Institution: 10007822

Unit of Assessment: 12

Title of case study: Composite landing gear brace for Boeing 787 Dreamliner – first in the market for Messier-Bugatti-Dowty

1. Summary of the impact (indicative maximum 100 words)

Components built using 3D composite manufacturing methods developed by Cranfield are now flying on the Boeing 787 Dreamliner aircraft. This is the first use of structural composites in commercial aircraft landing gear. The prototypes were assembled and reinforced using robot automated technology developed at Cranfield.
Cranfield's work has extended the use of composite materials into critical landing-gear systems, allowing Messier-Bugatti-Dowty to contribute to the use of 50% composite materials for the airframe of the new 787, delivering weight reduction and better fuel economy.

2. Underpinning research (indicative maximum 500 words)

Cranfield created a fibre tufting unit in 2003 [G1]. It used an industrial sewing head to create 3D (z-direction) reinforcement in addition to the traditional layers and winding, to improve shear and delamination resistance. In 2005, an interface between a robot and the tufting tool was added, along with the software routines enabling its practical use for composite preform reinforcement.

Cranfield had investigated stitching of dry preform plies in the previous decades. However, at the beginning of this century there was no systematic research work dedicated to tufting as a method for reinforcing composites, through-thickness. Cranfield published the outcome of the initial work in 2007 in the first two papers dedicated to this technology [P1, 2].

In 2006 Boeing wanted to replace a heavy metal structure with a lighter composite alternative. The objective was to meet the stringent performance requirement for a structure that would be used within the 787 Dreamliner's landing gear. When Aircelle and Messier-Bugatti-Dowty (MBD), parts of the Safran aerospace group, approached Cranfield, tufting capabilities were limited to processing flat preforms that inserted glass fibre or aramid thread tufts through relatively small thicknesses of material (up to 38mm). Nevertheless, the specifics of the component made it impossible for the through-thickness reinforcement to be carried out with any other form of stitching apart from tufting. Aircelle wanted to use a carbon-fibre thread to form tuft loops fully embedded within the thick shaft of a 1.2m long brace with large lugs at each end. Cranfield therefore embarked on a research programme to investigate the potential for tufting using carbon fibre threads. Our research met these requirements, demonstrating the improvement in terms of delamination resistance provided by tufting [P3, 6].

Figure 1: Tufted composite brace, 1.2m long, exhibited at the Farnborough Air Show (September 2012) [*http://www.compositesworld.com/articles/2008-farnborough-airshow-report*](http://www.compositesworld.com/articles/2008-farnborough-airshow-report) *(accessed 20/11/13)*

Cranfield's researchers tackled several challenges, starting with the requirement to use a carbon fibre thread which, at the time, was not readily available on the market. All available grades were too brittle to withstand needle penetration through tight preforms. The size and shape of the preform and the particular material combination of the part demanded novel customised hardware arrangements for the tufting unit, as well as the development of dedicated controlling routines.

We identified an innovative carbon-fibre thread (at the time still under development by Toho Tenax) and acquired and successfully tested the material on Cranfield's tufting system. Cranfield undertook innovative modifications to the robot setup to accommodate the large preform and developed the routines to enable tufts insertion on complex double curvature surfaces. These developments were based on Cranfield's exploratory research on the feasibility of the technology [P1] and its optimal utilisation for enhancing mechanical performance [P2]. The prototypes were impregnated with thermoset resin after tufting and mechanically assessed by Aircelle. The company now produces carbon fibre braces reinforced by tufting with carbon thread (figure 1) in its premises with a newly acquired twin-robot tufting cell. These landing gear systems have been flying on the Boeing 787 Dreamliner since its maiden flight in 2010.

Key Researcher	Post details	Dates involved	Research
Dr. G. Dell' Anno	Academic Fellow	2004-2013	Manufacturing, Mechanical performance, Process monitoring [G4, P1, P2, P4]
Prof. I.K Partridge	Professor,	2003-2012	Manufacturing, Mechanical performance [G1, G3, G4, G5, P1, P2, P4]
Dr D. D. R. Cartie	Academic Fellow	2003-2009	Manufacturing, Mechanical performance [G1, G3, P1, P2]
Prof. R. P. Tatam	Professor	2009-present	Optical fiber techniques for process monitoring [P4]
Prof. A. K. Pickett	Professor	2005-2006	Mechanical performance [G2, P3]
Dr A. A. Skordos	Lecturer	2006-present	Manufacturing, Mechanical performance, Modelling [G2, G5 P3, P5, P6]

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3. References to the research (indicative maximum of six references)

Evidence of quality – peer-reviewed journal papers

P1* Cartié DDR, Dell'Anno G, Poulin E and Partridge IK. 3D reinforcement of stiffener-to-skin T-joint by Z-pinning and tufting. *Engineering Fracture Mechanics*, **73**, pp. 2532–2540, 2006. doi: 10.1016/j.engfracmech.2006.06.012.

P2* Dell'Anno G, Cartié DDR, Partridge IK and Rezai A[a]. "Exploring mechanical property balance in tufted carbon fabric/epoxy composites". *Composites Part A: Applied Science and Manufacturing*, **38**, pp. 2366–2373, 2007. doi: 10.1016/j.compositesa.2007.06.004

P3* Colin de Verdiere M, Pickett AK, Skordos AA and Witzel V[b]. Evaluation of the mechanical and damage behaviour of tufted non crimped fabric composites using full field measurements. *Composites Science and Technology*, **69**(2) pp131-138, 2009. doi: 10.1016/j.compscitech.2008.08.025.

P4 Dell'Anno G, Partridge IK, Cartié DDR, Hamlyn A[c], Chehura E, James SW and Tatam RP. "Automated manufacture of 3D reinforced aerospace composite structures". *International Journal of Structural Integrity*, **3,** (1), pp. 22–40, 2012. doi: 10.1108/17579861211209975

P5 Colin de Verdiere M, Skordos AA, May M and Walton AC. "Influence of loading rate on the delamination response of untufted and tufted carbon epoxy non-crimp fabric composites: Mode I". *Engineering Fracture Mechanics*, **96**, pp. 11–25, 2012. doi: 10.1016/j.engfracmech.2012.05.01

P6 Colin de Verdiere M, Skordos AA, Walton AC and May M. "Influence of loading rate on the delamination response of untufted and tufted carbon epoxy non-crimp fabric composites: Mode II", *Engineering Fracture Mechanics* (2012), **96**, pp 1–10. doi: 10.1016/j.engfracmech.2011.12.011

*: 3 identified references that best indicate the quality of the research

[a] BAE Systems, Advanced Technology Centre, Filton, Bristol BS34 7QW, UK
[b] Institute of Aircraft Design, University of Stuttgart Pfaffenwaldring 31, D-70569 Stuttgart, Germany
[c] Coriolis Composites, Rue Condorcet 56530 Quéven, France

Further evidence of quality – underpinning research grants

G1 Robotic tufting & Resin Transfer Moulding, £118,300, 2004-2007, PI Prof IK Partridge, sub project within Cranfield IMRC, EPSRC GR/R68139/01.
G2 EU-FP6 (EU-516146), Integrated tool for simulation of textile composites (ITOOL), €180,000, 03/2005-09/2008, PI Prof. AK Pickett, CI Dr AA Skordos
G3 EPSRC (EP/F037937/1), Failure in Tufted Composite Structures, £153,700, 01/2008-01/2011, PI Prof IK Partridge, CI Dr DDR Cartie
G4 Moving tufting from laboratory into industry, £68,000, 2011, PI Prof IK Partridge, sub project within Cranfield IMRC, EPSRC EP/E001874/1.
G5 EU-FP7 (EU-234290), Advanced integrated composite tail cone (ADVITAC), €1,000,000 05/2009-07/2013, PIs A Skordos, Prof R P Tatam; CIs Prof. IK Partridge, Dr S W James

4. Details of the impact (indicative maximum 750 words)

Composites are now widely used in aircraft – the Boeing 787 Dreamliner uses 50% composites [C1]. The tufted composite braces, based on technologies developed at Cranfield, are the first use of structural composites in the landing gear of a commercial aircraft (figure 2). The use of Cranfield's tufting technology to assemble and reinforce the sub-components of the 3D woven preform has enabled Aircelle and MBD to achieve their goals in terms of material performance [C2, 7].

Figure 2: Detail of the landing gear of the Boeing 787 (the composite braces are shown in black).

The advantages of composites over the traditional steel components are: weight saving due to improved strength-to-weight ratio of the constituent material, which become significant considering that each Boeing 787 is equipped with eight such braces; higher resistance to corrosion, reducing maintenance work and servicing costs; higher resistance to fatigue; greater in-service reliability; and longer service time between overhauls. Ultimately the weight saving gives benefits in reduced fuel burn and CO_2 emissions, and better competitiveness for the manufacturer.

A traditional laminated composite could not bear the complex axial and shear loading pattern expected in such a critical structure, or withstand impact from potential bird strikes or debris flying from a runway. The adoption of a composite structure with a 3D fibre architecture was, therefore, an essential requirement in the material selection for the composite brace.

Three-dimensional weaving technologies allow the production of preforms with fibres arranged along three main directions, however, complex shapes are difficult to produce in a single step. The preform for the brace had to be manufactured as two subcomponents, subsequently tufted together. The option of using tufting within such an innovative manufacturing process had never been attempted before. Cranfield had to conduct several preliminary trials and tests on simple preforms to assess the tufting unit ability to produce the required result. (Figure 3 shows an example of the use of tufting in a complex aerospace component.)

Figure 3: Tufting robot at Cranfield inserting tufts in a double-curvature surface.

The preformed part was manufactured at Aircelle as two subsections of 3D woven carbon-fibre tows around a core of aluminium honeycomb. However, the designers required extra fibre reinforcement to be inserted through-the-thickness of the preform to join the two subsections and to enhance its damage tolerance. Cranfield's research showed that it could meet these requirements, demonstrating the improvement in terms of delamination resistance provided by tufting. This was established with the investigation of the influence of tufting incorporation on interlaminar behaviour, showing improvements in delamination toughness in the range of 60%-400%, whilst preserving in-plane properties, and the development of validated predictive models enabling consideration of property modification to be integrated within the design phase [C6].

The prototypes have gone into full production by Messier-Bugatti-Dowty and are currently flying on the world's fleet of Boeing 787s [C7]. The value to business can be appreciated by considering that landing gear typically comprises 2% of the cost of wide body jets. The price of the 787 is estimated at $200M and the current (2013) cumulative orders are circa 930 aircraft. The contract to supply Boeing Commercial aircraft was a first for Safran / Messier-Bugatti-Dowty and secures workshare for up to 20 years. The extensive use of composite materials for the airframe of this the new aircraft has brought benefits of weight reduction and consequent fuel economy. The Cranfield work has now extended the use of these materials into critical landing gear systems giving Messier-Bugatti-Dowty access to similar weight reducing advantages to their products [C3-5, 7].

5. Sources to corroborate the impact (indicative maximum of 10 references)

C1 787 Dreamliner program fact sheet http://www.boeing.com/boeing/commercial/787family/programfacts.page
C2 Leung E. "The Development and Certification of Composite Landing Gear Components for the Boeing 787". Messier-Bugatti-Dowty presentation at SAMPE UK Seminar, 27 February 2013 http://sampe.org.uk/assets/pdfs/SAMPE2013AGM/MessierDowtyInc-SAMPEUK2013.pdf (last accessed 10/2013)
C3 "First 787 landing with Messier-Dowty composite landing gear braces" Messier-Bugatti-Dowty press release, URL: www.safranmbd.com/actualites/actu-et-communiques-de-presse/article/first-787-landing-with-messier (last accessed 04/2013)
C4 "Boeing 787 Dreamliner" Messier-Bugatti-Dowty press release, URL: www.safranmbd.com/leader-mondial/programmes-majeurs/article/boeing-787-dreamliner (last accessed 04/2013)
C5 "Boeing 787: Composites make a successful landing" Safran press release, URL: www.safran-group.com/site-safran-en/press-media/media-section/article/boeing-787-composites-make-a?10605 (last accessed 04/2013)
C6 Contact: Resin Transfer Moulding engineering manager, Aircelle Le Havre
C7 Contact: Chief Engineer (PCE), Messier-Dowty Inc, Canada