Institution: Loughborough University

Unit of Assessment: B12 Aeronautical, Mechanical, Chemical and Manufacturing Engineering

Title of case study: Project HOTFIRE: Collaborative fundamental research leads to new, downsized, high fuel economy car engine

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

The HOTFIRE collaborative research project (2004-2008) into advanced engine combustion systems led directly to a new, high specific power output, high fuel economy, low CO_2 emissions turbocharged 'down-sized' three-cylinder engine that was demonstrated in the Opel Astra car in 2008. The valuable new knowledge, understanding and techniques gained in the HOTFIRE project has directly contributed to the successful delivery of a major engine family project for an ASEAN region OEM client of Lotus Engineering.

2. Underpinning research (indicative maximum 500 words)

This research created a new engine combustion system that dramatically reduced already class-leading fuel consumption and hence real-world CO_2 emissions by more than 15%. The HOTFIRE system avoids conventional engine throttling losses by directly injecting fuel into the engine cylinders and at the same time controlling charge air intake using advanced variable valve actuation systems.

The research, from 2004 to 2008, was collaborative, involving Loughborough University (lead institution) and University College London (UCL) and the industrial partners Lotus Engineering and Continental (formerly Siemens VDO, Toulouse). It was funded by the ESPRC (£459,144) **[G3.1, G3.2]** and industry (£850,000). The work at Loughborough crucially centred on the use of fully active valve trains and optical measurements using advanced laser techniques; the work at UCL focused on the design of the intake system and engine performance including emissions. Loughborough completed the entire in-cylinder flow and combustion research and analysis and this directly led to the new combustion system that was integrated into the new down-sized engine.

The research team comprised: Loughborough University's Dr Graham Wigley (Senior Research Fellow, 2004 to 2011), Prof Colin P Garner (2004 to date) and Dr Philip Stansfield (2004 to 2008); UCL's Prof N Ladommatos, Dr P Alierferis and Dr R Patel, Lotus Engineering's Dr Graham Pitcher and Dr James WG Turner (Loughborough part-time PhD student 2006 to 2011); Dennis Coltman, Russell Curtis, Darren Blake, Barry Holland, Dr Richard Pearson, Andrew Arden and Continental's Dr Hans Nuglisch and Dr Jerome Helie.

The research adopted fully active valve trains with close-coupled advanced direct injection fuel systems to enable SI gasoline (petrol) engines to operate un-throttled, which dramatically reduced already class-leading fuel consumption and hence real-world CO_2 emissions by more than 15% **[3.1, 3.3]**.

The work on the high-speed optical engine at Loughborough (the most advanced in the world **[3.1]** with highest speed and fully active valve train) included the application of particle image velocimetry (PIV) (this was pioneered by Loughborough researchers and is now a fluid flow measurement tool worldwide) to measure temporal charge motion in detail.

The novel combustion system approach was used directly in the development of a new three-cylinder 'down-sized', turbocharged, mild-hybrid engine **[3.2]**, which gave class-leading low CO_2 emissions of 150 g/km in an Opel Astra demonstrator car that still had excellent driving performance, i.e. classed as 'fun to drive' **[3.2].**

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

3.1 PA Stansfield, G Wigley, CP Garner, R Patel, N Ladommatos, Graham Pitcher, JWG Turner, H Nuglisch, JHelie, "Unthrottled Engine Operation using Variable Valve Actuation: The Impact on the Flow Field, Mixing and Combustion", SAE Paper 2007-01-1414, World Congress, Detroit, Michigan, April 2007, 1-16, ISSN 0148-7191. DOI: **10.4271/2007-01-1414 (Fully peer-reviewed international conference paper with ISSN).**

3.2. Dennis Coltman, James Turner, Russell Curtis, Darren Blake, Barry Holland, Richard Pearson, Andrew Arden and Hans Nuglisch "Project Sabre: A Close-Spaced Direct Injection 3-Cylinder Engine with Synergistic Technologies to Achieve Low CO2 Output", SAE Paper 2008-01-0138, SAE World Congress, Detroit, Michigan, April 2008. DOI: **10.4271/2008-01-0138 (Fully peer-reviewed international conference paper with ISSN).**

3.3 R Patel, N Ladommatos, PA Stansfield, G Wigley, CP Garner, G Pitcher, JWG Turner, H Nuglisch and J Helie, "Un-throttling a direct injection gasoline homogeneous mixture engine with variable valve actuation", *International Journal of Engine Research,* Special Issue Paper, 11(6), 2010, 391-411, ISSN 1468-0874. DOI: 10.1243/14680874JER604. Invited Paper.

These research outputs were strategically targeted at:

(i) The journal International Journal of Engine Research, which is widely read by both university academics and the global automotive industry. It is acknowledged as a high quality technical publication for archival research papers disclosing new theoretical developments and/or experimental results. The paper was invited for a special issue.

(ii) The SAE World Congresses, which are widely regarded as the premier annual international automotive conference organised by SAE International. The SAE is universally regarded as the premiere world resource for the design, manufacturing, operation and maintenance of automobiles, aircraft, space vehicles, on- and off-highway vehicles and machines. It sets global standards and is renowned for its technical and commercial depth, breadth and impact.

Grants:

G3.1 EPSRC Grant GR/S91734/01 'Operating strategies for new generation homogeneous charge DISI engines with fully variable valve control', 1 October 2004 – 30 September 2007, £230,153, Dr G Wigley, Prof CP Garner, Loughborough University (Project leaders).

G3.2 EPSRC Grant GR/S91727/01 'Operating strategies for new generation homogeneous charge DISI engines with fully variable valve control', 1 October 2004 – 30 September 2007, £228,991, Prof N Ladommatos, Dr P Alierferis, University College London.

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

Our research, as cited in s2 and 3, led to the delivery, by Lotus Engineering, of a major engine family project for a South East Asia manufacturer **[5.1]**. Unfortunately, client details cannot be included here due to extremely strict Lotus client confidentiality and the scale of the investment. Nevertheless, the research's impact is described by Lotus as: *"The valuable new knowledge, understanding and techniques gained from Lotus's collaboration in the HOTFIRE project has directly contributed to the successful delivery of a major engine family project for an ASEAN region OEM client of Lotus Engineering. Lotus has also been able to bid for major work in China, both with established OEMs and start ups. This would not otherwise have been possible. In addition to the direct commercial value, a considerable amount of exposure has been achieved in international learned symposia and in technical journals for Lotus and its collaborative partners both from industry and academia."* **[5.1]**.

Meanwhile, Continental Automotive France SAS, a major fuel injection system and Tier 1 supplier to the automotive industry, has said *"Especially important was the understanding of the influence of*

non-symmetric valve actuation on the fuel spray development and mixture process leading to the design definition in the 3 cylinder demonstrator engine." **[5.2]**.

Since the pioneering HOTFIRE project, many major automotive OEMs (e.g. BMW, Ford, PSA, Audi etc.) are now developing and producing down-sized three cylinder petrol engines to meet their aggressive fuel economy and CO_2 emission targets [ref 3.2]; these investments represent $100Ms. **[5.3-6]**

The economic and societal impact of these high specific power, low fuel consumption and low emission engines is substantial: they provide significantly lower operating costs and reduce impact on the environment [see **3.2**].

The Loughborough researcher Dr P Stansfield now works at MAHLE Powertrain (the high performance engine design and component company), being active in advanced engine powertrain system development working for a wide-range of international clients. Both MAHLE and Lotus are directly exploiting the expertise gained by the Loughborough team's researchers in their latest down-sizing engine programmes.

The HOTFIRE project won the automotive category at The Engineer Technology and Innovation Awards (2008) **[5.7]**. The HOTFIRE project was also chosen by the EPSRC for the transport category in their brochure *"10 WAYS WE HAVE MADE AN IMPACT"* (EPSRC 2009) and was heralded as an outstanding collaborative project between universities and industry **[5.8, 5.9]**.

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

The following sources of corroboration can be made available at request:

5.1 Letter from Project Manager, Lotus Engineering
5.2 Letter from Senior Manager, Advanced Development Engine systems, Powertrain Division, Continental Automotive France SAS, Toulouse www.continental-corporation.com
5.3 http://www.bbc.co.uk/news/business-18411602
5.4 BMW: http://www.carscoops.com/2012/09/bmw-announces-new-15-liter-turbocharged.html
5.5 PSA: http://www.greencarcongress.com/2010/04/psa-20100413.html
5.6 GM: http://www.thedetroitbureau.com/2013/04/gm-investing-332-mil-for-high-mileage-powertrains/
5.7 The Engineer Project Prize http://www.theengineer.co.uk/news/prized-pioneers/308303.article
5.8 EPSRC (2009):EPSRC Impact Case Studies
http://www.epsrc.ac.uk/newsevents/casestudies/2009/Pages/newengineslashesemissions.aspx
http://www.epsrc.ac.uk/SiteCollectionDocuments/Publications/casestudies/IMPACTCaseStudy17HOTFIRE.pdf
5.9 EPSRC Impact Example http://issuu.com/epsrc/docs/pioneer2 page 6