



Partners in power

MARK JEFFERIES, chief of university research liaison at Rolls-Royce, explains the role of the the company's links with academia in developing new aerospace technologies.

Here, we take a look at Rolls-Royce and its unique global network of University Technology Centres (UTCs) established to search for step-change concepts and to mature new technologies that will make a difference to the aero-engine products of tomorrow. The recently completed Europe-wide NEWAC (NEW Aero-engine Core Concepts) programme demonstrates how a broad slice of the aviation industry and academic community — including Rolls-Royce and members of its UTC network — can work collectively to advance the technologies needed to raise the thermal efficiency of future aero-engines.

Rolls-Royce is a major value generator for UK and global economies through the quality and excellence of its technology. Technical creativity is its byword: Over 30% of its employees are qualified engineers, it files over 400 patents each year, and the company devotes a high proportion of its turnover to research and development (with over £7bn invested on R&D in the past decade, two-thirds directly on improving the environmental performance of its products).

But, like other world-leading technology companies, Rolls-Royce recognises the vital

need to work together with its peers, and even sometimes its competitors, on challenges facing the whole aerospace industry — through global, European and UK collaborative programmes addressing globally-accepted environmental performance targets.

Enter NEWAC

NEWAC is one of a number of European collaborative research programmes seeking to bring on stream a range of new technologies that will help the aviation industry meet challenging environmental targets identified by the Advisory Council for Aeronautical Research in Europe (ACARE). This industry charter targets the reduction of noise and carbon dioxide (CO₂) emissions by 50% and oxides of nitrogen (NO_x) emissions by 80% by 2020 against a benchmark of year 2000 levels.

While the aero engine is only one of a number of instrumental factors, it is expected to contribute most towards NO_x reductions and 40% of total CO₂ reductions required.

NEWAC has just concluded following five years of studies by 40 partners from 11 nations, including many of Europe's leading equipment manufacturers such as Airbus, Avio, MTU,

Rolls-Royce, Sulzer, SNECMA, Turbomeca and Volvo, plus a wide range of research organisations and universities, including several Rolls-Royce-supported UTCs (see separate textbox for background on Rolls-Royce UTCs).

NEWAC research has been underpinned by a budget of €71m, and has investigated a range of new technologies for advanced engine core concepts. This has included incorporating novel heat management techniques for greater thermal efficiency, potentially leading to lower specific fuel consumption and a radical reduction in emissions.

In a conventional gas turbine cycle, thermal efficiency is largely a function of overall pressure ratio (OPR) and turbine entry temperature — further increases of which are limited by maximum material temperature capabilities and the need to avoid increasing NO_x emissions.

Higher thermal efficiencies can only be achieved without increasing temperatures by improving component efficiency: this has called for innovative technologies in the area of active systems, flow control technologies, and the integration of an intercooler to cool the airflow during its compression, which potentially enables higher OPRs without increasing NO_x. Another heat exchanger, a recuperator, can also

Left: Intercooled engine heat exchanger installation from Rolls-Royce, Volvo Aero and Loughborough University.

be added to exploit the heat of the engine's exhaust gases.

Sub-programmes

NEWAC research was conducted by way of six sub-programmes each with an industry lead and comprising several of the partners. Some partners were involved in a number of sub-programmes. Four focused on innovative cores — an intercooled recuperative engine (SP2), an intercooled core (SP3), an active core (SP4) and a flow-controlled core (SP5).

Sub-programme SP6 supported all core concepts by conducting research into three separate lean-burn combustor configurations for ultra-low NOx emissions — the lean premixed prevaporised (LPP), lean direct injection (LDI) and partial evaporation and rapid mixing (PERM) combustor types.

Finally, sub-programme SP1 evaluated the costs and benefits of each new concept and individual technologies at the whole-engine and whole-aircraft level.

Exploiting previous research, one of SP1's work packages deployed the TERA2020 analysis tool developed (originally for a counterpart programme, VITAL) by a consortium of universities. It incorporates a sophisticated conceptual design algorithm and considers a wide range of technical disciplines typically encountered during conceptual design; this enables a broadening of the technology assessments within collaborative pre-competitive studies to include socio-economic factors such as global warming potential. TERA2020 has proved useful for rapid optimisation and 'what-if' scenarios. TERA2020 activity was led by Cranfield University, which hosts the Rolls-Royce UTC in Gas Turbine Performance.

Where it fits in

NEWAC has not, of course, been run in isolation: it builds on earlier EU Framework programmes such as EEFAE (ANTLE¹ and CLEAN²), and complements the Framework 6 VITAL programme that has targeted noise and propulsive efficiency by focusing on low-pressure (LP) component design. Furthermore, projects undertaken as part of NEWAC but calling for more research will be pursued in

¹ Affordable Near Term Low Emissions technology

² Component vaLidator for Environmentally friendly Aero eNginE were test vehicles within the EU Framework 5 EEFAE (Efficient and Environmentally Friendly Aero-Engine) programme

forthcoming collaborative projects such as LEMCOTEC, and the larger-scale 'Clean Sky' Joint Technology Initiative that aims to accelerate some of these new technologies into active service more quickly than would typically be the case.

Andrew Rolt of the Rolls-Royce Strategic Research Centre, who was programme lead on SP1, says that some of the new technologies have already been demonstrated in validation testing during NEWAC and could relatively quickly feed through into new designs.

"Typically technology readiness levels are around TRL4-5 (level 6 being when they can usefully be considered by component or system designers), but we would expect to use other collaborative programmes such as Europe's Clean Sky JTI as a route to accelerate these technologies towards new product designs."

The role of UTCs

Rolls-Royce led two sub-programmes, SP1 and SP3, and was able to multiply its own efforts by harnessing the dedicated and specialist skills that exist within its network of highly-successful University Technology Centres.

Four Rolls-Royce UTCs have directly contributed as partners in NEWAC to work programmes that are of particular interest to Rolls-Royce, and several other universities across Europe where Rolls-Royce has established a UTC — including Karlsruhe in Germany and Chalmers in Gothenburg, Sweden — are also NEWAC partners. Each has applied its extensive knowledge and expertise to work on discrete technologies.

In the UK, the University Gas Turbine Partnership (UGTP) at Cambridge has utilised

its Whittle Laboratory to investigate new compressor technologies including tip injection for stability at part speeds, while both Cambridge and the University of Sussex — another university partner with a history of close collaboration with Rolls-Royce — focused on tip clearance control.

Loughborough's Combustion and Aerodynamics UTC has focused on the aerodynamics of intercooler ducting required to transfer air in and out of the engine's compression systems. The Oxford Heat Transfer and Aerodynamics UTC has primarily studied the flow characteristics of heat exchanger inlet and exits.

Loughborough and Oxford were involved in work programmes as part of SP3 that focused on intercooled aero engines which offer great promise as the foundation for significantly reduced fuel consumption or for 'trading' lower compressor delivery temperatures to limit NOx production.

In an intercooled engine, air diverted from the bypass duct is used to cool the flow exiting the intermediate pressure compressor before entering the high-pressure compressor. Intercooling becomes an attractive proposition as engine OPR increases because optimum intercooled cycles have lower temperatures for high-pressure compressor (HPC) delivery air and turbine cooling air, together with lower combustor flame temperatures that help reduce NO_x.

Challenges

On the debit side, however, these benefits could be outweighed by pressure losses in the intercooler and its associated ducting, smaller core



Rolls-Royce

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.

components leading to reduced component efficiencies, and by increased weight and nacelle drag if intercooled engines require larger nacelles.

SP3 sought to show these potential penalties can be controlled to the extent that the sub-programme goal of a four per cent reduction in specific fuel consumption would still be achievable. To do so, it launched research into component technologies — including a compact, lightweight and low-loss intercooler, low-loss inlet and outlet ducting for the intercooler, stiff structures to support the intercooler modules and maintain rotor tip clearances — together with new blading designs and systems to maintain compressor efficiency and operability.

Specific NEWAC work packages at Oxford investigated the flow specifics of heat exchanger intakes and exits. This involved a lot of interaction with the industry partners that set the challenge, and was overseen by the Rolls-Royce work package leader together with half-yearly technical reviews and annual reviews involving all partners in the programme.

Rolls-Royce investigated a cross-flow, cross-corrugated heat exchanger design developed at Oxford University. Aerospace potential centres on its light weight and, in volume production, cost advantages over current tube-type heat exchangers. Selective laser melting was used to make rapid prototypes in titanium but alternative manufacturing methods would be examined for production.



NEWAC Low Pressure Intercooler Ducting Test Rig at Loughborough University.

Loughborough undertook its work packages in collaboration with industry partners Rolls-Royce and Volvo, and involved the design of intercooler HP and LP inlet and outlet ducting that met performance targets on rig testing. Loughborough UTC deputy director Dr Jon Carrotte believes considerable progress has been made: “From almost a blank piece of paper, we developed design system methods and CFD optimisation techniques and conducted validation experiments, to a point where they could be applied to an intercooled engine.

“The development of this methodology, validated by rig testing, has addressed the need for such ducting systems to be short and compact, avoid adverse effects on upstream and downstream compressor modules, and minimise pressure losses that could negate inter-cooling performance benefits. There are a few more boxes to be ticked but performance validation courtesy of testing has shown targets are achievable and has moved the technology to TRL 4-5.”

Benefits of partnership

Dr Carrotte adds that the continuity afforded by the Rolls-Royce relationship, with its five-year horizon is vital: “It’s a tremendous benefit. It gives us the ability to acquire some very skilled staff, which has developed into an experienced team. It also gives the university the confidence to invest in the future, so we have some enviable facilities that enable us to build and maintain a world-class capability.

“Furthermore, the high-impact nature of applied research is a real boon to teaching as I can use fresh and current material in my lectures and can also welcome visiting professors like Rolls-Royce’s director of research and technology to deliver unique and exciting insights into how technologies students are working on in the UTC will be applied by aviation and other industries. Some may well even be operating in the 5-10 year timeframe.”

Loughborough’s team comprises around 40 people — led by several academics and several more technical and administrative support staff. “We also have a number of research assistants, a few post docs and between 15 and 20 research students. Our work is about 50:50 between theoretical and experimental, so they get plenty of chance to use specialised equipment housed in our heat transfer and aero-acoustic laboratories, jet nozzle facility and range of fully annular rigs.”

Director of the Oxford University UTC, Professor Peter Ireland, agrees that UTC projects should not be underestimated from the educational viewpoint: “These are big



A researcher at work on the High Speed Linear Cascade Facility in the University of Oxford UTP in heat transfer and aerodynamics.

knotty problems we are helping to solve and the students realise they are working on real-world challenges ... Exposure to senior, highly competent engineers from Rolls-Royce is an eye-opener. It shows the complexity of the tasks but also gives students an idea of what may lie ahead for them in their professional lives.”

Prof Ireland sees the ability to plan strategically as a key benefit of the UTC relationship. “The relocation of our Osney Laboratory to a more professional, modern and better equipped base is a good example. An investment of around £10m was involved, with much of the funding coming from Rolls-Royce, the regional development agency SEEDA — and from Oxford University itself.

“Those funds would not have been assured without the confidence of a long-term future for the Osney lab, underpinned by the continuity and volume of work placed there by Rolls-Royce ... We can then focus on our area of expertise, build up a critical mass of top-class researchers in that topic and exert a powerful effort into solving industry challenges — and that’s what Rolls-Royce gets in return. It’s a win-win.”

One of the more recently appointed Rolls-Royce UTCs — at PNU in Busan, Korea — specialises in heat exchanger technology. While not directly involved in NEWAC, recent Rolls-Royce projects have promoted strong links between PNU, Oxford and Loughborough — a relationship that has matured to the point where the respective



universities also exchange academic staff and students. A recently-appointed professor at PNU, for example — Dr Changmin Son — having previously worked at both Rolls-Royce and Oxford University, is intimately acquainted with UTC research priorities.

While heat exchanger and ducting technologies pursued in NEWAC are unlikely to see service operation much before 2025 — demonstrating the structured, long-term and thorough approach that aerospace engineers must adopt to research tasks — certain technologies can bring more rapid benefits. A novel form of over-tip casing treatment to extend stall margins in operational aero engines — one of the work packages investigated at the Whittle Laboratory in Cambridge University — could be available for production within five years.

Summary

NEWAC underwent a final review meeting in Brussels in April (visit <http://www.newac.eu> for more information). The results from all sub-programmes reflect considerable success against targets, with some examples still requiring further development or additional evidence of their value. Some have reached TRL5-6 following exhaustive validation via rig tests, while others remain at a lower readiness level indicating that validation activity is still required in a future programme.

Meanwhile, the hard work will continue and the focus will be fiercer still as the industry works together through a structured series of collaborative research projects to initiate new, more efficient and effective technologies and speed them towards active service where they can play their part in meeting the aviation industry's target reductions pledged by ACARE for 2020 and beyond. 

Leveraging academia

Rolls-Royce University Technology Centres lie at the very core of the company's 'Vision' strategy to develop technologies that can continue to deliver competitive advantage for its wide range of products. The UTC model has been developed and refined over two decades and has had a significant impact on the relationship between industry and the academic community.

Rolls-Royce launched its first two University Technology Centres (UTCs) in 1990, one studying vibration at Imperial College and the other solid mechanics at Oxford. Since then, a further 26 have been added to an increasingly global network that covers a wide-ranging set of technical disciplines — from aerodynamics and noise to electrical systems and manufacturing engineering.

Each UTC is selected as a world-authority in a specific discipline, each with a senior academic recognised globally in his or her field, leading a skilled research team comprising fellows, assistants, technicians and students mostly undertaking PhDs and other doctorates. They are funded by Rolls-Royce on the basis of a rolling five-year horizon, which offers much sought-after continuity of research and makes the inter-relationships and UTC role much more strategic. Complementary funding is often provided for fundamental research programmes by the EU or, in the UK, by bodies such as EPSRC (Engineering and Physical Sciences Research Council), TSB (the government's Technology Strategy Board), regional and local authorities and Learned Societies.

In the UK there are 19 Rolls-Royce UTCs at 14 different universities but, with its increasingly long global reach, the company has established nine UTCs outside the UK — four in Germany, and one each in the US, Italy, Sweden, Norway and South Korea, with many more relationships being developed. UTCs interact principally with engineers in one or more 'supply chain units' — the internal businesses of Rolls-Royce that design and make components for complete engines and systems — or with the company's strategic research centres. Working with the company's engineers, University staff will take the research to a technology readiness level (usually TRL 3 or 4) that the company can then pull in-house to move into large-scale validation, via rig or whole-engine testing, ahead of specific product application.

Assured funding

Rolls-Royce has experienced huge advantages from this approach — and so have the universities involved. Indeed, it is this mutual benefit that underpins and promotes an increasingly long-range, strategic approach to the research they conduct. Assured funding over several years creates continuity which, in turn, breeds confidence and shared technology strategies. Guaranteed funding also means universities can recruit well and build highly capable teams able to draw on world-class facilities to support their leading-edge projects.

For the company, the benefits lie in the high-calibre people and sophisticated facilities the universities can construct over time as a result of Rolls-Royce support, along with complementary funding from other research bodies and the support of the universities themselves who appreciate the strong foundation presented by UTC projects.

Furthermore, whereas in-house engineers can get pulled from one urgent task to another, UTC teams have a bit more time to widen the envelope of their thinking — and by challenging current thinking or technical practices, they can sometimes bring about more radical solutions. Such a rich pool of highly-skilled scientists and engineers also offers Rolls-Royce the potential to bring top-class recruits within its own ranks, and two-way secondments further enhance the technology transfer and skills development that the relationships provide.

Simply by their existence, UTCs make an impact on the broader technical community: ten per cent of Rolls-Royce patents are lodged as a result of UTC research, the network publishes 400 peer-reviewed technical papers annually, and around 350 doctorates are being supported through UTC projects at any one time.

Such credentials have seen UTCs recognised and lauded by peer groups as a model means for acquiring generic technologies that can subsequently be applied more broadly across a number of industries.