Institution: Ulster University

Unit of Assessment: Engineering (12)

Title of case study: Aerospace Materials & Manufacturing Impacts on the Economy

Period when the underpinning research was undertaken: 1 Jan 2000 to 31 Dec 2020

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Professor Alistair McIlhagger	Professor of Advanced Materials	2005 – present
Dr Edward Archer	Senior Lecturer (Composite Materials)	2006 - present
Professor Robert McIlhagger	ECRE Research Director (Retired)	1992 – 2004
Professor Eileen-Harkin Jones	Bombardier Aerospace-RAEng Professor of Composites Engineering	2014-present
Dr Alan Leacock	Reader, Advanced Forming (Emeritus)	2000 – 2019
Dr Dorian Dixon	Senior Lecturer (Polymer Engineering)	2005 - present
Dr Justin Quinn	Senior Lecturer and Director of the Renewable Energy Centre	2000-present
Dr Shaun McFadden	Lecturer (Mechanical Engineering)	2015 - present
Dr Calvin Ralph	Lecturer (Mechanical Engineering)	2019 – present
Dr Cormac McGarrigle	Lecturer (Mechanical Engineering)	2019 – present
Dr Atefeh Golbang	Lecturer (Mechanical Engineering)	2018 – present

Period when the claimed impact occurred: 1 August 2013 to 31 December 2020

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact

Research undertaken in the Advanced Future Materials and Manufacturing (AFM2) Cluster at Ulster, which incorporates the Engineering Composites Research Centre (ECRE) and the Advanced Metal Forming (AMFoR) Group, has generated new patented technologies, licence agreements, significant cost/performance improvements in manufacturing, spin-out companies (including Axis Composites Ltd and MFI-Ltd), new forms of material/process integration and the delivery of on-site industrial training, as follows:

I1. Multi-axial Preforming Technologies
I2. Skills and Training (Bombardier/Spirit, Eirtech and Artemis)
I3. In-situ [redacted]astic Materials (Eirecomposites)
I4. PEEK (Denroy)
I5. 3D Printing for the Manufacture of Functional Rapid Prototype Tooling (Denroy)
I6. Plastic and Metal Additive Manufacturing (LPE, CCP Gransden)
I7. Development of a New Respiratory Tubing Product (Armstrong Medical)
I8. Metal Forming Sheet Development (Bombardier/Spirit)

2. Underpinning research

ECRE & NIACE

Extensive research has been undertaken in the Engineering Composites Research Centre (ECRE) to develop composite and polymer science knowledge within a range of industrial partners, and to create new areas of shared interest spanning TRL levels 3-6. The establishment of the purpose-built Northern Ireland Advanced Composites Engineering (NIACE) facility as a state-of-the-art R&D centre has provided for a level of academic-industrial and industrial-industrial collaboration that is not possible through traditional mechanisms. Bombardier Aerospace, now Spirit AeroSystems, are the core industrial partner in NIACE making it a key driver for the manufacturing sector in NI and a focal point

of innovation to enable the region to compete more successfully on a global scale. NIACE has brought together a consortium of 2 universities and 15 companies to undertake collaborative projects and has facilitated 4 new companies to engage in composites R&D for the first time ( ) through competence centre projects (NIAECC) **(G1)**. Core projects that have generated research outcomes with clearly evidenced impact include:

Multi-Axial Composite Preforming Technologies.
The aerospace industry in NI required a competitive edge and Bombardier/Spirit identified the widespread use of composites in aircraft manufacture to be of critical importance to its future. In particular, dry fibre reinforcement technologies to tailor properties and improve performance of existing composite systems was deemed a priority. A project focused on the reinforcement via liquid resin infusion technology (termed RTI) was established. This research led to the design and manufacture of bespoke multiaxial preform architectures for specific geometrical and loading conditions (e.g. composite lugs and high load attachment components), with higher production speeds **(R1)**. Axis Composites was formed as a spin-out company from this Ulster research in 2010 and now undertakes industrial-scale prototyping of complex 3D woven structures. This work has included the to develop novel tailored 3D woven composite preforms for improved crash resistant properties **(G2)**. The long-standing collaboration between Ulster and Bombardier/Spirit was further strengthened by their financial sponsorship of a Royal Academy of Engineering Bombardier Chair in Composites **(G3)**.

In-situ thermoplastic materials.
Development of thermoplastic materials for composite tooling and large-scale composite structures has been undertaken from 2003 onwards. Thermosetting resin systems emit harmful volatiles during processing and create difficulties associated with exothermic reactions. New thermoplastic polymer systems have several advantages including ease of recycling. A novel form of dielectric analysis initially researched at Ulster for aerospace applications **(G4)** and, in partnership with Eirecomposites, was applied to monitor the process for new thermoplastic resins used in the manufacture of wind and tidal turbine blades **(R2)**.

Sustainable materials PEEK recycling.
Research undertaken in partnership with Denroy has determined the suitability of for moulding parts with the equivalent mechanical properties to those formed from 100% virgin material **(R3)**.

3D Printing for the Manufacture of functional Rapid Prototype Tooling.
3D printing has been used for the manufacture of tooling prototypes to produce plastic aerospace components with small production runs **(R4**). The savings on tooling costs, reduction in waste and the improved lead time have been shown to make the process financially viable compared to traditional metal tooling approaches **(G6)**.

NWCAM
Ulster is the lead academic partner in the Interreg VA funded Northwest Centre Advanced Manufacturing (NWCAM) consortium and is working with industry and university partners in Northern Ireland, Scotland, and the Republic of Ireland across 15 globally relevant research projects within the Life and Health Science sector **(G6)**. The following project confirms the high level of research attained through the industrial engagement undertaken.

New tubing from permeable polymer, for use in COVID-19 incubators (Partner - Armstrong Medical).
Research is being undertaken on a long-standing challenge in critical care treatment, namely . A new form of permeable polymer medical grade tubing has been developed within the NWCAM consortium in partnership with Armstrong Medical for use in adult, paediatric and neonatal incubation devices. This innovative product saves lives and frees up time of critical care staff who can be deployed to other vital ICU services **(R5).**

AMFoR

Metal forming in the aerospace industry is important as it can enable a reduction in drag around repair sections for damaged aircraft engine nacelles. In May 2008 AMFoR disclosed a technology entitled “a method for forming a sector for a Nacelle lipskin”. It allows for fast and low-cost production of metal sections using a flexible, accurate metal forming process **(R6)**. [redacted] expressed an interest in using the Ulster IP to develop nacelle lipskin technology, and a spin-out company Metal Forming Innovation Ltd (MFI) was founded (CEO, Dr Alan Leacock), with the [redacted]

3. References to the research Outputs can be provided by Ulster University on request.

R1 McIlhagger, R., Quinn, JP., McIlhagger AT., Wilson S., Simpson D., Wenger W. The influence of binder tow density on the mechanical properties of spatially reinforced composites. (2007), Composites Pt. A Applied Science and Manufacturing, 38 (3). p795-801
R2 Archer, E., McIlhagger, AT., McIlhagger, R., Quinn, JP., Mallon, P. & Bradaigh, C. Monitoring the Degree of Conversion of Cyclic Butylene Terephthalate using Dielectric Analysis, 2008, In: POLYMERS & POLYMER COMPOSITES. 16, 6, p. 365-373
R3 Golbang, A., Harkin-Jones, E., Wegrzyn, M., Campbell, G., Archer, A. McIlhagger, A. Production and characterization of PEEK/IF-WS2 nanocomposites for additive manufacturing. Additive Manufacturing, 2020, 31. p.1-8.
R4 Harkin-Jones, E., Vera-Sorroche, J., Kelly, A., Brown, E., Coates, P., Karnachi, N., Li, K., Deng, J. Thermal optimisation of polymer extrusion using in-process monitoring techniques. Applied Thermal Engineering, 2013, 53(2), p. 405-413.
R5 Dixon, D. Boyd, A. Degradation and accelerated ageing of poly(ether block amide) thermoplastic elastomers. Polymer Engineering and Science, 2011, 51(11), p. 2203-2209
R6 Leacock, A., Ludlow, M., Brown, D., McMurray, R.J., Method for forming a sector for a nacelle lip skin. 2011. United States. Patent number: US20110162429A1.

Note: All of the journal articles cited above have been subject to blind peer review practices by internationally based editorial boards.

Relevant Funding Awards:

G1 McLaughlin, Leacock, Quinn, McIlhagger. NIACE Centre 2011 - BIS /INI/Bombardier GBP1,800,000; McLaughlin, Archer, McIlhagger, Competence Centre funding NIAECC GBP2,318,654 (2012-2020)
G2 Archer, Harkin-Jones, McIlhagger. Improving the crashworthiness of composite transportation structures: ICONIC, CEC-H2020-MSCA-ITN, 1 Oct 16 - 30 Sep 20, GBP193,145
G3 McLaughlin, Leacock, McIlhagger. Royal Academy of Engineering Bombardier Chair in Composites, GBP479,072, 2014 - 2021
G4 McLaughlin, Archer, McIlhagger. Marincomp - MARINCOMP - Novel Composite Materials and Processes for Offshore Renewable Energy, CEC- Framework 7 - Marie Curie – PEOPLE, 1 Feb 14 - 31 Jan 18, GBP504,060
G5 Harkin-Jones. EPSRC Novel high performance polymeric composite materials for additive manufacturing of multifunctional components EP/N034783/1, 1 Oct 16– 1 Feb20 GBP325,687
G6 McIlhagger, Archer, Harkin-Jones. NWCAM. North West Centre for Advanced Manufacturing INTERREG VA SEUPB GBP3,218,059 2017 – 2021

4. Details of the impact

The impact on the wider economy achieved from underpinning research outputs from the three interrelated Aerospace Materials & Manufacturing areas (ECRE & NIACE, NWCAM and AMFoR) are detailed below.

ECRE & NIACE

I1 Multi-Axial Preforming Technologies [redacted]

The C-Series (now designated Airbus A220) wing programme, which utilises advanced composites, employs 1,000 people directly in Belfast at full production, with a further 2,000 employed in the supply chain. The acquisition of Bombardier Aerospace Belfast by Spirit

AeroSystems in 2020 was due in large measure to the unique composite technology within the Belfast facility, including the dry-fibre forming **(R1)** and processing expertise available through collaboration with ECRE-Ulster University, thus sustaining upwards of 1,000 high value jobs **(C1)**. The company have received over 600 firm orders for A220 aircraft (average list price USD91,500,000) as of November 2020 **(C9).**

The past 20 years have seen major developments in Belfast associated with the design and development of the world's first resin-infused wing designed for the Airbus A220 commercial aircraft. Early Ulster research activities and Spatially Reinforced Composites (SpaRC) projects are recognised as a precursor to the implementation of dry fibre preforming and Resin Transfer Injection (RTI) process technology within Bombardier Belfast, resulting in a lighter wing. Compared to a conventional metal wing, the carbon composite wing is approximately 10% lighter. The GBP520,000,000 investment by Bombardier in the aircraft wing program is the largest ever single inward investment in Northern Ireland.

The advanced dry fibre technologies initiated and then co-developed with Ulster led to Bombardier being awarded the prestigious Royal Academy of Engineering MacRobert Award in 2019. *"The Belfast-developed resin-infused composite wing epitomises the best in U.K. mechanical engineering, bringing together excellence in design, materials engineering and manufacturing technology. It is a key enabling technology for the Airbus A220, creating a unique combination of range, fuel efficiency and environmental friendliness,"* said the MacRobert Award judge (**C1)**.

The company has recognised leading activity at Ulster and has supported initiatives such as a Royal Academy of Engineering Professorship in Aerospace Composites in 2013-present. More recently a Royal Academy of Engineering Industrial Fellowship was awarded in 2017-2018 to explore the integration of advanced preforms for specific products including a composite lug, using Ulster's unique preforming capabilities and methodologies.

I2 Skills and Training (Bombardier, Eirtech and Artemis).

Ulster academic staff have also developed and delivered a series of on-site knowledge transfer training programmes at Bombardier/Spirit underpinned by research outputs **(R1/R2)** that enables skilled technical and production management staff to gain practical experience and understanding of new materials and processes. This is viewed as being a significant impact factor in the application of composite materials within Bombardier/Spirit's aircraft business. [redacted] were trained by Ulster in composites transformation by 2016 at Bombardier Belfast, and in Canada. It was stated by the Director of Engineering regarding this knowledge transfer from Ulster 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*' **(C1)**. The research capabilities and related infrastructure at Ulster have also been directly cited as a significant factor in the location of the Eirtech **(C3)** facility in Belfast. Artemis Technologies (**C4)** has also located in NI for similar reasons with both companies potentially bringing upwards of [redacted] new full-time engineering jobs to the region.

I3 In-situ Thermoplastic Materials (Eirecomposites).

Ulster research **(R2)** has directly contributed to additional activity into the renewable sector in NI and in securing the [redacted] This research work has facilitated new commercial contracts in renewable and aerospace sectors worth [redacted]. The work has enabled the company to attract subcontracts from [redacted] of aeroplanes. These research/commercial contracts have also ensured employment for [redacted] employees (FTE 10) **(C2)**.

I4 PEEK [redacted] (Denroy).

Research at Ulster indicates that no degradation of thermal and mechanical properties of PEEK takes place throughout the recycling process, to a maximum of 2 injection moulding cycles **(R3).** This allowed Denroy to reduce material [redacted] This project also allowed for sharing

of information with customers to confirm benefits of using [redacted], and for Denroy to continue with this approach **(C5)**.

I5 3D Printing for the Manufacture of Functional Rapid Prototype Tooling (Denroy).
Ulster research has addressed several challenges for the adoption of 3D printing for rapid prototype tooling, namely high temperature printing of thermoplastic filaments, adaptive cooling strategies and achievement of injection moulding standards of cavity replication and quality surface **(R4)**. Denroy have seen benefits to the company from this research that include rapid tooling that can be specifically designed for low volume production (aerospace). Importantly, it provides the capability to undertake bespoke, small quantity orders with short lead times, thereby increasing competitiveness, coupled with the ability to [redacted] **(C5)**.

I6 Plastic and Metal Additive Manufacturing (LPE, CCP Gransden).
Research on the development of a glass filled polymer blends **(R4)** has led to [redacted] saving on the materials for LPE, offering an annual saving of [redacted] per annum to the company. In addition, R&D on titanium-made parts and thermal simulation of material behaviour carried out at Ulster have translated to company sales, e.g., securing [redacted]. This work also strongly influenced [redacted] contract with LPE **(C6)**. The underpinning research on dry fibre/placement technologies has also been applied to filament winding with CCP Gransden purchasing a 7-axis robotic filament winder and securing a [redacted] **(C7)**.

NWCAM

I7. Development of a New Respiratory Tubing Product (Armstrong Medical).
Ulster research in partnership with Armstrong Medical has developed permeable polymer medical grade tubing for use in adult, paediatric and neonatal incubation devices **(R5)**. A licensing agreement between the Ulster and the company has been executed. With the COVID-19 pandemic, the product has seen unprecedented global demand in over 60 countries, opening new markets; global sales of this new product are more than [redacted] **(C8)**. Demand has also required Armstrong to double staffing levels.

AMFoR

I8 Metal Forming Machine Development (Bombardier/Spirit).
Working in partnership with Bombardier/Spirit, a new form of laminar flow aircraft nacelle manufacturing process has been developed, resulting in a 1-3% drag reduction with the new design. This work has leveraged funding from various sources, including Bombardier/Spirit for commercialisation of a large next generation metal forming machine, to produce extended trailing edge lip skins for engine nacelles to exacting aerospace tolerances. A further benefit of the Ulster process is the elimination of unnecessary heat treatment, [redacted] The invention within the project has led to the award of a patent **(R6)** which is active in numerous countries. A licence agreement which was in place with Bombardier Aerospace has transferred to the new owners Spirit AeroSystems **(C1)**.

5. Sources to corroborate the impact

[**C1**] Letter of Evidence: Director Engineering, Spirit Aerosystems, Belfast.
[**C2**] Letter of Evidence: Chief Executive Officer, Eirecomposites.
[**C3**] ECRE Impact Media: Eirtech Aviation Services Investment. https://www.investni.com/media-centre/news/new-investor-eirtech-aviation-services-create-124-new-jobs-northern-ireland
[**C4**] NIACE Impact Media: Artemis Technologies Investment. https://www.belfast-harbour.co.uk/news/artemis-technologies-arrives-in-belfast-218/
[**C5**] Letter of Evidence: Managing Director, Denroy Plastics.
[**C6**] Letter of Evidence: Managing Director, Laser Prototypes Europe (LPE).
[**C7**] Letter of Evidence: Managing Director, CCP Gransden.
[**C8**] Armstrong Medical CTO, confirmation of product sales.
[**C9**] Airbus Impact Media: A220 Orders, Nov 2020. https://skiesmag.com/news/airbus-a220-program-aircraft-bright-future-industry-turmoil/