CASE STUDY

Loughborough University
Wolfson School of Mechanical and Manufacturing Engineering
Automotive Powertrain NVH Research

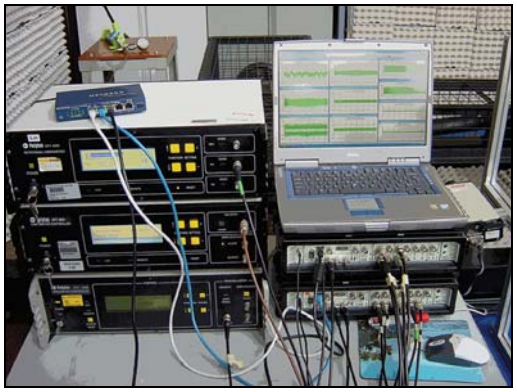
United Kingdom

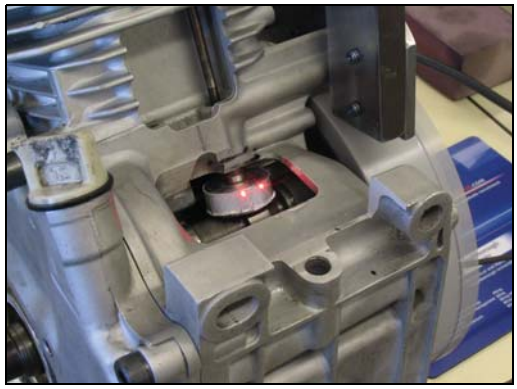
Automotive

PULSE™, Transducers

Located in the county of Leicestershire in central England, Loughborough University was granted full university status in 1966. Today, it has 3000 staff, 12 000 students, and an impressive campus of 410 acres (166 hectares).

The Wolfson School of Mechanical and Manufacturing Engineering was created in August 1997 and is one of the United Kingdom's largest Engineering Schools. A PULSE data acquisition and analysis system is used extensively in automotive powertrain research.





A Research-intensive University

Loughborough University was granted full university status almost forty years ago. During this time it has gained an international reputation for excellence in teaching, research and technology transfer. Today's University has 24 academic departments and over 30 Research Institutes and Centres, organised around three faculties – Social Sciences & Humanities, Science and Engineering.

The University is research-intensive and all departments have a strong research base. Close links with industry have always been a key feature of the way the University works and they are an important factor in maintaining a number of sponsored degree programmes and in generating research funding.

Brüel & Kjær

The Wolfson School of Mechanical and Manufacturing Engineering

Through the generosity of the Wolfson Foundation, the Wolfson School of Mechanical and Manufacturing Engineering was created in August 1997 bringing together the two long-established Departments of Manufacturing Engineering and Mechanical Engineering. With over 100 academic and research staff supporting 140 Ph.D students, 200 M.Sc. students and 850 undergraduates, the School is now one of the United Kingdom's largest Engineering Schools devoted to these subject areas and makes up about one-third of Loughborough's Faculty of Engineering.

Fig. 1
Loughborough University's 3000 staff and 12000 students occupy an impressive campus of 410 acres (166 hectares). A major investment programme costing £18 million was undertaken to build new facilities for the Integrated Engineering Faculty. These were commissioned in 2000

Senior members of academic staff, each a world-leader in their respective field, lead the School's thirteen Research Groups. The Groups span core areas of Mechanical Engineering, including Dynamics and Thermofluids and Combustion, and core areas of Manufacturing Engineering, such as Manufacturing Technology and Rapid Manufacturing.

Inter-disciplinary groups such as Optical Engineering and Sports Technology, combine the expertise of staff from several core subject areas within the School and from other departments across the University.

Academic Excellence

Steve Rothberg was appointed Head of the Wolfson School of Mechanical and Manufacturing Engineering in 2001 and became Professor of Vibration Engineering in July 2004. He joined the University in 1990 as a lecturer in acoustics and vibration with funding from Brüel & Kjær and the EU Eureka programme to investigate laser technology for vibration measurement.

Today, applications of laser technology remain his main field of interest and he has continued to cooperate with Brüel & Kjær on a number of laser-related products. This work has attracted national awards, most recently for synchronised scanning laser vibrometry, a technique to enable rotating components such as turbine blades to be tracked and simultaneously scanned under operating conditions.

Professor Rothberg says, "About one third of my time is for teaching and research. I am actively involved in vibration research, including automotive projects as well as other areas such as sports technology where we study the effects on both the human body and sports equipment".

"The remainder of my time is devoted to management of the School. My aim is to build the strong and supportive research culture needed to establish our research in Mechanical and Manufacturing Engineering amongst the very best in the UK and to develop international collaborations with the world's best."

Automotive Powertrain NVH research is led by Homer Rahnejat whose research includes tribological applications, vehicle dynamics, vibration, noise and multibody analysis. He joined the School in 2000 and became Professor of Dynamics in 2003.

Fig. 2
From left to right: Dr. S. Theodossiades, Dr. M. Teodorescu, Professor Rothberg, Dr. M. Gnanakumarr, Dr. S. Balakrishnan

His team includes Professor Rothberg and additional academic staff. Dr. Stephanos Theodossiades gained his Ph.D. from the Aristotle University of Thessaloniki on Gear Dynamics and he has worked in NVH research at Loughborough University for three years, initially as a Research Fellow and now as Lecturer. Paul King brings significant industrial and academic experience to the team, particularly in engine and vehicle dynamics.

The academic staff and the research students they supervise are backed up by a team of research staff. Dr. Mircea Teodorescu gained his Ph.D from Wayne State University, Michigan on valve-train tribodynamics. He joined the team at Loughborough as a Research Fellow in 2003. Dr. Max Gnanakumarr recently gained his Ph.D from Loughborough University in the NVH area as did Dr. Sashi Balakrishnan, now Perfect Bore Research Fellow, investigating advanced piston dynamics and lubrication, and Dr. George Mavros who studied vehicle handling and transient tyre behaviour.

Automotive Research

Fig. 3
One of The Wolfson School of Mechanical and Manufacturing Engineering's laboratories

Loughborough University's involvement with the automotive industry has its origins in its technical courses initiated in 1919. Today, it undertakes cutting-edge research with, amongst others, Ford Motor Company, Jaguar Cars Ltd., Perkins Engines, Perfect Bore Motorsport, SKF and Lotus Engineering.

Professor Rothberg says, "Together with the Department of Aeronautical and Automotive Engineering, the School is heavily involved in automotive research, especially vehicle powertrain (engine and transmission). We work with many global automotive manufacturers and suppliers and we also cooperate with other universities. For instance, our Thermofluids and Combustion Group are currently working with Oxford, Leeds, and University College London on the 'Combustion Concepts for Sustainable Premium Vehicles' project funded by Jaguar, Shell and the UK government's Engineering and Physical Sciences Research Council (EPSRC) to the extent of £2.4 million. The consortium members were specifically chosen by Jaguar, highlighting the industry's high regard for our expertise in this area.

Research grants and extensive industrial sponsorship support a range of Research Assistant posts or Research Studentships. Professor Rothberg adds, "We actively promote our work to industry. Our external research funding is now in excess of £5 million per year and growing. This income supports a substantial number of research posts and enables the purchase of specialist laboratory equipment that we also use to enhance the experience of our taught students. Both short and long term collaborations feature in our portfolio. An initial short-term cooperation with a company can often lead to establishment of a research project with funding from the UK Research Council or the European Union".

"Like many University researchers, we are also active in organising and participating in conferences under the auspices of bodies such as SAE, ASME and IMechE. The results of our research, including the methodology, generally go into the public domain, but we also work in commercially sensitive areas. A particular example is the research project with Perfect Bore, who make pistons and liners for a number of Formula One teams."

Long Relationship

Professor Rothberg says, "I first became aware of Brüel & Kjær in the 1980s and today we use a lot of their products. Most of our microphones, force transducers, sound level meters, and accelerometers come from Brüel & Kjær. Reliable, high quality equipment is important to us because our philosophy is to get students into our laboratories for as much hands-on experience as possible".

Dr. Theodossiades adds, "The company has a great reputation not only in our university, but worldwide. Their solutions are world-class and have assisted us enormously in our research".

PULSE

The first PULSE system was delivered to the Wolfson School of Mechanical and Manufacturing Engineering in April 2003.

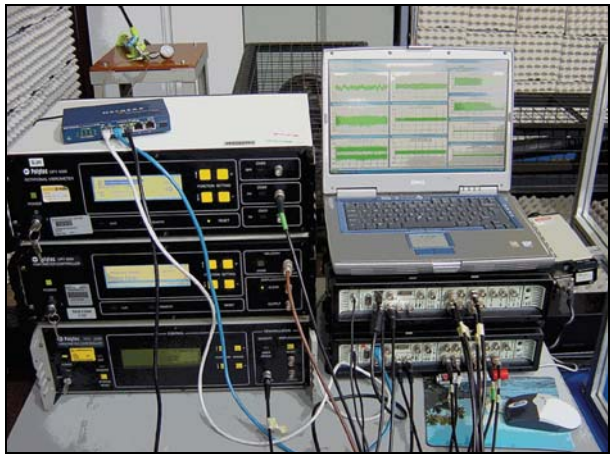


Fig. 4
To measure the noise and vibration response (NVH) in the powertrain, two PULSE front-ends are stacked to provide the required number of dynamic and DC measurement channels

Dr. Theodossiades explains, "The decision to choose PULSE as our NVH data acquisition and analysis platform was taken collectively. We selected a Type 3560 C frame. Although we currently have four channels, a major factor in our purchase decision was that PULSE is modular and scalable. So, we have the option for future expansion to add more channel capability".

The software used includes PULSE FFT & CPB Analysis Type 7700 and Time Capture Type 7705.

The PULSE systems run under Windows® XP. Test data is initially saved on the PC's hard disk. It is backed-up on CD-ROMs. The acquired data is viewed in real-time, but also extensively post-processed using PULSE and other software.

Some Projects and Methodologies

Valvetrain Tribodynamics

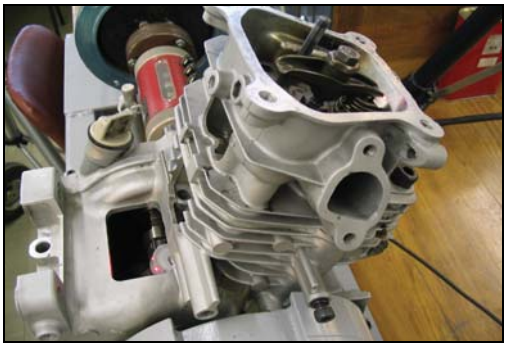
SKF Research Fellow Dr. Mircea Teodorescu is working with Professor Rahnejat on a project to evaluate the friction between the cam and tappet in an engine. Increased friction leads to loss of power and excessive wear.

Dr. Teodorescu says, "To analyse friction, we took a single cylinder engine and machined it so that the cam and tappet are visible. The engine is driven by an electric motor and the speed can be varied through a wide run-up/run down range. As the valvetrain moves and the tappet goes up and down, we also know that the tappet spins and this is one of the important parameters that we need to evaluate".

To measure the movement of the tappet requires a parallel beam laser vibrometer. The laser is connected to the PULSE front-end, which is used for data acquisition and analysis. The test data is used to validate a mathematical model.

Powertrain NVH

Professor Rahnejat, Dr. Theodossiades and Dr. Gnanakumarr have worked together with Dr. Mike Menday and Dr. Patrick Kelly of Ford Motor Company on a major project to identify the root cause of impact-induced noise in the powertrain of a light truck.



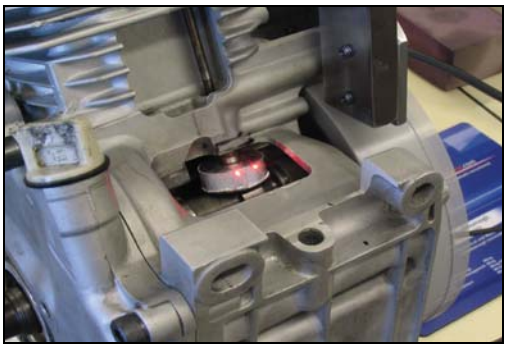


Fig. 5
Left: A single-cylinder engine was machined to expose the moving parts of its valvetrain Right: A parallel beam laser vibrometer is focused on the tappet to measure its movement. The laser is connected to a PULSE front-end

Experimental results are correlated with a virtual prototype, also developed in the project, which was funded by Ford Motor Company, MSC Software and Foresight Vehicle Initiative.

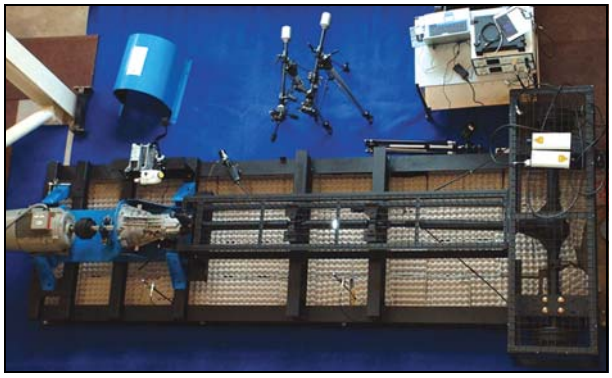


Fig. 6
An overhead view of the complete setup used for evaluation of drivetrain 'clonk'

Funded by the UK Government's Department of Trade and Industry and the EPSRC, the Foresight Vehicle Initiative is administered by The Society of Motor Manufacturers and Traders Limited (SMMT), and is the UK's prime knowledge transfer network for the automotive industry.

Dr. Gnanakumarr explains, "A metallic noise is often heard when rapidly engaging and releasing the clutch. This is known in industry as 'clonk'. It is especially prevalent on vehicles with rear wheel-drive. The driveline shafts are hollow steel tubes and these tend to act as loudspeakers and amplify this metallic noise".

He continues, "We want to find a cost-effective solution to minimise 'clonk' noise in the drivetrain but without increasing the overall drivetrain weight. We have experimented with various configurations, using the drivetrain of a light truck. Torque from an electric motor produces shock impact waves through the drivetrain and these cause the low-inertial components to vibrate. The frequency range of interest is from 1.5 kHz to 5 kHz, as this is the range where mechanical noise is propagated".

Fig. 7
Prepolarized Condenser Microphone Cartridges Type 4155 were used to measure noise radiated from the vehicle drivetrain

Dr. Theodossiades adds, "In this study, we had to consider a large number of factors in the operating conditions including lubricants, backlash, flywheel characteristics, operating speed, load and speed of clutch engagement".

"Our studies have established a correlation between noise and vibration and the frequencies at which 'clonk' manifests itself. We have also correlated

the signal frequency content in particular components in the drivetrain, including the propshafts, bearings and transmission/differential gears, by conducting impact hammer testing", says Dr. Theodossiades.

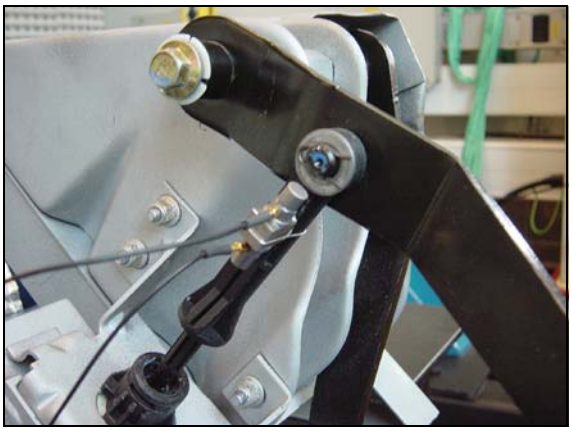


Fig. 8
Two Piezoelectric Charge Accelerometers Type 4393 are attached to the clutch master cylinder to measure the clutch actuation characteristics

Dr. Gnanakumarr continues, "For the data acquisition, we used three microphones, two accelerometers, three laser channels and two channels for measuring the speed of the clutch engagement – there is a significant difference between the way that an aggressive driver and a more sedate driver will use the clutch pedal. The measured data were post-processed, using FFT analysis, data window wavelet and the ARMA (auto regression moving average) method".

"The numerical investigation that was correlated to the experimental results included multi-body dynamics, Finite Element Modelling and Boundary Element Method investigations."

The success of work carried out on clonk with Ford Motor Company has resulted in a new contract with Jaguar Cars Ltd. involving Dr. George Mavros. He will be using the PULSE system as well as laser vibrometers and microphones, made by Brüel & Kjær.

Piston Dynamics and Lubrication

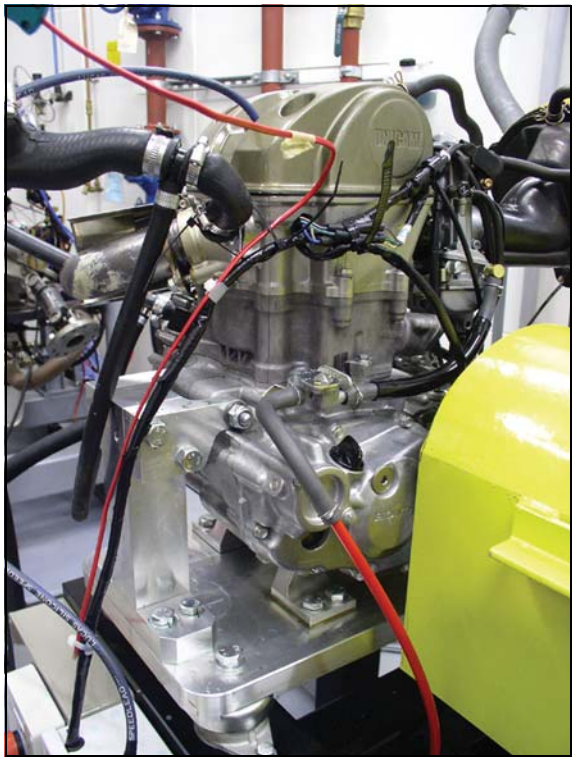


Fig. 9
This test stand is used to investigate the dynamics and lubrication of pistons developed for Formula One engines

Perfect Bore is a UK-based company specialising in the processes of gun-drilling, deep hole boring, honing and superfinishing. They design and manufacture pistons and liners for companies providing engines for use in motor sport, including a number of Formula One motor racing teams. Dr. Sashi Balakrishnan, Professor Rahnejat and Paul King are working closely with Sebastian Howell-Smith of Perfect Bore to investigate piston dynamics and lubrication.

Dr. Balakrishnan says, "We use a special dynamometer test stand for our investigations. As you will appreciate, Formula One motor racing is highly competitive and for this reason, the testing methodology and the results of the project will remain confidential".

Confidence

Dr. Max Gnanakumarr says, "PULSE is very easy and quick to set up. For our powertrain NVH project, the total channel requirement was greater than available with our PULSE system and we are very grateful to Brüel & Kjær for loaning to us an additional front-end. We don't take anything for granted, but frankly this is the sort of terrific back-up, service and support that we have come to expect from Brüel & Kjær's UK office at Stevenage. We have confidence

in the Brüel & Kjær solutions we use as we know that they are the result of thorough and state-of-the-art research. Our intention is to buy another PULSE front-end to increase our channel analysis capability".

Professor Rothberg concludes, "Customers are continually expecting vehicles with greater refinement. Engines are now so quiet that manufacturers are focusing on other vehicle NVH sources including powertrain. Drivers associate mechanical noise with mechanical failure, obviously an undesirable impression, and we foresee buoyant demand for our research work in this area".

Key Facts

- Loughborough University was granted full university status in 1966
- The Wolfson School of Mechanical and Manufacturing Engineering was created in August 1997 and is one of the United Kingdom's largest Engineering Schools
- Loughborough University's involvement with the automotive industry has its origins in the automobile engineering courses initiated in 1919
- The University undertakes cutting-edge research with major automotive companies
- "A large selection of our transducers and sound level meters come from Brüel & Kjær"
- The first PULSE system was delivered in April 2003
- "The company has a great reputation not only in our university, but worldwide. Their solutions are accurate, world-class and the benchmark"
- "This is the sort of terrific back-up, service and support that we have come to expect from Brüel & Kjær's UK office at Stevenage"