**Institution: University of Nottingham**

**Unit of Assessment: 15 General Engineering**

**Title of case study: Development of a novel carbon fibre manufacturing process for high performance automotive applications**

## 1. Summary of the impact

Underpinned by research at the University of Nottingham, the development of automated discontinuous carbon fibre preforming (DCFP) technology has helped drive more than half a billion pounds in sales of Aston Martin's DBS sports car across 42 countries, boosting the company's brand worldwide. Recognising the potential of this process, Bentley Motors invested £1.3M directly to develop this technology for its next generation of models. The Royal Academy of Engineering acknowledged the body of research as an "outstanding" contribution to the reputation of British engineering through the award of a silver medal to Professor Warrior.

## 2. Underpinning research

Increasingly stringent emissions targets are pushing vehicle manufacturers to find novel ways of reducing vehicle mass. A fall in the cost of carbon fibre has increased the viability of using carbon-based body panel systems as a cost-effective, lightweight alternative to steel in order to improve fuel consumption. Research carried out at the University of Nottingham (UoN) from 2003 set out to demonstrate that carbon fibre composites are suitable materials for the high-volume production of vehicles.

The UoN team, headed by Nick Warrior (Professor of Mechanical Engineering, 1989 - present) and Chris Rudd (Professor of Mechanical Engineering and Pro Vice-Chancellor, 1989 - present), began by investigating how the established Ford Programmable Preform Process (F3P) – a process that fabricates vehicle parts from lightweight and strong glass fibre composites, could be translated to carbon fibre preforms.

Using F3P, a robot sprays the glass fibres on to a screen. The material is consolidated with an upper screen to form a preform in the shape of the vehicle part. However, this process was not directly transferable to carbon fibre composites. Glass fibre preforming is facilitated by a special form of glass fibre roving that has characteristics that make it suitable for automated processing. Similar product forms are not available for carbon fibre, as the production volumes do not warrant costly fibre modifications. Various technical issues related to the fibre handling and placement also had to be solved to allow processing of off-the-shelf carbon fibres. In addition, the modelling of the manufactured carbon fibre parts posed major challenges, as there is significant heterogeneity in the fibre architecture.

Using experimental and numerical techniques, Warrior and Rudd carried out a range of simulations and analyses to develop scientific understanding in two key areas. Firstly, work on benchmarking carbon body panel systems, carried out from 2002 to 2008, focused on the comparison of DCFP with commercial body panel systems [2.1] and the design of an optimal body panel system. Secondly, from 2006 to 2009, processing studies were carried out to support carbon DCFP manufacture, including analysis of microstructural parameters [2.2], the effects of fibre length [2.3] and filamentisation [2.4], permeability and resin injection simulation [2.5] and fibre alignment [2.6].

The research concluded that carbon fibre composite structures could make mass-produced vehicles up to 50% lighter while still maintaining crash-test performance. From 2004 to 2012 the team developed the carbon DCFP process and commissioned a DCFP machine at UoN, the first of its kind in Europe. A four-stage process was established, comprising spraying, heating, cooling and preform extraction. During spraying, carbon fibre yarns (tows) are chopped and sprayed on to a perforated tool where a vacuum holds the desired pattern and shape of fibres.

The work at Nottingham moved on to property prediction of the DCFP and developing an in-depth understanding of the material and how different fibre architectures perform. This succeeded in aiding the design of new components and identifying improvements in the overall design process, which in turn led to the creation of an Aston Martin technology demonstrator. It was subsequently deployed at tier one supplier SOTIRA (now part of France-based SORA Composites) and ultimately allowed Aston Martin to apply carbon fibre technologies to the door opening reinforcement and the trunk lid surround components on its DBS sports car.

The DCFP technology is being developed further as part of the EPSRC Centre for Innovative Manufacturing in Composites at Nottingham.

**3. References to the research**

References *(Items marked with an asterisk indicate 3 most significant papers):*

2.1 *Turner, T.A., Harper, L.T., Warrior, N.A. and Rudd, C.D., 2008, Low-cost carbon-fibre-based automotive body panel systems – a performance and manufacturing cost comparison, *Journal of Automobile Engineering – Proceedings of the Institution of Mechanical Engineers Part D*, Volume 222, Issue 1, 53-64 DOI: 10.1243/09544070JAUTO406:

2.2 *Harper, L.T., Turner, T.A., Warrior, N.A., Dahl, J.S. and Rudd, C.D., 2006, Characterisation of random carbon fibre composites from a directed fibre preforming process: analysis of microstructural parameters, *Composites Part A: Applied Science and Manufacturing*, Volume 37, Issue 11, 2136-2147 DOI: 10.1016/j.compositesa.2005.11.014
- JS Dahl, Ford Motor Company, USA (owners of Aston Martin at that time)

2.3 *Harper, L.T., Turner, T.A., Warrior, N.A. and Rudd, C.D., 2006, Characterisation of random carbon fibre composites from a directed fibre preforming process: the effect of fibre length, *Composites Part A: Applied Science and Manufacturing*, Volume 37, Issue 11, 1863-1878 DOI: 10.1016/j.compositesa.2005.12.028

2.4 Harper, L.T., Turner, T.A., Warrior, N.A. and Rudd, C.D., 2007, Characterisation of random carbon fibre composites from a directed fibre preforming process: the effect of tow filamentisation, *Composites Part A: Applied Science and Manufacturing*, Volume 38, Issue 3, 755-770 DOI: 10.1016/j.compositesa.2006.09.008

2.5 Endruweit, A., Harper, L.T., Turner, T.A., Warrior, N.A. and Long, A.C., 2008, Random discontinuous carbon fibre preforms: permeability modelling and resin injection simulation, *Composites Part A: Applied Science and Manufacturing*, Volume 39, Issue 10, 1660-1669 DOI: 10.1016/j.compositesa.2008.07.006, copy available on request.

2.6 Harper, L.T., Turner, T.A., Martin, J.R.B. and Warrior, N.A., 2009, Fibre alignment in directed carbon fibre preforms: a feasibility study, *Journal of Composite Materials*, Volume 43, Issue 1, 57-74 DOI: 10.1177/0021998308098151

Grants:
- EPSRC CASE studentship on studying the durability of DCFP for high performance structural applications under severe conditions (extreme temperatures, fatigue etc) (PI Warrior)
- Advanced Composites Truss Structures (ACTS), Feb 2008 - Sept 2011, TSB project #100447, Grant value £939k with Bentley Motors Limited (PI Long)
- Affordable Discontinuous Carbon Composites for Structural Automotive Applications, Feb 2008 – July 2012, TSB project #100442, Grant value £1.8M with Aston Martin Lagonda Ltd. (PI Warrior)
- EPSRC Centre for Innovative Manufacturing in Composites, July 2011 – June 2016, EP/I033513/1, £5.9M (PI Long)

Research contracts and income from industry:

2.7 Directly sponsored project with Bentley Motors Ltd on Multiscale Material Modelling of discontinuous fibre composites (Total Value £698k), 2008-2011

**4. Details of the impact**

The discontinuous carbon fibre preforming process developed through Warrior and Rudd’s body of underpinning research at UoN has made a significant contribution to the economic competitiveness of two of Britain’s leading manufacturers of luxury vehicles, Aston Martin Lagonda and Bentley

Motors, and in the process has showcased British engineering excellence.

Aston Martin employed the technique for the production of the door opening reinforcement and the trunk lid surround for its DBS, 12MY Virage, 13MY DB9 and new Vanquish models [4.1]. For DBS alone - since 2008 3,300 cars have been sold in 42 countries at around £180,000 each, which equates to sales revenue of £594M. In 2011 more than 80% of Aston Martin's sales were to buyers outside the UK [4.2]. This surpassed Aston Martin CEO Ulrich Bez's aim of selling a third of the company's cars in Europe and a third in America. By comparison, in 2000 the brand's annual sales were 800 cars, of which 700 were sold in the UK [4.2].

The two carbon fibre parts are manufactured and supplied by Sora Composites, which is based in St Meloir, France. They represent a weight saving of 52% and 44% respectively compared to the alternative glass fibre materials. Over 23 tonnes of discontinuous carbon fibre composite material has reached the market through this process on the DBS alone. The technology has been a key enabler for reducing mass and therefore improving both performance and economy - making the car lighter, faster and stronger [4.1].

"The Discontinuous Carbon Fibre Preform (DCFP) work with the University of Nottingham resulted in the uptake of chopped carbon fibre composite technology into the Trunk Lid Surround (TLS) and Door Opening Reinforcement (DOR) panels of the DBS… These parts were originally one of the main differentiators between the top of the range DBS model and other models in our range of supercars… The technology has been a key enabler for reducing mass and therefore improving both performance and economy across our range of vehicles." Source: Roland Snell, Aston Martin [4.1]

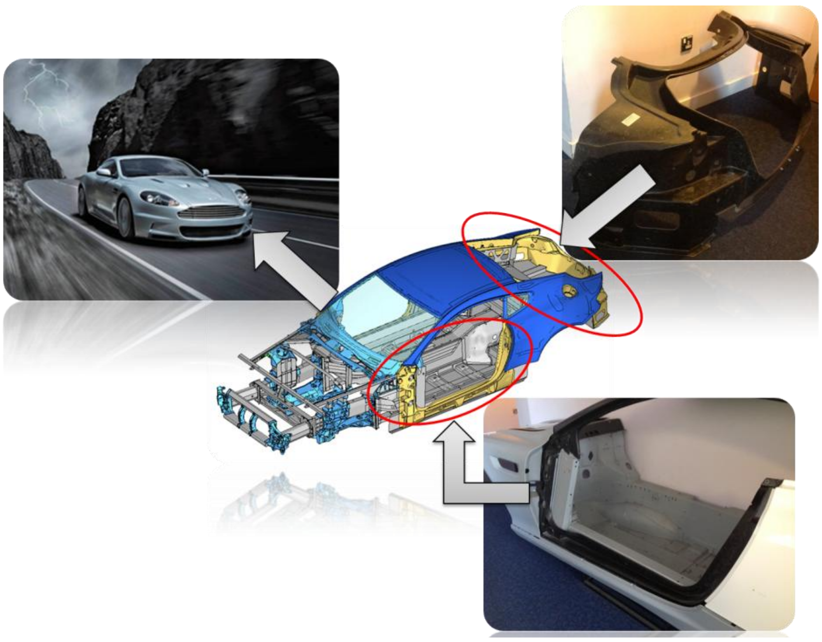

Figure 1: showing carbon fibre parts manufactured using DCFP and their location on the automobile

The successful development of DCFP by the University of Nottingham convinced Bentley Motors Ltd of the value of DCFP. A total investment of £800k ([2.7] and contribution to studentships) was made by Bentley Motors in developing an enhancement to the DCFP process – in collaboration with Warrior – that involved using carbon fibre in its least processed form and spraying it with resin into a mould, eliminating the need for heating and cooling [4.4].

UoN's work formed the basis of Bentley's RayCell technology, which Bentley employed, through investment of a further £500,000 in 2010, for the production of a demonstration vehicle that showcases the next generation of cars to be produced by the company [4.4]. The demonstration vehicle specifically showed that it is possible for the carbon fibre chassis rails to support the weight of the vehicle [4.3].

"The Raycell technology developed at the University of Nottingham has been used to develop the composite elements for the demonstrator vehicle. The research has indicated that it is feasible to manufacture major structural elements in our next generation of cars using carbon fibre in this way." Source: Lee Bateup, Bentley Motors [4.4]

Figure 2: carbon fibre chassis rails manufactured using the Raycell concept and its location on the Bentley T35 demonstration vehicle

The underpinning research led to Warrior receiving the Royal Academy of Engineering's prestigious Silver Medal in July 2009 for his "outstanding personal contribution to British engineering" – further evidence of the positive impact of the research on the reputation of the British engineering industry. On presenting the award, the RAE said the research into carbon fibre composites had "shown that mass-produced vehicles can be up to 50% lighter and still maintain crash-test performance using lightweight carbon fibre composites". It added: "High material costs and labour-intensive manufacturing have restricted composites to motor sports and supercars until now... [Warrior] has demonstrated that composites are now a legitimate material for use in high-volume production (up to 20,000 vehicles a year)" [4.5].

**5. Sources to corroborate the impact**

4.1 Roland Snell, Principal Engineer – Body Structures, Aston Martin Lagonda Ltd
4.2 Press article regarding Aston Martin sales growth
http://europe.autonews.com/apps/pbcs.dll/article?AID=/20120226/ANE/120229916/1131/aston-martin-plans-double-digit-sales-growth#axzz2M0S6ajyf
4.3 RayCell Technology
http://www.innovate10.co.uk/uploads/02%20-%20AD%20-%2012%20October%20GRAND%20CHALLENGE%20Slides%20-%20FINAL.pdf
4.4 Lee Bateup, New Technologies/Processes and Properties Manager, Concept Engineering, Bentley Motors Ltd
4.5 Press release regarding award of Royal Academy of Engineering Silver Medal
http://www.raeng.org.uk/news/releases/shownews.htm?NewsID=509