable investment pays dividends. Only long-term success, measured over decades, will establish whether this was the right strategy for Airbus.

What we are witnessing today is not just the competition between two major aeroplane producers, but a contest of visions. Boeing and Airbus have developed new aircraft based on a premise that one of two modes of air travel will prevail.

The Airbus Superjumbo assumes increased demand from airlines and their customers for a ‘hub-and-spoke’ model. To improve operational efficiencies and ultimately profits, passengers will travel en masse aboard high-load, fuel-efficient aircraft between major hubs and then transfer to connecting flights for their final destination.

Conversely, the new mid-size Boeing Dreamliner, which seats 467 in a three class configuration, assumes that passengers and airlines will want a highly efficient aircraft that can operate increased point-to-point flights, opening up more existing airports and potentially new ones across the world that are not part of the hub-and-spoke system.

Over the next ten years the aerospace industry and shareholders will discover who took the right commercial decision. The winner will be the company that most accurately predicts or shapes consumer behaviour.

Both visions attest to a single truth, which is that air passenger numbers will continue to rise. Air travel is becoming globally pervasive and rising per capita incomes in China, India and South America will see passenger travel grow inexorably as disposable income increases.

In parallel, fuel costs have escalated rapidly over the last decade, today accounting for 29% of an airline’s operating costs[10] and environmental legislation on noise and pollution has increased pressure to reduce emissions.

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**SINCE 1970, BOEING HAVE BUILT OVER 1,418 747S OVER FOUR SERIES.**

# READY FOR RADICAL CHANGES?

Increased demand for air travel, rising fuel costs, reduction in availability of scarce resources and environmental pressures could create a tipping point in the next 50 years which forces the classic ‘tube and wing’ architecture to draw to a close.

The International Air Transport Association’s (IATA) technology roadmap for environmental improvement, developed with more than 20 industry partners, has identified that achieving a combination of hybrid-wing-body, variable cycle engine and fuel cell system could deliver a 25%–50% fuel burn reduction from 2020–2030 onwards. [11]

Companies are already working on radical designs and technologies that could transform the way we fly.

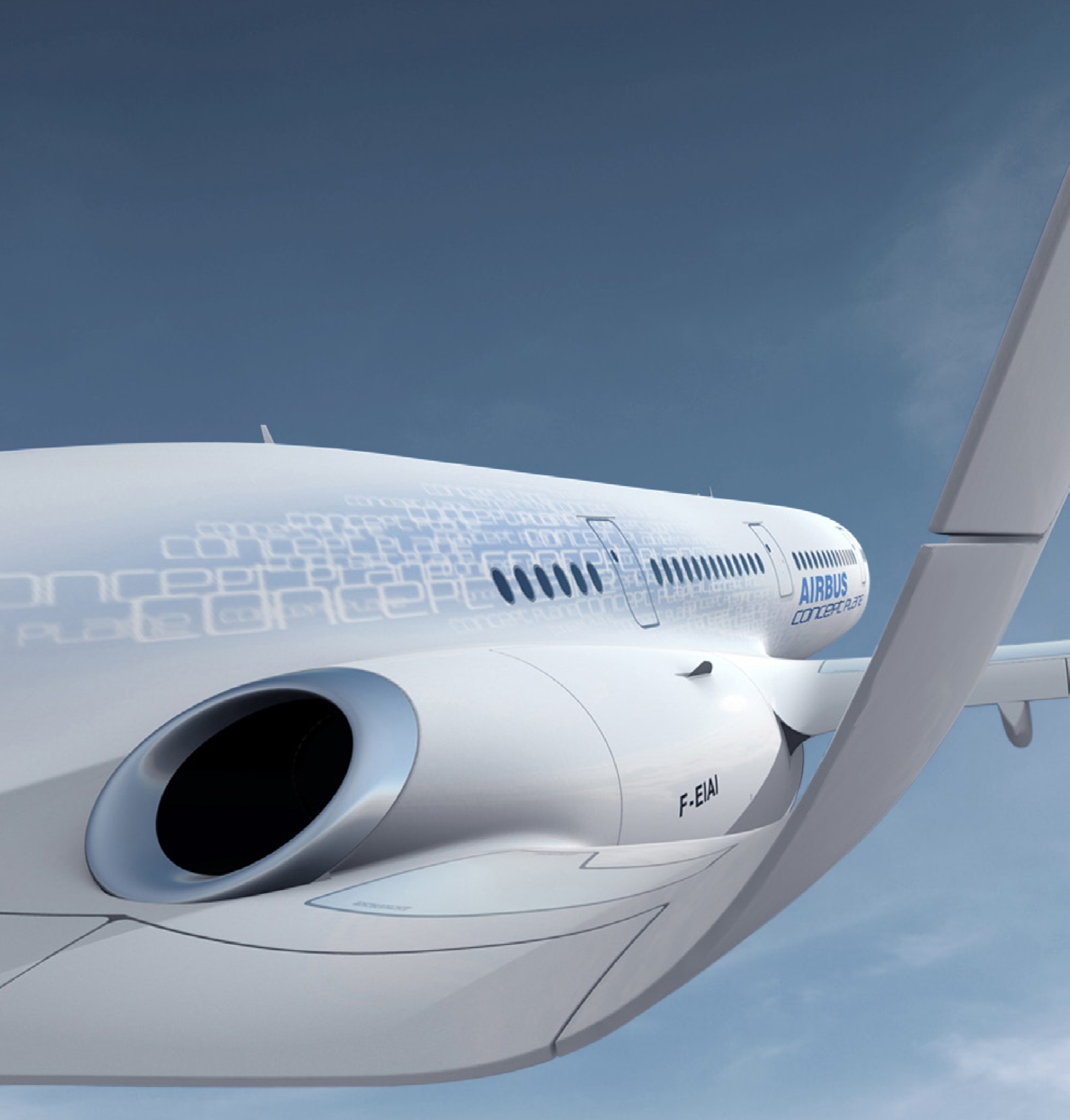
The question is, “When change does happen – will Britain be able to retain and grow its world-class aerospace industry?”

With such long developmental cycles, decisions taken in the next ten to 20 years will impact on Britain’s long-term competitiveness within this industry over the next 50 years.

Not having a strong vested interest in whole aircraft development could liberate UK aerospace companies and academics to go further and faster in developing the new systems, components and materials required for game-changing aircraft design.

But the UK aerospace industry needs the right support mechanisms to capitalise on prospective radical shifts in design and technology and the confidence to commit.

This report sets out the visionary ideas already in play for 2075, the disruptive technologies required to deliver these visions, as well as identifying potential opportunities for UK companies to turn these opportunities into commercial success.

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**AEROSPACE COMPANIES ARE ALREADY WORKING ON RADICAL NEW DESIGNS THAT MAY TRANSFORM THE WAY WE FLY.**

# UK AEROSPACE: ENGINEERING TRIUMPH, FRAGILE FUTURE?

## SHARING IDEAS, BUILDING SUCCESS

Over the past century, British engineering expertise has left an indelible mark on the history of world aviation, often radically transforming mechanical flight.

In the early days of the industry a ‘hot house’ engineering environment existed and there was a free flow of ideas, especially between the rapidly developing worlds of aerospace and automotive, that would have profound impacts.

Brooklands, Surrey, was the incubator for much of the modern aerospace industry; the world’s first technology park encircled by the first purpose-built motor racing circuit, it was the focal point for a generation of engineers, adventurers and entrepreneurs. Brooklands was all about speed, and the desire to go faster has long been one of the defining goals and drivers of aerospace innovation.

The fledgling aeroplane companies benefitted from developments in materials, manufacturing and lubrication technology that were tested – often to destruction – in the automotive endurance races and speed trails taking place on the vast, banked concrete track. Aerodynamics was a new science being keenly investigated, and there is evidence that pioneering racers in the 1920s were evaluating their cars in Brooklands wind tunnel, sharing what they learned about stability and cooling at speed with their aircraft colleagues.

The idea of an air-speed competition was made reality by French aviation enthusiast, Jacques Schneider in 1911. This fired the imaginations of British aerodynamicists such as R J Mitchell. His series of Supermarine aircraft raised the technology bar and speeds, culminating in the 6B. The 6B won the Trophy outright in 1931 and, a few weeks after the competition, set a world record speed of 407.5mph.

This was not simply an esoteric exercise. The Supermarine programme greatly boosted aerodynamic understanding and use of all-metal monocoque construction. It also prompted the rapid development of the Rolls-Royce Type R engine. These led, in turn, to the Merlin and the Spitfire – two of the most iconic and influential pieces of mechanical engineering in history.

A year before the Supermarine’s ultimate victory, Frank Whittle had patented his idea for a turbojet engine. The story of his struggles with funding, physical collapse and ultimate success is well known and uncomfortably prescient: Britain very nearly failed to capitalise on the game-changing technology it had in its hand.

In 1952, the de Havilland Comet ushered in the era of the commercial jet airliner and looked set to make the UK the world leader in jet travel. However, a series of design flaws, principally the inclusion of a square window design in the fuselage which created stress points leading to crack propagation, lead to a series of crashes and loss of life. Confidence in UK-built aircraft was severely shaken and the uniquely high-profile, high-stakes environment of the aerospace industry plain to see.

Lessons were learned from the Comet experience, not least in terms of materials science, modelling and testing. These found their ultimate expression in Concorde, which took its maiden flight in 1969. By this time, Boeing’s 707 had become the market leader, filling the void left by the Comet’s failure. Concorde’s *raison d’être* harked back to the early days of Brooklands: to travel as fast as possible.

It was also, famously, a commercial disaster. Staggering state-supported development costs could never be recouped by the profits generated by the mere 25 craft in eventual service. Its Rolls-Royce Olympus engines were powerful but fuel-hungry, and 70 potential orders were cancelled during the 1973 oil crisis.

The aircraft came to symbolise a duality that confronts the modern aerospace industry today: it pushed technological boundaries to deliver other-worldly capability, but at vast cost and with crystallised debates about emissions and noise.

# UK AEROSPACE: PUNCHING ABOVE OUR WEIGHT

Within the UK, 70% of the aerospace industry's revenue comes from exports driven primarily (39%) by civil aerospace activities, and there is a strong heritage of knowledge transfer into the wider economy. The use of carbon fibre by the UK motorsport industry for example, evolved from aerospace R&D in lightweight materials to reduce aircraft weight and improve fuel efficiency.

While Rolls-Royce and BAE Systems feature in the Top 20 global aerospace companies,[12] for every contract they win, they are supported by hundreds of innovative companies across the UK supply chain. 55% of UK civil aerospace sales are from SMEs and 19% of SME revenue is derived from exports.†

UK aerospace remains less dependent on Government defence spending to boost industry growth than other countries (19% of total sales, compared to 57% in the USA), and has developed a robust and globally competitive civil aerospace industry.

Despite a year-on-year decrease in orders since 2007, the £29.08bn of aerospace orders received in 2010 is still above the average for the last decade of £27.5bn. Recent declines are mainly the result of defence spending cuts, as civil aerospace orders actually rose by 3% last year.

Although employment levels may have dropped from 100,327 to 96,510 from 2009 to 2010, with demand projections of 26,000 new civil aircraft up to 2029, the outlook for growth over the next decade is positive but not assured.

Within the UK there are a number of companies and universities that have an aerospace R&D focus.

The Aircraft Research Association (ARA) is an independent research and development organisation that offers a range of services including experimental aerodynamics, computational aerodynamics, design and manufacture.

QinetiQ is another company that is an independent provider of impartial technology-based advice, test and evaluation. It offers a range of R&D facilities including a low-speed wind tunnel, which is one of just three in the world and is used regularly by Boeing under a ten-year contract. QinetiQ also operates the West Wales UAV Centre, Europe's only airspace where unmanned aerial vehicles (UAV) can be tested and flown, providing expert support and facilities to complete the acceptance trials for the MOD's Watchkeeper UAV system.

Along with these two organisations there are also a number of universities that have active involvement with R&D and the training of UK and overseas aerospace engineers. Notable examples include Cranfield, Nottingham, Sheffield and Kingston.

Footnote: Unless otherwise indicated, all figures are taken from the UK Aerospace Industry Survey 2011 published by A|D|S, 9 June 2011

† Data taken from UK Aerospace Industry Survey 2011, but the number of responses received from SME companies is volatile year-on-year and represents a small fraction of the total SME community; as a result absolute figures may not give an accurate picture of the SME community.

## WHO BUYS BRITISH?

The UK has a reputation as a world leader in the manufacture of aircraft wings and engines. UK-based companies design, develop and manufacture 25% of all aircraft engines sold around the world and the wings for 50% of all large aircraft.[13]

Importantly, 25% of the value of a Boeing Dreamliner is made in the UK and 50% of the value of the Airbus A380 (both when fitted with Rolls-Royce engines) is made in the UK.[14]

Furthermore the UK makes and exports to aircraft manufacturers around the world major equipment such as landing gear, flight control systems, avionics and electrical power systems.

According to the latest industry figures, the European Union is the main purchaser of UK aerospace products (£6.53bn in sales), followed by ‘the rest of the world’ (£6.46bn in sales) and the USA (£3.07bn in sales).

Sales of aircraft systems and frames accounted for just over a third of UK aerospace revenue in 2010 (36.2%), aircraft equipment sales for just over a quarter (25.6%) and revenue from aircraft engines just under a quarter (24.7%).

## GROWING GLOBAL COMPETITION?

The leading aerospace global players have established operations in the UK. This is a testament to our engineering talent that has been exhibited through the speed at which new aerospace technology innovations have reached the market, and as a reflection of the quality of manufactured products.

UK aerospace R&D is predominantly self-financed, with industry accounting for 48% of a £1.77bn spend in 2010 and UK Government funding contributing 24%. The global recession has triggered a flat-lining of R&D spend over the past two years which, according to analysis by A|D|S, the trade organisation advancing the UK aerospace, defence, security and space industries, is now at a ‘historical low’.

In the meantime, China and India both seek to build their indigenous aerospace capability and Brazil and Russia are also looking to increase their share of the global market. In this context, any decline in UK R&D makes our position vulnerable.

The major aerospace contractors rely on a robust supply chain that can move technology rapidly from university research to production, and a lack of investment could see other countries race to fill the gap. If we are to compete in the next game-changing generation of aircraft, we need to invest to win.

**Growing Competition from India**

One of the main threats to the UK supply chain comes from India, whose aerospace industry has seen dramatic growth over the last few years. Already Airbus has established an Indian design and research centre and plans to employ over 500 engineers by 2012. Boeing is also planning to spend $1bn on aerospace manufacturing work and has established Boeing International Corporation India to support the growing demands of India’s aviation, aerospace and defence industries.

The Indian State is heavily supporting this investment by offering valuable tax incentives, establishment subsidies, and providing access to state-owned resources – both infrastructure and inter-governmental alliances for design and manufacturing.

# INVESTING TO WIN: THE POLITICS OF AEROSPACE

When the British Government cancelled the BAC TSR-2 military strike-and-reconnaissance aircraft in 1965, the renowned aeronautical engineer, Sir Sydney Camm, said, "All modern aircraft have four dimensions: span, length, height and politics. TSR-2 got just the first three right..."

Over 50 years later, 'politics' both state and commercial continue to play a pivotal role in the race to build super-efficient, profit-making aircraft.

In the UK, as Government seeks to 'rebalance' the economy, aerospace is an outstanding example of our advanced manufacturing capabilities. Our industry produces world-class high-technology products, delivers exports, employs large numbers of highly skilled people and generates significant spin-out and spill-over effects.

But aerospace is a global industry and the big aircraft manufacturers look to invest where conditions are most favourable. The UK has always been an attractive hub for technology innovation and manufacturing, competing predominantly with the USA, France and Germany.

But the competitor landscape is widening with the emergence of new airframe, equipment and engine manufacturers from China, India, Brazil, Canada, Japan and Russia. While these countries represent an opportunity for some of our global firms, they also pose a threat to our innovation supply chain. It is not just their lower labour costs that are attracting investors; these are powerful emerging economies with the capital to invest in research and development.

Public-funded R&D opportunities for aerospace companies are the lifeblood of new aeroplane development, but are high risk and long return on investment projects. This makes these funding mechanisms a source of political and legal controversy.

Boeing and Airbus have been locked in a seven-year battle at the World Trade Organisation over government subsidies that the *New York Times* describes as "the most complex and voluminous case ever to have been brought before the global trade body."[17]

We must ensure these disruptive technologies don't fall into the R&D 'Valley of Death' just because we couldn't transition them from the laboratory to the market fast enough.

## RESEARCH AND TECHNOLOGY (R&T) TO RESEARCH AND DEVELOPMENT (R&D)

In 2010, total UK aerospace industry (civil and defence) research spending was £1.93bn – largely unchanged from the previous year. The total R&D spend amounted to £1.77bn, again unchanged from 2009 and R&T fell by 1% to £159m.[18]

In the UK, R&D funding is predominantly self-financed by industry (48%) with Government providing just under a quarter (24%) of total R&D expenditure.[18]

In comparison to other industries, aerospace is still an R&D intensive industry, second only to pharmaceuticals in the UK. In the table of the UK's top 1,000 R&D investors, Rolls-Royce, Airbus and BAE Systems dominate the R&D spend, together comprising 65% of the aerospace sector total and just over 4% of the overall UK R&D spend.[19]

While the global recession has inevitably led to budget tightening across the private and public sector, the aerospace community also believes it has become a victim of its own success.

In a report published by the Business, Innovation and Skills (BIS) Select Committee in 2010, leading figures from the aerospace community suggested public R&D funding was moving away from aerospace because of a perception that the sector had "got more than its fair share and therefore we [Government] need to divert a bit to demonstrate that we are not giving more than a fair share to aerospace."[20]

But it is precisely because aerospace has a track record of success that in tough economic times, when companies are struggling to increase R&D investment, that Government needs to stay committed to investing in technology innovation.

The major players are already taking advantage of opportunities in India and the Far East: in 2007, EADS opened a technology centre in India; Rolls-Royce has been operating in China for 40 years; and Airbus opened the company's first assembly line outside Europe in Tianjin, China in 2008. The emerging nations pose a threat to the UK supply chain.

In 2004, a report commissioned by the Farnborough Aerospace Consortium predicted that between 30% and 50% of the UK aerospace industry's smaller suppliers could close due to competition from low-cost economies.[21]

## BIG TICKET INVESTMENTS

Long payback periods, high product development costs and high technological and market risks have made the capital markets reluctant to invest in new generations of aircraft.

To secure contracts, either direct (government launch investment) or indirect (tax breaks, access to national research programmes) support from Government is essential.

France, Germany, Spain, the Netherlands, Italy and the UK all have a form of 'launch investment'. In the USA, companies benefit from NASA, the Department of Defense research programmes and individual state tax breaks.

In the UK, Repayable Launch Investment (RLI) is a risk-sharing Government investment for the design and development of civil aerospace projects. The investment is repayable at a real rate of return, usually via levies on sales of the final product. There is no formal budget for RLI, instead each application is considered on its merits against a range of established criteria and also by the Treasury, against Government priorities and constraints on public spending.

According to BIS, over the last 25 years the Government has invested nearly £1.9bn in RLI projects, receiving £2.4bn in income as a return on investment.[22]

Recent projects include:[23]

- £114m to Bombardier Aerospace (Shorts) in Belfast towards the development of the CSeries composite wing (July 2008)
- £60m to GKN for the design and development of Airbus A350XWB trailing edge and rear spar composite wing components (September 2008)
- £340m to Airbus towards development of the A350XWB (August 2009)

In 2010, RLI expenditure totalled £100m, while committed expenditure to 2013/14 is an average of £70m pa.[18]

While RLI has supported large-scale projects, it has not been an effective financial resource for equipment manufacturers. In 2005, the then Department for Trade and Industry reported to the Trade and Industry Select Committee that no equipment manufacturer had received launch aid since 1982. The Committee urged Government to "adopt a more positive attitude towards applications by equipment makers" as "the development of aerospace equipment has become increasingly complex, risky and expensive."[24]

Governments also help aerospace exports by guaranteeing loans: the Export Credits Guarantee Department in the UK, Coface in France, Hermes in Germany, and the Export-Import Bank of the United States all provide these services. Companies operating across EU states have to co-ordinate activity with multiple agencies. Currently there is no appetite from the UK Government to devolve this work into one single administration. [25]

BIS facilitates new investment and where appropriate considers the case for public funding support, with initiatives such as the Technology Strategy Board (TSB) and opportunities such as the Regional Growth Fund which, for example, will address policy issues directly affecting the sector at an international level such as World Trade Organisation (WTO) trade policy matters and environmental legislation.

# FUNDING TECHNOLOGY INNOVATION

**A National Strategy**

In 2003, an Aerospace Innovation and Growth Team (AeIGT) comprising representatives from industry, academia and Government set out a 20-year vision for the aerospace sector. The AeIGT recommended the establishment of a National Aerospace Technology Strategy (NATS) with a focus on core strengths mapped to what aircraft are coming into service over the next ten to 20 years.

*"The UK will offer a global aerospace industry the world's most innovative and productive location, leading to sustainable growth by 2022."*[26]

The strategy is based around a series of roadmaps for key UK technology capabilities: Airframes and Structures, Rotorcraft, Powerplants, Equipment, Autonomous Systems and Air Traffic Management.

The NATS roadmaps currently outline the requirement for a £1bn investment programme over the next five years. When NATS was launched there were dedicated 'aerospace' calls for funding to support NATS via the Civil Aeronautics Research and Technology Demonstration (CARAD) Programme which helped industry to focus its research tenders. Since 2007/2008 the funding has been subsumed into the Technology Strategy Board where programmes are across technology areas e.g. advanced materials, nanotechnology rather than industry sectors.

In 2010, NATS received about £150m in funding from industry and Government (Central and regional), with both parties sharing the costs equally since NATS launched. Underpinning, early R&T research for NATS comes from the Research Councils, specifically the Engineering and Physical Science Research Council (EPSRC).

Although funding for NATS has increased year on year, looking forward the figures outline huge shortfalls in requirements (potentially £130m in 2011, £180m in 2012 and £260m in 2013).

NATS will continue to support a rolling programme of innovation and could provide the framework for developing the technology required for radically new aircraft design from 2075.

The Coalition Government has dissolved the Regional Development Agencies (RDAs) and replaced them with Local Enterprise Partnerships (LEPs). Government see these LEPs as having an important role to play within the aerospace industry. Indeed there is a critical need for the LEPs to work with BIS to ensure that local initiatives are consistent with the national UK aerospace policy and that issues which affect the sector locally are raised with the aerospace team. Examples of this would be if there was an opportunity for a new supply chain business to grow or conversely if there were jobs or facilities at risk of redundancy and closure.

"" THERE IS A CRITICAL NEED FOR LEPS TO WORK WITH BIS TO ENSURE LOCAL INITIATIVES ARE CONSISTENT WITH THE UK'S AEROSPACE POLICY.

**One-Stop-Shop**

The Institution of Mechanical Engineers is concerned that the lack of key strategic facilities in the UK aerospace industry are eroding and jeopardising our technology capability.

While there are a number of successful models of science-to-business partnerships, including the Rolls-Royce University Technology Centres, the Advanced Manufacturing Research Centre supported by Boeing and the National Composites Centre, many believe the UK is now at a disadvantage because it lacks a national aerospace research institute akin to ONERA in France and DLR in Germany.

The Aerospace Technology Steering Group (ATSG) argues that “large-scale technology validation is essential in aerospace, and despite increasing use of simulation, key experimental facilities are needed to mature technologies to acceptably low risk for application to products… and there tends to be strong national alignment between facilities and capability. In the medium to long-term, skills aligned to design and manufacture, will tend to cluster around world-class facilities. These can be large and costly to maintain… but are essential to the future success of the aerospace industry.”[26]

In many countries, these facilities tend to be government-owned and part of a national research establishment, but in the UK they frequently operate as “independent cost centres owned by private companies or universities and as such are at risk of under-investment and/or closure due to under-utilisation.”[26] While short-term solutions have been found, such as the Noise Test Facility at QinetiQ, the ATSG is calling for a long-term plan for strategic facilities in the UK.

Such facilities would also help overcome a current “lack of single focus for research carried out nationally”. The Institution of Mechanical Engineers believes this puts the UK at a disadvantage within European research programmes and that a dedicated resource would better co-ordinate early technology investments which could yield valuable returns on investment. Furthermore, if it were established as an institute, it could ensure better co-ordination of research centres and enable the R&D facilities to work together.[27]

**Adding Value**

Research conducted by the Oxford Economics consultancy found the contribution of Rolls-Royce alone to the UK economy in 2009, was £7.8bn of value added-output, out of Britain’s total GDP of £1,400bn. Nearly half of this value (£3.4bn) was identified as a ‘spill-over’ effect, i.e. technology ideas developed by Rolls-Royce that have filtered through to other areas of the economy.[1]

**Recommendation**

Establish a UK Advanced Technologies Aerospace Research Institute. While the Institution welcomes the Government’s recent measures to support advanced manufacturing, the Institution also supports industry calls for a dedicated aerospace research establishment. The unique pressures on aerospace (large-scale and investment-intensive technology validation programmes) require a national, single focus for research with world-class facilities.

The Government must see the value of this long-term vision in research to underpin our current world leader position. Air travel is a great enabler for economic growth and the UK is already in a leading position. Emerging economies are responding to climate change, which will be a key influence in the market in the medium to long term. More formation flying, permanent automatic pilots and novel aircraft designs could all be seen in the skies over the next 50 years.

# THE TIPPING POINT: DEMAND, EFFICIENCY AND ENVIRONMENT

**The Efficiency Timeline**

The classical aircraft form of a tube with wings, an inverted T-shaped tail fin and engines mounted underneath the wing, has been in service for decades. Apart from some notable exceptions, including the de Havilland Comet, it has become the industry standard.

Its popularity has persisted in part, because the location of the engine under the wing allows easy access for maintenance and the possibility of 're-engineering' the engines as technology develops, a restriction with the embedded engines of the Comet.

Today there are approximately 23,000 aircraft in commercial service transporting two billion people around the world every year.[28]

While pioneers of aircraft design were obsessed with going further, faster and higher, in the 1960s it became apparent that the cost of flying was not simply a measurement of the price per barrel of oil – jet planes were noisy.

To deliver more power at lower noise levels, engine designers developed the 'high-bypass ratio' engine which since the 1970s has delivered a step-change in power and a dramatic decrease in noise. Incremental improvements to the design of the high-bypass turbofan have made aircraft 50% quieter on average today than ten years ago.[28] With the 1970s oil crisis also came a renewed focus on fuel efficiency.

The aim of airlines is to transport more people, more efficiently across great distances. Fuel is expensive and heavy. Its weight can limit the distance an aircraft can travel and it needs to be stored in tanks that impact on the size of the wings and the payload it can carry.

Aircraft entering service today are about 80% more fuel-efficient than they were in the 1960s. For a passenger travelling across the Atlantic or Pacific today in a full aeroplane, the rate of fuel consumption is about three litres per 100km – comparable to a small family car.

But engineers are reaching a point where tweaks to the 'tube with wings' design is drawing to its natural closure, as the airline industry faces mounting pressures of demand, cost of fuel and environmental legislation.

**Pressure Points**

The growth of air transport is likely to be impeded by increasing environmental and operational costs. While it is unlikely that these pressure points will individually create a shift to radical redesigns, combined they are likely to increase costs for the airlines to a point where the 'cost-per-seat' of game-changing new aircraft designs becomes increasingly attractive.

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**OVER THE NEXT 20 YEARS, THE AIRLINE INDUSTRY WILL ORDER IN THE REGION OF 25,000 NEW AIRCRAFT.**

**Engineering Efficiency Timeline**

**Flight Management Systems:** Introduced in the 1970s, these systems automatically set the most efficient cruise speed and engine power settings.

**Wings:** Engineers have made improvements to aerofoils (the cross-sectional shapes of wings), finding ways to better balance the pressures of span, thickness, area and weight. In addition, winglets added to the wingtips have delivered a 3–5% reduction in fuel burn. The initial concepts date back to 1897 but they were not applied until 1979.

**Systems:** In the 1980s, the mechanically signalled flaps and slats and flying controlled surfaces on the wings were replaced with lighter and more powerful electrical systems know as ‘fly-by-wire’ systems. Similarly engines used Full Authority Engine Control (FAEC) to balance fuel usage with air speed and demand thrust.

**Mechanical Systems:** Engineers have looked to reduce weight by introducing new materials, for example, steel brakes have been replaced by carbon, providing a weight saving in large passenger aircraft of at least 250kg and all-electric braking systems, which are lighter and easier to monitor than the previous hydraulic or pneumatic systems, are currently being introduced. Introduction of the brake-to-vacate system – pilot selects a runway exit point and the system manages the braking process to ensure the aircraft reaches the chosen exit point at the right speed, factoring in runway and weather conditions.

**Materials:** Developed in the 1950s, composite materials – typically consisting of relatively strong, stiff fibres in a tough resin matrix – are increasingly used in aircraft structures, especially wings. Through a process known as Resin Fibre Infusion (RFI), the fibres are set into resin to form sheets which are laid on top of each other and then heated to bond them in an autoclave. Main materials used in aerospace composite structures are carbon and glass-fibre-reinforced polymer. Composite materials are, in general, 60% of the density of aluminium and can deliver up to a 20% better strength-to-weight ratio. These RFI structures can be formed into more complex shapes than their metallic counterparts, reducing the number of fuselage parts and the need for fasteners and joints.

**Engines:** Turboprop engine introduced in the 1940s – a gas turbine which powers a propeller. A modern turboprop can consume 25–40% less fuel than an equivalent turbofan engine on short-haul routes. In the late 1960s, introduction of the high-bypass ratio turbofan engine which was more than twice as powerful but much quieter and cheaper to operate than the turbojets it replaced, enabled new wide-body (twin-aisle) aircraft design. The higher the bypass ratio, generally the better the fuel consumption as more thrust is being generated from slower speed air. The first commercial high-bypass ratio turbofan engines had about a 5:1 bypass ratio. The latest models are about 11:1. A steady investment in engine technology has enabled engine efficiency to improve at about 1% per year. Three new technologies moving forward: advanced high-bypass turbofans (2016), geared turbofans (2013) and open-rotor (2020).

**Avionics:** They are a fundamental part of all new aircraft, as their function is to monitor the communication available, the navigation, the weather and the anti-collision systems. Health and Usage Monitoring Systems (HUMS) are found in helicopters and airplanes and are used to give maintainers early warnings if components or modules will need replacing. HUMS will be replaced with Integrated Vehicles Health Management (IVHM) systems. IVHM has the capability to be used for diagnostics, predicting, recommending, knowledge capture and retention of the vehicle through every phase of its operation relayed back to the ground in real time. Flight Navigation is a fundamental part of the avionics system and currently there are estimates that 8% of fuel is wasted as a result of inefficient routes aircraft have to fly. Change from controlled routes to air traffic management systems under the Single European Sky ATM Research Programme (SESAR) in Europe and the Next Generation Air Transportation System (NextGen) in the USA may well reduce these losses beyond 2020.

**Demand**

Over the next 20 years alone, the airline industry will look to order in the region of 25,850 new aircraft with a market value of $3.2 trillion.[29]

Since the 1950s rising income, expanding economies and increased globalisation have driven a dramatic growth in aviation – averaging 9% growth per annum,[30] and doubling every 15 years since the mid-1970s.[29]

The volume of passengers travelling in the past ten years, despite the attacks on the World Trade Centre, SARS and the global recession, has increased by 45%. Forecasts indicate that air traffic will continue to grow internationally at 4–5% per annum[31] as world wealth increases.

While growth is predicted in the more mature markets of North America and Europe, it is the emerging economies (China, India, Latin America and Eastern Europe) that are driving the demand. It is expected that Asia–Pacific will account for 33% of passenger volume in 2029 compared to 25% for Europe and 20% for North America.[29] By 2029, 68% of traffic volume will be between these expanding regions.

People will be encouraged to change the way they travel in the future – the UK Government is looking to high-speed rail to encourage people to reduce short-haul flying.[32] But the net gain is small – videoconferencing and rail travel would reduce aviation demand only by up to 8% in 2050.[33] Demand for long-haul travel will persist.

**Fuel**

The Institution of Mechanical Engineers has raised in previous reports, that there is much conflicting analysis on the size and accessibility of the world's reserves of fossil-fuel energy sources. Few would argue that 'Peak Oil' is a genuine concept but there are many opinions on when oil production from existing sources will outstrip the discovery of new fields. In the case of conventional sources, the UK Energy Research Councils reports that there is a significant risk of a peak before 2020,[34] whereas a UK Government report commented that proven reserves are equal to over 40 years of current production.[35]

What is certain is the amount of energy that needs to be used to extract fossil fuel will rise inexorably in the coming decades, effectively reducing the net energy available from them and having a significant impact on the price of energy. This scarcity, combined with the need to reduce greenhouse gas emissions, may lead to fossil fuels being restricted to use for the purposes that most suit their characteristics. For example, the high-energy density required by aviation is most suited to liquid fuels, be they biofuels or fossil fuel derived.

In 2011, fuel prices are expected to account for 29% ($166bn) of an airline's operating costs – this is an increase from 14% in 2003.[36] By 2030, oil prices are predicted to rise from just under $80 (US$ per bbl) in 2010 to just under $120 by 2030, meaning aviation fuel prices will continue to rise.[29]

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**GLOBAL AVIATION EMISSIONS ARE PROJECTED TO REACH 2.4GT $CO_2$ BY 2050.**

**Emissions**

In 2009, domestic and international aviation[39] in the UK accounted for about 6% of UK greenhouse gas [GHG] emissions, or 21% of the transport sector's GHG. This compares to 43% emitted by cars, 13% by heavy goods vehicles and 7% by domestic and international shipping.[40]

In January 2009, the UK Government set a target that $CO_2$ emissions from UK aviation in 2050 should be at or below 2005 levels. UK aviation $CO_2$ emissions in 2005 were estimated to be 37.5 Mt $CO_2$ (million tonnes of carbon) on a bunker fuel basis. If the target is achieved, aviation emissions would account for about 25% of the UK's total allowed emissions under the economy wide 80% cut in 2050 relative to 1990, included in the Climate Change Act.[33]

While the UK Government and the aviation industry have been progressive in their attempts to cut carbon emissions, there is currently no comprehensive global policy on aviation emissions. In the absence of any policy action, global aviation emissions are projected to reach 2.4 Gt $CO_2$ in 2050 – about a four-fold increase on today's levels.[38]

The CCC has developed scenarios for reducing emissions based on improvements to fleet fuel efficiency, use of biofuels, modal shifts (high-speed rail and videoconferencing) and policy instruments such as carbon taxes[33] but moving forward they will need to be set within the context of any international agreements.

The UK Government is also pressing ahead for the inclusion of aviation in the EU Emissions Trading System (ETS) from 2012. Government believes that "by including aviation in the EU ETS and exposing it to the carbon market, aircraft operators will be incentivised to deliver emissions reductions from their own operations".[32]

To deliver the UK aviation emissions target, airlines, airports, manufacturers and air navigation services launched the Sustainable Aviation Group in 2005. Together they have built a roadmap to reducing $CO_2$ that focuses on operations, incremental technology improvements and the introduction of sustainable fuels.

The plan is ambitious and the UK aviation industry is rightly proud of the leadership role it has taken in sustainable aviation.

But looking further forward, even the CCC highlighted in its 2009 report[33] that "more radical technology innovation (e.g. blended wing aircraft) could offer significant potential for emissions reductions, although this would require as yet unplanned high levels of investment".

In addition, targets on emissions have focused on $CO_2$ and not included other environmentally damaging emissions such as $NO_x$, sulphate aerosol, soot aerosol and linear contrails. As the emissions reductions remit widens to include these chemical components, new legislation is likely to create even tougher targets.

### Noise

In 2010, Heathrow was the fourth busiest airport in the world after Atlanta, Beijing and Chicago O'Hare.[41]

In the UK, the Minister for Transport is responsible for setting the noise levels for so called 'designated aerodromes', those considered of importance to the UK economy: Heathrow, Gatwick and Stansted. The noise regulations for all three airports are the same.

There are no international regulations on aircraft noise, instead ICAO (International Civil Aviation Organisation) has a set of standards based on aircraft design and country signatories to ICAO are supposed to adopt the standards into their national legislation. The standards are published in a series of 'Chapters'; ICAO is looking to develop a new Chapter in 2013 and is analysing the potential for a new noise standard.

Night noise legislation has the greatest commercial impact on the airline industry. Night flights are revenue generators. Flights to the Far East tend to leave around midnight and the vast majority of long haul flights will arrive around 6am. To remain profitable, airlines need to buy an aircraft that is quiet enough to leave at night and arrive in the early hours. As Heathrow noise regulations are the toughest in the world, they are considered to have influenced the design of the A380 (an aircraft that actually beats these standards).[42]

### Passenger Challenge

When these pressures combine to create a tipping point, the airframe manufacturers will be taking the risk that the cost of development of new radical aircraft will deliver cost per seat reductions that are attractive to airlines. In other words, they will have a customer base. Conversely, airlines will need to be sure that any passenger fears over radical designs continue to be off-set by attractive seat prices. While passengers are likely to view major new designs with suspicion, by 2075, the world will have experienced regular 'space passenger flight' with Virgin Galactic's Spaceship 1 and potentially others. It is their safety record and passenger confidence in the technology that will also be a pull factor in new aircraft design.

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