Institution: Ulster - UoA 13: Electrical and Electronic Engineering, Metallurgy and Mats.

Title of case study: Aerospace Materials Impacts on Economy – the NIACE Centre

1. Summary of the impact

Ulster research groups in the fields of composites and metal forming have had a long-term and fruitful engagement with major industries such as Caterpillar (FG Wilson), Rolls Royce and Bombardier. Since 2008 this has resulted in new patented technologies, significant cost/performance improvement in manufacturing, the delivery of on-site industrial training, the formation of spin-out companies and the establishment of the £6m N. Ireland Advanced Composites and Engineering Centre with currently 10 member companies. In particular, Ulster research has been at the heart of patented Bombardier processes which underpinned their strategic entry into the commercial narrow body aircraft market which is worth $43billion per annum globally. The C Series wing programme, which utilises composites, employs 800 people directly in Belfast at full production, with a further 2,000 employed in the supply chain. As of today, Bombardier has global orders and commitments for 388 C Series aircraft, which include firm orders for 177 of the new airliner.

2. Underpinning research

At Ulster, the Engineering Composites Research Centre (ECRE, ecre.ulster.ac.uk) has been at the forefront of engineering research in integrated textile weaving and composites since 1993, initially under the leadership of Professor R. McIlhagger and now led by Dr A. McIlhagger (2008). R McIlhagger was an original pioneer in the field of composites and championed their research and development within the major aircraft companies, where eventually his ideas took hold. ECRE has continued and built upon his work and is now nationally and internationally recognised as a leader in the design and manufacture of advanced textile preforms, advanced composites and in the development of associated manufacturing and analysis processes.

Weaving technology is increasingly being used to produce dry multi-layered preforms that are subsequently infused with a liquid matrix material to produce high performance composites. Three dimension (3D) woven composites, in particular, have been shown to possess many advantages compared to traditional preforming methods with the ability to tailor fibre placement in the X-, Y-, and Z-axis directions. Manufacturing and performance advantages include, for example, improvements in compression-after-impact (CAI) strength compared with two-dimensional (2D) laminated composites and the ability to produce 'near-net-shape' preforms. The 3D woven composites produced at ECRE exhibit crack propagation values an order of magnitude greater than 2D woven structures and therefore a significantly higher resistance to delamination growth (AMcI, EA, JQ).

ECRE has attracted significant funding from Centre of Excellence Programmes and collaborative industry – Invest NI partnerships to undertake industrially focussed materials research into structural composites, the simulation and modelling of 3D woven fabrics and the investigation of composites manufacturing through pilot process development [1-4] as well as involvement in industrially-led programmes in the design and manufacture of preforms [5]. Associated avenues of research include collaboration with Rolls Royce via DEL CAST Awards on the modelling and integration of sensing technologies and the development of hybrid structures (metallic and thermoplastic yarns) in collaboration with the Advanced Manufacturing Research Centre, Sheffield University/Boeing. Through a Bombardier sponsored PhD programme, and in collaboration with Nanotechnology groups at Ulster, ECRE has undertaken research on the incorporation of new nanomaterials (e.g. carbon nanotubes, nanoclays and graphene) into the composite matrix and our composite design and manufacturing experience has been transferred into the field of bio-composites. ECRE research expertise in fibre preparation and 3D weaving for tailored preform manufacture has expanded into the use of alternative fibres such as carbon, glass, basalt and polymeric fibres (including aramid, UHMWPE) and the use of natural fibres including wool, flax and viscose rayon for the production of 3D woven textile reinforcements aimed at the automotive and construction sectors. More recently this has developed into designing, developing and manufacturing textile structures for the defence industry through DSTL supported PhD programmes and private venture funding. The translation of research outputs

into industrial uptake and the study of commercial feasibility is a core philosophy of the group. Examples of recent activities include a funded Proof of Concept study into the commercial viability of the reuse of carbon fibre and thermoplastic materials and, in partnership with Bombardier, research and development of the latest advanced preforming processes based on spatially reinforced composites (SpaRC). This was funded through the InvestNI managed SpaRC LLP commercial programme.

The Advanced Metal Forming Research (AMFoR) Group at Ulster is at the forefront of materials characterisation and modelling for the sheet metal forming industries and has a close working relationship with international aerospace manufacturers. This has led to mutually beneficial advancement in understanding of mechanical metallurgy and forming processes. The group has established a unique laboratory within the EU, combining conventional and special purpose test equipment. AMFoR works collaboratively with leading researchers in the field of metallic formability and with European aerospace manufacturers, including Bombardier Aerospace and CERTETA (Romania), providing a unique blend of capabilities including mathematical modelling of plasticity, mechanical metallurgy along with materials characterisation and industrial forming process optimisation. It collaborates with ECRE to investigate and exploit synergies in modelling e.g. modelling individual grains [6].

In response to the complex interactions observed while solving industrial forming problems, AMFoR has developed a rare approach in the field of applied metal forming that involves a mix of curiosity led scientific research and pragmatic engineering. The introduction and exploitation of fundamental materials characterisation for industrial sheet metal forming materials and process development remains a strategic objective of the group (AL).

3. References to the research

1. Y.Q Ding, Y. Yan, R. McIlhagger, D. Brown; Comparison of the fatigue behaviour of 2-D and 3-D woven fabric reinforced composites.; 1995; J. of Mat. Processing Tech., Volume 55, Issues 3-4, , pages 171-177; DOI:10.1016/0924-0136(95)01950-2
2. L. Limmer, G. Weissenbach, D. Brown, R. McIlhagger, E. Wallace; The potential of 3-D woven composites exemplified in a composite component for a lower-leg prosthesis; Composites Part A: Applied Science and Manufacturing, 1996, Volume 27, Issue 4, pages 271-277; DOI: 10.1016/1359-835X(95)00040-9
3. J.P. Quinn, B.J. Hill, R. McIlhagger; An integrated design system for the manufacture and analysis of 3-D woven performs; Composites Part A: App. Sci. and Manufacturing, 2001, Vol. 32, Iss. 7, 911-914; DOI: 10.1016/S1359-835X(03)00084-8
4. J. Quinn, R. McIlhagger, A.T, McIlhagger; A modified design system and analysis of 3D woven structures; Composites Part A: Applied Science and Manufacturing, 2003, Volume 34, Issue 6, Pages 503-509; DOI:10.1016/S1359-835X(03)00084-8
5. R. McIlhagger, J.P. Quinn, A.T, McIlhagger, S. Wilson, D. Simpson, W. Wenger; The influence of binder tow density on the mechanical properties of spatially reinforced composites: Part2–Mech. Prop.; Composites Part A: App. Sci. and Manufacturing, 2008, Vol. 39, Iss. 2,334-341; DOI 10.1016/j.compositesa.2007.10.006
6. A.G. Leacock; A mathematical description of orthotropy in sheet metals; (2006), J. Mech. Phys. Solids, 54(2), pp. 425–444 DOI: 10.1016/j.jmps.2005.08.008

Funding Examples:

7. A. Leacock; Finite element modelling of springback in stretch formed complex curvature aluminium aircraft skin panels EPSRC GR/R41125/0 £60k 2001-04;
8. R McIlhagger Integration of complex 3D woven preforms into composite components EPSRC GR/K33613/01 £50k 1994-97;
9. A McIlhagger BIS /INI/Industry £6m NIACE Centre 2011;
10. A McIlhagger Chair in Composites; Royal Academy of Engineering £800k 2013

4. Details of the impact

Structural materials research involving ECRE and AMFoR groups has achieved significant impact and global reach in varying industrial contexts through close collaboration with companies such as Bombardier, BAE Systems, Rolls-Royce, Wrightbus, BE Aerospace, Sigmatex, DeepSea Engineering, Creative Composites and Eirecomposites, amongst others. These represent activities across the supply chain from manufacturer to end-users

and necessitate development of new technologies and processes as well as the development of engineering practices e.g. a “cradle to cradle approach”

Since 1993, Bombardier has involved ECRE and AMFor in a range of EU programmes, PhD CAST awards, InvestNI-funded joint university – industry START programmes, gift funding, event sponsorship and, most recently, the sponsorship of the Royal Academy of Engineering Bombardier Chair in Composites at Ulster which was awarded in 2013. The company has obtained significant tangible benefits from this collaboration; in the recruitment of high quality staff, trained to MSc and PhD in Composites and Advanced Engineering; in advancement and optimisation of manufacturing processes, including the introduction of surface science characterisation and new test/analysis approaches e.g. impedance spectroscopy.

Through Bombardier, we have established extensive international academic links with universities in Quebec and Ontario and have gained access to Bombardier facilities and engineers in Canada. *[text removed for publication].* The CSeries wing programme employs 800 people directly in Belfast at full production, with a further 2,000 employed in the supply chain. As of today, Bombardier has global orders and commitments for 388 CSeries aircraft, which includes firm orders for 177 airliners.

ECRE academic staff have also developed and delivered a unique strategic technology transformation of on-site training programmes at Bombardier enabling skilled technical and production management staff to gain practical experience and understanding of new materials and processes. This training programme involves critical proprietary information from within the company and is viewed as being a significant factor in driving significant changes in the company mind-set to create an inspirational innovation-led environment focussed on the novel design and application of composite materials within the aircraft business. This initiative has been running for five years with approximately 1,600 engineers trained to various skill levels and course provision is also provided to Bombardier in Canada (Montreal). It has been stated by Gavin Campbell, Director of Eng. Design and Development, Bombardier, [1], that *‘The Ulster programme is integral for our future aircraft systems development, with research driving new materials/applications/processes and the ability to provide detailed analysis of previous programs through this training system’*.

A number of senior ECRE staff founded and are currently Directors of an Ulster commercial spin-out company, Axis Composites Ltd (AMcI, AL, JQ: 2011). Their primary goal is to commercialise their 3D Carbon Fibre preform expertise, research and advanced manufacturing techniques developed within ECRE. The company currently employ 5 staff, has already demonstrated a significant first year growth with major contracts signed with companies such as GE, Windpro, Thales and have plans to grow dramatically over the next 5 years [5].

The AMFoR group can demonstrate major impact arising from long term relationships with companies requiring metallic solutions, research or development. Their strong track record in aerospace stretch forming process optimisation and material modelling has led to the elimination of unnecessary heat treatment processes in Bombardier Aerospace. *[text removed for publication].* Mathematical modelling has also been applied to supply chain support and to problem solving as a service to the aerospace sector, most notably analysing the skin component design around the cockpit for the Bombardier CSeries aircraft. These optimisation methods were then extended to the analysis of Friction Stir Welded blanks for material waste reduction in high value alloys such as Al-Li. Documentary validation by Bombardier of the beneficial cost impact of our process and design improvements is available [2].

Sizeable and direct contract research funding was provided by Bombardier Aerospace to develop reduced cost stretch forming processes for the CSeries. *[text removed for publication].* This work leveraged subsequent funding from various sources, supported by Bombardier, for the development of a next generation forming technology to produce extended trailing edge lipskins. The success of this innovative project has led to the award of a patent (EP2328698B1) in numerous countries (2009); the establishment of a University of Ulster spin-out company, LenisAer Ltd, in 2010 (AL); a highly successful exhibition at the Paris Air Show (2011); and a keynote presentation at the 15th International Conference on

Sheet Metal Forming (2013). Lenis-Aer Ltd won both the 25k Award and the All-Island Seedcorn Business Competition [10].

The Ulster – Bombardier research partnership that has been developed over the past 20 years has inspired the establishment of a new £6m R&D centre called the Northern Ireland Advanced Composites and Engineering (NIACE, www.niace-centre.org.uk) research centre. This state-of-the-art 3,700 m^2 not-for-profit research centre is based at Bombardier but is jointly owned by the University of Ulster and Queen's University with full-funding supplied by Bombardier, InvestNI and the Department of Business Innovation & Skills. It currently has ten subscribed (member) companies namely Thales (UK & France), Wrightbus, BASE, Axis Composites, Williams Industrial Services, ADS, Salamander, Datum Design, CPI Technologies, Laser Prototypes Europe and Bombardier (UK & Canada) itself. The Centre hosts up to 120 research and technical staff from participant organisations and provides a collaborative office environment, a composites research laboratory, materials analysis laboratories, meeting rooms and a lecture theatre, as well as a wide range of laboratories and workshops equipped by Bombardier and the two universities [4, 8, 9]. The company engineering staff are co-located with academic staff and work together to develop world-class technology solutions for a breadth of manufacturing applications.

This co-location in a state-of-the-art R&D centre establishes a level of academic – industrial and industrial – industrial collaboration not possible through traditional mechanisms and the NIACE centre has become an international innovation showcase for Composites R&D. Moreover NIACE is at the centre of the Northern Ireland manufacturing sector's strategy for growth and the government strategy to place NI at the centre of innovation in Europe and to compete more successfully on a global scale. The centre has set about establishing close links with the 55 main companies representing Aerospace, Defence, Security and Space industries in NI, who contribute over £1bn to the economy, in order to develop long term strategies and international partnerships.

5. Sources to corroborate the impact

1. Letter of Evidence: Dir. of Bombardier Design Eng. & Tech. Dev. Aerospace. CO1
2. Letter of Evidence: Head of Advanced Metallics at Bombardier: CO2
3. Letter of Evidence: ADS - Aerospace Defence Securing and Space, CO3
4. Letter of Evidence: NIACE General Manager relating to NIACE developments. CO4
5. Letter of Evidence: Axis Composites CEO relating to impact of ECRE. CO5
6. ECRE Impact Media: http://www.eri.ulster.ac.uk/uploads/documents/irish_times_composites.pdf CO6
7. ECRE Impact Media http://www.eri.ulster.ac.uk/uploads/documents/ecre_backgroud_press_v3.pdf_CO7
8. NIACE Impact Media: http://www.belfasttelegraph.co.uk/business/business-news/new-centre-of-excellence-puts-firms-on-the-fast-track-29079374.html_CO8
9. NIACE Impact Media: http://www.eri.ulster.ac.uk/uploads/documents/niace_print_media_coverage.pdf_CO9
10. AmFor Impact Media: Lenis Aer Impact http://www.eri.ulster.ac.uk/uploads/documents/lenis_aer_press.pdf__CO10