Institution: University of Southampton

Unit of Assessment: 15 General Engineering

Title of case study: 15-18 Decision Analysis and Support Tools for the Aerospace Industry

1. Summary of the impact

Research carried out at the University of Southampton has enabled major players in the aerospace industry – among them Rolls-Royce, Airbus, and Boeing – to produce more fuel efficient, longer lasting engines and aircraft at reduced cost. The research has provided the aerospace industry with modelling tools and software enabling companies to explore complex new designs quickly whilst managing product risk in a competitive market. The research team has also developed new design processes for unmanned aircraft, which – as a result of strong media interest - improved public understanding of such new technologies through worldwide coverage. A spin-out company has achieved strong technological and economic impacts in its own right.

2. Underpinning research

In an extremely aggressive civil and military aviation market, companies constantly need to push the known boundaries of materials, structures, aerodynamics and thermodynamics to remain competitive. New designs have to be developed in short timescales, yet there is a very fine balance between technology risk and product performance. At the heart of a company's critical advantage is its ability to explore very complex new designs quickly whilst managing product risk.

It is in this area that world-leading aerospace provider Rolls-Royce (R-R) relies on the University of Southampton's University Technology Centre (UTC) for Computational Engineering, one of 28 UTCs worldwide funded by R-R.

Research led by Andy Keane, Professor of Computational Engineering at the University since 1996, and James Scanlan, Professor of Design since 2004, has enabled the creation of a range of new tools to support design teams working on complex aerospace products. Spanning the period from 2002 to 2010**,** the research was supported not only by R-R, but also through grants from the Engineering and Physical Sciences Research Council (EPSRC) and the European Union totalling over £2 million since 2008. Prior to the R-R UTC being established in 2009**,** Keane led the BAESystems / Rolls-Royce University Technology Partnership for Design (which included Airbus). This also aimed to apply modern design search and optimization tools to problems in aerospace engineering.

The primary research activity has consisted of developing and exploiting models of engineering systems using powerful computational facilities. The outcomes have equipped R-R with sophisticated optimization and cost management tools.

In the DATUM project (Design Analysis Tool for Unit cost Modelling) Keane, Scanlan et al provided Rolls-Royce's Integrated Project Teams with unit cost information to enable them to make informed trade-off decisions and to allow for the effects of uncertainty to be captured and understood in an industrial setting. Costing of an entire gas turbine with many thousands of parts is now accomplished in a few hours; prior to DATUM it would have taken Rolls-Royce weeks.

As part of the research, Keane, Scanlan and their teams also investigated a number of advanced stochastic analysis methods.

The tools resulting from this research are now in daily use not only with Rolls-Royce, but also BAESystems, Airbus, Boeing and related aerospace companies. Examples include new methods that allow rational trade-off between competing objectives using probability of improvement theory (a novel extension in this area of applied mathematics), its application to design and then its deployment to tackle problems in robust design approaches where trade-offs can be made between nominal performance and variance in that performance caused by variations in operating

conditions or wear in a controlled way.

Similarly, the team have developed new ways of combining data from factory inspection processes with geometry manipulation schemes coming from the field of cinema film animation to allow designers to model uncertainty in turbine blade shape and its consequences on blade life in operation. The use of highly structured cost and manufacturing knowledge tools has dramatically improved capabilities in the aerospace companies. Rolls-Royce, for example, can now routinely undertake a very detailed cost analysis of an entire three-shaft engine in less than a couple of days at the concept design stage. This would have taken many weeks in the past.

More recent work, carried out between 2010 and 2012 has focused on the impact of newly emerging manufacturing technologies such as laser sintering of powders directly into finished components and the consequences of such new methods on the freedoms available to designers. These approaches allow the reduction of part count and an increase in part complexity without associated cost rises, which leads to enhanced industrial competitiveness. The team built and flew the world's first unmanned aircraft (SULSA) manufactured wholly in this way, without any conventional screws or other fasteners.

Another of Scanlan's research interests, designing aerospace systems using "Value Driven Design" (VDD) principles, led to the development of unmanned systems under the DECODE project (Decision Environment for COmplex Designs, 2009-2012), among them an autopilot system for civilian use.

3. References to the research (the best 3 are starred)

Research outputs

1. * A.J. Keane and J. P. Scanlan, "Design search and optimization in aerospace engineering", Phil. Trans. R. Soc. Lond. (ISSN0962-8428) 365(A) pp. 2501-2529 (2007).
2. A.J. Keane, "Comparison of Several Optimisation Strategies for Robust Turbine Blade Design", J. Propulsion and Power 25(5) pp. 1092-1099 (2009).
3. * A.I. J. Forrester and A. J. Keane, "Recent advances in surrogate-based optimization," Prog. in Aerospace Sciences, 45 pp. 50-79, Elsevier (2009).
4. * A.J. Keane, "Statistical Improvement Criteria for Use in Multiobjective Design Optimization", AIAA Journal 44(4) pp. 879-891 (2006).

Grants

5. EPSRC award for an investigation into Grid enabled optimisation and design search for engineering - GEODISE - £2,872,450 (with Prof. S.J. Cox, Prof. N. Shadbolt, Prof. M. Giles, Oxford and Prof. C. Goble, Manchester), 2001-2005.
6. Rolls-Royce plc award for UTC in Computational Engineering - £1,347,639, 2009-2012.
7. EPSRC award for DECODE (Decision Environment for COmplex DEsigns) - £773,757, 2009-2012.
8. EU FP7 Integrated Project award for Collaborative and Robust Engineering using Simulation Capability Enabling Next Design Optimisation (CRESCENDO) - €384,007, 2009-2012.

4. Details of the impact

The research described has been crucial in enabling the aerospace industry to produce more fuel efficient, longer lasting engines and aircraft at reduced cost.

The roll-out of the DATUM project results across all R-R businesses worldwide began in 2008. As a direct result of the project, the use of unit cost modelling tools applicable at different levels from whole engine to feature, and from preliminary to detailed design, offers Rolls-Royce a novel

capability to facilitate the dialogue between design and manufacture. The roll-out is on-going both in the United States and Germany. In 2008, Professor Scanlan was given the Rolls-Royce R&T Directors Award for Creativity in recognition of the under-pinning research. In the last four years, the tool has been further developed and integrated into design optimisation workflows [5.1].

Throughout the impact assessment period, Scanlan has been the Director (and founder) of a spin-out business based on his academic research. Plexus Planning Ltd, founded in 2003, now has a turnover of over £500,000, with annual growth of over 20%. Plexus has developed a software toolkit that enables massively complex problems to be simplified. For example, Plexus was used by Boeing to help find high risk problems in a network of over 500,000 suppliers. This enables the representation of a wide range of management problems from project planning to supply chain management. In 2011, Plexus was chosen by Rolls-Royce as a strategic tool which has since been rolled out across their global IT infrastructure. This ensures that the widest possible community within Rolls-Royce is able to make use of the research of the Southampton UTC following a £300k licence deal [5.1]. Plexus has now established a strong reputation within the aerospace industry, with customers including Airbus (since 2005 [5.2]), Boeing (2007), Bombardier (2004) and the UK Ministry of Defence (2009). In 2011, the US Navy bought Plexus licences to model all concept design work.

Another tool developed as a direct result of the research is the Optimat toolkit, a collection of optimization tools that plug into Rolls-Royce's chosen integration framework (Isight). From 2009, this toolkit was made available to Rolls-Royce staff worldwide for strategic design improvement work on aero-engine components. It makes use of advanced surrogate modelling methods that offer world leading capability for dealing with problems with multiple goals and multiple levels of analysis fidelity. For example, this toolkit was used in the improvement process for the fan in the Trent 1000 engine used in the latest Boeing 787 airliner now entering service. A study carried out by R-R engineers in December 2009 showed that Optimat doubled the gains being made by computational studies of the fan system as compared to the previously used approach. [5.1]

As a direct result of the research into stochastic analysis methods, in 2010 these methods were inserted into the Rolls-Royce production finite element analysis system (SC03). This permits an assessment of the impact of manufacturing and operational uncertainty on the lives of critical engine components up to ten times more quickly than by conventional approaches. The results of the research are now being used in the development of the high pressure turbine assembly of the R-R Trent XWB engine for the next generation Airbus mid-range airliner, for which R-R has more than 500 orders worldwide.

In 2012, Scanlan and Keane facilitated the setting up of a new company, Solair Aviation Ltd, in collaboration with a local company and local investors, using the sophisticated computational engineering modelling developed by their team. The company is developing a new piloted micro light aircraft (The Swallow) under a licensing arrangement with the university. The local entrepreneur [5.3] who is supporting this initiative has estimated that there will be a market of over 100 Swallow aircraft per annum with an eventual turnover of over £6 million.

Scanlan's work on unmanned systems under the DECODE project led to him assisting an ex-Southampton PhD student to develop an autopilot for unmanned air vehicles. This in turn led to the creation of a successful spin-out business called SkyCircuits in 2010 (http://www.skycircuits.com/) of which Scanlan is now a director, assisting its growth and development. This company has a large number of customers to whom it has sold over £100k worth of autopilot systems including the MET office and several leading airborne surveying companies, including QuestUAV and CAllen Lenz. In addition the systems have been bought by Bath, Cranfield and Reading Universities.

Some aspects of the research have attracted strong public interest, leading to widespread international publicity. This is true in particular of the team's work developing the world's first plane manufactured wholly through 3D printing using laser sintering (SULSA). Publications that reported

this development in detail included BBC online (February 2011); the New Scientist [5.4]; the Los Angeles Times; MSN India; the Irish Times (all August 2011) and others. These articles, all written for non-specialist audiences, enhanced understanding of the new technology and its practical significance among the wider public. A YouTube video of the SULSA project has now attracted over 200,000 viewings.

In November 2010, Scanlan - on the strength of his research activities and excellent industry connections – was invited to organise a seminar on Design Search for leading aerospace industry and academic experts, which was held at the Institution of Mechanical Engineers, London.

5. Sources to corroborate the impact

5.1 Head of Design Systems Engineering,Rolls-Royce plc, Derby.

5.2 CAE Coordinator, Flight Physics Integration Methods, Airbus U.K., England.

5.3 Managing Director, Solair Aviation Ltd, Formosa, Fordingbridge, Hampshire.

5.4 New Scientist coverage of 3D printed aircraft: http://www.newscientist.com/article/dn20737-3d-printing-the-worlds-first-printed-plane.html

Patents:

[1] "Generating a multifidelity model of a system", UK Patent number: GB2399187A / GB2399187B, Publication dates: 2004-09-08 / 2005-06-15, Inventors: Leary Stephen John; Bhaskar Atul; Keane Andrew John.

[2] "Optimisation of sequential combinatorial processes utilising a surrogate model", UK Patent number: GB2405961A / GB2405961B, European Patent Number 1665146, Publication dates: 2005-03-16 / 2005-08-17 , Inventors: Olsen Tor-Morten Overby; Runnemalm Karl Henrik; Keane Andrew John; Voutchkov Ivan; Bhaskar Atul.

[3] "Design by Space Transformation from high to low dimensions", Inventors: C.M.E. Holden and A.J. Keane, UK patent no. GB1673732, European patent no. 1673732, US patent application no. 12081788.

[4] “Agent-like discrete event modelling software architecture” Inventors: Tai-Tuck Yu, James P. Scanlan and Gary B. Wills. March 2008. UK Patent GB0903852.