Institution: University of Birmingham

Unit of Assessment: UOA 14 – Civil and Construction Engineering

Title of case study: Impact of research on vehicle aerodynamics on UK and European railway codes and standards

1. Summary of the impact

This case study describes the impact of the work at the University in the field of rail and road vehicle aerodynamics, which has primarily been through the integration of research into UK and EU standards and codes of practice. This has resulted in impacts on practitioners and professional services in the field of rolling stock and infrastructure construction and operation, and has also provided information for industrial testing work and for use in expert witness work. Specifically the work has been incorporated into the following codes and standards.

- CEN code of practice and the rolling stock Technical Standard for Interoperability (TSI) describing the measurement methodology of train slipstream velocities;
- The UK national annex to a CEN code of practice for transient aerodynamic pressure loading on trackside structures;
- UK and CEN codes of practice for wind tunnel testing of rail vehicles in cross winds;

The methodology in these codes is widely used by the railway industry in the UK and Europe in train and infrastructure design, and indeed in some situations their use is obligatory. The work has also directly informed recent testing work for Network Rail and HS2 (via Arup) that have addressed fundamental issues associated with major electrification projects for the former and basic track spacing determination for the latter. It has been used in two court cases that were concerned with lorries blowing over.

2. Underpinning research

Fundamental work has been carried out into the field of vehicle aerodynamics at the University since 1998 by Baker and his co-workers (Sterling, Quinn and Hemida) using full scale, wind tunnel, computational and analytical techniques. A unique aspect of the work is the use of the TRAIN Rig facility – a 150m long moving model rig based at Derby, which allows 1/25th scale vehicles to be propelled at speeds of up to 80m/s . Specifically the work has included the study of cross wind effects on trains and lorries, ballast flight beneath trains, train and lorry slipstream studies and studies of the pressure transient forces on roadside and trackside structures. (http://www.birmingham.ac.uk/research/activity/railway/research/train-rig.aspx).

In terms of the impact that will be discussed here, the relevant fundamental research work is as follows.

1. *Measurement of slipstreams of ground vehicles (1998-2000) Inland Surface Transport LINK scheme (with BRR and MIRA) (approx. £100k including industrial contribution)* – use of the moving model TRAIN Rig to measure the fundamental nature of vehicle slipstreams.
2. *Production of RSSB RACOP on wind tunnel testing (2004) (£15k)* – technical advice on the development of methodologies for carrying out wind tunnel tests of trains in cross winds
3. *WEATHER; Investigation of cross wind effects on vehicles, EU CRAFT programme (2004-2006) (215keuro)* – full scale, wind tunnel and CFD calculations on the cross wind forces on ground vehicles.
4. *The slipstreams and wakes of trains, RSSB Contract and Studentship (2005-07) (£45k)* – development of a model for predicting the stability of passengers and track side workers as train pass.
5. *Rail Research UK – 2nd phase (2006-2010) (£700k to Birmingham)* – specifically project A5 that investigated the interaction between turbulence cross winds and the train dynamic system
6. *AEROTRAIN (£2.5m - £350k to Birmingham), EU grant with 20 other partners (2009-2012)* – involved in cross wind and tunnel aerodynamics work packages, and leader of the slipstreams work package.
7. The measurement of wind loading on trackside structures. RSSB contract (£60k) (2010-2011)
8. *The measurement of train aerodynamic phenomena in operational conditions (Network Rail*

/ *EPSRC) (2011-2014) £550k* – the measurement of operational aerodynamic characteristics and a comparison of the measurements with equivalent model scale and CFD measurements.

The above projects include a mix of fundamental research into various aspects the aerodynamic behaviour of road and rail vehicles, and more applied work aimed at specific projects, usually concerned with the development or revision of codes of practice and design guides. Very often these two aspects are contained within the same project. A major aspect of this work is the way in which the wide expertise of the group allows a range of experimental, analytical and computational techniques to be combined in a manner that allows fundamental understanding of the flow field to be obtained, as well as data of immediate practical significance.

Lead researchers:
Rev Prof Christopher Baker, Professor of Environmental Fluid Mechanics
Prof Mark Sterling, Beale Chair of Engineering
Dr Andrew Quinn, Senior Lecturer (from April 2005 onwards)
Dr Hassan Hemida, Lecturer (from January 2009 onwards)

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

1. C J Baker, S J Dalley, T Johnson, A Quinn, N G Wright 2001 "The slipstream and wake of a high speed train", Proceedings of the Institution of Mechanical Engineers F Journal of Rail and Rapid Transit, 215, 83-99 (awarded James F Alcock Memorial Prize by Railway Division of the IMechE, 2002) DOI: 10.1243/0954409011531422
2. M. Sterling, C. J. Baker, S. C. Jordan, T. Johnson, 2008 **"**A study of the slipstreams of high speed passenger trains and freight trains**",** Proceedings of the Institute of Mechanical Engineers Part F: Journal of Rail and Rapid Transport. 222, 177-19 (the most cited paper from JRRT in 2010) DOI: 10.1243/09544097JRRT133
3. C J Baker, A Quinn, M Sima, L Hoefener, R Licciardello 2013 "Full scale measurement and analysis of train slipstreams and wakes: Part 1. Ensemble averages; Part 2 Gust analysis". Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit, published online May 14, 2013 DOI:10.1177/0954409713485944
4. C Baker, S Jordan, T Gilbert, A Quinn, M Sterling, T Johnson, J Lane 2012 "Transient aerodynamic pressures and forces on trackside and overhead structures due to passing trains. Part 1 Model scale experiments; Part 2 Standards applications". Journal of Rail and Rapid Transit DOI: 10.1177/0954409712464859, 10.1177/0954409713488098
5. C J Baker, F Lopez-Calleja, J Jones, J Munday, 2004 "Measurements of the cross wind forces on trains", Journal of Wind Engineering and Industrial Aerodynamics 92,547-563 DOI: doi.org/10.1016/j.jweia.2004.03.002
6. A. D. Quinn, M Sterling, A. P Robertson, and C. J Baker, 2008 "An Investigation of the wind induced rolling moment on a commercial vehicle in the atmospheric boundary layer". Proceedings of the I.Mech.E, Part D, Journal of Automobile Engineering. 221, 1367-1379 DOI: 10.1243/09544070JAUT0537

References 2, 3 and 4 best indicate the quality of the underpinning research

4. Details of the impact

The impact of the above work is broadly in the provision of information for design guides and codes of practice, specifically the Railway Group Standards produced by the Railway Safety and Standards Board, the CEN codes on Railway Aerodynamics and the Rolling Stock and Infrastructure TSIs (Technical Standards for Interoperability, which have been developed to allow railways to operate across national borders). The use of these documents is mandatory in any new railway project / train design and thus the influence of changes to these codes is felt across the sector. Changes to the codes may not have direct economic benefits to the infrastructure or train operators (indeed they may increase immediate costs), but the impact will be felt in terms improved safety and reliability and, in the case of the TSIs, in allowing international operations across borders. The specific impacts of the ongoing work can be described under a number of headings as follows.

Revisions to CEN code* EN 14067-4 *and Rolling Stock TSI for the train slipstream measurement methodology (2012). The work on train slipstreams in projects 1, 4 and (most importantly) 6, and reported in references 1, 2 and 3, have been used to develop a revised methodology for the testing of new trains to ensure that the slipstream velocities measured caused by the trains do not exceed safety limits. The most important concept to emerge from this work was the inherently stochastic nature of train slipstream measurements and a full appreciation of the need to properly treat the resulting sources of uncertainty in the codes. After analysis of the data, it proved possible to greatly simplify the existing methodology, that required tests to be carried out for multiple train passes both at trackside and above a platform, such that the platform based tests are no longer required. This simplification will result in costs savings of the order of a hundred thousand euros in the authorisation process for a new train. An example of this would be the current work on the authorisation of the double unit Class 350 in the UK, where the adoption of a simplified testing technique will substantially speed up the certification process.

Provision of data for the development of a National Annex to the CEN code for transient pressure forces due to train passing (2012). The work of project 8, and reported in reference 4, in which the moving model TRAIN rig was used to determine the transient train passing aerodynamic pressure forces on a variety of structures, was used to develop a UK National Annex for the Eurocode EN 1991-2, that related specifically to UK track spacings rather than the continental track spacings assumed in the main text of the code. Without the information contained in the new National Annex the code is very conservative from a UK perspective, and the new provisions allow for much more economical design of trackside structures. For example, it will allow the design loads due to passing trains on overbridges to be reduced by around 50% in some cases, which, depending upon the design used and bridge span, may result in savings of many tens of thousands of pounds in the construction of any new bridge.

Development of wind tunnel testing methodology for trains in cross winds for Railway Group Standard and CEN code (2009/10). This work was again based on the experience of Baker and the work carried out in projects 2 and 5 and partially reported in reference 5. It resulted in a methodology for wind tunnel testing that is included in the Railway Group Code of Practice GM/RT2542 (2009) and as an Appendix in the CEN code EN 14067-6. (2010).

***Measurement of slipstream velocities and pressure transients for a variety of practical applications (2012-2013*).** A number of recent projects have been carried out that incorporates the applied and fundamental knowledge obtained in all the projects listed above. The first of these involved full scale measurements of the slipstream velocities experienced on an overhead line installation vehicle as trains pass at line speed (Network Rail) with a view to establishing safe working practices. This will enable work to proceed on overhead line installation in such a way that allows traffic on the adjacent line to continue to operate. This uses the methodology developed in project 6 and reported in reference 3. A Network Rail study indicates that the cost savings of such an operation over the normal method of obtaining a complete possession will be of the order of £1.2m / year during construction, and this methodology is being used in the Great Western Electrification process. The second involves the use of the TRAIN rig measurements of train slipstreams and pressure transients for the proposed high speed line north of London (Arup and HS2), in order to allow track spacing to be determined. This builds on the work of project 8 as reported in reference 4. Finally, work has recently been carried out on the TRAIN Rig for HS2, to measure train slipstreams and pressure forces on passing trains. This information is required to determine safe track worker clearances for the very high speed running that is envisaged, in order to validate the assumption of the proposed track spacing (which is on the critical path for the design of HS2); to optimise aerodynamic forces on passing trains, and to allow modelling to be carried out on the effect of the new line of birds and flying invertebrates. This work is based upon the work of projects 6 and 7 as reported in papers 3 and 4.

Provision of expert witness advice for a court case and an inquest (2008 and 2012/3). The work of project 3 and reported in reference 4 has enabled advice to be given in a court case and an inquest. The first of these (in 2008) involved a high-sided vehicle loaded with lightweight building material (insulation) which was blown sideways such that the wheels on one side lifted off the road. This caused an oncoming vehicle to swerve and have an accident. Analysis suggested that the driver of the lorry would not have been able to avoid the situation. The inquest concerned the death of a pedestrian when a lorry blew over onto him, allegedly due to high winds caused by the construction of a high rise structure. The advice offered was again based on the outcome of project 3 and reference 4, and, whilst the verdict of the coroner is pending, the advice offered may lead to significant revision of the methodologies and criteria for assessing the effect of tall buildings on wind conditions that affect both pedestrians and vehicles around the base of the building.

It can thus be seen that the fundamental research work outlined above underpins and directly informs a number of practical applications. The work has proved to be of significance to a wide reach of organisations – specifically codification bodies, train designers and builders and train infrastructure operators, as well as being of legal significance in some court cases. The impact takes a number of forms but will have economic impact (in terms of more efficient ways of train aerodynamic testing, or of solving specific issues in a cost efficient way), impact on practitioners and professional services (in terms of the specification of new and revised codes of practice) and also impact on public safety (in making the railway safer for passengers and trackside workers). The work continues in project 8, which is examining the inherent conservatism in railway aerodynamic codes of practice through the carrying out of full scale aerodynamic measurements on the operating railway.

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

1. *Revisions to CEN code and Rolling Stock TSI for the train slipstream measurement methodology (2012).* Technical leader of AeroTrain project, Bombardier Transportation, Stockholm (statements 1a and 1b)

2. *Provision of data for the development of a National Annex to the CEN code for transient pressure forces due to train passing (2011).* Structures Engineer, Railway Safety and Standards Board (statement 2)

3. Development of wind tunnel testing methodology for trains in cross winds for Railway Group Standard and CEN code (2004), Professional Head of Aerodynamics Railway Safety and Standards Board (statement 3)

4. *Measurement of slipstream velocities and pressure transients for a variety of practical applications (2012-2013).* Traction and Rolling Stock Engineer HS2 Ltd (statement 4) Further corroboration available from Network Rail.

5. *Provision of expert witness advice for a court case and an inquest (2008 and 2012).* Letters of instruction from the solicitors and the coroner can be supplied on request to the University.