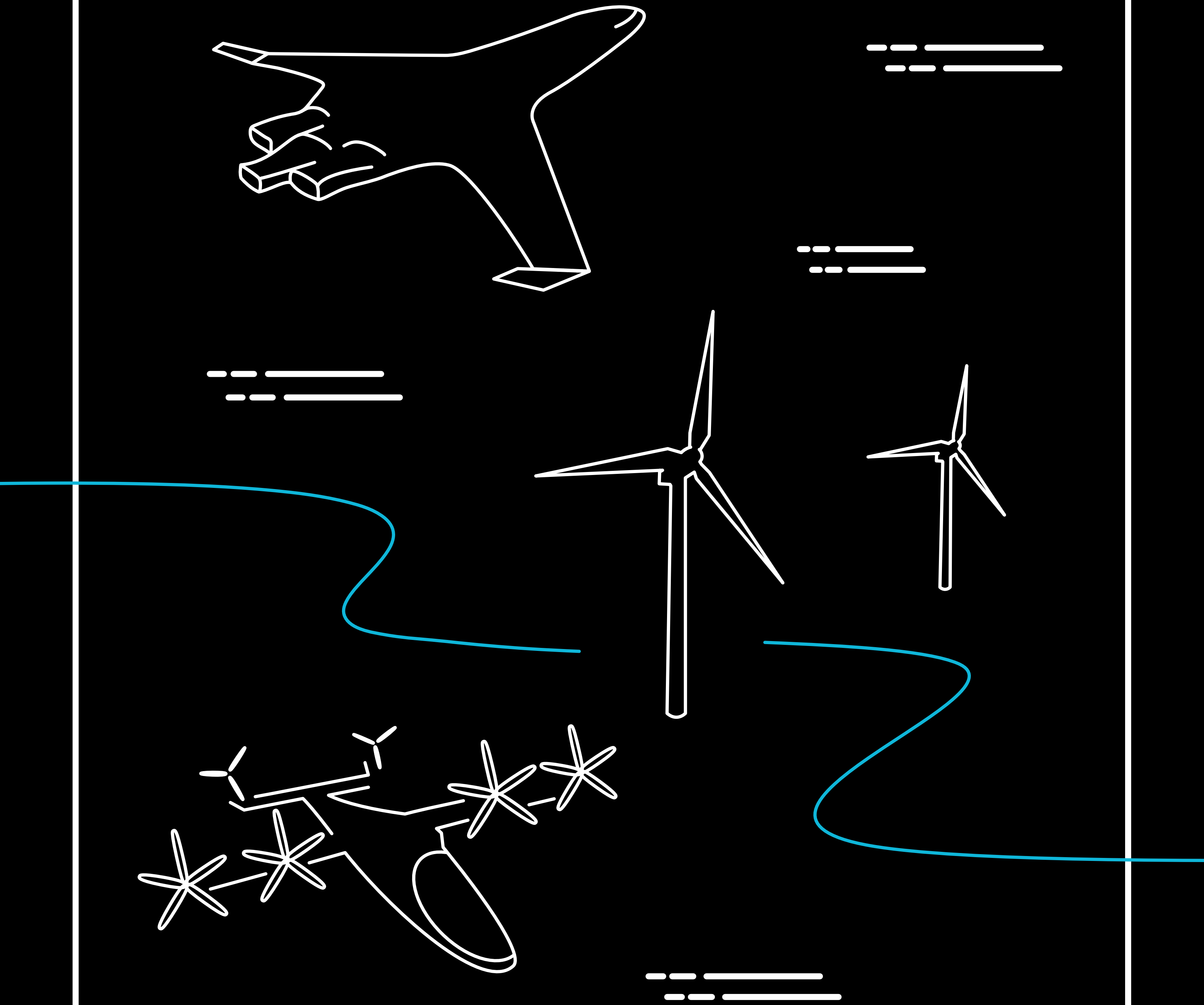
The New Whittle Laboratory

Decarbonising Propulsion and Power



UNIVERSITY OF CAMBRIDGE

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The impressive work undertaken by the Whittle Laboratory, through the National Centre for Propulsion and Power project, demonstrates the University’s leadership in addressing the fundamental challenges of climate change. The development of new technologies, allowing us to decarbonise air travel and power generation, will be central to our efforts to create a carbon neutral future.

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Professor Stephen Toope, Vice-Chancellor of the University of Cambridge

Summary

Cambridge has a long tradition of excellence in the propulsion and power sectors, which underpin aviation and energy generation.

From 1934 to 1937, Frank Whittle studied engineering in Cambridge as a member of Peterhouse. During this time he was able to advance his revolutionary idea for aircraft propulsion and founded 'Power Jets Ltd', the company that would go on to develop the jet engine. Prior to this, in 1884 Charles Parsons of St John's College developed the first practical steam turbine, a technology that today generates more than half of the world's electrical power.*

Over the last 50 years the Whittle Laboratory has built on this heritage, playing a crucial role in shaping the propulsion and power sectors through industry partnerships with Rolls-Royce, Mitsubishi Heavy Industries and Siemens. The Whittle Laboratory is also the world's most academically successful propulsion and power research institution, winning nine of the last 13 Gas Turbine Awards, the most prestigious prize in the field, awarded once a year since 1963.

Aviation and power generation have brought many benefits – connecting people across the world and providing safe, reliable electricity to billions – but decarbonisation of these sectors is now one of society's greatest challenges. While there is a strong public desire to combat climate change, there is also an increasing demand for air travel and energy. The only way to resolve this conflict is to accelerate technology development – the transformation of inspiration into industry application – to enable the urgent delivery of novel technological solutions for a carbon neutral future.

The New Whittle Laboratory, housing the National Centre for Propulsion and Power, is designed to revolutionise technology development, making the process at least 10 times faster and cheaper. The state-of-the-art facility will allow for the scale-up of recent pioneering trials undertaken at the Whittle Laboratory. This will enable rapid technology development for ultra-low emission aircraft and low carbon power generation, ensuring that the UK remains a world leader as these sectors enter a period of unprecedented disruption. The New Whittle will be vital in helping the UK to maximise the economic opportunities of becoming a greener economy and in meeting its commitment to net zero carbon emissions by 2050. Initial funding for the project has come from the UK Government's Aerospace Technology Institute (ATI), Rolls-Royce, Mitsubishi Heavy Industries, Siemens, Dyson and the University.

**The International Energy Agency World Energy Outlook 2018 (https://www.iea.org/weo/)*

Transforming the world through propulsion and power

Opening of the Whittle Lab in 1973: a partnership of industry and academia with the aim of making safe, reliable, air travel available to the world (left to right: Sir John Horlock, Sir Stanley Hooker, Sir Frank Whittle, Sir William Hawthorne, and Geoffrey Bertram Robert 'Bob' Feilden CBE')

By setting up their own companies, Charles Parsons and Frank Whittle were able to see their inventions through to commercialisation and to transform the way we live today. Following in their footsteps, the Whittle Laboratory has worked with the world's leading turbomachinery manufacturers over the last 50 years to deliver high impact research that responds directly to real-world challenges.

Sir Frank Whittle (1907–96) attended Peterhouse, Cambridge, where he graduated in 1936 with first-class honours in the Mechanical Sciences Tripos after only two years of study. He then stayed on for a further postgraduate year.

At Cambridge, Whittle was supervised by the Professor of Aeronautical Engineering, Sir Melvill Jones, and was encouraged to pursue his ideas for the jet engine, which he had first patented in 1930. In 1936, while still at Cambridge, Whittle joined with associates to found a company called Power Jets Ltd. This led to the first ground test of his invention in 1937, and by 1944 Whittle's jet engine was ready to power the RAF's Gloster Meteor.

Since the 1940s, the jet engine has revolutionised air travel, connecting people, cultures and commerce across the world. The principles of the jet engine are also used in gas turbines for power generation and to produce electricity all around the globe. The Whittle Laboratory was named after Sir Frank in 1972 and is world renowned for its study of 'turbomachinery': machines that transfer energy between a rotor and a fluid.

Sir Charles Parsons (1854–1931) read mathematics at Trinity College, Dublin and St John's College, Cambridge, graduating from Cambridge in 1877 with a first-class honours degree.

In 1884, Parsons developed the first practical steam turbine capable of driving an electrical generator. His major breakthrough was to connect a number of turbines in series to extract power from the steam, and it is this idea that remains at the heart of all power generation turbines and jet engines today. In the 1880s and 90s, the invention of the steam turbine made cheap and plentiful electricity possible and launched a revolution in power generation and marine transport.

Today, the Parsons turbine company is still based in Newcastle-upon-Tyne and is part of the Siemens group.

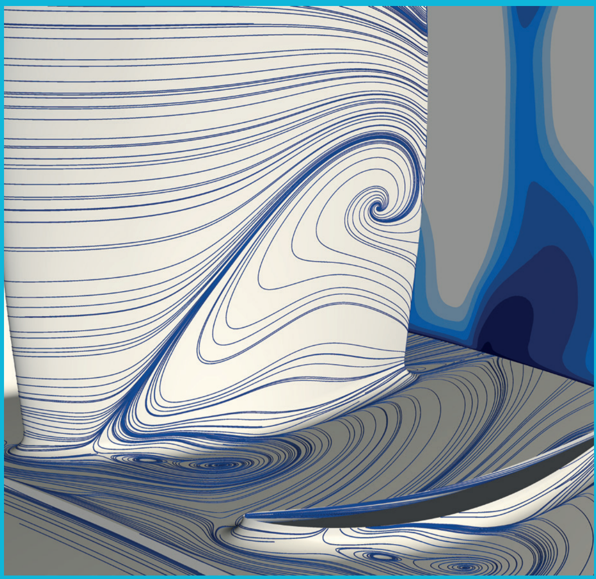
Industry impact

Since opening in the early 1970s, the Whittle Laboratory has built up an exceptional track record of delivering research and technology projects, including the development of hundreds of technologies that have driven down CO_2 emissions (see inset for example). A trusted partner of industry leaders, just under 10 per cent of total University industrial income is generated by the Laboratory, which is the Rolls-Royce University Technology Centre in Aerodynamics and a key part of the Mitsubishi Heavy Industries' Global Research Network.

The Whittle Laboratory has always combined its state-of-the-art experimental tests with pioneering advances in the simulation of fluid flows, or 'computational fluid dynamics' (CFD). Computer codes developed at the Whittle are now used by companies around the world to improve the efficiency of machines from wind turbines to jet engines. In 2019, the Royal Aeronautical Society presented their prestigious Heritage Award to the Whittle Laboratory for their fundamental contributions to aeroengine and turbomachinery research, design tools and education.

Case Study

A modern jet engine contains approximately 4,000 compressor blades in 30 rows, used to compress air to 50 times the inlet pressure. The image to the right has been generated using CFD and shows a compressor blade with streamlines over the blade surface and downstream contours representing regions of air which result in reduced engine efficiency. Recent research at the Whittle Laboratory linked a branch of mathematics known as topology with the structure of the streamlines and found from both CFD and experimental studies that a sudden switch in the streamline topology causes a drop in efficiency. Three-dimensional compressor blade design philosophies developed at the Whittle Laboratory are now used in all of Rolls-Royce's engines. Between 2008 and 2013, these technologies alone reduced Rolls-Royce CO_2 emissions by 460,000 tonnes.



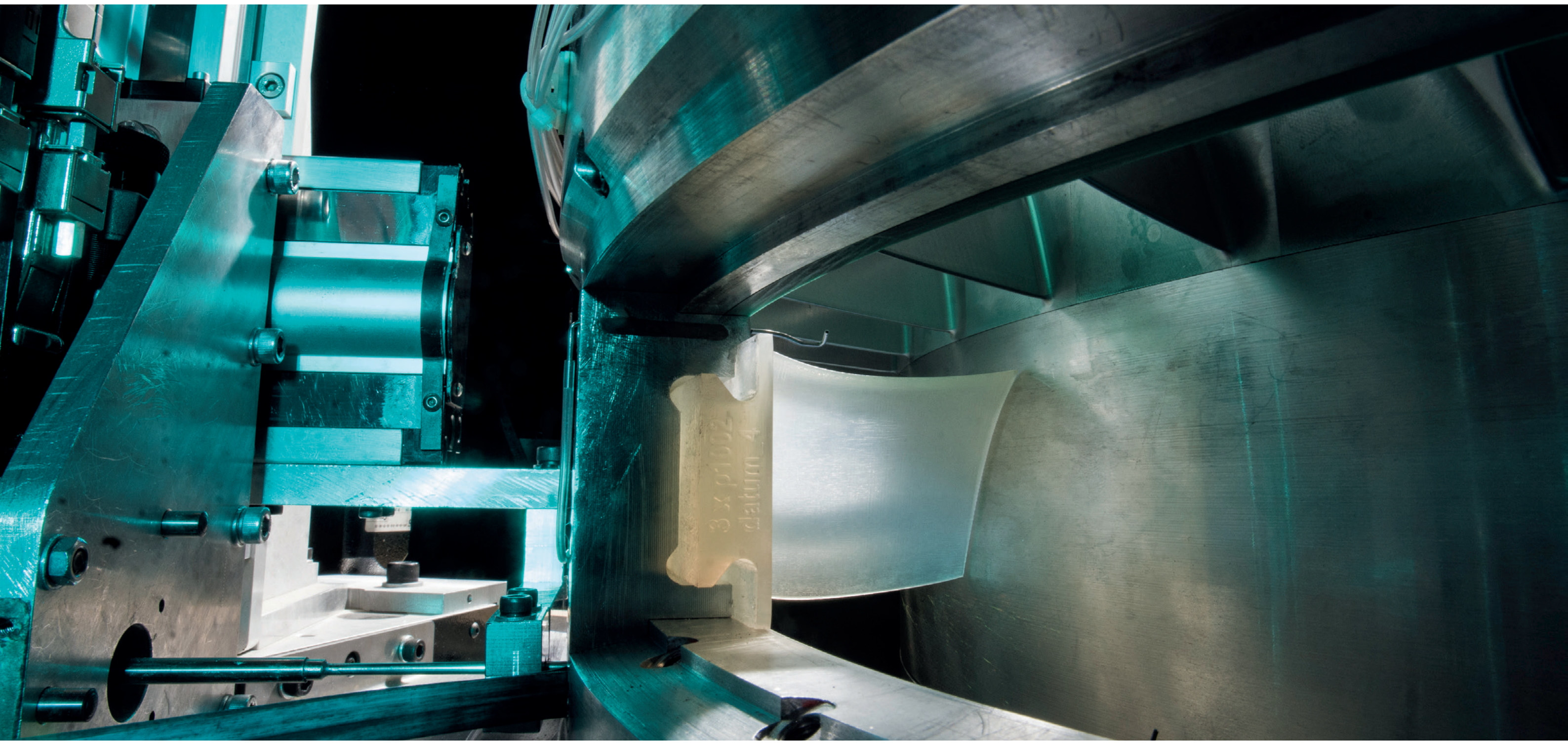
Academic excellence

Strengthened by its industry partnerships, the academic excellence of work produced by the Whittle Laboratory has been recognised by more than 100 international awards, including 14 American Society for Mechanical Engineering (ASME) Gas Turbine Awards. Other recognition includes 41 ASME best paper awards; 11 awards from the Institute of Mechanical Engineers, including two Thomas Hawksley Gold Medals for the best original papers published during the past 12 months; three prizes from the Royal Aeronautical Society; three awards from the American Institute of Aeronautics and Astronautics; and two awards from Rolls-Royce.

> "In the past, technical innovations from the Whittle Laboratory made mass air travel a possibility. In the future, its unparalleled academic prestige and strong industrial links will give it a unique role in decarbonising mass air travel and power generation and enabling new forms of flexible air transport. No other lab has come near to nine Gas Turbine Awards from the American Society for Mechanical Engineering over the last 13 years."

Professor Richard Prager, Head of the Department of Engineering

A new laboratory to inject pace and simplicity into technology development



Rapid test compressor with modular casing section removed

At the Whittle Laboratory, we believe that 'injecting pace and simplicity' into aerospace is key to the UK meeting the challenge of transformational sector change.

The challenge of decarbonisation is transforming the propulsion and power sectors. For small and medium-sized aircraft, electrification offers the possibility of fully decarbonised aviation, with more than 70 companies planning a first flight of electric air vehicles by 2024.* For large aircraft, no alternative currently exists to the jet engine, but radical new aircraft architectures, such as those developed by the Cambridge-MIT Silent Aircraft Initiative and the NASA N+3 project, show the possibility of reducing CO_2 emissions by around 70 per cent.

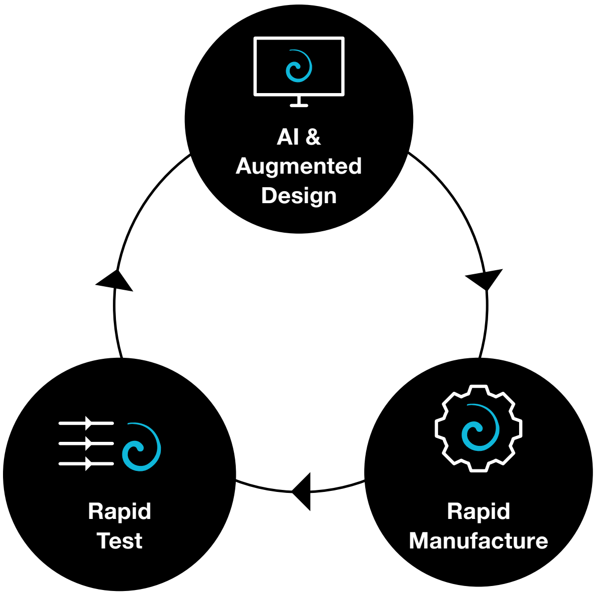
The changes occurring in aviation are part of a wider trend towards electrification across many sectors, so with demand increasing, calls for power generation to decarbonise are growing ever stronger. A carbon neutral future is possible with large-scale deployment of renewable energy, increased use of nuclear power and development of carbon capture, utilisation and storage (CCUS). A common thread through all of these technologies is their reliance on efficient, reliable turbomachinery, meaning the Whittle Laboratory is perfectly positioned to support their development.

To meet the urgent challenge of climate change, the time required to develop new technologies must be significantly reduced. The winners in this new world will be companies that can adapt to technology change more quickly and at a lower cost than the competition. Over the last five years the core focus of the lab has been to radically transform the UK propulsion and power technology development process, making it at least 10 times faster and cheaper. The solution, we believe, is to merge the digital and physical systems involved in technology development to `tighten the circle' between design, manufacture and testing.

In September 2017, a pioneering trial of the new method of technology development was undertaken. A team were embedded in the Whittle and given four technologies to develop. The results were astonishing. In 2005 a similar trial took the Whittle two years. In 2017, the agile testing methods took less than a week, demonstrating a hundred times faster technology development. We found that when technology development occurs on a human timescale of around a week, innovation explodes.

**Roland Berger report, "Aircraft Electrical Propulsion – The Next Chapter of Aviation?", September 2017*

Creating an agile technology development process



AI & Augmented Design

The time taken to design new technologies has been reduced from around a month to one or two days using automated systems augmented with machine learning algorithms. These make use of in-house flow simulation software which is accelerated by graphics cards developed for the computer gaming industry.

Rapid Manufacture

Manufacturing times for new technologies have been cut from two or three months to two or three days by directly linking the design systems to rows of in-house 3-D printing and rapid machining tools, rather than relying on external suppliers. This allows designers to try out new concepts in physical form very soon after an idea is conceived.

Rapid Test

Testing times have been reduced from around two months to a few days by undertaking a 'value stream analysis' of the experimental process. This involved analysing each sequential operation in the testing process, which enabled over 95 per cent of the operations to be removed, producing a much leaner process of assembly and disassembly. Test results are automatically fed back to the augmented design system, allowing it to learn from both the digital and physical data.

The New Whittle Laboratory will house the National Centre for Propulsion and Power, due to open in 2022, which will contain a unique test facility and state-of-the-art manufacturing capability. A national asset, the Centre is designed to combine a scaled-up version of the Whittle Laboratory's agile test capability with high-power rigs and wind tunnels that will cover around 80 per cent of the aerodynamic technologies needed to achieve the UK's decarbonisation ambition.

Another central component of the new development will be a 'Propulsion and Power Challenge Space'. Here teams from across the University will co-locate with industry to develop the technologies necessary to decarbonise the propulsion and power sectors.

New offices and collaborative space

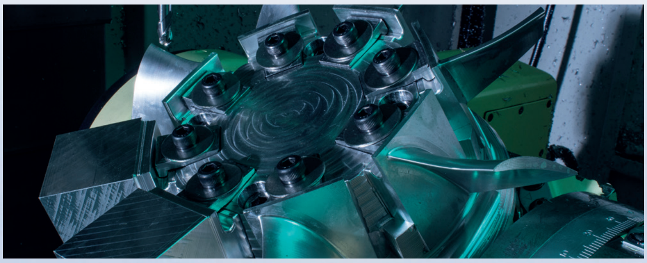
To take full advantage of an agile technology development process, a new way of working is required. The National Centre for Propulsion and Power will achieve this by setting up small, autonomous, teams, similar to those in Formula 1, which are formed for the duration of a project to work on specific challenges. These teams will have a level of flexibility usually only experienced by small start-ups and will benefit from access to the new facilities and the University's world-leading high-performance computing resources.

Co-location of staff enables academic researchers to work much more quickly and flexibly with industrial experts and designers

Using 3-D printer for rapid prototyping

New manufacturing facilities

The state-of-the art manufacturing facilities will include computer-controlled milling, turning and 3-D printing machines. This will allow new blade designs, aircraft concepts and rig components to be made at the Whittle: an important factor in ‘tightening the circle’.

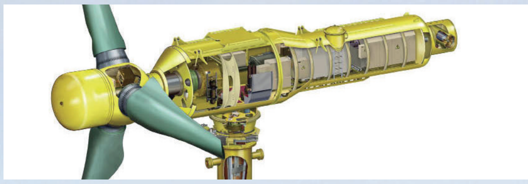


Compressor blade manufacture using computer-controlled 5-axis milling machine

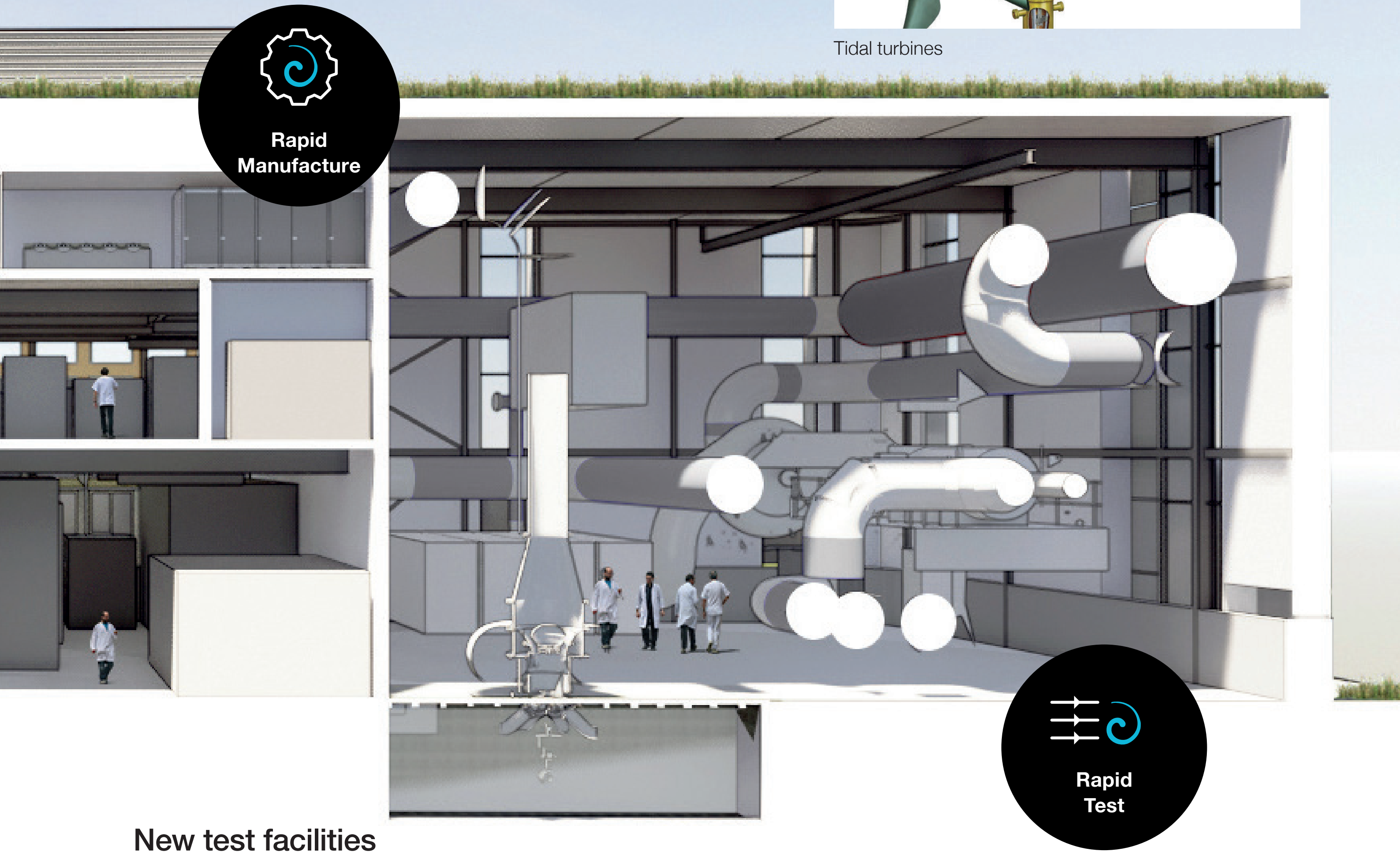
Technologies that will be tested in the new facility

Urban air taxis

Electric small aircraft



Tidal turbines



New test facilities

The National Centre for Propulsion and Power will contain a new flexible high pressure air station. This will be internationally unique in terms of the wide range of flow conditions which can be achieved. Initially two new test facilities will be connected to the station:

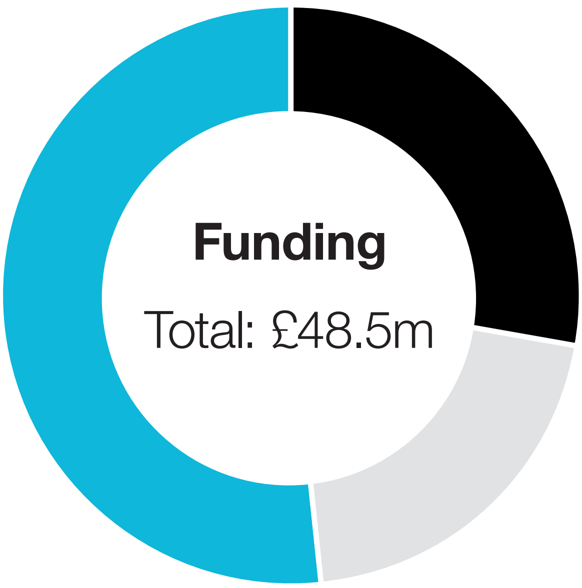
- A pressurised wind tunnel for testing of novel aircraft/propulsor concepts and new renewable power generation technologies.
- A pressurised rotating facility for rapid development of novel blade designs for boundary layer ingesting fans, compressors and turbines.

Easy installation of further rapid test facilities is embedded in the Centre’s design to ‘future proof’ it for changes in the propulsion and power sectors for at least the next 30 years.

Cambridge and the UK poised to lead the way

The New Whittle Laboratory will be situated on the University's West Cambridge site, close to the new Department of Engineering, the new Cavendish Physics Laboratory and the Department of Computer Science and Technology. The West Cambridge development is the realisation of the University's plan to bring together its world-class science and technology expertise. The aim is not only to create a concentration of state-of-the-art facilities for academic research, but also to collaborate with commercial partners, support innovation and entrepreneurship, and foster the "Cambridge Phenomenon" – the term used to describe the incredible explosion of technology, life sciences and service companies that has occurred in the city since 1960.

Funding



The New Whittle Laboratory, housing the National Centre for Propulsion and Power, has received:

- **£13.5m** of government funding through the Aerospace Technology Institute (ATI)
- **£10m** from industry partners including Rolls-Royce, Mitsubishi, Siemens and Dyson
- **£25m** to be sought from philanthropy and external partners

A collaboration between government and industry, the ATI was established to create the UK's aerospace technology strategy, advising and challenging the sector through research and technology investment to ensure the UK retains its globally competitive position.

Education

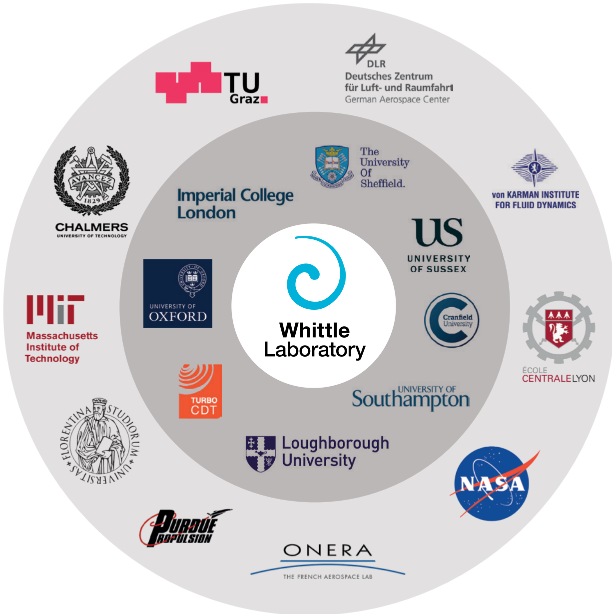
The Whittle Laboratory plays a vital role in educating the technology leaders of the future through its Centre for Doctoral Training (CDT) in Future Propulsion and Power, established five years ago. A collaboration between three universities (Cambridge, Oxford and Loughborough) and four companies (Rolls-Royce, Mitsubishi Heavy Industries, Siemens and Dyson), and sponsored by the Engineering and Physical Sciences Research Council (EPSRC), the CDT offers students the opportunity to learn from experts from all over the world and to undertake practical training with industry partners. Students do their first year of training in Cambridge and then go on to undertake PhDs at the Whittle, Oxford or Loughborough. Students at all three universities will have access to the National Centre.

An interdisciplinary approach

The Whittle Laboratory is part of one of the top five University engineering departments in the world (QS World University Rankings in 2019). The Department of Engineering is home to a dynamic community of internationally renowned engineers, and benefits from strong interdisciplinary links with researchers in departments and faculties across the University, including Mathematics, Physics, Computer Science, Chemical Engineering and Biotechnology.

UK and worldwide aerospace networks

The inner circle shows the Whittle Laboratory's links with UK Universities. The outer circle shows connections with universities and research institutes around the world. The Whittle Laboratory counts among its collaborators 10 universities, and government laboratories in Europe and North America. These connections will be crucial to the dissemination of future research results and to establishing partnerships to take advantage of the work that will be undertaken in the New Whittle.

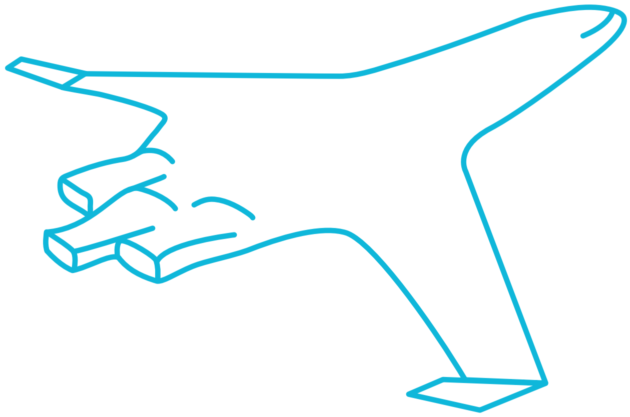


Outreach

The Whittle Laboratory launched the Women in Aerospace annual dinner, hosted by Professor Dame Ann Dowling in 2017 and Professor Dame Julia King in 2018. The initiative aims to build a network of women working in the sector and to encourage more female undergraduates to consider postgraduate study. In 2019 the proportion of successful female applicants for the CDT increased to 27 per cent compared to an average of eight per cent in 2014–16. The Whittle also reaches out to broader society through a number of STEM activities for schools and its annual Science Week open day, which in 2019 attracted more than 600 people to engage in laboratory tours, demonstrations and hands-on activities.

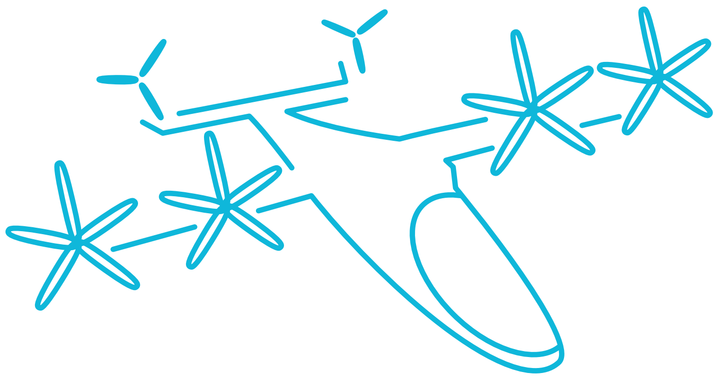
2017 dinner to promote and celebrate Women in Aerospace, hosted by Professor Dame Ann Dowling

Technology for the future



The overriding goal of the New Whittle Laboratory is a carbon neutral future, with research falling broadly into two categories: propulsion and power. Electrification is disrupting and driving both sectors.

Propulsion



Aviation is responsible for around 2 per cent of CO_2 emissions and growing. The Advisory Council for Aviation Research in Innovation in Europe (ACARE) has set a target to reduce CO_2 emissions in 2050 by 75 per cent, compared with levels in 2000, with improvements in engine technology to account for 30 per cent of the reduction. Research at the New Whittle will be vital to achieving these ambitious targets.

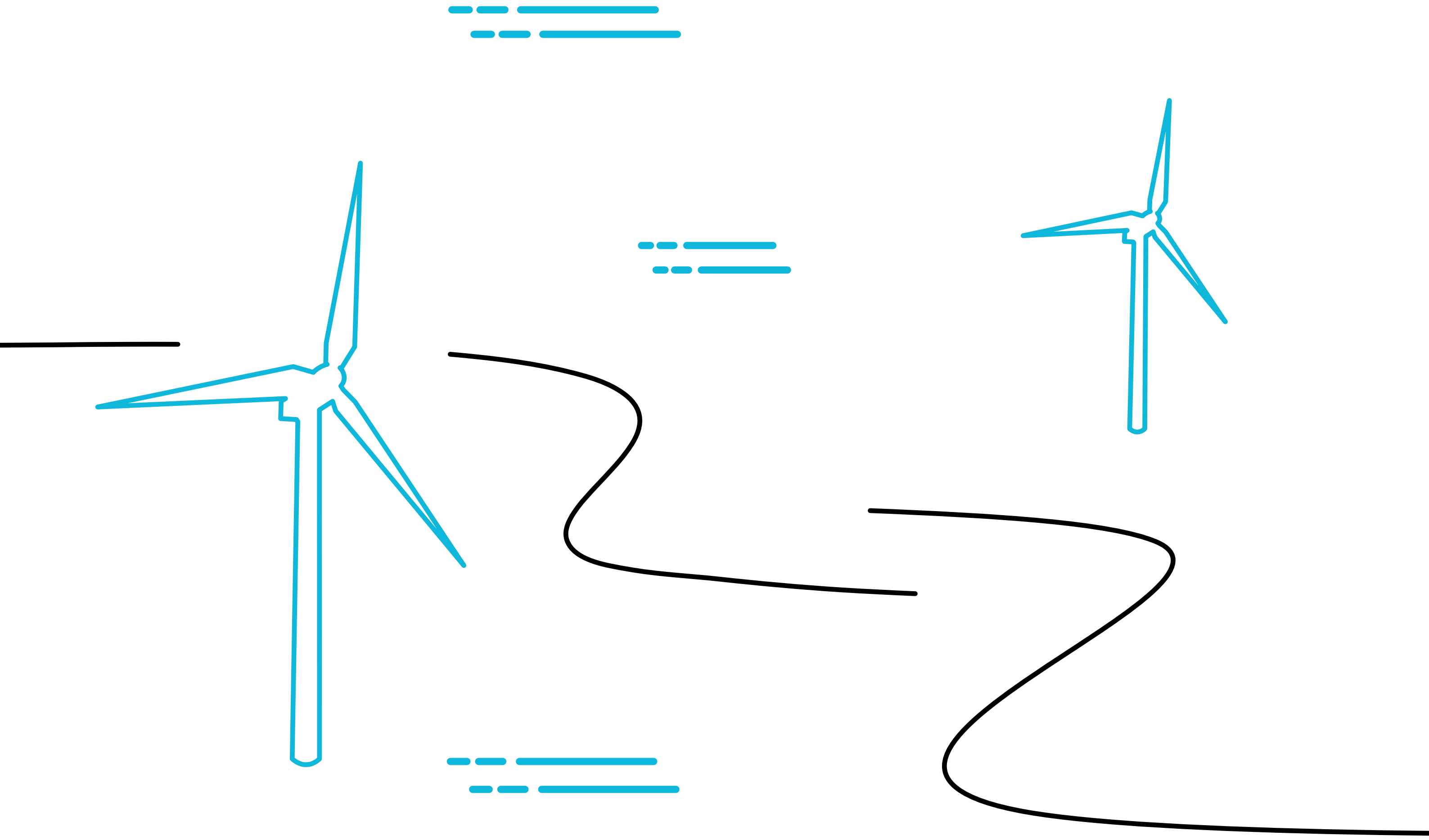
Key to reducing emissions will be aircraft designs that more closely combine the airframe (the mechanical structure of the aircraft) and propulsion systems.

- The Silent Aircraft Initiative SAX40 and EU2020 CENTRELINE project demonstrate how the ambitious ACARE targets can be met.
- The test facilities will be used to identify and develop new technologies that will help bring concepts such as boundary layer ingesting fans and fuselage-embedded propulsors from concept to reality.

A market is emerging for small, electric-powered, zero emission, flying vehicles. Around 200 programmes are expected to have launched by the end of 2019,* many of these are new entrants to the aerospace sector.

- Access to research facilities is a significant barrier to entry for SMEs; the National Centre will solve this problem, making rapid, affordable wind tunnel testing available to the entire UK aerospace sector.
- A start-up urban air taxi company will be able to design, test and optimise brand-new aircraft configurations using the test facilities located at the new Whittle.

**Robert Thomson, "Global electric aircraft Developments continue rapid upward trend", May 1, 2019, https://www.rolandberger.com/en/Point-of-View/Electric-propulsion-is-finally-on-the-map.html*



Power

Electricity generation is responsible for around 25 per cent of CO_2 emissions. The International Energy Agency (IEA) has published a 'Sustainable Development Scenario', aligned with the Paris Agreement's goal of limiting global temperature rise to 1.5 °C above pre-industrial levels. In this scenario the carbon intensity of global electricity generation is transformed from today's figure of 478gCO_2/kWh, to 69gCO_2/kWh by 2040.

The IEA describes how this could be achieved through increasing the share of renewable energy to 66 per cent (it is currently 25 per cent), increasing nuclear power output by 60 per cent, and rolling out large-scale carbon capture projects. The new technologies needed to meet this challenge are varied and multi-disciplinary in nature. However, turbomachinery is a common theme across most forms of power generation and the new Whittle will be ideally placed to take a leadership role in the development of a carbon neutral future.

For the scenario above to play out, low-carbon power generation needs to be at least as reliable and affordable as fossil fuel-based sources of energy.

- Whittle Laboratory research into tidal power is developing solutions that will allow turbines to operate more efficiently, and for longer, in the harsh ocean environment.
- Wind turbine research is helping to understand the performance of very large blades so that they can be developed to generate more power over a wider range of wind conditions.

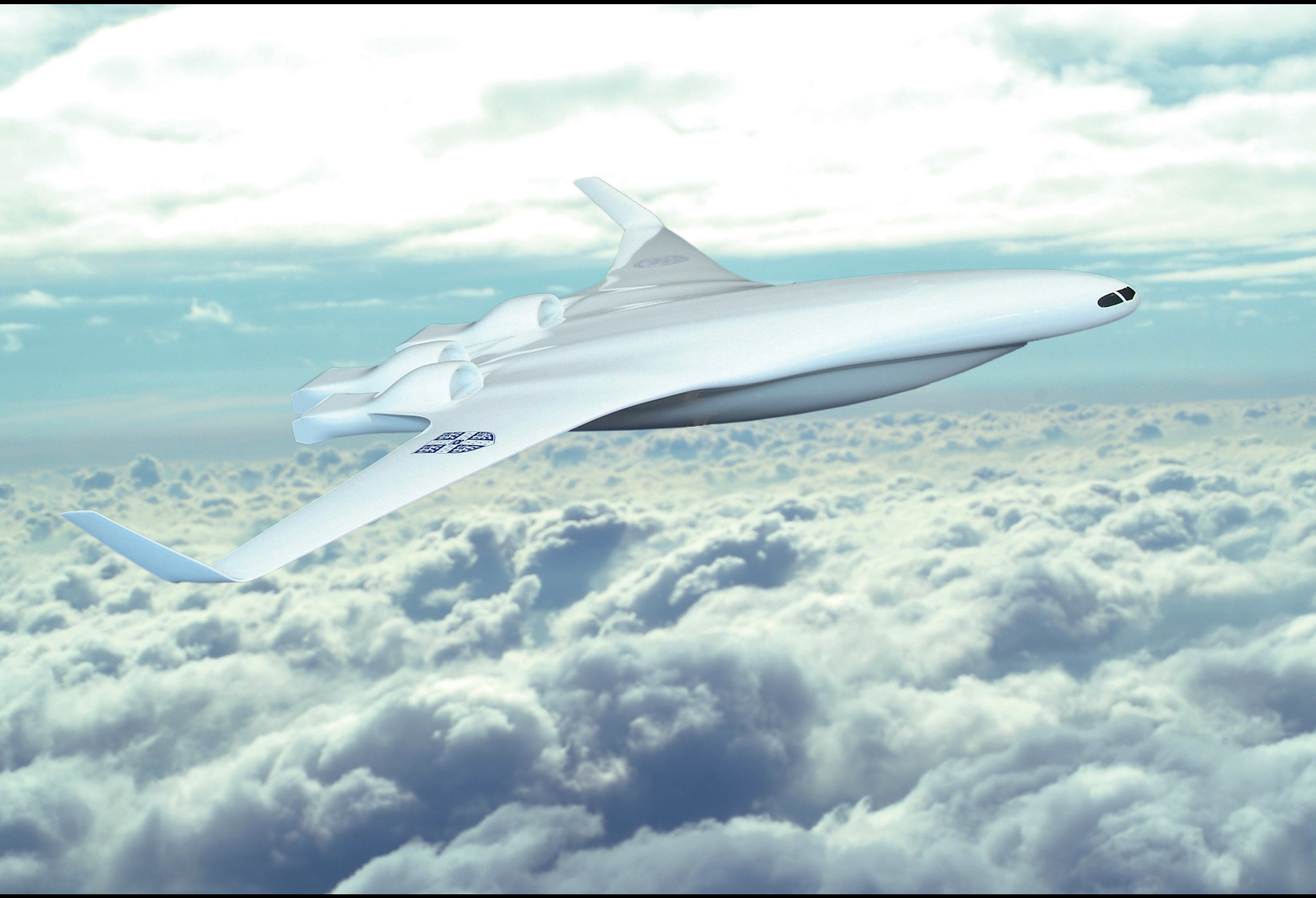
Increased use of renewable energy requires the rest of the generation network to become more responsive to changes in supply and demand. Energy storage solutions will also be required.

- Whittle Laboratory research aims to develop ultra-efficient turbines that can turn on and off quickly in order to support a higher use of renewables on the grid.
- New technologies, which use hydrogen and ammonia as energy storage mediums, will rely on efficient, flexible turbomachinery to convert the stored chemical energy into electrical power.
- Whittle Laboratory research also includes the development of Organic Rankine cycles for power extraction from waste heat, the supercritical CO_2 Allam Cycle for carbon capture, and helium cycles in nuclear reactors.

How to get involved

Our vision is to build a cutting-edge laboratory, transforming propulsion and power research and education in the 21st century. We will also create a space for industry leaders and academics to come together to develop cleaner, more sustainable, and more flexible aerospace and power sectors.

In order to realise this vision, we are seeking to partner with individuals or organisations interested in supporting the New Whittle Laboratory project. A range of high-profile naming opportunities will be available in the new laboratory and opportunities for donors to be involved at all levels.



"We are at a pivotal moment, both in terms of Cambridge's history of leading technology development in propulsion and power and humanity's need to decarbonise these sectors.

The Whittle Laboratory has demonstrated a unique international capability and, in partnership with the Aerospace Technology Institute, Rolls-Royce, Mitsubishi Heavy Industries, Siemens, and Dyson, this has been developed into a world-leading project – the National Centre for Propulsion and Power.

Just 50 years ago, at the opening of the current Whittle Laboratory, Cambridge and its industrial partners faced the challenge of making mass air travel a reality. Now the New Whittle Laboratory will enable us to lead the way in making it carbon neutral.

We must do what Cambridge has always done, and step up to the challenge."

Professor Robert Miller, Director of the Whittle Laboratory

Dear World,

Thought this might take off.

Yours, Frank

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