Institution: University of Bradford

Unit of Assessment: B12

Title of case study: Expertise in automotive braking systems helps vehicle and brake manufacturers to improve their designs to increase customer satisfaction and sales, and reduce costs

1. Summary of the impact

Research at the University of Bradford has enabled many major vehicle and brake manufacturers to improve the design of their brakes and braking systems to increase customer satisfaction and sales, and reduce costs. Methods have been developed to predict the thermo-mechanical and dynamic performance of brakes and provide design improvements. Durable solutions have been developed for noisy brakes, which have reduced warranty costs for approximately ten international collaborating companies including Bentley, where a squeal noise from the front brakes of a new vehicle had prevented it from being released for production. Our research has been embedded into short courses, which have trained over 250 engineers since 2008 and is incorporated into Jaguar Land Rover's (JLR) professional training.

2. Underpinning research

Research into brakes and braking systems at the University of Bradford by a team led by Andrew Day (Professor 1993-2013) and including John Fieldhouse (Honorary Professor, 2012-2013), Dr Khalid Hussain (Lecturer 1994-2005, Senior Lecturer 2005-present), Dr David Bryant (2012-2013) and Mr A Alasadi (KTP Associate 2010-2011), extends over more than 25 years and includes drum brake design and manufacture (ROR Rockwell TCS 1997, MCB/VALX 2008), car brake system design and simulation (Honda 2003, Jaguar 2004), braking stability (1) (Ford 2003, 2005, 2009), drum and disc brake noise (2,3) (Hyundai 1996, Ford 2005, JLR 2010, 2013, Mando 2012), drum brake judder (4) (Hyundai 2006), disc brake judder (5,6) (Bentley 2013), regenerative braking and failure mode avoidance (TMETC KTP 2011). The Bradford group's research has generated advanced and unique knowledge and expertise in many aspects of brake performance and vehicle behaviour during braking. The understanding of contact and pressure distributions between the rotor and stator components of a brake has led to fundamental changes in brake design including more compliant friction materials for disc brake pads which provide more uniform pressure distributions, and has highlighted the importance of improved distribution of actuation force applied to the pad back plate. The use of Finite Element methods for thermo-mechanical and modal analyses has been correlated with experimental data, and has demonstrated how predictive techniques can be used to avoid operational problems at the design stage. We have recently published the first fully comprehensive non-linear simulation of brake noise generation using multi-body dynamics software from current research with JLR (2). Much of this research has been actively promulgated through the annual 'Braking of Road Vehicles' short course for industry.

Warranty claims from brake noise and judder have become a major problem for all road vehicle manufacturers and research expertise in this area has recently been strengthened in the Bradford group. Companies including JLR, Bentley, Ford, Hyundai, TMD, BPW, BMW, Meritor, Volvo, Bosch, Toyota, and Mando have sponsored brake noise research since 1993. Examples include two CASE awards and continuing research collaboration with Bentley (5,6) which has led to an advanced understanding of brake judder and the effects of thermo-elastic and thermo-plastic behaviour. It has generated a revised approach to brake disc design that includes aerodynamic design of the disc vents to give overall even heating and cooling of the disc and has demonstrated elastic distortion during heavy braking for the first time. In addition it has led to the suggestion of disc stress relieving to avoid in-service stress relieving and subsequent disc distortion. Advanced whole body visual techniques (holographic interferometry) have been developed to analyse the vibration characteristics of brake systems, forming the basis of a predictive tool (3). These enable both in-plane and out-of-plane absolute displacements to be investigated. The techniques were extended to record time-related images of disc modes while braking, and showed that the disc

continues to vibrate under the pad and is not suppressed by it. We explained why certain frequencies were more likely to occur by investigating the disc/pad interface geometry and have provided a predictive tool for industry. We measured the dynamic interface pressure of the pad and showed that the general centre of pressure varied during braking. Correlated over car and commercial vehicle brake systems, we showed that a 15-20mm leading contact offset would increase disc brake noise propensity and predicted this to be possible with normal μ values and existing brake designs (3).

3. References to the research

1. Mirza N, Hussain K, Day AJ, Klaps J. (2010) An assessment of steering drift during braking: a comparison between finite-element and rigid body analyses. *Proceedings of the Institution of Mechanical Engineers (K): Journal of Multi-Body Dynamics*, 224(3): 307-317.

2. Alasadi A, Bannister P, Bryant D, Day AJ, Hussain K. (2013) The prediction of pad vibration in a noisy disc brake using multibody dynamics analysis. *Eurobrake 2013 Conference Proceedings*. FISITA. ISBN 978-0-9572076-0-8

3. Fieldhouse JD, Steel WP, Talbot CJ. (2008) The measurement of the absolute displacement of a noisy disc brake. *Proceedings of the Institution of Mechanical Engineers (D): Journal of Automobile Engineering* 222(7): 1121-1140.

4. Hussain K, Yang SH, Day AJ. (2007) A study of commercial vehicle brake judder transmission using multi-body dynamic analysis. *Proceedings of the Institution of Mechanical Engineers (K): Journal of Multi-body Dynamics* 221(2): 311-318.

5. Bryant D, Fieldhouse JD, Talbot CJ. (2011) Brake Judder – An Investigation of the Thermo-Elastic and Thermo-Plastic Effects during Braking. *International Journal of Vehicle Structures & Systems* 3(1): 57-72.

6. Bryant D, Fieldhouse JD, Claffey E. (2013) Hot Judder – An Analysis of the development process. *Eurobrake 2013 Conference Proceedings*. FISITA. ISBN 978-0-9572076-0-8

(2), (3), and (5) are the three references best indicating the quality of the work.

The following grant is also indicative of the quality of the research:

Industrial research grant (Jaguar Land Rover, £360k, 2011-2014), "*Brake noise propensity*" AJ Day, D Bryant. Bradford led with Cranfield and Liverpool universities. This developed enhanced computer-aided engineering (CAE) methods to predict noise propensity from brake system design parameters.

4. Details of the impact

Modern automotive brakes have to provide consistently high performance over a wide range of operating conditions including high temperatures and high speeds. It is a technologically challenging area of automotive engineering, and vehicle and brake manufacturers are continually required to improve their designs. We have worked closely with many companies (a,b,c,d,e) so that our research into road vehicle brakes and braking systems has enabled them to understand better the underpinning scientific principles, and implement new knowledge and methods. The result for the industry is improved customer satisfaction and reduced warranty costs, for example by 50% for JLR since 2010 (a).

On-going promulgation of research knowledge and expertise in the field is achieved via the annual "Braking of Road Vehicles" short course run at Bradford since 1997. Delegates attend this course each year from all over the world, and it is internationally regarded as the 'industry-standard' short

course for the road vehicle and braking industries. It is also delivered in-house to several companies including JLR (a) where it is part of their Masters level professional training programme. Since 2008 we have trained over 250 engineers in advanced knowledge and expertise (e.g. in brake NVH) and have substantially improved the knowledge and understanding of staff. For example, in JLR's Brakes Engineering Department (a) this training is already enabling new CAE procedures to be developed e.g. in the minimisation of brake noise propensity at the design stage (2,a). Concerns relating to brake noise and vibration within JLR have decreased as a result of better understanding of brake noise among braking systems design engineers which has resulted in a saving of 471 days, and 3800 hours amongst the Brakes Engineering Department staff (a). For example, JLR took the decision to lower their in-house standard friction level to 0.38, reducing noise propensity because of the reduced leading contact offset (2). Associated with other design improvements, the result has been that since 2009 the number of identified concerns relating to brake noise and vibration has halved, warranty costs have been substantially reduced, and customer satisfaction has increased (a).

The advanced techniques of holographic interferometry developed by the team have revealed details of noisy brake systems that were previously unknown (3). Our results have been disseminated internationally and have been used to validate predictive Finite Element (FE) analysis procedures for brake design which have been adopted and used by many brake and vehicle manufacturers for noise prediction (a,b,c,d,e). Our predictive tool for brake NVH is currently being used by four vehicle and brake system manufacturers to support understanding of how brake noise is generated and to propose design improvements to avoid it. Currently two UK car manufacturers are using noise counter measures that were originally proposed by the Bradford team (Bentley and JLR). Prior to successful application of the countermeasure, new Bentley vehicles were unable to be released for production because of brake noise (b).

We have worked closely with Bentley (5,6,b) over many years to advance their understanding of brake judder. This has resulted in their adopting stress relieving of brake discs to ensure that warranty claims arising from judder are minimised. The research is also being used to direct Bentley's future disc design and selection.

5. Sources to corroborate the impact

a. Manager, Brakes, Jaguar Land Rover,
"*Jaguar Land Rover recognises and values highly the brake noise and vibration expertise at the University of Bradford …".*
"We recognise that members of the research group are internationally recognised experts in brake and braking system design …".
"In the area of brake noise JLR has achieved high levels of customer satisfaction and it is essential that we continue to develop our scientific understanding and knowledge to underpin our technological expertise by working with universities such as Bradford with specialist expertise." (Letter dated 24/4/12.)

b. Functional Manager (Foundation Brakes), Bentley Motors Limited,
"Bentley Motors has funded research projects with Professor Fieldhouse since the 1990s …"
"Bentley Motors currently expects to continue to collaborate with the Centre in the research and development of methods for improvements in brake NVH refinement." (Letter dated 21/6/12.)

c. President and CEO, TMD Friction worldwide, TMD Friction Services GmbH
"I am acutely aware of the challenges the automotive brake business faces in the coming years. Undoubtedly, we in the industry will face a whole gamut of challenges – technical, environmental and economic, over the next decade and strong research capabilities in the UK will be an essential support to ensuring the future of friction material manufacture both in the UK and the EU. TMD Friction would be happy to support you in establishing the new Centre as a key step towards this goal." (Letter dated 26/4/12.)

d. Chief Engineer, Meritor H.V.B.S. (UK) Ltd,
"The new Braking Laboratory which is being established in the Research Centre should include "state of the art" equipment & facilities to make it one of the best equipped braking research laboratories in the world. I believe that this will provide braking related R&D facilities which are not currently available in the UK, and will help to develop stronger links between academia & industry which in turn will help develop a more competitive UK manufacturing industry." (Letter dated 24/4/12.)

e. Group Chief Engineer, Advanced Engineering, Tata Motors European Technical Centre,
"The partnership has directly contributed to the expanding capability of TMETC by developing key technological expertise in 2 areas, viz. braking systems and new product introduction within a Failure Mode Avoidance (FMA) framework. This has increased the value of TMETC in serving the strategic needs of its parent group TML through the delivery of a design methodology for regenerative braking for low carbon vehicles (FEV's and HEV's) based on analysis and prediction, which is presented within a new product development process based on the Bradford FMA framework." (KTP 007377 final report, July 2011.)