Institution: University of Southampton

Unit of Assessment: 15 General Engineering

Title of Case Study: 15-40 Leading the way in aircraft noise reduction

1. Summary of the impact

Research at the University of Southampton's Airbus Noise Technology Centre (ANTC) and the Rolls-Royce University Technology Centre (UTC) in Gas Turbine Noise has given Airbus and Rolls-Royce tools to understand, predict and reduce noise pollution from commercial aircraft, ensuring that they are on track to meet the EU's stringent noise reduction targets, and maintaining their competitive edge over key rivals Boeing, GE and Pratt and Whitney. The implementation of new low-noise technology from Southampton has already begun to benefit the millions of people who live near our busiest airports (250,000 within the inner 57dBA Leq contour at Heathrow alone).

2. Underpinning research

The International Civil Aviation Organisation (ICAO) reports aircraft noise as the most significant cause of public opposition to the expansion of airports and growth of air transport. It is more than simply an annoyance to residents near airports. According to the World Health Organization, it is an 'underestimated threat' that can cause short and long-term health problems. Its overall financial impact is estimated by the European Commission to lie between 0.2% and 2% of GDP, £3.1 billion for the UK alone at the lower estimate.

Aircraft noise threatens the growth of the UK aerospace manufacturing sector. This is of particular concern to Airbus, with total annual revenues of €38.5 billion (in 2012), and to the civil aerospace division of Rolls-Royce, with annual revenues of £6.4 billion dominated by the sale and maintenance of large civil aero-engines.

For this reason Rolls-Royce set up the University Technology Centre (UTC) in Gas Turbine Noise in 1999 at Southampton, consolidating a thirty year research collaboration with Southampton's Institute of Sound and Vibration Research (ISVR) on aircraft engine noise.

Airbus established their own Aircraft Noise Technology Centre (ANTC), also at Southampton, nine years later (in 2008). These two centres have made Southampton University the largest provider of aero-acoustic expertise in the UK with a total of 10 academic staff and more than 30 researchers and doctoral students working on aircraft noise at any one time. Southampton is the 'UK focal point' (http://www.xnoise.eu/about-x-noise/focal-points/) for the X-NOISE European aero-acoustic network bringing together industry and academic partners across the EU to collaborate on aircraft related noise research.

Fundamental research on turbofan noise has been undertaken in the UTC since 1999 by a team of academic and research staff led by Jeremy Astley, Professor of Computational Aero-acoustics (2001-present), Phil Joseph, Professor of acoustical engineering and turbo-machinery noise (1997-present), and Dr Rod Self, Senior Lecturer in jet noise and installation effects (1998-present). Other members of the team include Dr Brian Tester, Principal Research Fellow (2002-present), Dr Keith Holland, lecturer/senior lecturer (1999-present), Dr Alan McAlpine, lecturer (1998-present), Dr Gwenael Gabard, lecturer (2005-present) and Dr Mike Kingan, lecturer (2008-present). UTC researchers are typically responsible for half of the noise deliverables committed by the Rolls-Royce noise department in the internal Rolls-Royce R&T resource allocation process.

A complementary programme of research in aero-acoustics, focussing on airframe noise – the noise generated by the aircraft itself as opposed to its engines - was established in 2000 by Xin Zhang, Airbus professor of Aircraft Engineering. Zhang and his team pioneered the development and application of high order, numerical schemes for aero-acoustic noise prediction [3.5]. In 2008 the Airbus ANTC was formed with Prof. Zhang as director. Dr David Angland joined the ANTC as a lecturer in 2012.

Five specific areas of underpinning research are identified here as having had a profound impact on Rolls-Royce and Airbus noise reduction technology for current and future commercial aircraft.

Sound absorbing 'liners' placed on the inner surfaces of an engine in the intake and the exhaust are an important method for reducing fan noise, the largest single source of engine noise both at take-off and approach. UTC researchers have focussed their research since 2001 on applying advanced numerical techniques to predict the effect of these liners in aero-engine ducts. Professor Astley pioneered the development of these methods in the 1990s [3.1] and his work is implemented in commercial computer programs, such as SYSNOISE and ACTRAN which are widely used by the aerospace industry for aircraft noise predictions. The UTC team have further developed and applied these methods to real engines, validated them against Rolls-Royce data and integrated them in new acoustic design and optimisation procedures for liners [3.2],[5.7],[5.9].

Growing interest in fuel efficient, **advanced open rotor (AOR)** powered aircraft prompted Rolls-Royce to initiate research on AOR noise in 2007. This work, led by Dr Kingan, has resulted in new theoretical models to predict noise from AORs [3.3]. These are now incorporated in in-house Rolls-Royce prediction codes and have resulted in new patentable technology [3.4],[5.10]. Collaboration between the UTC and ANTC has used modified versions of these models for noise predictions of installed AORs on specific aircraft configurations (rear or wing mounted, for example).

A third area where UTC research has had a large impact on current engines relates to noise produced by **bleed valves.** These are used in aero-engines to manage air flow, mainly in the approach to landing condition. Rolls-Royce identified bleed valves as an important noise source in 2007 and a programme of fundamental theoretical and experimental research was initiated at the Southampton UTC led by Dr Rod Self, and facilitated by a new £500k experimental facility funded directly by Rolls-Royce. This research has led to a much clearer understanding of bleed valve noise, a redesign of the valves and reductions of up to 15 dB at source. This work is proprietary and has not been published in the open literature.

Particular ANTC programmes that have had high impact for Airbus are studies on predicting and reducing **landing gear noise**, a major source of airframe noise for Airbus. A result of this research was the creation of a physics-based landing gear noise prediction model, SotonLGAP (see section 4). As well as simply predicting noise levels, fundamental research has been undertaken on both active and passive control methods to reduce the noise of landing gear installed on existing aircraft types [3.7], [3.8]. Fundamental computational and experimental research has also been conducted on noise from **high-lift devices** [3.6].This has led to an optimised low-noise flap incorporating a porous side-edge which has a negligible aerodynamic penalty [5.12].

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

*[3.1] **Astley R J, McCaulay G J, Coyette J-P and Cremers L**: (1998) 'Three dimensional wave envelope elements of variable order for acoustic radiation and scattering. Part 1. Formulation in the frequency domain: Part 2. Formulation in the time-domain' J. Acoust. Soc. Am. 103(1), 49-63 & 64-1998. Doi:10.1121/1.421106 & 10.1121/1.421107.

[3.2] **Astley, R. Sugimoto, P. Mustafi**.(2011) 'Computational aero-acoustics for fan duct propagation and radiation. Current status and application to turbofan liner optimisation'. *J. Sound and Vib.*, 330(16) 3832-3845 2011. Doi: 10.1016/j.jsv.2011.03.022

*[3.3] **Sinayoko, S., Kingan, M.J. and Agarwal. A**.(2013) Trailing edge noise theory for rotating blades in uniform flow. Proc**.** R**.** Soc. A . 2013 469 **2157** 20130065; doi:10.1098/rspa.2013.0065

[3.4] **McAlpine, A. and Kingan, M J.** (2012) 'Far-field sound radiation due to an installed open rotor. International Journal of Aeroacoustics', 11, (2), 213-245. (doi:10.1260/1475-472X.11.2.213).

*[3.5] **G Ashcroft and X Zhang** (2003) 'Optimised prefactored compact schemes'. Journal of Computational Physics, 190(2), 459-477. doi:10.1016/S0021-9991(03)00293-6

[3.6] **Angland, D., Zhang, X. and Molin, N**., "Measurements of flow around a flap side edge with porous edge treatment," AIAA Journal, 47(7), July 2009, pp. 1660-1671, doi: 10.2514/1.39311

[3.7] **Li, Y., Zhang, X. and Smith, M. G.,** "Identification and attenuation of a tonal-noise source on an aircraft landing gear," Journal of Aircraft, 47(3), May-June 2010. pp. 796-805. Doi: 10.2514/1.43183

[3.8] **Angland, D., Zhang, X. and Goodyer, M**., "The use of blowing flow control to reduce bluff body interaction noise," AIAA Journal, 50(8), 2012, pp. 1670-1684, doi: 10.2514/1.J051074

4. Details of the impact

Research at the University of Southampton's Rolls-Royce UTC and Airbus ANTC has transformed the way RR and Airbus tackle noise prediction and mitigation in the design of current and future aircraft. New methods introduced to both companies, mean that they are on track to meet the EU's tough noise reduction targets and enjoy a competitive edge in noise reduction over rivals Boeing, GE and Pratt & Whitney. However, a global market exists over the next 20 years for 27,000 new passenger aircraft worth £2.0 trillion [5.6] and the UK will retain or expand its current 17% share of this market only if can match or exceed noise reductions achieved by its competitors. Research in the UTC and ANTC at Southampton has already contributed to meeting this technical challenge.

Chief noise specialist at Rolls-Royce Andrew Kempton [5.1] in reference to Southampton's UTC has said: "*..it brings a breadth and depth of knowledge, an independence of thought and an aptitude for innovation that helps ensure the best technology is built into Rolls-Royce engines.*"

Referring specifically to the impact of the highlighted research areas in section 2, Rolls-Royce now routinely uses the numerical methods developed by Astley *et al.* [3.1],[3.2] in validated in-house Rolls-Royce codes to optimise sound absorbing liners [5.1]. These codes were developed during the Trent 900 engine programme (2000-2005) and have contributed to the design of liners for the Trent 1000 and Trent XWB engines (for the Boeing 787 and Airbus A350 aircraft) and in Germany by RR(Deutschland) to the design of smaller engines such as the BR725. **Similar methods developed at Southampton have been used to design novel combustion and exhaust liners and special low-frequency liners to reduce cabin noise and fan blade instability ('flutter') in current engine programmes resulting in two Rolls-Royce patents with named Southampton inventors [5.7],[5.9]** ("*the firm's patents.. bear the names of students who have worked on its technology…."* [5.6]).

Research on Advanced Open Rotors, at the UTC [3.3],[3.4] has led to a new Rolls-Royce code for predicting the noise from the next generation of AOR propellers. **The Southampton model has been fully implemented within Rolls-Royce and forms the basic tool for assessing noise from AOR designs [5.2].** There are compelling arguments for developing AORs since they consume approximately 25% less fuel than current engines. Attempts to introduce AORs in the 1980s were abandoned in part because it was widely believed that noise levels would prevent their acceptance. Current predictions using new tools developed at Southampton supported by test data, show that this is no longer the case. Aero-acoustically optimised propeller blades, manufactured and tested in European projects, DREAM and CLEANSKY, have shown that a new generation of AORs *can* be designed to meet current and anticipated noise certification requirements. **Research at the UTC has indicated that further noise reductions are possible for AORs by including sound absorbing lining material over the centre body of the propeller. A Rolls-Royce patent to protect this invention has been filed with named Southampton inventors [5.8].** The AOR prediction code developed at the UTC will provide key data when a decision is made whether to proceed with the AOR concept to power the next generation of mid-range,150-seat aircraft for entry into service around 2025.

In the area of bleed valve noise, the UTC's improved understanding of this source - resulting from a test campaign in 2008-9 and subsequent modelling - has led to a new design for Rolls-Royce bleed valves. This was tested in 2011 and shown to be up to 15dB quieter than existing valves, effectively removing them as a significant noise source on Rolls-Royce engines**. The new bleed valve design has been installed on the Trent XWB engine, powering the A350, and will be incorporated on all future large Rolls-Royce engines [5.3].**

In reference to the ANTC's impact on reducing airframe noise, Dr Raj Bissessur [5.4] of the Flight Physics Centre of Competence at Airbus in Toulouse, has said; "*It is about expertise, tools, methods and people. Within the UK, no one comes close to the level of methods and expertise on landing gear noise offered to Airbus by the ANTC. With his industry links and expertise, Xin Zhang is the leading academic in this area and we want to work with him. The ANTC has moved Airbus to the edge of understanding of noise generation on aircraft and how to mitigate it*."

In the important area of landing gear noise, **Airbus engineers employ the SotonLGAP computer program at both their UK and French sites to evaluate landing gear designs.** It can be used on a regular desktop PC and saves Airbus £20,000 for each day of wind tunnel testing that is avoided, saving many hundreds of thousands of pounds for a full test campaign [5.4]. SotonLGAP predictions take minutes rather than weeks to perform (compared to a full Computational Fluid Dynamics analysis) allowing Airbus engineers to tackle the issue of noise early in the design process, instead of identifying problems during wind tunnel testing when the landing gear design is effectively fixed. It also cuts out time-consuming and costly remedial work. In this way, SotonLGAP has given Airbus a competitive advantage over its American rival, Boeing [5.4]. Engineers at Airbus have used the SotonLGAP model to design landing gears for the A350 aircraft which will enter commercial service in 2014. Further research at the ANTC has led to a design change of the A350 landing gear doors [5.5].

In parallel with the development of SotonLGAP, research studies undertaken for Airbus within the ANTC have shown that acoustic liners can reduced high-lift device noise by up to 2.4dB, fairings placed in front of the landing gear struts by 10dB, porous slats and flap surfaces by 1.5dB and fairings applied to landing gear bogie beams by 4.5dB [5.6]. Given that fractions of a decibel can be important in determining noise certification data, the combined effect of these noise reduction techniques is significant. **Research on blowing flow control, and splitter plates [3.8] has demonstrated the potential of these technologies to reduce landing gear noise. This has resulted in two Airbus patents [5.11],[5.12] with named Southampton inventors.**

Further evidence of the importance that Airbus, Roll-Royce and the wider industry, attach to noise research at Southampton has been reflected in grant awards. During the REF impact period, the UTC and the ANTC together secured in excess of £10m of funding for research on aircraft noise for which Rolls-Royce and Airbus have been the sole or prime beneficiaries. Southampton academics occupy key industry-focused roles on the back of their research expertise. Astley is a UK representative on the scientific committee of the X-noise EC funded network which has coordinated industry led submissions for EC programmes on aircraft noise in frameworks 5, 6 and 7. Tester is co-chair of the Noise Technology Independent Expert Panel, which has advised the ICAO's Committee on Aviation Environmental Protection (CAEP) since 2006**.** Self is a member of the WG3 on Aircraft Noise, which aims to define the research needed to meet 'Flightpath 2050' targets as part of the Advisory Council for Aeronautics Research and Innovation in Europe.

5. Sources to corroborate the impact

[5.1] Chief Noise Specialist, Rolls-Royce plc, corroborator for the impact of research undertaken at the Southampton UTC on liner and nacelle acoustic technology in RR.

[5.2] Associate Fellow, Rolls-Royce plc, Derby; Impact of Southampton research on the development of advanced open rotors within RR.

[5.3] Staff Technologist, Rolls-Royce plc, Derby: Impact of Southampton research on reducing noise from Rolls-Royce bleed valves.

[5.4] Airbus Flight Physics Communications and Externals (EGDD), Technical Assistant to Axel Flaig. Research impact of Southampton ANTC on Airbus noise technology.

[5.5] Noise Expert, Airbus Toulouse. Research impact of Southampton ANTC on Airbus noise technology.

[5.6] Article by Kathryn Cooper, The Sunday Times, Business Section, p9 16th June 2013, titled; 'Starter for 10, Design an engine to make us proud, Rolls-Royce calls on British Universities to find a new jet's power'

Rolls-Royce and Airbus patents with named University of Southampton inventors;

[5.7] Patent. Gas turbine engine with acoustic liners https://www.google.com/patents/EP1849987A3 (06/04/2011) also US20070251212

[5.8] Patent. Attenuation of open rotor noise https://www.google.com/patents/EP2481669A3 (27/03/2013) also US20120195739

[5.9] Patent. An acoustic liner https://www.google.com/patents/EP2466095A2 (24/07/2013) also US20120156006.

[5.10] Patent. Blade for a rotating machine https://www.google.com/patents/WO2013092368A1 (27/06/2013)

[5.11] Patent. Blowing to reduce interaction noise between components with applications for landing gear noise http://www.google.com/patents/US20110168483

[5.12] Patent. Split plates (physical and pneumatic) to suppress bluff body noise http://www.google.com/patents/US20100288876