A Rolls-Royce Trent 900 engine on the wing of an Airbus A380. Six University Technology Centres helped develop the Trent 900 fan © Wikipedia/Kolossos

COLLABORATIVE RESEARCH

Rolls-Royce has a long history of collaborative research with universities. These have reached a maturity over the past two decades with the creation of University Technology Centres (UTCs). Mark Jefferies, Chief of University Research Liaison at Rolls-Royce, describes how UTCs are established and operated, giving examples of some of the key technologies that they have helped to deliver.

Rolls-Royce University Technology Centres are at the heart of the company's approach to developing the technology, to deliver its vision and secure a competitive advantage. The UTC model has been developed over two decades and has had a significant impact on the relationship between industry and academia. Initially concentrated in the UK – the first were set up at Imperial College and Oxford University in 1990 – today's international UTC network reflects the company's global footprint.

As well as the 19 centres at 14 UK universities, four UTCs are located at German universities, with others in Italy, Norway, Sweden, the US and Korea. Each UTC addresses a technical discipline whether be it noise, combustion, aerodynamics, electrical systems or manufacturing. Each is led by a senior academic with a global reputation in their field. They are supported by academics, research fellows, research assistants, technicians and a number of students undertaking PhDs and other higher degrees.

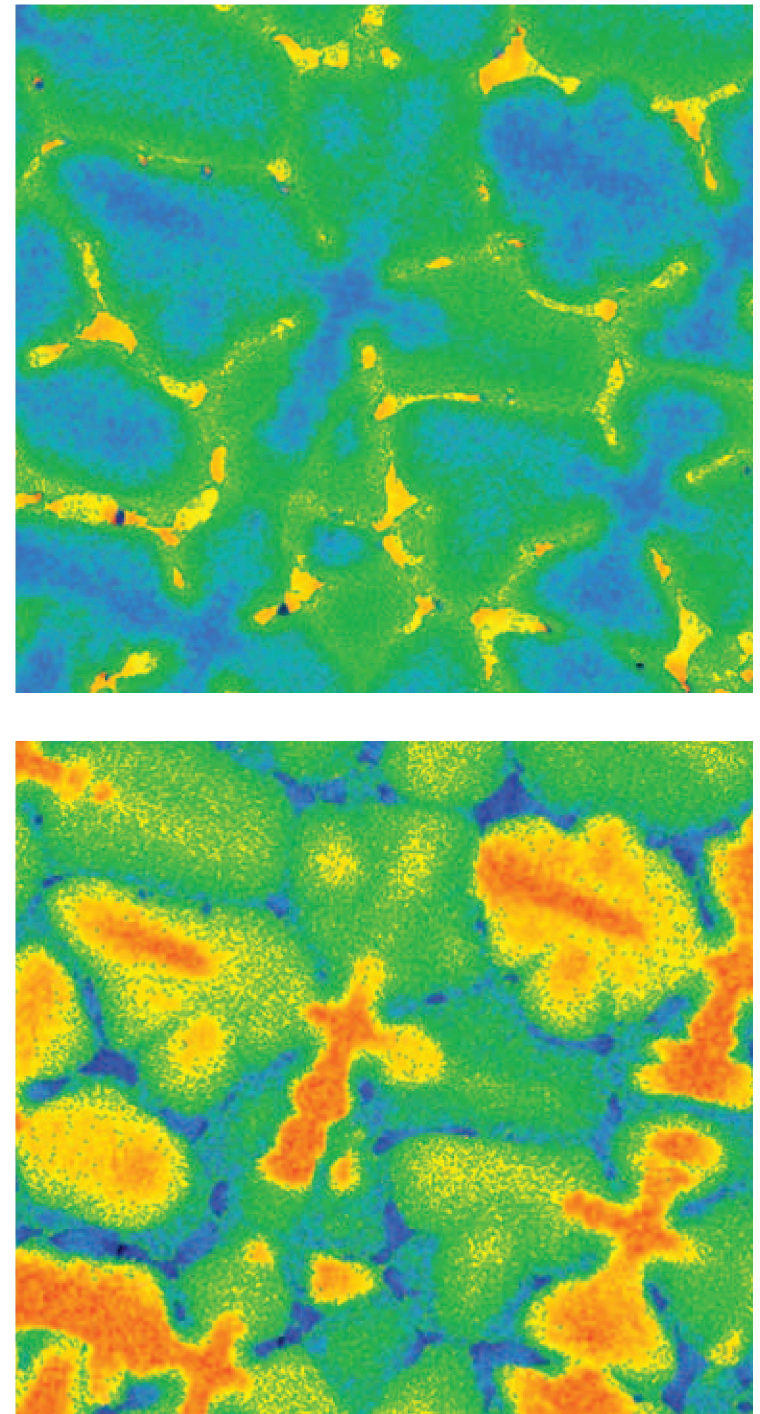
Funding is provided through rolling five-year contracts, which enables UTC teams to take a long-term strategic view of how to achieve specified research programme targets set together with Rolls-Royce. Additional funding in support of fundamental and collaborative research may be provided from complementary sources such as the EU and, in the UK, the Engineering and Physical Sciences Research Council (EPSRC), the Technology Strategy Board, learned societies and regional agencies.

STRATEGIC VISION

To minimise duplication and maximise focus, the establishment of UTCs demanded an organisational and cultural change in Rolls-Royce's approach to research and development. Instead of the more usual large inhouse R&D function, the company has developed a UK based Strategic Research Centre. This is made up of around 45 specialist staff on 'technology watch' – evaluating and developing new concepts that may make giant strides in performance or show potential for brand new markets.

Each UTC is 'owned' by an internal Rolls-Royce business unit, typically the engineering team of a supply chain unit seeking new technology and fresh capability that could play a part in new product development. Technologies undergo regular reviews and pass through formal 'gates' as they mature. A UTC will generally take development to the third or fourth level of technology readiness (TRL3/4) before a new technology is transferred back to the company to conduct validation activity advancing it towards TRL6, at which point it can be utilised as a feature of new product designs.

Ownership of Intellectual Property Rights (IPR) on emerging technologies



Maps of chemical elements in cast superalloys developed by the Cambridge UTC. Rhenium (top) and tantalum (bottom) are added to provide additional strength to the matrix and precipitates in these alloys respectively. When these alloys are cast, the rhenium partitions to the growing solid and tantalum partitions to the liquid, leaving the patterns shown above
© University of Cambridge

depends on the arrangement Rolls-Royce has with universities. Alternatively they may be governed by national regulation, but Rolls-Royce retains access to the IPR while simultaneously providing for its use by the academic bodies, including for research and teaching purposes. Where IPR remains with the universities, it is licensed back for use by its sponsor.

RESEARCH EXAMPLES

There have been a wide range of successful research collaborations in recent years. One such key research area for engine makers is that of materials research. With virtually all current commercial aircraft and many power generation plants using gas turbines, the challenge is to find radically new materials – beyond today's nickel-based superalloys – that will enable engines to run hotter in order to raise thermal efficiency, cut fuel burn and reduce harmful emissions.

The high-pressure turbine blade is the most demanding individual component as it sits in the hottest part of the engine. Manufactured as single-crystal blades to eliminate grain boundaries, they can run at temperatures hundreds of degrees hotter than the melting point of the materials they are made of. This is due to the tough, specially-developed coatings and elaborate cooling labyrinths within the blade's core.

Today's high pressure turbine blades are composed of several elements to deliver the required temperature capability. However, as fourth-generation superalloys, the pace of their continued development is slowing to the point where researchers must look past the small iterative increases offered by nickel-based materials towards entirely novel materials.

This is where the blue-sky vision and focused technical expertise existing within UTCs can generate significant results. The materials research team comprises Cambridge UTC which drives high-temperature research, Swansea, specialising in the testing of mechanical properties and lifing capability, and Birmingham which undertakes materials-and-process modelling *(cont. on page 38)*

The machining centre - the WFL M100 millturn funded by EMDA is capable of carrying out a range of turning, boring, milling and measurement operations. It allows almost all machining work to be conducted on large components up to 5 m length without having to move it between different machines. The AMRC is using the machine to apply its research in innovative techniques for machining high-performance materials (using technologies such as dynamic analysis, simulation and modelling, advanced fixturing and tool design). The WFL is being used with Rolls-Royce to create efficiency gains in the production of shafts and spindles for jet turbines, as part of the SAMULET project (Strategic Affordable Manufacturing in the UK through Leading Environmental Technologies) funded by EPSRC and TSB © AMRC

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NEWAC RESEARCH

Rolls-Royce and members of its University Technology Centre network are among 40 partners lending their expertise to the European MTU-led NEWAC research programme. This initiative began in May 2006 and concludes at the end of this year. At a time when global air traffic is forecast to grow annually at five per cent over the next two decades, NEWAC (New aero engine core concepts) has looked at developing novel engine cores that will radically reduce levels of pollutants such as carbon dioxide and oxides of nitrogen.

Six sub-programmes generated the research. Four focused on innovative cores – an intercooled recuperative engine, an intercooled core, an active core and flow controlled core – all supported by a sub-programme working on advanced combustors. Rolls-Royce led two sub-programmes, including the one co-ordinating whole-engine integration issues. UTCs at Loughborough (ducting aerodynamics), Oxford (heat exchanger flows), Cambridge (compressor stability) and Sussex (tip clearance control) have all worked on technologies within NEWAC.

Dozens of new technologies – chiefly centred around compression, combustion, heat exchanger, mechanical design, manufacturing and whole engine integration – have emerged from NEWAC research programmes. Some of these have already been demonstrated and begun validation during NEWAC and could quickly feed through into new designs.

Intercooled aero engines offer great promise for higher overall pressure ratios to reduce fuel consumption or 'trade' lower compressor delivery temperatures in order to reduce mono-nitrogen oxides (NOx). These require aerodynamically-designed low-loss ducting systems to transfer core air to and from heat exchanger modules within the engine and provide a cool airflow from the bypass duct.

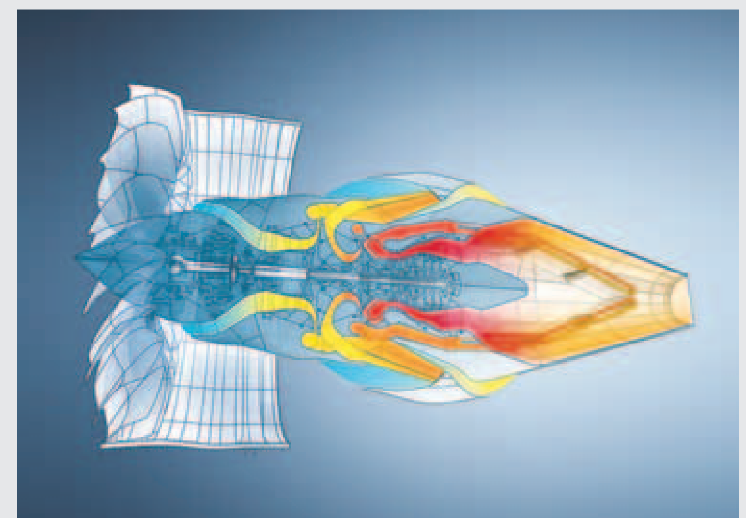
Work at Loughborough University has developed a design methodology, validated by rig testing, which addresses the need for such ducting systems to be short and compact, and avoid adverse effects on upstream and downstream compressor modules, while also minimising pressure losses that could negate inter-cooling performance benefits. System performance targets have been shown to be achievable.

Rolls-Royce investigated a cross-flow, cross-corrugated heat exchanger design developed at Oxford University that has potential for aerospace applications because of its light weight and, in volume production, cost advantages over current tube-type heat exchangers. Selective laser melting was used to manufacture rapid prototypes in titanium, though alternative manufacturing methods would be examined for production.

Both this and the ducting technologies will be unlikely to see service operation much before 2025, but a novel form of over-tip casing treatment to extend stall margins in operational aero engines that has been under investigation at the Whittle Laboratory in Cambridge University and could be available for production in the next five-years

This new method adapts itself to prevailing compressor operating conditions, extracting air from over the rotor blade tips and re-injecting it just upstream of the same blade row.

For more information on its organisation and technical results, visit www.newac.eu



An intercooled/recuperative engine, one of four different core engine architectures that the NEWAC research programme looked at. This one uses heat exchanger modules in the main exhaust to extract thermal energy and transfer it back into the combustion chamber. NEWAC is aiming to reduce the fuel consumption of engines by 6% by improving core engine technologies and with it carbon dioxide emissions too © MTU Aero Einiges

The research focus is now on producing refractory metal silicides for much higher temperatures and titanium aluminides for lighter weight components.

and manufacturing issues such as alloy production and joining technologies. This partnership has led to the development and securing of patents for several new alloy systems.

The research focus is now on producing refractory metal silicides for much higher temperatures and titanium aluminides for lighter weight components. These pose an entirely new set of design and manufacturing challenges for researchers. It is only by developing new materials that step-change benefits can make significant inroads into the ambitious efficiency and environmental targets set by the industry.

MUTUAL BENEFITS

Rolls-Royce derives considerable value from working with universities. Formalised UTC relationships offer the company much more efficient access to high-quality research that delivers significant technology advances. Loughborough UTC, for example, supports the Rolls-Royce energy business research out of Montreal in Canada, and the network facilitates increased international collaboration with other leading universities around the world. The creation of a sophisticated Unsteady Fluid Dynamics Facility at Loughborough University in 2008 was underpinned by the joint relationship with Rolls-Royce.

Another mutual benefit lies in recruiting the best staff. Working on leading-edge industrial challenges is an attractive proposition and UTCs draw in highly capable researchers and students. The universities benefit from the quality of research and the subject matter for papers, dissertations and speeches from Rolls-Royce's visiting professors. The UTC gains from this critical mass of talent and the company benefits as a proportion of students are attracted by the opportunity to work for a firm that is recognised worldwide.

Rolls-Royce also sends its own employees to work and study within UTCs. A number of Rolls-Royce engineers have completed PhDs at Loughborough, enabling the company to develop its own staff.

A senior researcher setting up a Low Pressure Turbine 'cascade' experiment in the Whittle lab – a high speed airflow facility that allows detailed testing of turbine aerofoil geometry to determine the aerodynamics of the blade sequence at engine representative conditions © University of Cambridge

WIDER COLLABORATION

Rolls-Royce collaborates in numerous national and international long-term external research programmes outside UTCs. One of the biggest is Europe's Clean Sky Joint Technology initiative – involving 54 companies, 15 research centres and 17 universities from a total of 16 countries – for which Rolls-Royce leads two of the propulsion-focused demonstrators designed to validate new engine technologies. Another pan-European collaboration in which it is partnered is NEWAC (see NEWAC Research) that has studied new aero-engine core concepts.

The successful UTC model has been extended to work with other industrial partners to create several advanced manufacturing research centres. Rolls-Royce joined the Advanced Manufacturing Research Centre in Sheffield in 2004, launching its own Factory of the Future – a four-fold expansion of the AMRC – on the same site five years later. An Advanced Forming Research Centre was established in 2010, when the company also announced its partnership in the Midland Technology Centre and the Nuclear Advanced Manufacturing Research Centre. Specialist manufacturing centres are also being launched close to the company's major operations in the US and Singapore.

IMPACT OF UTCS

Over 600 people are working in the UTC network of world-class research teams at any one time. Over 350 doctorates are being supported by Rolls-Royce, mostly through the UTC network, and around 400 technical papers are published annually by UTC staff independently or in conjunction with company engineers, and around 10% of patents filed by Rolls-Royce emerge from the network, with UTC staff invited to participate in the company's patent rewards scheme.

With long-term funding, alongside privileged access to data, tools and people, universities secure continuity and stability as well as the real-world technical challenges so attractive to high-class research staff. In return, Rolls-Royce stays directly connected to cutting-edge academic capabilities, with access to world-class skills and highly motivated staff.

BIOGRAPHY

Mark J Jefferies has led numerous national and international collaborative research programmes into propulsion-related technologies, with particular emphasis on technology transfer from the science base. He has worked in aerospace for 24 years and been responsible for Rolls-Royce's international network of strategic academic partnerships since 2008.

The author would like to thank Professor Peter Ireland, Dr Howard Stone, Andrew Rolt, Dr Jon Carrotte and Gary Atkins for their help in compiling this article.

TRENT 900 DEVELOPMENT

No fewer than six Rolls-Royce UTCs contributed technologies during the development of the swept fan blade for the Trent 900 that powers the Airbus A380.

Birmingham's Materials UTC set to work characterising material properties. They measure and model crack growth resistance through fracture mechanics, enabling designs to be made that could control the behaviour of cracks in non-uniform stress fields at elevated temperatures.

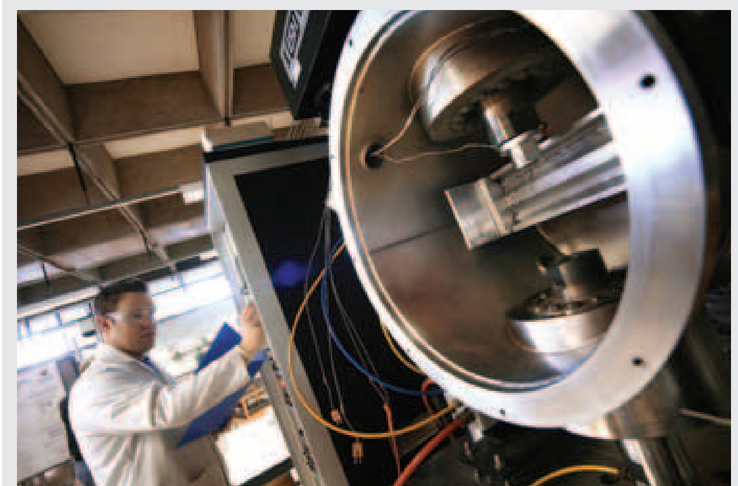
The Solid Mechanics UTC at Oxford addressed the effects of 'foreign object damage' (anything entering the front of the engine, from large birds to runway debris) on the very large fan blade. It developed models to understand and predict material behaviour under high strain-rate conditions, allowing engineers to design the blade to resist failure.

Complementary research into blade integrity was undertaken by Imperial College London. Imperial College focused on unsteady flow modelling, aeroelasticity, bladed-disc vibration with emphasis on non-linear behaviour, mistuning (to avoid resonance) and modal test planning.

Research in the Whittle Laboratory in Cambridge developed a range of fan flow models. These were based on complex 3D flow calculations, validated through detailed experimental studies, that enabled a blade design embodying increased efficiency yet still tolerant to inlet distortion and providing sufficient surge margin for safe off-design operation.

Other UTC inputs benefiting the Trent 900 fan blade design came from Southampton, which studied the flow effects on fan noise, introducing an acoustic liner to eliminate the fan tones that generate 'buzz-saw' noise. Additionally, Nottingham, which specialises in manufacturing issues, particularly fixturing and tooling for complex environments and processes, delivered tooling concepts now in use to embed a more efficient blade production process.

The Airbus A380 had its first commercial flight in October 2007 and by the end of 2011, 50 had been completed and delivered.



A test set up in the Metallurgy laboratory high temperature vacuum test chamber. It is used for the measurement of fatigue and crack growth data for high temperature (usually turbine) alloys © University of Birmingham