ROYAL ACADEMY OF ENGINEERING

ROYAL AERONAUTICAL SOCIETY

Innovation in aerospace

Summary of an event held on Wednesday 4 June 2014
at the Royal Academy of Engineering in association with the Royal Aeronautical Society

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1. Introduction

Over the past three years, Sir John Parker GBE FREng, President of the Royal Academy of Engineering, has chaired a series of events to highlight the opportunities and challenges of innovation in engineering sectors that have potential for growth and global reach.

On 4 June 2014, a half-day event on *Innovation in aerospace* brought together leading engineers, businesspeople and academics to discuss issues and trends in the global and UK aerospace industry.

The event heard presentations from industrialists, academic researchers, innovators, and aircraft builders and operators. There was an emphasis on the application of technologies and opportunities for UK-based companies to maintain a leading role. This report is not a verbatim record of the conference; rather, it seeks to highlight some of the issues raised and to contribute to further discussion.

The UK's aerospace sector contributes **£24** billion a year to the economy

2. The global business

The UK aerospace sector is a global leader, number one in Europe and second globally only to the US. The UK's aerospace sector contributes £24 billion a year to the economy with high growth potential in the near future. Aerospace leads in the development and application of innovation in both product and process. With the overriding duty of safety, aerospace as a sector has a mature and well-defined innovation methodology that makes it a challenging and exciting field to work in.

Aerospace is widely seen as the instigator of technology change in many fundamental engineering disciplines, including electronics, sensing and communications, the use of new metals, composites and plastics, and the development of new, more efficient and sustainable power and energy systems.

In addition, aerospace is pioneering changes in business process, including the servitisation trend, where customers buy the availability of the service provided by an engineered product, rather than the product itself. Airlines, for example, are increasingly devolving responsibility for aero-engines to manufacturers, rather than owning the power units themselves. Aerospace is at the forefront of product data management, which automates the statutory requirement for traceability of materials and components.

There is innovation too in manufacturing processes. Aerospace is an important testbed for broader developments in automation, assembly and inspection. Aircraft, seen as highly complex examples of systems and assemblies, present manufacturing challenges that have implications for many other engineering sectors.

As an engine for economic growth, aerospace is prized as an industrial sector worldwide. Air traffic, which barely slackened during the recent downturn, is now forecast to rise at a rate of 4.7% a year between now and 2030, meaning a doubling in the next 15 years. Airlines and other commercial aerospace companies are investing heavily in new aircraft and more sustainable technologies. There is a lot of business to be won for the UK but also a lot of competition to win it. Aerospace is seen as a core sector in the industrial development strategies of many countries.

Air traffic is now forecast to rise at a rate of 4.7% a year between now and 2030, meaning a doubling in the next 15 years

Photo © NATS

The UK has 3,000 companies directly involved in the industry, accounting for 100,000 jobs

3. The UK opportunity

The UK has a lot to win with the forecast growth in global aerospace. The UK has 3,000 companies directly involved in the industry, accounting for 100,000 jobs directly and a further 130,000 indirectly.

The importance of aerospace to the UK has been recognised by a government and industry initiative, the Aerospace Growth Partnership (AGP). The work of the AGP was outlined at the event by Paul Everitt, chief executive of ADS, the aerospace, defence and security industry association. The partnership, Everitt said, was part of a new political consensus in the UK that saw designing and manufacturing as "a good thing" and that also believed there was a legitimate role for government in helping UK industry to win business around the world through a modern industrial strategy.

To support the work of the AGP, the Academy and Royal Aeronautical Society have been proactive in initiatives to enhance the competitiveness of the sector through innovation and skills development. Together they administer a scheme to award Aerospace MSc bursaries to deliver more masters-qualified engineering professionals for the UK aerospace industry.

The need for special measures within the aerospace sector, Everitt said, was identified from the sheer scale of the opportunities: "It's a £4.5 trillion market in the next 20 years, with a forecast for 29,000 large aircraft, maybe 40,000 helicopters and many thousand more business jets". The UK currently has capabilities in all of these product areas, and perhaps 16 to 17% of the global market. "With the scale of the opportunity, to miss it would be a crime."

AGP Aerospace Growth Partnership

In order for the UK aerospace industry to capture a significant share of this growth, the UK must position itself for the next phase, making investments both to increase capacity of the industry to meet growing demand and capability to match customer requirements.

Those requirements are not simple. "For example, you can see that the volumes are growing, but at the same time the airlines are not getting richer," he said. "One of the reasons for growth is that the cost of travel is going down, and we have to have to have products that will be cleaner, more efficient but still cheaper."

The strategy for innovation within the AGP is founded on a £2 billion investment by government and industry in the Aerospace Technology Institute over the next six years. This investment into technology and manufacturing is intended to build on existing strengths in areas such as wings, aeroengines and advanced systems. A key message here, Everitt highlights, is that the investment horizon extends beyond the next two UK general elections, indicating the degree of political consensus.

At the same time, the UK industry's ability to export components and systems to other countries is also being developed. The National Aerospace Technology Exploitation Programme has been set up with a £40 million fund specifically aimed to develop innovation within the supply chain outside the big name companies such as BAE Systems and Rolls-Royce.

The Rolls-Royce Trent XWB © Rolls-Royce

96%

of those who took the survey agreed that they wanted flying to be more environmentally friendly

4. Innovation in aircraft

Most fixed-wing aircraft in service today are recognisably the descendants of the first planes that flew just over a century ago. There has been limited change in their configuration and reliance on fossil fuels since the introduction of the jet engine in the early 1950s. The predicted demands on aerospace industry as 2050 approaches suggest that more radical change will be needed if CO_2 emissions targets are to be met.

More electric flight

Sébastien Remy, Head of Airbus Group Innovations, said that the pressure to change the norms of the aerospace industry was coming from consumers as well as regulators. A survey of airline passengers indicated a finding that was apparently contradictory: 32% of those polled said that flight delays and late arrivals are the greatest annoyance of air travel, yet two-thirds said they still expected to fly more.

Demands from the public are for more sustainable forms of aviation: 96% of those who took the survey agreed that they wanted flying to be more environmentally friendly. The same demand can be heard from the regulators. The European Union's *Flightpath 2050* strategy, which set targets for the European industry to 2050, wants to see carbon dioxide emissions associated with aviation reduced by 75% and noise by 65% compared to the year 2000.

These targets, Remy said, demanded a new approach: "We have to rethink the nature of the basic vehicle for the first time since about 1950," he said. Recently, Airbus Group's all-electric technology demonstrator, the E-Fan, made its maiden flight. The small plane has two 30kW motors, using lithium-ion batteries, and can fly for around 45 minutes.

Airbus Group is not the only company that is investigating electric propulsion, but it is the biggest. Remy highlighted the potential for electrical concepts to be transferred to helicopters or regional jets. Despite the existence of the prototype, however, and the intention to build several more examples from 2017, there are fundamental questions that need to be addressed before electric flight becomes a viable option. Aircraft have to undergo rigorous certification processes before they are allowed to operate commercially and this would need to be adapted for electric aircraft, he pointed out.

There are technological fundamentals that have to be tackled as well. As illustrated in the automotive industry, low battery storage capacity is a current barrier. Weight and power density also are problems that have appeared in the demonstrator. The E-Fan has been an attempt to design an electric aircraft from first principles, but Remy said there was a lot further to go in terms of rethinking aircraft architecture. This had to be done within the context of customers – both the operators and potential passengers – who now expect improving technology and costs kept down.

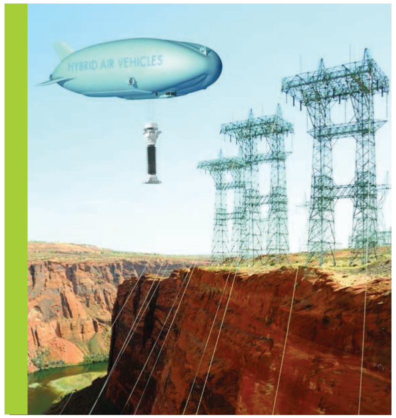


Photo © Hybrid Air Vehicles Ltd

The hybrid air vehicle

Innovation is also being seen in earlier aerospace vehicles. Airships never quite went away, but attempts to commercialise their development and operation have proceeded very slowly over the past 60 years, in contrast to the rapid growth in more conventional aerospace.

What makes a return to airships attractive, said David Stewart, Head of Flight Sciences at Hybrid Air Vehicles Ltd, is their inherent sustainable credentials and a series of operational virtues that have been rather overlooked in the period when aerospace growth was achieved through increasing passenger numbers and a concentration on speed.

"There are in fact a lot of persistent airborne applications and some new ones for which lighter-than-air hybrid vehicles are a real option," he said. These include tasks such as telecoms relay work and climate observation, where the ability to fly for five days at up to 100 mph without refuelling is more important than any requirement for speed. "We also see a big opportunity in supplying very remote areas," Stewart said. "Essentially, hybrid air vehicles can take off and land on any flat surface."

Hybrid Air Vehicles' current Airlander 10 is due to make its first flight in late 2014. It will act as a testbed for a range of innovative technologies to be used in a much bigger version, the Airlander 50, that the company intends to launch before the end of the decade. "The Airlander 10 will tell us a lot," Stewart said. New systems for the Airlander 50 are being tested

Photo © Hybrid Air Vehicles Ltd

not just on the smaller version, but also using CFD software and in a wind tunnel.

The Airlander 10, which is already the biggest aircraft of any type in the world, has a payload of around 10 tonnes, but the Airlander 50 will lift up to 65 tonnes and can accommodate up to six standard 20-foot ISO shipping containers, as well as 50 passengers. The aircraft includes features such as vectored thrust for lifting, landing and precision positioning control at low speeds, with a hovercraft landing system also being developed. The hull fabric is a combination of strong materials and is designed not to stretch; the vessel as a whole has been designed for safety and stability, with a small pressure differential so that any leaks would be very slow.

The Airlander series is seen as a cross between an aircraft and a blimp-style balloon. It has attracted government research funding as well as significant financial backing from the lead singer of the heavy metal rock band Iron Maiden.

> "We also see a big opportunity in supplying very remote areas… essentially, hybrid air vehicles can take off and land on any flat surface."

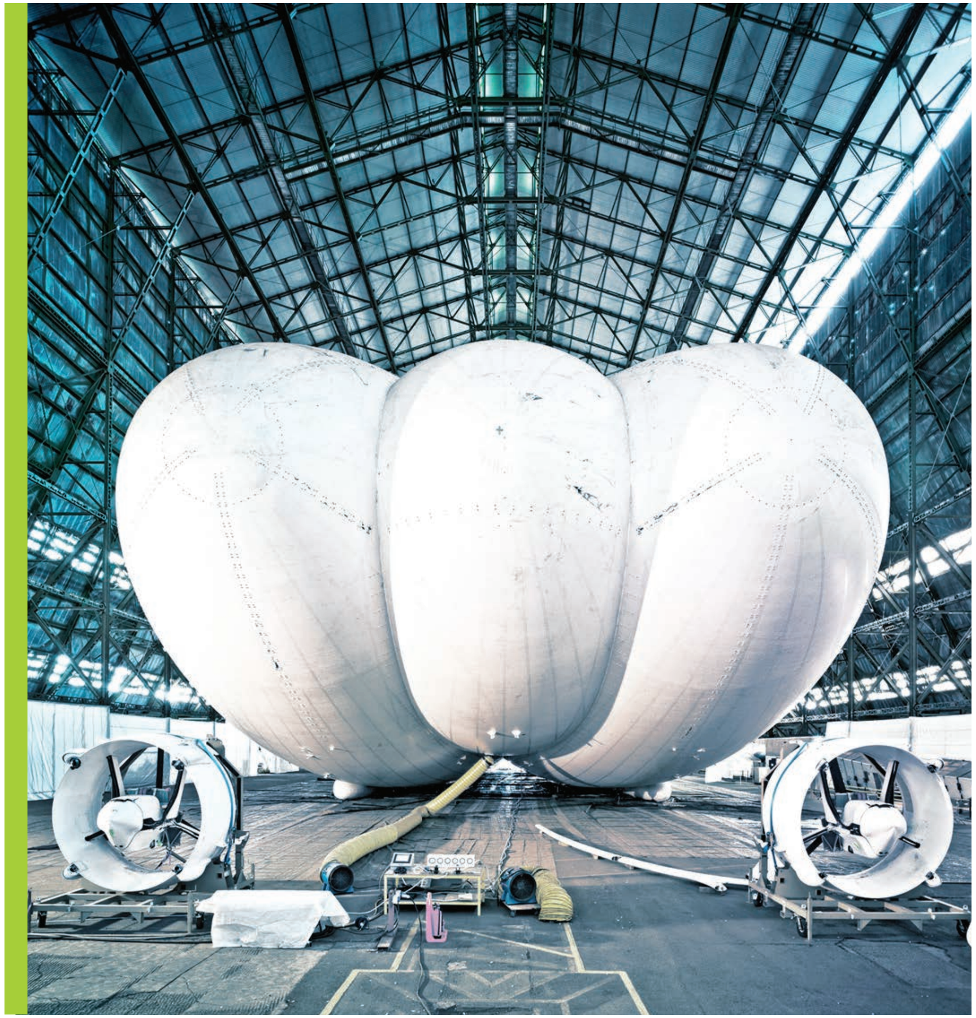


Photo © Hybrid Air Vehicles Ltd

"Our goals are to improve safety, reduce delays, improve flight efficiency and reduce the costs…"

5. Innovation in flight operations

Proposals to expand airport capacity in South East England have been controversial for more than a generation, and are part of a wider debate about the need to add flight infrastructure capacity to cope with projected increases in air traffic. Ground-based infrastructure is only part of the debate. Increasing numbers of flights create the need for continuous innovation in air traffic control to keep the skies safe.

There is additional pressure on systems from the different kinds of aircraft now under development, including airships and unmanned air vehicles, that do not fit into the current patterns of air traffic and that need to be integrated into control systems.

Innovation in air traffic control

David Hawken, Engineering Director of Operations at NATS (formerly the National Air Traffic Services), outlined the existing system of complex sensors that are used to schedule the 6,000 flights each day in the UK. The system comprises a vast network of radars, ground-to-air communications systems, ground-to-ground infrastructure, other navigational aids and links to satellites. The challenge is to optimise flights that are, by their very nature, difficult to predict and control.

Delays in the air and on the ground rated as some of the most complained about features of air travel, and are used by NATS as the base measures of its success. Increasing traffic is driving new ways of thinking. "Our goals are to improve safety, reduce delays,

Photo © NATS

improve flight efficiency and reduce the costs," Hawken said. Aircraft being forced to circle before landing are an environmental and economic cost as well as an annoyance. "But we also see flight operators wanting to start up a new route in a matter of weeks rather than years," he said.

Innovation in air traffic control means being "more dynamic and more agile" – and increasingly, that means using the power of software systems to optimise the complexities. "Our future air-traffic control tools are a four-dimensional control system. It enables us to look ahead by 18 minutes to see where individual flights might come into conflict on their flight plans and what we can then do about it," Hawken said.

The 18 minutes are not an arbitrary measure: "It proved to be the best optimisation between accuracy and usefulness," he said. Aircraft vary in their performance and in the way they are piloted, so any longer extrapolation would create uncertainties. The system works from the aircraft's current position, its flight plan, weather conditions and aircraft type.

Results so far have been encouraging, Hawken said. "Our estimate is that there has been about a 20% improvement in the safety risk index. You can also measure it in terms of fuel saved through more efficient aircraft handling, and we think it's saved around £6 million or 10,000 tonnes of fuel." More than that, unlike

previous manual systems, the new software-based system enables direct links to be made to the cockpit of each individual flight for seamless data flow.

Further innovation in software is also proving the safety case for a change to landing patterns at UK airports. Air traffic control uses a time-based separation of aircraft, which gives the required safety margin with an element of contingency for factors such as gusty headwinds. "We're now doing a simulation to see if, by slowing the landing speeds down, we could bring aircraft closer together," Hawken said. "The evidence so far is that we might save about half the delays we get at Heathrow, which could be around 1,300 hours a year, and the hard part in all of this will be convincing ourselves that it is safe."

Unmanned air vehicles

Fixed-wing aircraft, helicopters, airships – what most 'air vehicles' have had in common is that they are piloted. The pilot's responsibilities include the safety of any passengers and cargo, liaison with ground-based air traffic control, monitoring the health of the aircraft and the difficult manoeuvres of take-off, landing and avoiding others in the same airspace. Unpiloted aerial vehicles such as rockets and drone planes have been used as weapons and for surveillance in times of war, but have otherwise been rigidly segregated from other airspace users where they might cause problems.

Watchkeeper unmanned aircraft © Thales

"The challenge now is to get out of this constraint of segregation," said Lambert Dopping-Hepenstal FREng, Programme Director of ASTRAEA, the UK consortium of aerospace companies that is researching how unmanned aircraft might be allowed to operate safely in non-segregated airspace. ASTRAEA is not talking about dropping the pilot from regular scheduled passenger flights, Dopping-Hepenstal stressed. Rather, there are a wide range of applications in areas such as telecommunications, agriculture, and search and rescue, where unmanned aircraft can take advantage of longer endurance and an ability to operate in hazardous environments as they are not carrying a pilot on board. Already, there are examples of small-scale unmanned aircraft being used in restricted areas for tasks such as televising sports and aerial archaeological investigation.

"Essentially, this is a systems engineering problem," Dopping-Hepenstal said. "If we take the pilots out, we have to be able to replicate the tasks that are done by them."
To some degree, this can be achieved by transferring some of the pilot's responsibilities to a ground-based pilot, perhaps sitting alongside air traffic control, but some will have to remain in the aircraft.

Last year, the ASTRAEA project flew a small turboprop aircraft under ground control from BAE Systems' Warton base in Lancashire to Inverness, using the commercial airways. There were safety pilots on board, but the flight was controlled from the ground.

Agricultural monitoring with unmanned aircraft © Callen-Lenz

This flight showed the potential of unmanned flight, but it also highlighted areas for further research.

"We could transmit all the on-board data to the ground pilot, but there would be a lot of it," Dopping-Hepenstal said. "We have limited bandwidth and we also have to allow for the possibility of losing the link and for aircraft technical failures. For that reason, we need to transfer some of the pilot's intelligence into the aircraft itself, our autonomous system."

ASTRAEA is now setting out a follow-on programme of work to verify and validate the key technologies, which include detect and avoid, and communications integrity and security. The programme team is working with the aerospace industry's new Aerospace Technology Institute as well as regulatory bodies in the UK, Europe and beyond. Technology innovations, Dopping-Hepenstal said, are only part of it, there are also legal and societal issues that need to be addressed.

"If we take the pilots out, we have to be able to replicate the tasks that are done by them."

> "Weight is a key factor in today's industry, and composites have a role to play in taking weight out." Lower weight can be equated directly to savings in both fuel usage and emissions

6. Innovation in components and materials

Since the very beginning of manned flight, aerospace has been a testbed for new materials, especially composites, and also for broader technology innovations in the engineering of power efficiency. Although the engineering of subsystems such as aero-engines and the air frame might appear very diverse in terms of technology, there has been surprising crossover and commonality in some aspects; for instance, titanium alloys and ceramics have found applications in both.

The final session of the event brought together two of the UK's world-leading aerospace groups. Meggitt is a diversified materials, components and sensors group, while Rolls-Royce is one of the global giants of the aero-engines business.

What the two share from their different perspectives and their different technologies is the broader innovation challenge that faces the whole aerospace sector: how to make the projected growth in air traffic to 2050 sustainable in terms of environmental impact, fuel efficiency and cost.

Multifunctional composites in components

Composites that combine the properties of one set of materials with those of another have been widely used in the aerospace industry since the 1950s, said Mark Hancock, Chief Engineer at Meggitt Polymers and Composites. The benefit that the industry has derived from them has been the ability to 'tune' materials to survive the range of harsh conditions that aerospace structures meet in service.

Composites are also an important technology in terms of meeting other requirements, Hancock said. "Weight is a key factor in today's industry, and composites have a role to play in taking weight out." Lower weight can be equated directly to savings in both fuel usage and emissions.

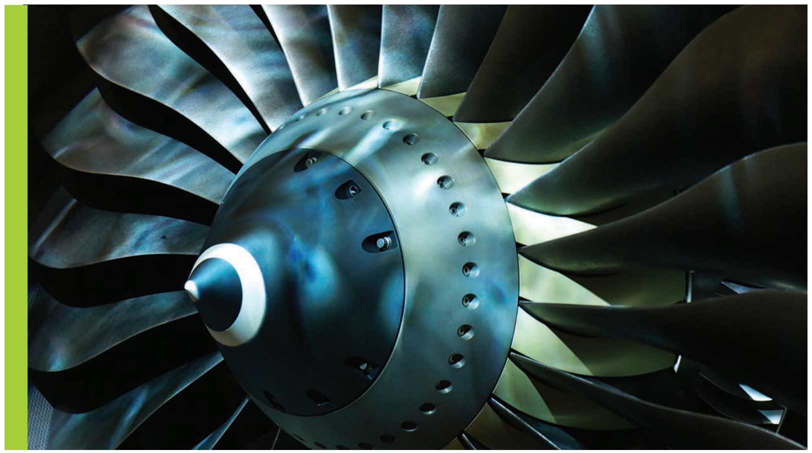
Technologies such as carbon nanotubes and high temperature resins offered potential for weight-saving within their own right. But Meggitt is looking beyond the material gains that can be made to a new kind of 'multi-function composite' that blends material properties with component functions in the same structure. "It's about composites that bear load but are also carrying out other functions," he said.

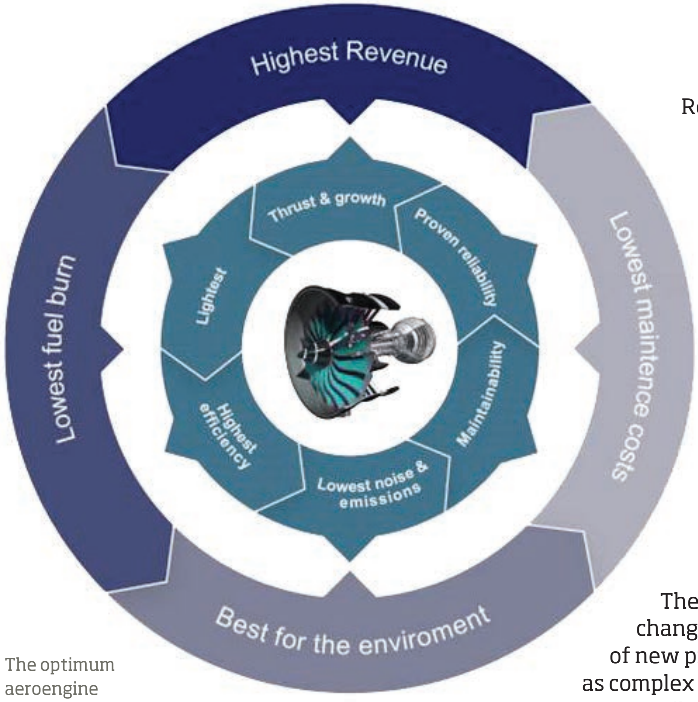
Functions that might be considered for incorporation in future composites include cost, weight, power efficiency or diagnostics. A current Meggitt project is looking at an ice protection system where an electrofoil with a low-power heating element is encapsulated inside the composite.

"We can look at other functions as well by bringing metallic elements such as aluminium into the composite construction," Hancock said. Resistance to physical phenomena such as lightning strikes, erosion, bird strikes and thermal performance might be built in, but there is scope too to design composites specifically for other factors, such as their manufacturability.

This kind of thinking could go further still. If a new layer within a composite material is a sensor of some kind, then there is potential to modify its behaviour during a flight: to switch functions on and off. Further layers might add new functions such as prognostics and diagnostics.

Hancock said that these ideas from an integral part of both the Clean Sky programme, which is funded by the EU, and internally funded programmes to support the 'more electric aircraft'. Their potential effects on weight and reaching sustainability challenges facing the industry are large.





The optimum aeroengine
© Rolls-Royce

Innovation in propulsion units

Rolls-Royce, one of the most powerful companies in world aerospace, is under constant pressure to improve the fuel efficiency and the environmental impact of its aeroengines. Alan Newby, Chief Engineer of its Future Programmes and Technology Division, told the event that two-thirds of the group's £1.118 billion a year research and development expenditure went on environmental issues.

The environmental targets that Rolls-Royce has been set are pressing and ambitious. Specific goals to achieve by 2020 are carbon dioxide emissions reduced by 20%, nitrogen oxide reduced by 60% and noise halved from levels in 2000. Newby said that Rolls-Royce is close to achieving these targets, but then there are even bigger targets for the middle of the century. "We still have a long way to go on CO_2, NOx and noise," he said. And the pressure is on. The rise of fuel cost over the lifetime of the Trent engine series, since 1995, means that fuel now accounts for around half of the cost of flying.

The pace of technology change and the introduction of new product in something as complex as aeroengines is necessarily slow. Rolls-Royce has a highly structured innovation strategy: Vision 5 is about near-market innovations that will be realised within the next two to five years; Vision 10 concepts are under development today for potential introduction in perhaps 10 years' time; and Vision 20 technologies are a distant view of ideas that could make a big difference over a longer time scale.

The targets for 2050 are challenging, Newby said, "but we're confident that there is a lot of life still in the gas turbine engine. To get to all of the Trent engines achieving environmental goals is going to require some radical solutions at the engine and air frame level. On our side, we are working on improving the propulsive efficiency and the thermal cycle."

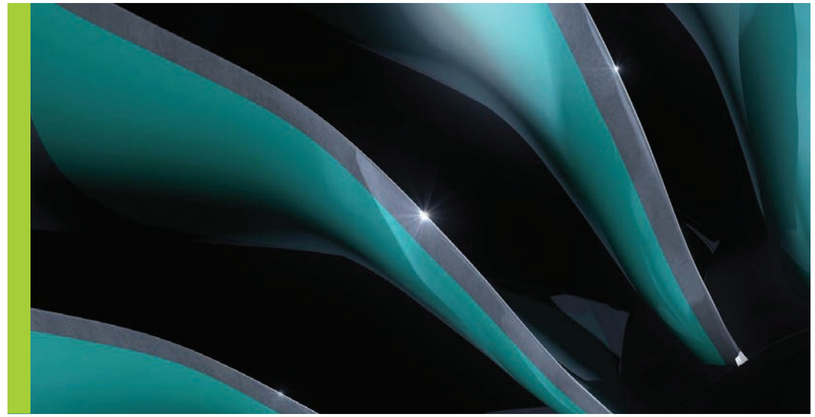


Photo
© Rolls-Royce

Specific goals to achieve by 2020 are carbon dioxide emissions reduced by 20%, nitrogen oxide reduced by 60% and noise halved from levels in 2000

The breadth of technologies that Rolls-Royce has to investigate in order to achieve gains in these areas is huge: from high temperature materials to combustion technologies to infinitesimally small changes in fan design and operation. Innovation at Rolls-Royce is about continuous improvement that feeds into what is already a well-defined path of new engine launches scheduled for the next 10 years. At the same time, more novel concepts such as gear-driven fans, variable pitch and open rotor engines are investigated, and fundamentals such as the basic architecture of the aircraft and where propulsion units are sited are also questioned.

The experience of Rolls-Royce, Newby said, is that there will continue to be no shortage of challenges that will require innovation. There will be no shortage, either, of potential technologies that will be brought in to fuel the growth of the future in this globally important industry.

7. Further information and reading

Unmanned air vehicles
CAA CAP 722: Unmanned Aircraft System Operations in UK Airspace – Guidance

European Remotely Piloted Aircraft Systems Roadmap
www.ec.europa.eu/enterprise/sectors/aerospace/uas/

ASTRAEA programme
www.astraea.aero

Autonomous Systems
Social, Legal and Ethical Issues
www.raeng.org.uk/news/publications/list/reports/Autonomous_Systems_Report_09.pdf

8. Acknowledgements

We would like to thank the following speakers for their contribution to *Innovation in aerospace*:

Chair

Sir John Parker GBE FREng
President, Royal Academy of Engineering

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Paul Everitt
Chief Executive, ADS Group

Sébastien Remy
Head of Airbus Group Innovations

David Stewart
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David Hawken
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Programme Director, ASTRAEA

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