Institution:
Loughborough University

Unit of Assessment:
B12: Engineering

Title of case study: Improving the competitiveness and sustainability of UK Automotive Industries.

Period when the underpinning research was undertaken: 2001 - 2018

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Martin Passmore	Prof. of Automotive Aerodynamics	1996 – present
Georgios Mavros	Reader in Vehicle Dynamics	2003 – present
Kambiz Ebrahimi	Prof. of Advanced Propulsion	2015 – present
Byron Mason	Senior Lecturer in Powertrains	2015 – present
Gary Page	Prof. of Computational Aerodynamics	1996 – present
Dan O'Boy	Senior Lecturer in Structural Vibration	2008 – present
Andrew Garmory	Senior Lecturer in CFD	2012 – present

Period when the claimed impact occurred: 2014 to present

Is this case study continued from a case study submitted in 2014? No

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

The translation of our multi-disciplinary engineering science research in simulation, validation, and calibration methods, has directly impacted the nationally and strategically important automotive and motorsport sectors' competitiveness and sustainability. The impacts are evidenced in: 1) **process development and product innovation** enabling multi-million-pound cost savings; 2) **improved vehicle dynamics, stability and safety**, and; 3) a significant and quantifiable **reduction in CO_2 emissions** helping to reduce the impact of transportation on the environment.

2. Underpinning research (indicative maximum 500 words)

Loughborough University has an outstanding record of collaboration with the automotive industry that is focused on addressing relevant research challenges and translating underpinning engineering science into tools and processes that improve the product development process, product quality and capability, all of which are key elements in maintaining a commercially competitive position. The body of research that underpins the impact in section four extends back to 2001. The team of experts comprises Professor Martin Passmore, Dr Byron Mason, Dr Dan O'Boy, Dr George Mavros, Dr Andrew Garmory, and Professor Gary Page. Collectively, their research has generated research and new knowledge in a broad range of technical areas.

First, using the world's first electronic throttle systems for petrol engine vehicles, developed by Loughborough University, our novel research on mapping engine characteristics to the customer demonstrated, for the first time, the advantages of tailoring the feel of the vehicle to the driver and therefore improving vehicle drivability **[R1]**. Second, our research on powertrain calibration, required prior to the launch of a new vehicle to optimise the emissions, fuel consumption and drivability of the vehicle, has led to novel applications and adaptations of two stage regression models and dynamic neuro-fuzzy models in the model identification process for complex non-linear systems. This has provided the underpinning research for revolutionary dynamic methods that can speed up the costly calibration processes for vehicle powertrains **[R2]**.

Third, the team conducted a body of fundamental research in vehicle dynamics, including model parameter identification, physics-based approaches for tyre modelling, rubber friction models and tyre modelling on deformable terrain with both soil modelling and the tyre/soil interaction, have provided the underpinning physics for new models to be used in multiple applications, including for off-road driving. In addition, underpinning research into structural dynamics, including modal decomposition/superposition methods and experimental modal testing, has resulted in fundamental explanation/prediction of the relationship between tyre construction and tyre forces, which dictate the ride and handling response of ground vehicles **[R3, R4]**.

Finally, to address the need for more fundamental understanding of the flow physics and improved simulation capability, our underpinning research in computational and experimental vehicle aerodynamics and multi-physics has explored the complex aerodynamics of turbulent and separation dominated flow-fields, and the associated relationship to drag, vehicle dynamics and the deposition and motion of contaminants. Experimental approaches including large volume, high Reynolds number Particle Image Velocimetry (PIV) and filtered flow-field reconstruction using proper orthogonal decomposition have provided new understanding of wake structure and dynamics. Computational approaches have investigated two way coupled vehicle dynamics and Computational Fluid Dynamics (CFD), validated methods for soiling prediction using Lagrangian particle tracking methods with bespoke models of droplet coalescence and evaporation, and resulted in new in-house codes, including for multiphase flow employing Coupled level Set Volume of Fluid (CLSVOF) combined with experimentally based contact angle models **[R5, R6]**.

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

An extensive body of research, in a broad range of technical areas, underpins the impacts claimed in Section 4. Six references are provided that exemplify contributions to creating the impact claimed. Every publication listed is published in a high-quality international journal and has been peer reviewed.

R1 Passmore M. A., Patel, A., Lorentzen, R. (2001). The influence of engine demand map design on Vehicle perceived performance. *International Journal of Vehicle Design*, 26 (5), pp. 509-522. DOI: https://doi.org/10.1504/IJVD.2001.005221

R2 Mason, B., Bradley, W., Pezouvanis, A. and Ebrahimi, K. (2016). Repeatable steady-state measurement of particulate emissions in engine experiments. *International Journal of Engine Research*, 17 (10), pp. 1108–17. DOI: https://doi.org/10.1177/1468087416643667

R3 Tsotras, A. and Mavros, G. (2009). The simulation of in-plane tyre modal behaviour: a broad modal range comparison between analytical and discretised modelling approaches. *Vehicle System Dynamics*, 47 (11), pp. 1377-400. DOI: https://doi.org/10.1080/00423110802635405

R4 Bekakos, C. A., Papazafeiropoulos, G., O'Boy, D. J., Prins, J. (2016). Pneumatic tyres interacting with deformable terrains. *Journal of Physics: Conference Series*, 744 (1), 012213. DOI: https://doi.org/10.1088/1742-6596/744/1/012213

R5 Pavia G., Passmore M., Sardu C. (2018). Evolution of the bi-stable wake of a square-back automotive shape. *Experiments in Fluids*, 59:20. DOI: https://doi.org/10.1007/s00348-017-2473-0

R6 Kabanovs, A., Garmory, A., Passmore, M., Gaylard, A., (2017). Investigation into the dynamics of wheel spray released from a rotating tyre of a simplified vehicle model. *Journal of Wind Engineering and Industrial Aerodynamics*, 184 (January), pp. 228-46. DOI: https://doi.org/10.1016/j.jweia.2018.11.024

The underpinning research was funded from a mix of sources including direct industrial funding from Ford Motor Company and Jaguar Land Rover and F1 teams: EPSRC grant EP/K014102/1 – 'Multi-Physics and Multi-functional Simulation Methods'; follow-on EPSRC Case Awards, including Advanced Propulsion Centre / Innovate UK (78938-506185), 'Dynamic Analysis Modelling and Optimisation of GDI Engines', DYNAMO, Advanced Propulsion Centre / Technology Strategy Board (39215-287151), 'Advanced Combustion Turbocharged Inline Variable valvetrain Engine', ACTIVE.

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

The automotive and motorsport sectors contribute a net £19 billion annually to the UK economy and are responsible for 12% of all UK exports. Ensuring their competitiveness and sustainability are central to the UK industrial strategy of supporting high-value manufacturing and high-skill jobs. The impacts reported in the case study are the result of a series of well-established research partnerships with Ford of Britain and Jaguar Land Rover: two of the UKs leading motor industry brands.

Efficient knowledge exchange has been central to the success of these partnerships with an industrial champion appointed to each project ensuring that that the research was strategically aligned to company priorities and research outcomes were effectively disseminated. This approach was formalised in the EPSRC/Jaguar Land Rover funded project EP/K014102/1: "*As a technical specialist […] I worked closely with the academic team to ensure that the research was relevant and impactful for Jaguar Land Rover*" **[S1]**.

A significant proportion of the following research-based impacts have been embedded in validated digital models that have been incorporated into the commercial packages used by the companies or have been delivered as stand-alone expert systems. Pathways to impact have been further strengthened by training our postgraduate research students as new experts, addressing issues of skills shortages, who have gone on to take leading roles in industry **[S2, S4-6]**. The success of this collaborative approach, and the body of multi-disciplinary research in engineering science, simulation, validation, and calibration methods upon which it is based, has led to the following research-based impacts.

Impact 1: Process development and product innovation

The new dynamic powertrain calibration technology using adaptations of two stage regression models **[R2]** has "*revolutionised Ford's engine development process*". By speeding up engine development, the new technology has produced a saving to Ford of "*around $12 million/year globally*" **[S2]**.

The impact of our research collaboration with Ford of Britain extends beyond powertrain calibration, taking full account of the relationship between the driver demand (throttle) and vehicle performance **[R1]**, which has been described to be "*critical in changing the way in which engineers understood this vehicle attribute*" **[S2]**. It is now implemented globally in the Ford Motor Company product development process and "*incorporated in approximately 5.4 million vehicles per year*" **[S2]**. The new computer-controlled throttle systems enabled improvements to the feel of the vehicle "*in ways that had not previously been possible* and enabling Ford to maintain "*its reputation as a world-leading brand for vehicle performance and drivability excellence*" in an increasingly competitive market. **[S2]**

Similarly, our research into vehicle aerodynamics **[R5]** and two-phase modelling of spray and surface contamination **[R6]** have changed "*the design, function and appeal of new Jaguar Land Rover products*". For example, "*a novel flow through rear spoiler that reduces rear screen contamination and drag simultaneously. This would not have been possible without the profound insight into wake dynamics, surface contamination and their interaction provided by research at Loughborough*" **[S1]**.

The vehicle aerodynamics research at Loughborough has "*set the development agenda for specific sub-models in the commercial software*" and is judged to have been "*significant in Jaguar Land Rover maintaining its reputation for providing high quality vehicles to its customers*" **[S1]**.

Impact 2: Improved vehicle dynamics, stability, and safety

Loughborough's research in automotive aerodynamics "*was a significant component in Jaguar Land Rover's goal of introducing more virtual engineering into the product development process*" **[S1]**. For example, new understanding of base drag arising from Loughborough's "*internationally-leading expertise in bluff body wake dynamics*" **[R5]** has been "*built into the criteria we use for vehicle development"*. New computational methods providing fully coupled aerodynamics and vehicle handling "*are now embedded into the Jaguar Land Rover aerodynamic stability assessment process to improve the safety and refinement for the more than 500,000 cars we sell each year*" **[S1]**.

Our research in modelling vehicle dynamics and dynamic systems have produced both finite element and real-time physics based off-road tyre models (terra mechanics) **[R3, R4]** that have been integrated into the Jaguar Land Rover product development process and "*allowed us, for the first time to simulate off-road tyre behaviour*" **[S3]**. The integration of these models into the commercial software used in Jaguar Land Rover (Dassault Systems - Simpack) has enabled the company "*to offer better designs at a reduced cost*" ensuring that the business retains its class leading off-road capability **[S3]**.

Impact 3: Reduced CO_2 emissions and environmental impact

Loughborough University's research into model identification methods for non-linear systems **[R2]** has "*revolutionised Ford's engine development processes*" through the introduction of dynamic methods for powertrain calibration **[S2]**. Our methodology and associated advanced technology have been implemented on "*approximately 1.5 million Ford engines globally between 2015-2020*" thereby contributing to "*reducing CO_2 by an estimated 7.5 million tonnes per year*" **[S2].**

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

Letters to provide supporting confirmation of the impacts claimed are available from the following sources. Quotations in Section 4 are taken directly from the letters.

S1 Dr Adrian Gaylard – Jaguar Land Rover, Technical Specialist Aerodynamics.
S2 Dr Graham Hoare – Chairman Ford of Britain
S3 Mr Jan Prins – Technical Specialist Tyres - Jaguar Land Rover
S4 Dr Hubertus v. Chappuis - Chassis Foundation Engineer Ford Werke GmbH
S5 Dr Achillefs Tsotras - Head of NVH, Continental Reifen Deutschland
S6 Dr Vasileios Tsinias - Tyre Performance Technical Lead, Renault Sport Racing