Energy Efficient Transport for Tomorrow

Professor Hongming Xu
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Introduction

- Research in land transport at Birmingham:
  - Vehicle and Engine Technology Research
    - Mechanical Engineering
    - Chemical Engineering
  - Birmingham Centre for Railway Research and Education
    - Electronic, Electrical and Computer Engineering
    - Civil Engineering
    - Metallurgy and Materials
    - Mechanical Engineering
Acknowledgement

- Both groups have been successful in gaining funding from the Science City Energy Efficiency initiative and also the University investment (total over £6m in the last 6 years)
- Support from industrial partners, and funding from TSB and EPSRC
- Contributions from colleagues within the 2 groups
Vehicle and Engine Technology Research Centre

Prof Hongming Xu
Chair in Energy & Automotive Engineering
Head Vehicle and Engine Technology Research

Prof Mirosław Wyszynski
Chair in Novel Vehicle Technology

Dr Athanasios Tsolakis
Senior Lecturer in Automotive Engineering

Dr Karl Dearn
Lecturer in Mechanical Engineering

Dr Oluremi Olatunbosun
Senior Lecturer in Mechanical Engineering

Dr Andrew M Tobias
Senior Lecturer in Railway Systems Engineering

Prof Farhang Bakhtiar

Prof (Hon) Steve Richardson (Jaguar)

Prof (Hon) Roger Cracknell (Shell)

Dr Jun Qiao (ETI)

Major research activities

- Fuels pretreatment and mixture preparation for engines
- Flow and combustion diagnostics in engines
- New and bio-fuels and their combustion and emissions
- Exhaust gas aftertreatment systems
- Tribology in vehicles
- Tyres dynamics
- Vehicle ride and handling dynamics
- Noise vibration and harshness (NVH)
- Railway systems and management

- 3-5 pre-doctoral Research Assistants
- 30-40 PhD research students
- 5-10 academic visitors (Senior Research Fellow)
Ultra Low Carbon Vehicles Roadmap

Source: Ultra Low Carbon Vehicles in the UK – BERR/DfT; Ricardo roadmaps and technology planning; Shell Energy Scenarios to 2050 (2008)
Future Engines and Fuels Lab Refurb. - £1.5 m
Future Engines and Fuels Lab 2009 (G48)
New facilities

New transient engine cell for cold start (-20°C) with fuel testing facilities
Tyre and vehicle ride and handling dynamics

Vehicle Dynamics Lab: Suspension Test Rig

Four-Post Vehicle Dynamics Rig

Vehicle Structural Dynamics Analysis Facility

Section of ECO RR Tyre concept

Tri-Axial Tyre Dynamics Tyre Test Rig
Spray characteristics (3-D PDPA)
Advanced Laser Diagnostic (PIV, 2D PLIF/LII) studies

Ultra-high speed CCD
Shimadzu Hyper Vision
HPV2
Maximum speed: 1,000,000 fps
Resolution: 320*240 (fixed)

Phantom speedsense
V710 high speed ICCD camera with intensifier
high speed imaging and PIV

DANTEC High speed PIV
PLIF/LII system

UNIVERSITY OF BIRMINGHAM
Gaseous and particle emission studies

**Figure 11b**
1500rpm, $\lambda = 1$

- DMF KL-MBT
- DMF SR10

$ST_{KL-MBT} = 16^\circ$TDC
IMEP$_{KL-MBT} = 8.5$bar

$dN/d\log Dp$ (#/cm$^3$)
Particle Diameter (nm)
New biofuels and alternative fuels

Biofuel engine modeling and validation
New combustion systems
to merge gasoline and diesel engine technologies

Conventional compression engines

New management

Conventional spark-ignition Engines

Low Temperature, Efficient and Clean Combustion

In-direct injection     Direct injection     High EGR       Complex-injection
UK FORESIGHT projects on HCCI

**CHARGE** (Controlled Homogeneous Auto-ignition Reformed Gas Engine),
2 yrs DTI/EPSRC sponsored, total funding = £840K

- Facilitate natural gas HCCI using fuel reforming

**CHASE** (Controlled Homogeneous Auto-ignition Supercharged Engine)
3 yrs DTI/EPSRC sponsored, total funding = £1,539K

- Expand gasoline HCCI window

partners: Jaguar Cars, Birmingham University
Johnson Matthey, MassSpec UK
National Engineering Laboratory Race Technology
Current Biodiesel project sponsored by TSB

SERVE (Flex-diesel Engines with Sustainable Bio-fuels for Clean and Efficient On- and Off-Road Vehicle Engines)

3 years TSB(DTI) sponsored, total funding £2,124K (UoB £593k)

1) to identify the changes required by the engine system (including aftertreatment) to run on blends containing up to 30% of a variety of both generations bio-diesel fuels

2) to develop novel ‘Flex-diesel’ technologies involving onboard pre- and after-treatment to maintain optimized engine performance and emissions with increasing percentages of fully sustainable bio-fuels
Ongoing project, sponsored by TSB

CREO - CO2 Reduction through Emission Optimisation (3 years, total funding £8m, UoB £400k)

Oct 2010 to Sept 2013

to investigate on-board fuel pre-treatment technologies (e.g. catalytic fuel reforming) that, when integrated within the engine system (i.e. combustion or aftertreatment) will primarily improve the fuel economy and CO2 emissions. In addition, benefits in engine and aftertreatment catalyst operability and emissions (including regulated and unregulated) will be assessed.
Collaborative Research Sponsored by EPSRC

Impact of DMF on Engine Performance and Emissions as a New Generation of Sustainable Biofuel, £509k

Feb 2009 - August 2012

To study the characteristics of combustion and emissions of a newly proposed generation of Biofuel for gasoline (SI) engines with bench-marking to ethanol, involving modelling and experimental study of fuel spray, direct injection mixture preparation, combustion and emissions (regulated and unregulated)

partners
Railway Power and Energy Research at Birmingham

- Energy accounts on average for around 15% of the operational costs for railway companies, and it is growing ~ £500 million PA
- Research in railway traction at Birmingham dates back to the early 1970s
- Nowadays the main focuses of our research are:
  - Monitoring
  - Simulation and testing
  - Optimisation
- Collaborative working with key industry players in UK, EU, Singapore, China, Australia, Hong Kong

- Department for Transport – Calculation of energy consumption
  - Phase 2 - DMU (Class 150 and Pacer replacement)
- Department for Transport / DeltaRail – Discontinuous electrification
- Department for Transport / TRL – Evaluation of novel train propulsion systems
- Department for Transport / MerseyRail / Network Rail – Evaluation of losses and energy saving strategies in DC railways
- Atkins – Multi-Train Simulator development
- KTP / Atkins – AC railway power network simulator
- Singapore Land Transit Authority – Bespoke train simulator
- Kuala Lumpur Metro – Power system analysis
- Chinese Government – Energy usage assessment for high speed rail
- General Electric – Hybrid commuter train analysis
- ATOC – Strategic distribution of energy meters
- PhD Student – Hydrogen trains
- PhD Student – Optimised Supervisory Control for Hybrid Rail Vehicles
MerseyRail monitoring

Train based:
- Traction and auxiliary currents and voltage
- Cam shaft position
- Driver’s handle position
- Position on track
- Inertial measurement
- Temperature

Sub-station based:
- Voltage and currents

Passenger km / 10^9
Freight Moved (tonne km /10^9)
Detailed analysis

- Traction current
- Half Train
- Line voltage
- Speed
- Handle position
- Brake tests
Current Voltage

Also:
1x up current return
1x down current return
At each substation

WEST KIRBY

Current [A]  

Time [s]
University of Birmingham Railway Energy Simulators

- University of Birmingham STS
  - MATLAB based
  - Simple to configure
  - Quick simulation time for optimisation processes
  - Extremely modular and able to deal with a range of traction systems
  - Used by UK Department for Transport, Singapore Metro, RSSB

Atkins / University of Birmingham MTS
- Full power system simulation
- Multi-train operation
- Configurable to specific applications/outputs
- Used by Hong Kong Metro, London Underground, Singapore LTA, Docklands Light Railway
Alternative Power System and Hybrid Traction System Simulation and Test

- 1. Capture and reuse of braking energy
- 2. Able to operate prime mover at optimum efficiency

- Hybridisation degree is dependent on the type of duty cycle
  - High speed – no downsizing but energy saving
  - Sub-urban – moderate downsizing possible
  - Shunting loco – significant downsizing possible
Conventional DEMU

Diesel engine → G → V_{DC} → Inverter → M

Brake chopper

Brake resistor bank
Alternative Power System and Hybrid Traction System Simulation and Test

**Power Cycler**
- Electrical device evaluation
  - Energy storage
  - Power converters
- Dynamic load cycling
- Specifications (max)
  - 170 kW sink
  - 125 kW source
  - <100ms out response timing
Alternative Power System and Hybrid Traction System Simulation and Test

Machine Rig and Dynamometer

- Drivetrain evaluation
  - Electric
  - Hybrid (Parallel & Serial)

- ESD Evaluation
  - Kinetic (Flywheels)
  - Electric (Batteries)

- Specifications (max)
  - 700 Nm Torque
  - 100 kW Power
  - 3000 rpm base speed
Optimisation using Single Train Simulation

- **Input variables** (to be optimised)
  - Coasting rate, $K_v$
  - Motoring rate, $K_f$
  - Braking rate, $K_{br}$

- **Output**
  - Journey time, $T_{run}$
  - Energy consumption, $E$
  - Train trajectory

**Input**

- Coasting rate, $K_v$
- Motoring rate, $K_f$
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**Output**

- Journey time, $T_{run}$
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- Train trajectory
Optimised Train Control

- The optimal solution depends on the cost function (speed vs. time)

\[ n/a (T_{\text{min}}) \]

\[ T_{\text{run av}} = 6.51 \]
Effect of partial fleet fitment of energy meters on the DC railway fleet

![Graph showing the standard deviation of error in meter reading as a percentage of the true cost (MS3) vs. the percentage of fleet fitted with meter and meter accuracy. The graph uses a color scale ranging from 0 to 0.14 to represent the standard deviation of error.]
Collaborative Future directions

- Novel traction technologies (Hybrid, hydrogen, entirely battery power, carbon capture)
  - Optimal control (energy, state-of-health)
- High speed rail (power scales with speed cubed)
- Local energy storage and improved infrastructure systems
- Pavement (rail and road) based on energy
- Optimal driving strategies
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