Institution: Oxford Brookes University

Unit of Assessment: 15 - General Engineering

Title of case study: Light-weighting of automotive and aerospace transport

1. Summary of the impact

The automotive and aerospace industries are keen to reduce their environmental impact and so have looked to move to lightweight materials. This creates issues in terms of joining, using and disposing of dissimilar materials. Oxford Brookes has therefore worked with national and multi-national companies in the adhesive, materials, automotive and aerospace industries to try to solve these problems. This has resulted in high quality research publications, innovative test equipment, improved numerical methods, novel designs, design guidelines, manufacturing procedures, British Standards, patents, commercial products and further funding. The impact of the work has global safety, environmental and economic benefits with multi-national aerospace and automotive companies implementing the results in current developments.

2. Underpinning research

The Department of Mechanical Engineering and Mathematical Sciences at Oxford Brookes University has been working on the use of novel materials in the automotive and transport sector for over 20 years. The issues with using lightweight materials is multi-faceted and departmental researchers such as Professor Alec Beavers, Professor Allan Hutchinson, Professor John Durodola, Professor Denise Morrey, Dr James Broughton, Dr Neil Fellows and Dr Patricia Winfield have looked at material design, joint design, end of life recycling, fatigue performance and noise, vibration and harshness (NVH) performance.

The DTI funded LIVEMAN and PAJ projects and EU funded DOGMA project provided the base for the current work on developing lightweight components. The LIVEMAN project looked at the effect of adhesive modulus on the torsional stiffness of automotive vehicles [1] and the DOGMA project [2] developed guidelines on the use of hybrid materials, via a network of 26 European partners. One of the key contributions from Oxford Brookes was the dissemination of research, done by Oxford Brookes, on the LIVEMAN project (22 industrial reports, two conference papers and three journal papers) and from the PAJ project (adhesive bonding test methods).

This work led to a Jaguar Land Rover funded project to improve the prediction of joint performance of automotive structures under crash conditions. This project ended in 2008 but due to confidentiality the first publication in the International Journal of Vehicle Structures & Systems did not appear till 2011.

An effect of using lightweight materials in vehicle structures is that NVH transmission become more significant. An EPSRC funded project was therefore undertaken to develop lightweight components with good NVH properties [3]. A key issue with developing NVH components is the numerical time required to carry out predictive modelling. To overcome this a one-sided, first order Arnoldi based Model Order Reduction (MOR) method has been developed [4]. This showed one order of magnitude improvement in solution times as well as an improvement in error levels. In addition a new novel joint design called the reverse bent joint was developed. These joints have significantly higher failure strengths and have been shown to provide significant improvements in fatigue performance [5]. The papers on the reverse bent joint and Arnoldi based Model Order Reduction (MOR) method have been well cited due to their novelty.

In aerospace applications the approach required is very different to the automotive sector as the use of high cost composite materials is more viable and more complex joints can be developed. The NOTS project developed innovative composite frame designs for supporting lightweight struts [6]. Additionally the safe design of bolted hybrid joints [7] and fuel sealant performance have been investigated.

A key concern using hybrid materials is the difficulty in recycling the materials due to the problem of separating and sorting the different materials from one another. To help with this issue work has been carried out in defining the problem and a network formed [8] to help develop guidelines for the whole life design on vehicles.

3. References to the research

[1] N A Fellows, A Harris, J F Durodola and A Beevers, 'Effects of design and adhesive modulus on the torsional stiffness of automotive structures', Proc. of the IMechE, Part D: Journal of Automobile Engineering, Vol. 222, No 8., pp 1421-1428, 2008, DOI: 10.1243/09544070JAUTO510.

[2] Principal Investigator: Professor Alec Beavers
'Design Optimisation and Guidelines for Multi-material Applications' (DOGMA), EU BRITE/EURAM3, BRRT-CT97-5029,1997-2000, £907k. http://ec.europa.eu/research/brite-eu/thematic/html/2-1-08.html

[3] Principal Investigator: Professor John Durodola
EPSRC GR/S27245/01 'Design and Fabrication of Low NVH Multi Material Automotive Vehicle Structures' 1997-2000, £371,897.
http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=GR/S27245/01

[4] R. S. Puri, D. Morrey et al. Reduced order fully coupled structural-acoustic analysis via implicit moment matching. J. Applied Mathematical Modelling, Volume 33, Issue 11, pp 4097-4119, November 2009, DOI: 10.1016/j.apm.2009.02.016.
Submitted to REF2014, Oxford Brookes University, UoA15-General Engineering, REF2, D Morrey, Output identifier 7902.

[5] G Fessel, J G Broughton, N A Fellows, J F Durodola, A R Hutchinson Fatigue performance of metallic reverse-bent joints', Fatigue and Fract Engng Mater Struct, Vol. 32, pp 704-712, 2009, DOI: 10.1111/j.1460-2695.2009.01378.x
Submitted to REF2014, Oxford Brookes University, UoA15-General Engineering, REF2, AR Hutchinson, Output identifier 8096.

[6] Principal Investigator: Dr James Broughton
DTI 'Nodal Optimization of Truss Structures' (NOTS), 2003-2006, £400k

[7] F Rosales-Iriarte, N A Fellows and J F Durodola (2012), 'Failure prediction in carbon composites subjected to Bearing versus Bypass Loading', Journal of Composite Materials, Vol. 46, pp 1859-1878, 2012, DOI: 10.1177/0021998311427766.
Submitted to REF2014, Oxford Brookes University, UoA15-General Engineering, REF2, NA Fellows, REF2, Output identifier 7794.

[8] Principal Investigator: Professor Allan Hutchinson
'Network for the design for dismantling, reuse & recycling in road vehicles' (DRIVENet), EPSRC GR/S87577/01, 2004-2007, £62,493.
http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=GR/S87577/01

4. Details of the impact

The DOGMA project brought together industry, research institutes and universities to collaborate and exchange ideas. Procedures were developed for multi-material structures that looked at joint design, material development, life cycle analysis, recycling and clean manufacture. Several industrial case studies were prepared by ADTRANZ, BAE Systems, FY-Composites, IDMEC, Adtranz, Hoogovens, Neste and INASMET to show how well the procedures worked. A special conference,'technology' days and promotion online were used for dissemination. Enquires related to the DOGMA project were still being taken up to 2010 and a current website with all the case studies is still accessible to companies [9].

The success of the DOGMA project and the LIVEMAN project fed into the development of the Adhesives Toolkit. TWI, one of the LIVEMAN and DOGMA partners, led this work which was sponsored by the DTI. This toolkit incorporated the work developed by Brookes to provide software that could advise industry in selecting and designing adhesive joints. The rationale behind the toolkit was to ensure a consistent approach to adhesive joint design to improve the competitiveness of UK industry [10]. This toolkit was updated in 2006 and is currently well used

with active news and forum website pages.

The NVH project built on the work of DOGMA and LIVEMAN by investigating the feasibility of replacing conventional metal panels and damping materials with single-piece composite panels. The work was supported by five companies (Bi Composites Ltd, Crompton Tech. Group Ltd, Ford Motor Co Ltd, Oxford Magnet Tech. Ltd and Salex Acoustic Materials) across different industrial sectors who were interested in the design and manufacture of composites and their acoustic performance. The main outcomes of the project were:

A new design of adhesive joint that is easy to implement and increased joint strength by 40% and fatigue life by 100% when compared with conventional lap joints.
The design and manufacture of an acoustically improved polypropylene glass filled roof to fit a Ford van.
The first application of the Arnoldi-based MOR method to structural-acoustic problems [11].

Siemens Hydropower used the technique developed to deal with structural acoustic problems to develop a model of a hydropower turbine for which a paper was presented at the 2009 International Conference on Theoretical and Computational Acoustics.

Through the “High Strain Rate Modelling of Adhesively Bonded Joints” project an epoxy adhesive that was used extensively in Jaguar vehicles was characterised for use in impact studies. This part of the work was particularly successful and the materials data generated from this project are used currently by Jaguar Land Rover as their standard for epoxy based adhesives in Finite Element analyses of bonded vehicle structures [12].

The NOTS project succeeded in producing a patented 2D CFRP truss structure modelled on an Airbus No17 wing rib which resulted in a weight saving greater than 33% [13] and has been cited in 6 further patents. A website was also created to share good practice between the partners and articles written for magazines. A follow on project (ACTS, Advanced Composite Truss Structures) looking at developing 3D trusses won the JEC Composites 2011 Innovation Award.

The Bamboo bike project which came out of the cycling passion of staff combined with their expertise in composite joint design lead to a fully certified bike design. The design has had a patent application filed and has been commercialised, with an outside company, RAW Bamboo, manufacturing the bicycles on license [14].

Test apparatus for determining bearing versus bypass failure and for testing aircraft sealants were developed for Airbus (UK) ltd. The results from the bearing versus bypass testing showed that current methods employed by Airbus in terms of final failure are conservative. Loss of fuel from aircraft wings is environmentally damaging, mainly due to the additional weight of the fuel and aircraft required to account for the loss. A unique test method was developed that provides a standardised method for testing sealants with traditional and composite materials that was not achievable before [15].

The DRIVENet project sought to develop a network focussed on material waste reduction at vehicle end of life. The success of this can be seen in the growth of the network to more than 300+ partners. Stannah stairlifts have applied the design guidelines developed through the DRIVENet project to improve the environmental impact of their products and have now incorporated the guidelines into their operating procedures [16]. Oxford Brookes have also been involved in developing national standards for designing for end of life [17].

A follow on project that has started is the TARF- LCV (Towards Affordable, Closed-Loop Recyclable Future Low Carbon Vehicle Structures). Oxford Brookes is looking at active disbonding and design to reduce end of life recycling problems. This project involves three Universities and five major car companies [18].

5. Sources to corroborate the impact

[9] Website showing guidelines and procedures developed through DOGMA.
http://www.dogma.org.uk/vtt/design/designindex.htm

[10] Links to Adhesive Design Toolkit website (showing connection to LIVEMAN and PAJ projects)
http://www.adhesivestoolkit.com/About/ProjectSummary.xtp#intro
http://www.adhesivestoolkit.com/Docu-Data/Reports.xtp

[11] One of the authors who highlights the novelty of MOR approach developed:
Y.-T. Li, Z Bai et al., A Structured Quasi-Arnoldi procedure for model order reduction of second-order systems, Linear Algebra Appl. (2011), DOI: 10.1016/j.laa.2011.07.023.

[12] Corroborative statement author 1. Letter from Technical Specialist - Crashworthiness CAE, Jaguar Land Rover – Aug 2013
"the materials data generated from this project are used by Jaguar Land Rover as our standard for epoxy based adhesives in Finite Element analyses of bonded vehicle structures."

[13] International patent application: WO2006061617 (A1)
Title: Composite Truss Structures
Publication Date: 15th June 2006
Further Patents citing this one US2012082547 (A1), US2012082555(A1), US2009196758(A1), US2009196757(A1), US2009191063(A1), US2007217918(A1).

[14] International patent application: WO2013017872 (A1)
Title: Method of joining ligneous materials and products made by the method
Publication Date: 7th Feb 2013

[15] Research paper written with Surface Technology,Materials and Processes – EDSWBU, AIRBUS UK, Filton
"model sealed system (MSS), was developed under contract to Airbus UK to undertake the full range of test parameters for the evaluation of sealants for current and future aircraft."

[16] Corroborative statement author 2. Letter from Joint Managing Director Stannah Stairlifts – Oct 2013.
"apply the design guidelines developed .. to improve the environmental impact of our products and we have now incorporated the LCA guideline into our operating procedures."

[17] http://standardsdevelopment.bsigroup.com/Home/Committee/50165253

[18] Brookes Investigators: Prof D Morrey, Prof A Hutchinson, Dr P Winfield
EPSRC EP/I038616/1, 'Towards Affordable, Closed-Loop Recyclable Future Low Carbon Vehicle Structures - TARF-LCV' 2011-2015, £ 4,221,482.
http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/I038616/1