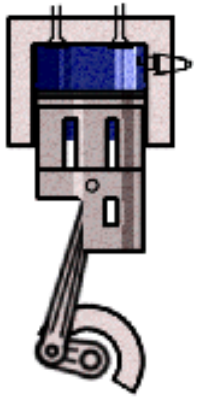
The effect of ethanolled gasoline on the performance and gaseous and particulate emissions on a 2/4-stroke switchable DI engine



FAPESP
Aplicação do Etanol para Motores Automotivos
04/10/2012 - FAPESP - São Paulo

Yan Zhang & Hua Zhao

Centre for Advanced Powertrain and Fuels (CAPF)

Brunel University London

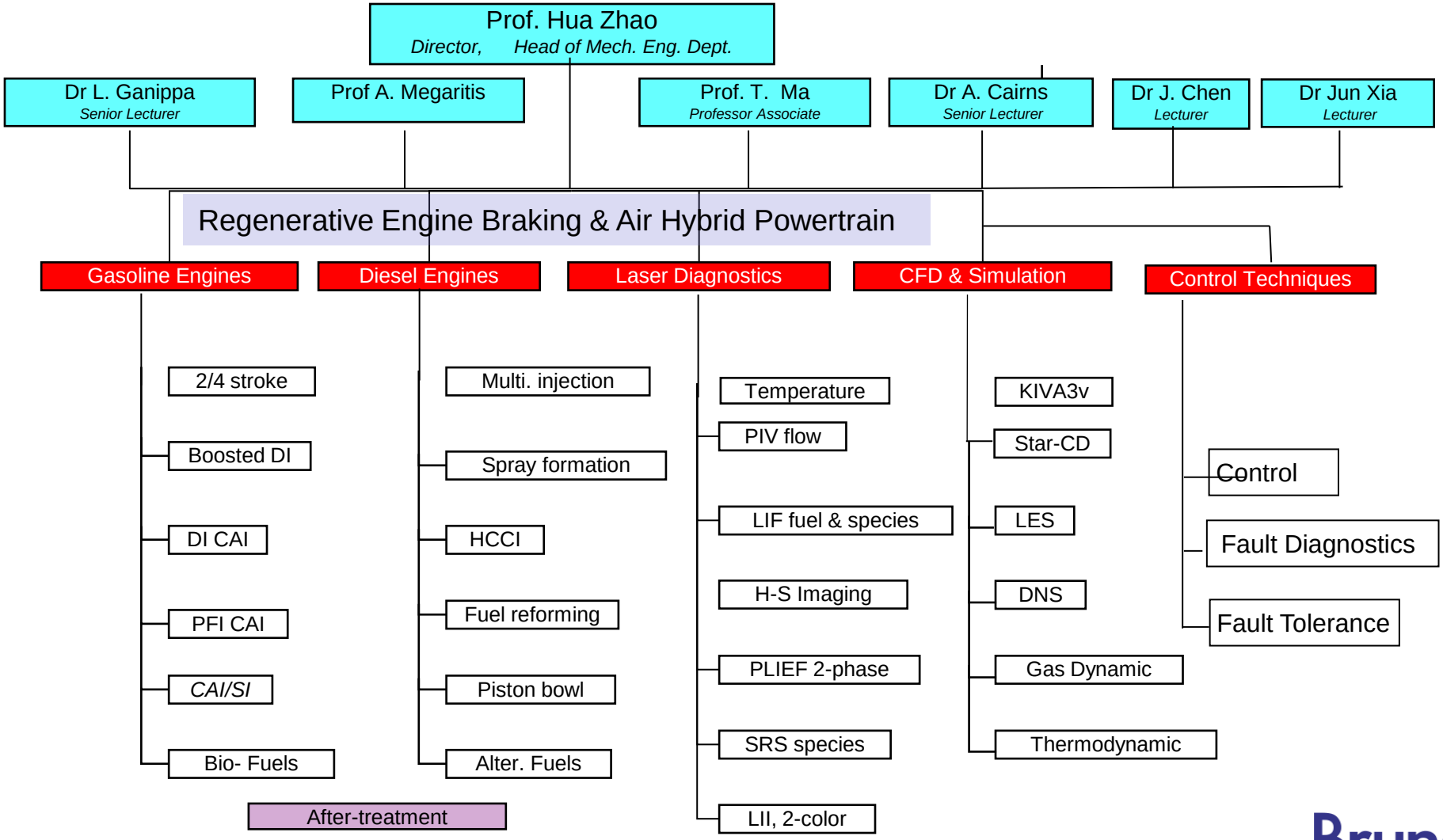
Ethanol Combustion Engine Workshop at Sao Paulo

4th, October, 2012

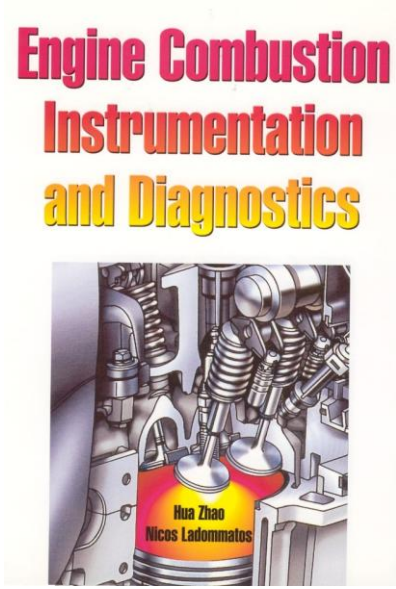
Brunel UNIVERSITY LONDON

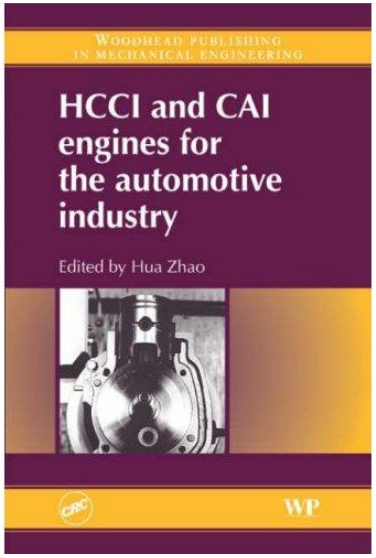
Overview of Centre for Advanced Powertrain and Fuels (CAPF) at Brunel University London

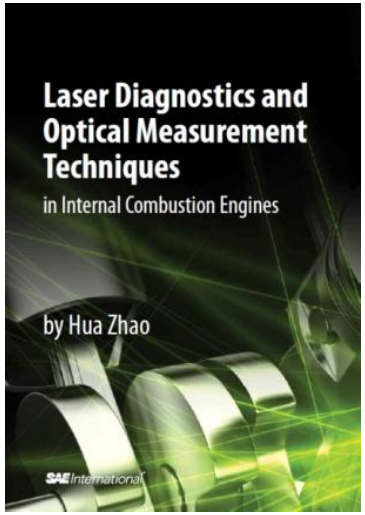
Centre for Advanced Powertrain and Fuels (CAPF)



Recently Published Books







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Motorsport Engineering

McLaren F1

Brawn GB F1 Team

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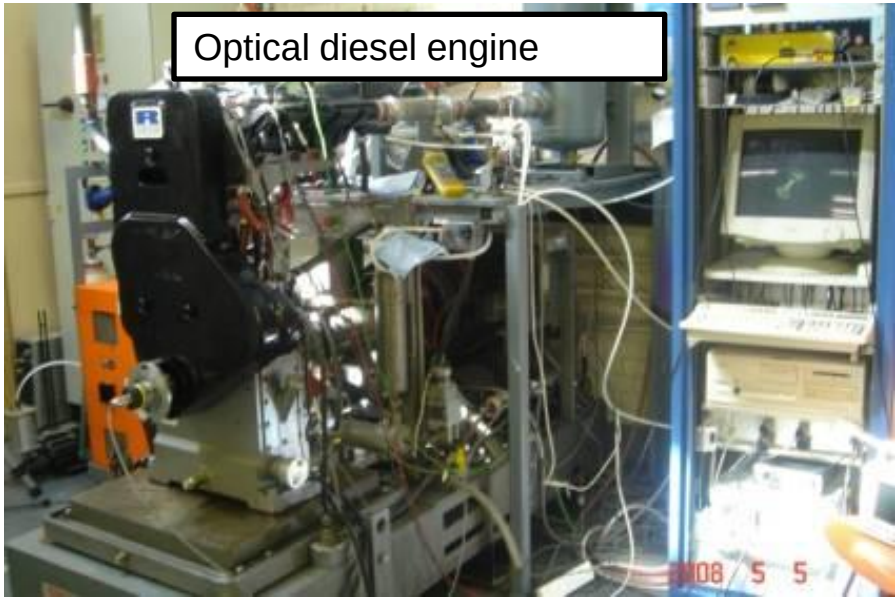
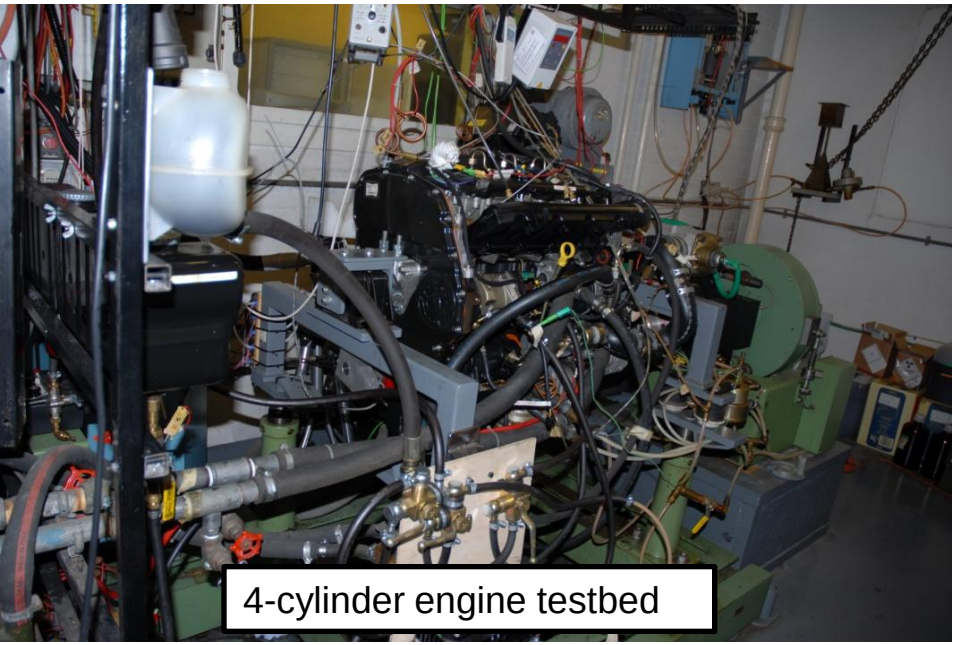
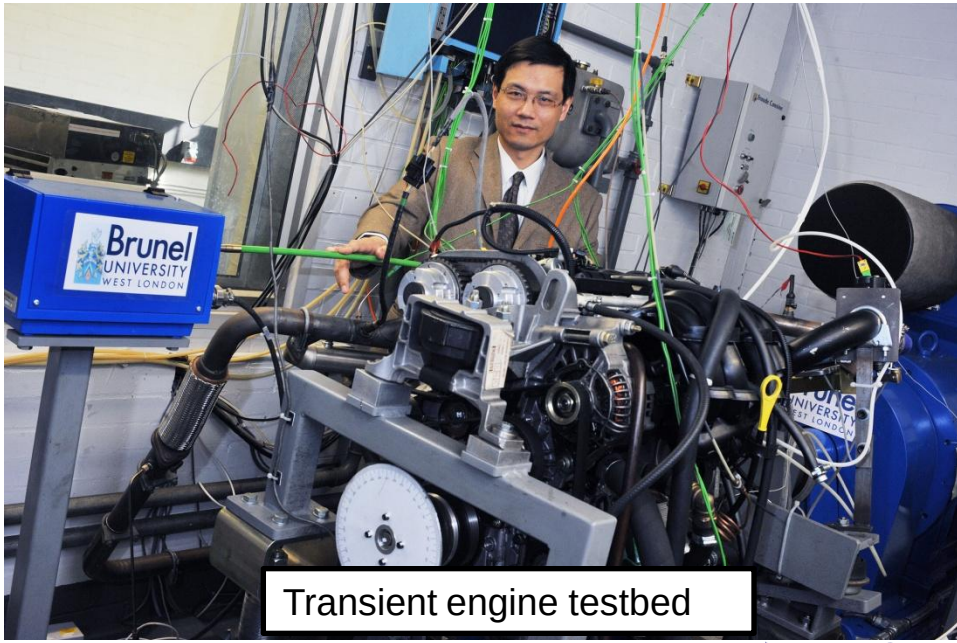
World class Facilities

Optical gasoline engine

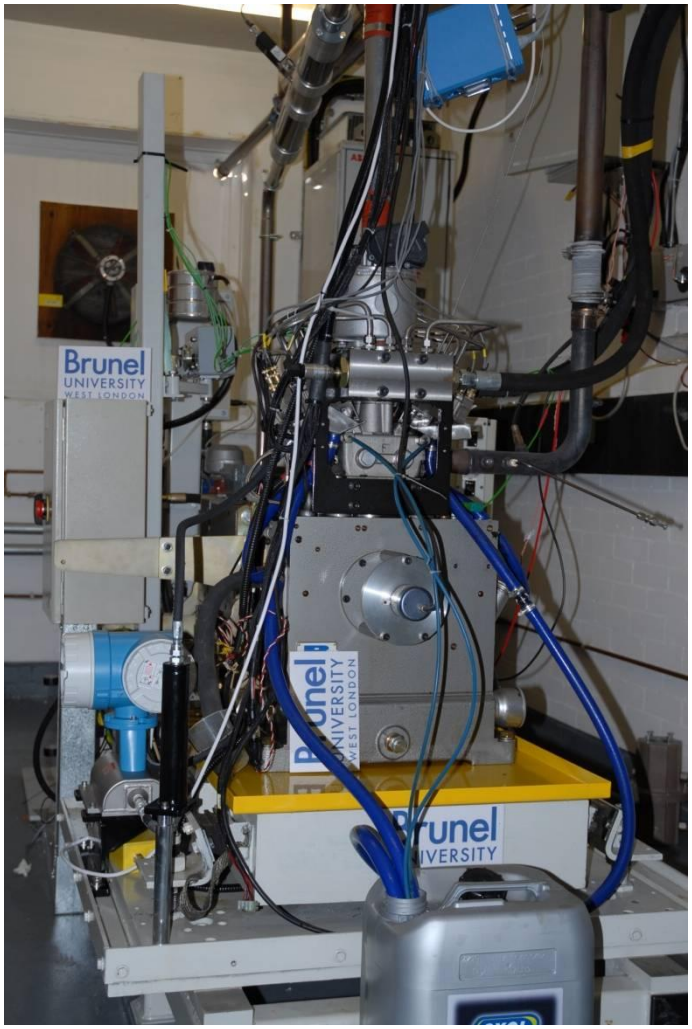

Optical diesel engine

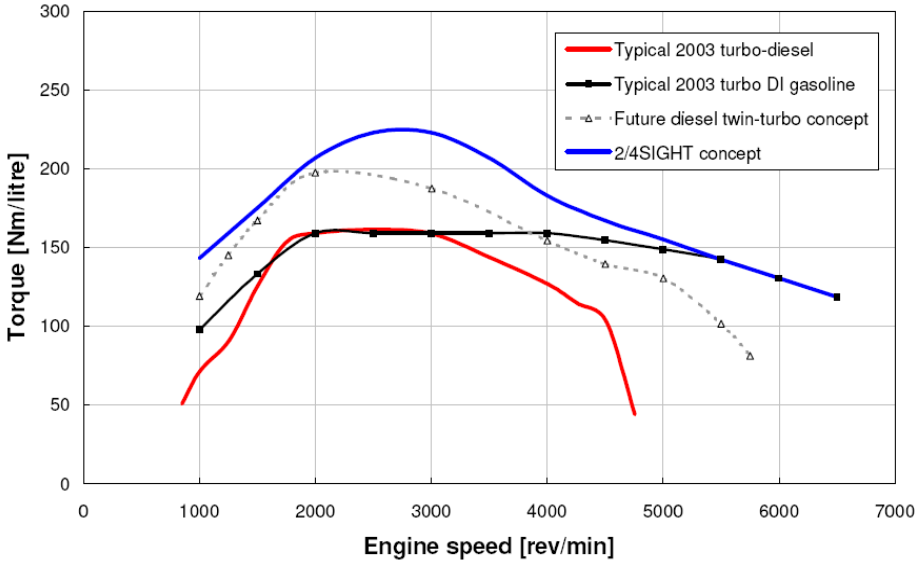

4-cylinder engine testbed

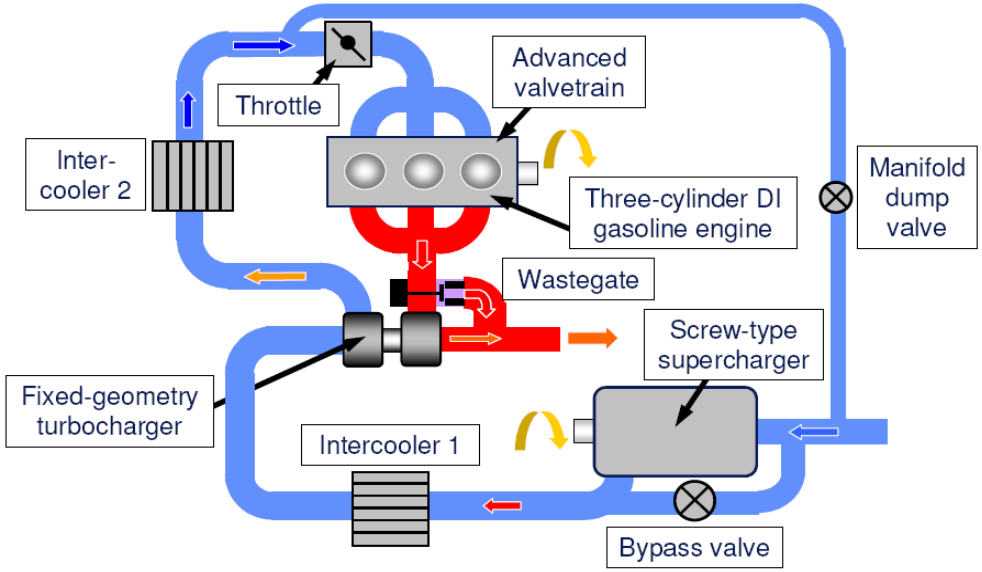


Transient engine testbed

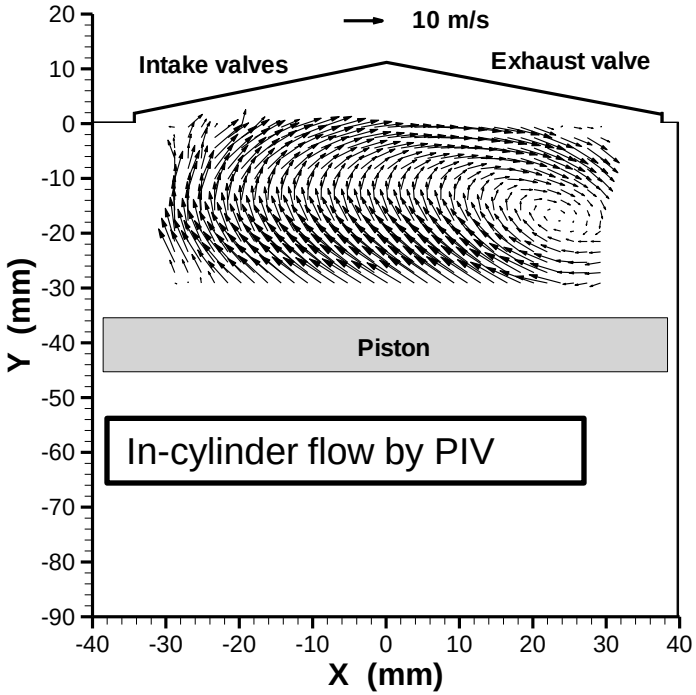
2/4 stroke switchable engine



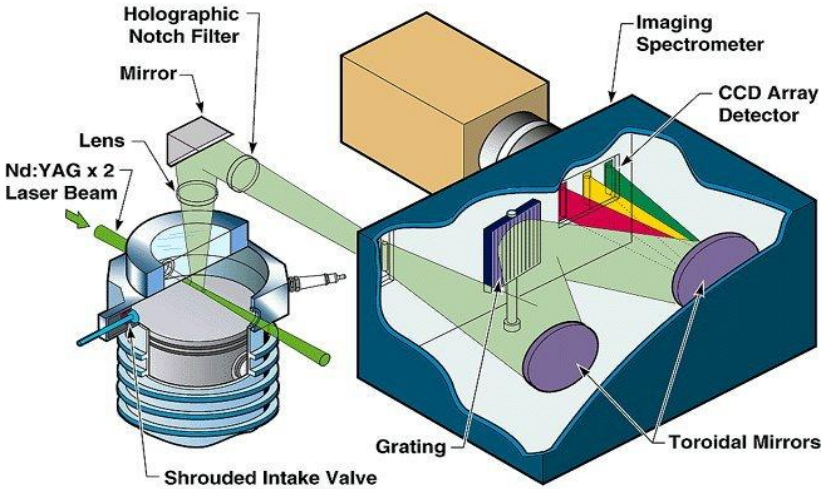




Advanced Laser Diagnostics



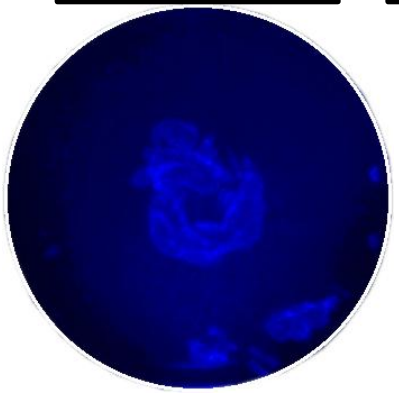
In-cylinder flow by PIV



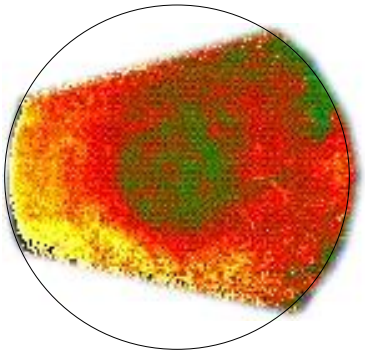
Broadband Multi-point Raman Scattering for the Measurement of Major Combustion Species

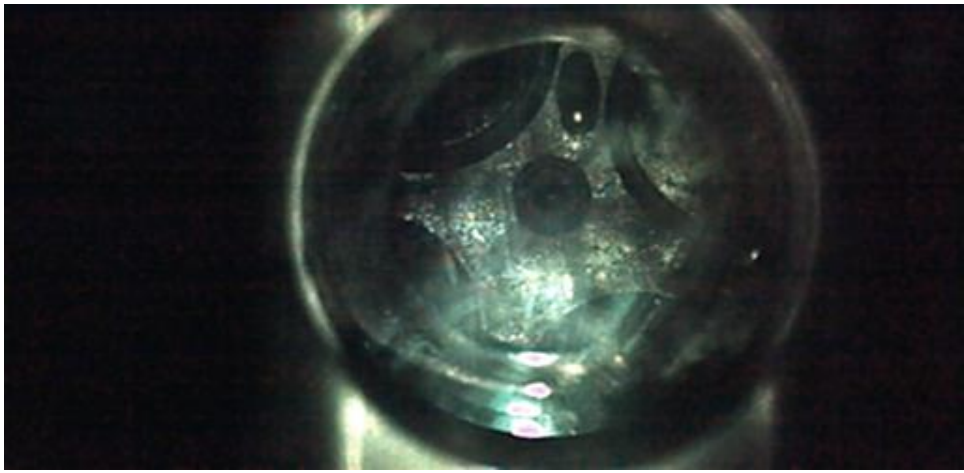
1200 bar fuel injections movie

Auto-ignition



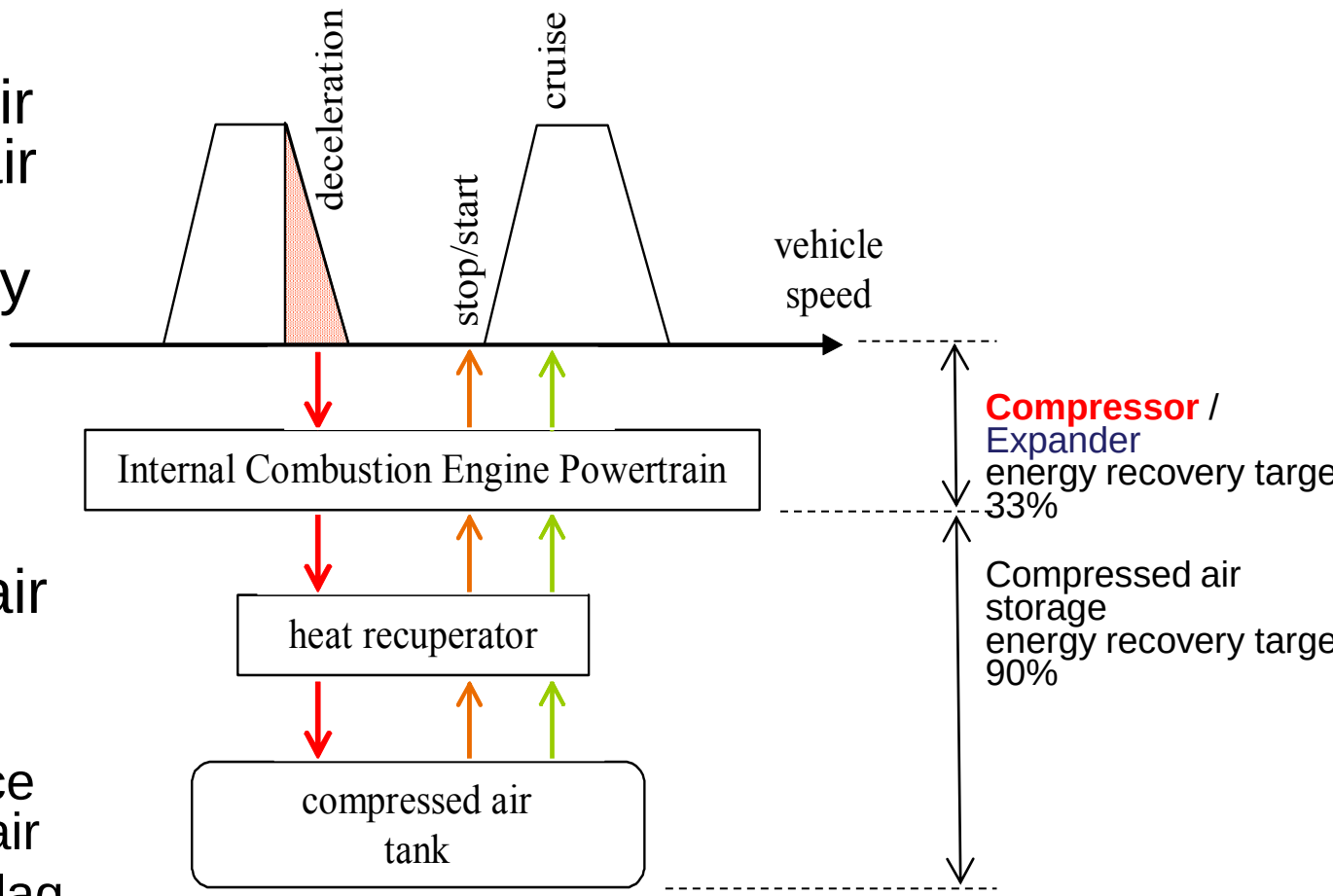
Fuel distribution by PLIF





Air Hybrid Engine Concept

- Regen compressed air charged into air tank during deceleration by operating the engine as air compressor
- Compressed air then used to:
  - stop/start
  - provide service compressed air
  - reduce turbo-lag
  - less smoke



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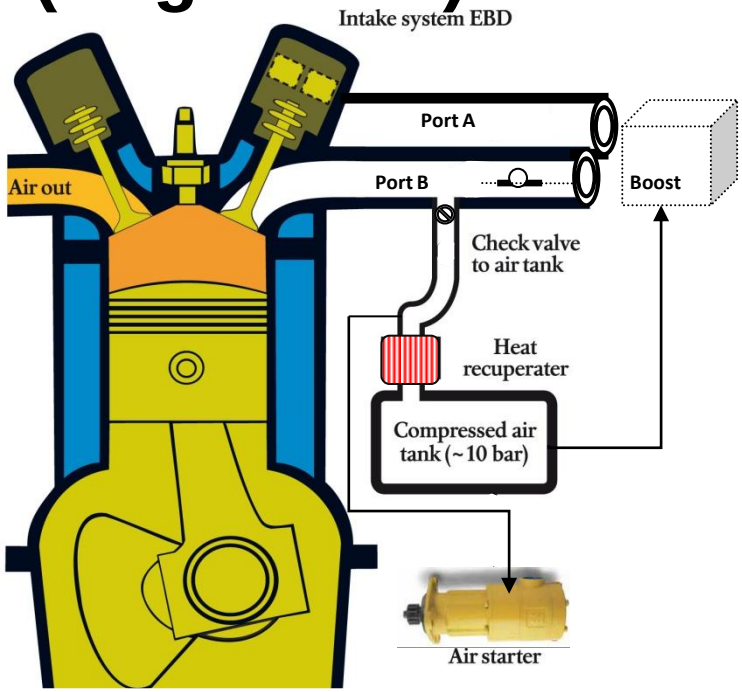
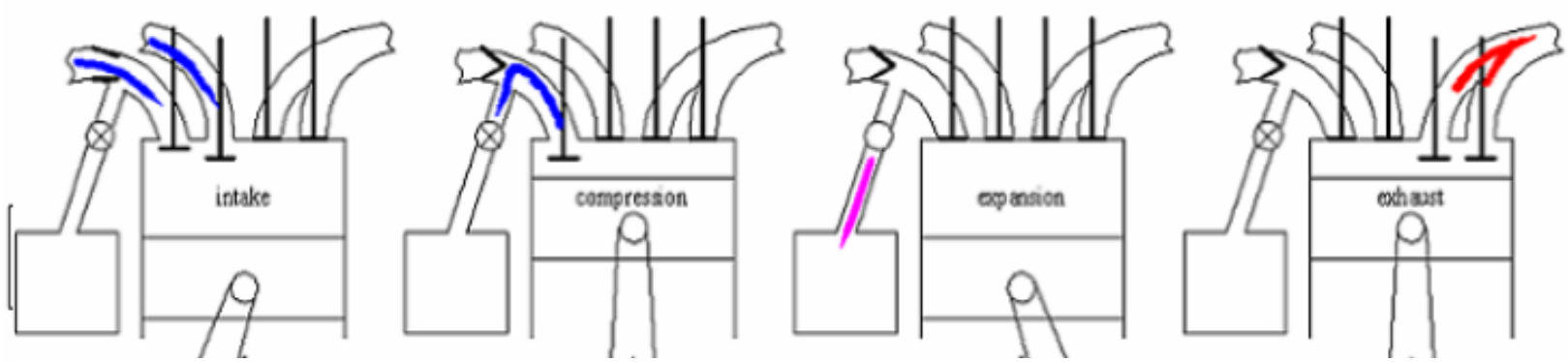
Air-hybrid/Regenerative Engine Braking (RegenEBD)



- **Synergy with downsized engine**
  - **Instant boost to overcome turbo-lag**
- **Engine stop/start**
  - uses **commercially available** air starter for stop/start
  - Direct engine start with mech. VVA
- **Integration**
  - Service air
  - Replace on-board compressor



Engine operating as a compressor during braking

3-cylider downsized GDI engine

3-cylider 1.2L downsized GDI engine

- Combustion system
- Cooling system

- Ethanol content effect on performance and knock.
- Ethanol injection spray pattern in an optical engine.

MAHLE Powertrain

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- One of the largest and most active engine research groups in the UK
  - 14 engine test cells
  - 7 academic staff
  - More than 20 PhD students
  - 3 professional technicians

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Contents

- Introduction of 2-stroke CAI
- Experimental Setup
- Results and Discussion
- Conclusions

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Introduction

- **Why 2-stroke engines?**
- **Advantages:** (compared with 4-stroke engines)
  1. **High power density** (doubled firing rate)
  2. **Less heat loss** (less time for heat transfer)
  3. **High Mechanical Efficiency** (Halved stroke numbers)
- **Disadvantages:**
  1. **High emissions** (uHC and CO)
     - **Short-circuiting of Fuel** (can be avoided by DI)
     - **Poor scavenging** (high residual concentration for HCCI/CAI)
  2. **Durability issues** (caused by poor lubrication and deformation, due to the high thermal load especially in port-scavenged engines) (Poppet valve)

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Introduction

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2-stroke DI poppet-valved engine with CAI

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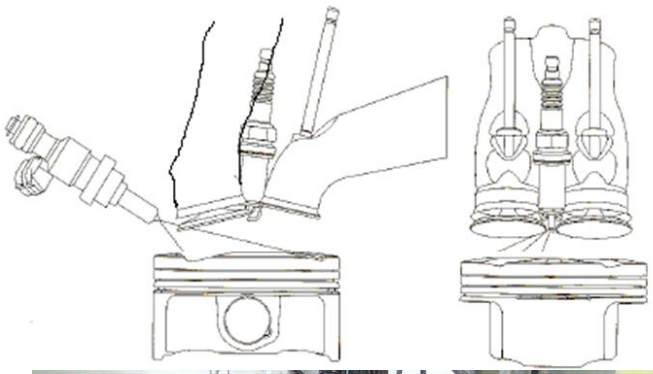
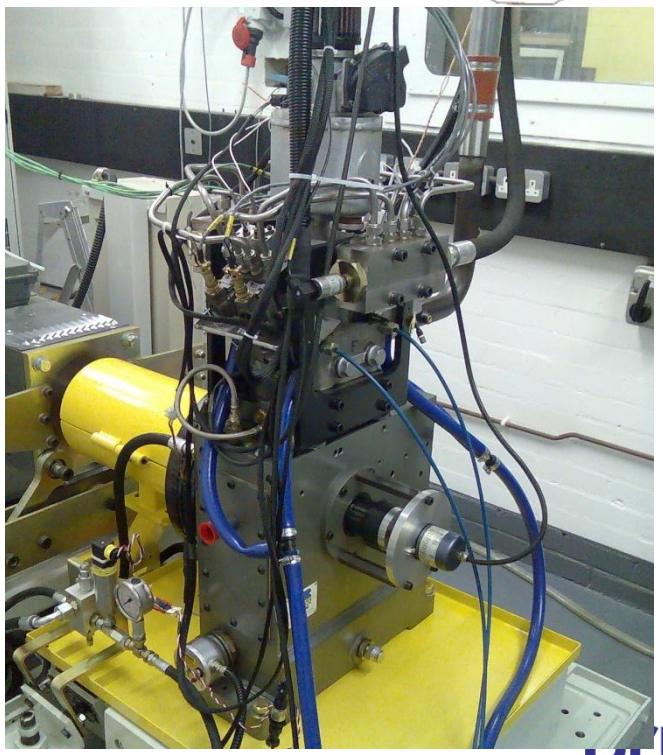
2/4 stroke switchable GDI Engine

Table 1 Engine specifications

Bore × Stroke	81.6mm×66.94mm
Swept volume	0.35L
Compression ratio	11.78:1
Combustion chamber	Pent roof / 4 valves
Valve train	Electro-hydraulic actuation
Fuel injection	Direct injection
Fuel	Standard gasoline (RON 95) E15, E85
Injection Pressure	100bar
air/fuel ratio	Stoichiometric
Intake temperature	25°C





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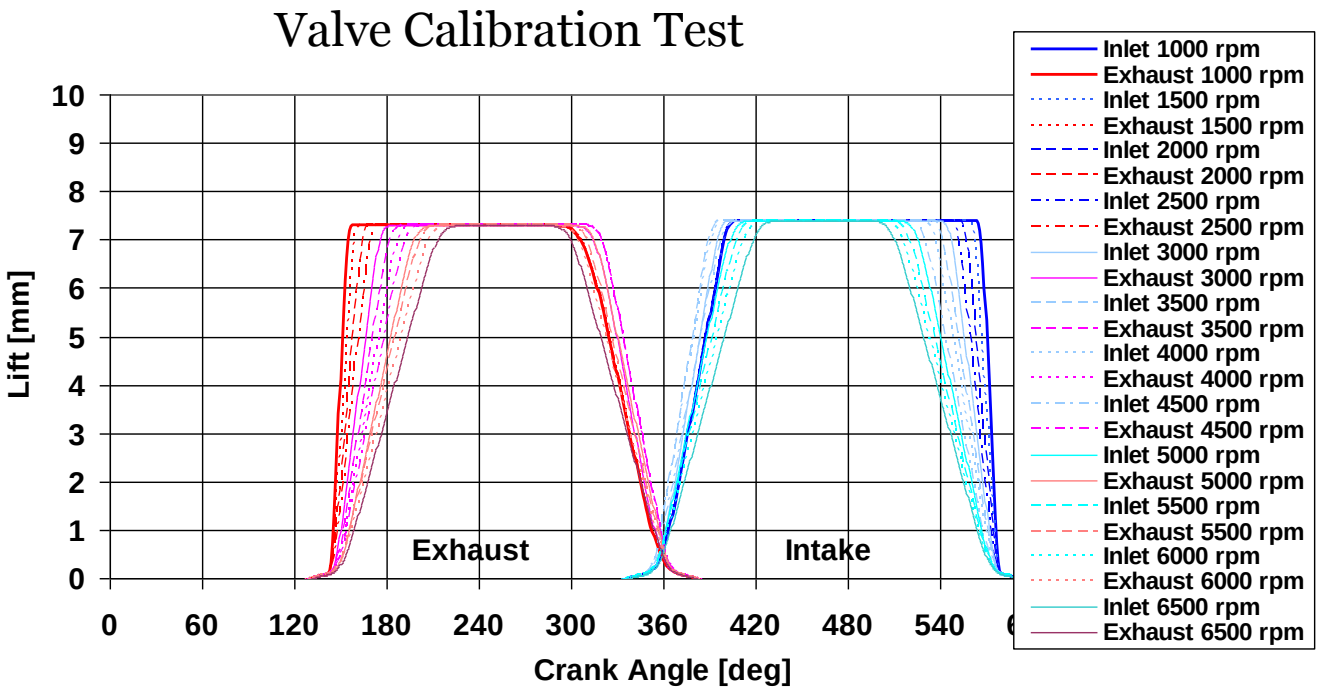
Electro-hydraulic Valve Actuation

- Oil pressure: 100bar.
- Valve Lift: 0~7.3mm.



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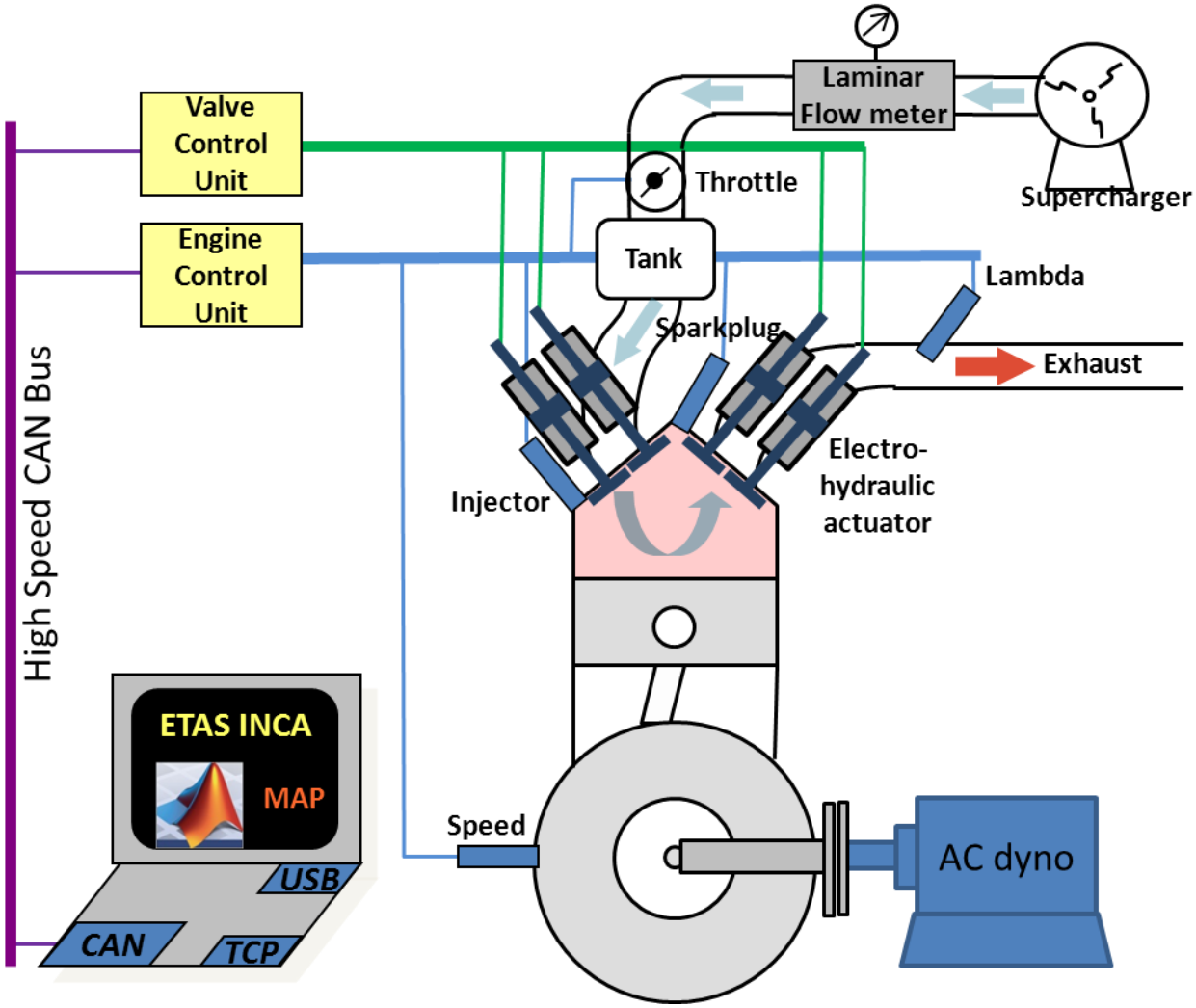
Engine Testbed Control System



- Installed on a 50kW AC motor dynamic testbed
- up to 3.5 bar boost pressure by a fully conditioned supercharger system
- Fully instrumented for air and instantaneous fuel flow, intake/exhaust and in-cylinder pressure measurements

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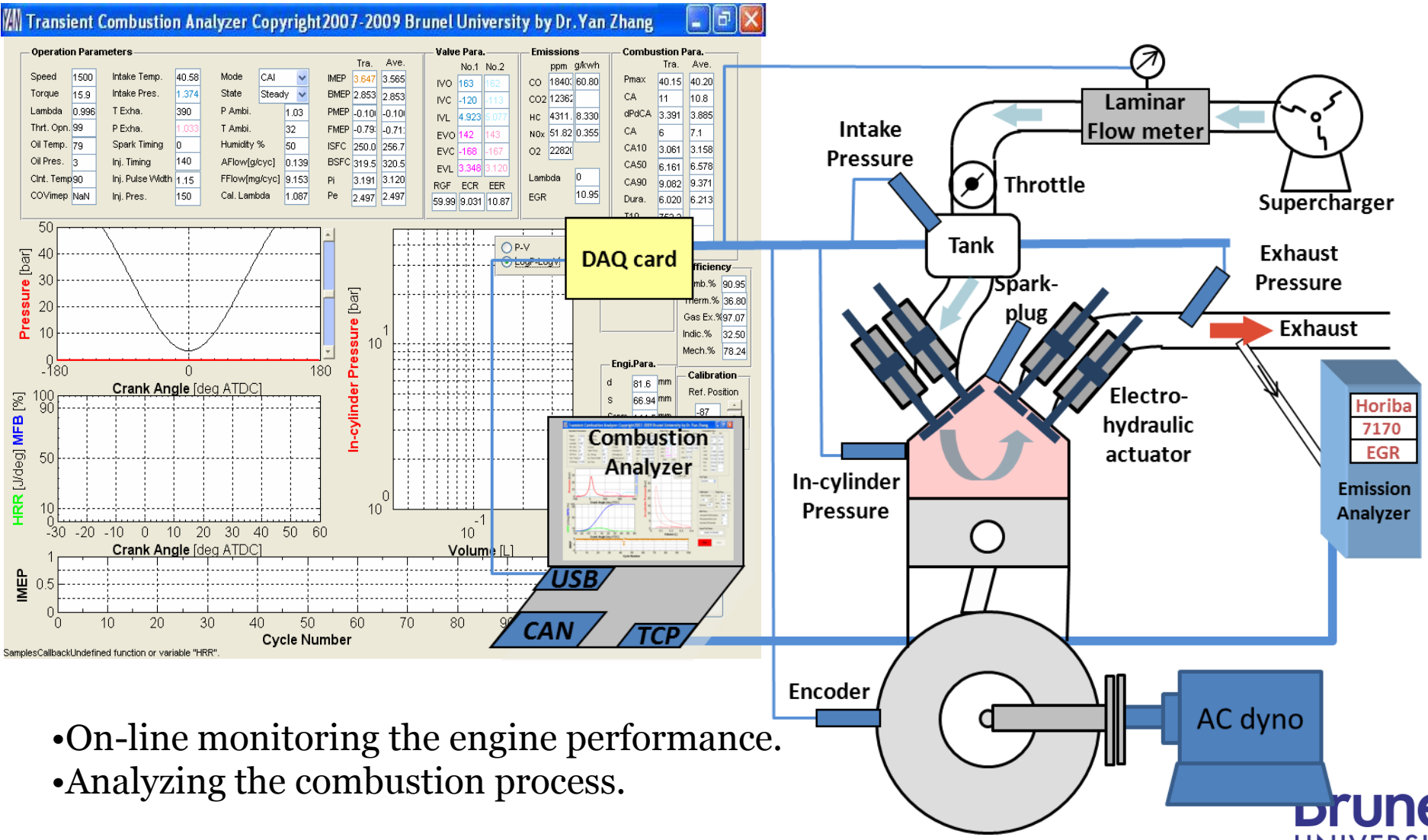
Data Acquisition System



- On-line monitoring the engine performance.
- Analyzing the combustion process.

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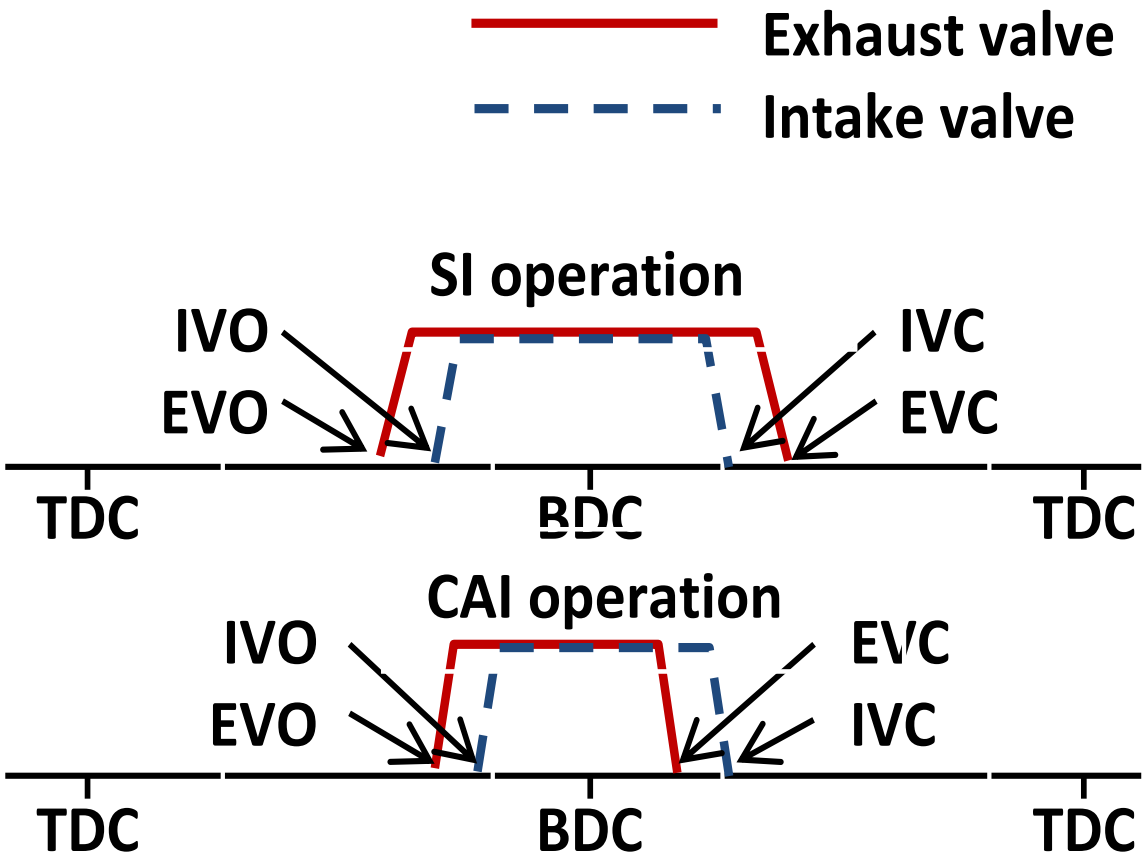
Valve Profiles for 2-Stroke Operations



- For CAI combustion, the EVC was advanced to trap more residual gas in the cylinder.

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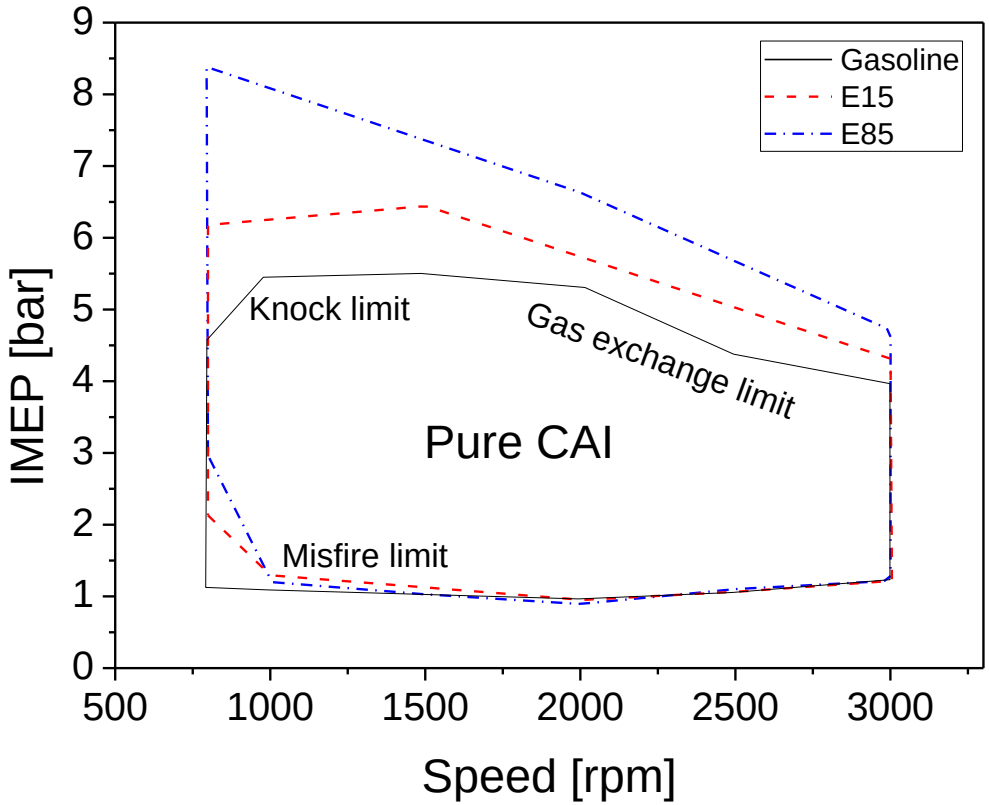
2-Stroke CAI Operation @ λ_{exh}=1.0



- Pure CAI operating range is constrained by misfiring, knocking and gas exchange.
- The knocking and gas exchange limits can be extended by increasing ethanol concentration in the fuel.
- The upper limit could be further extended by lean burn boost.

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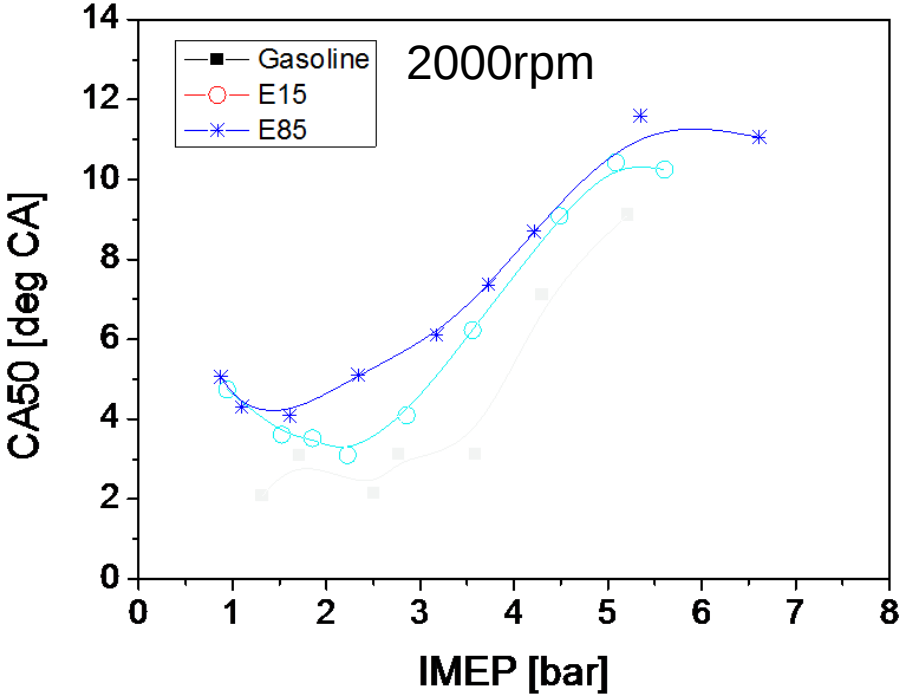
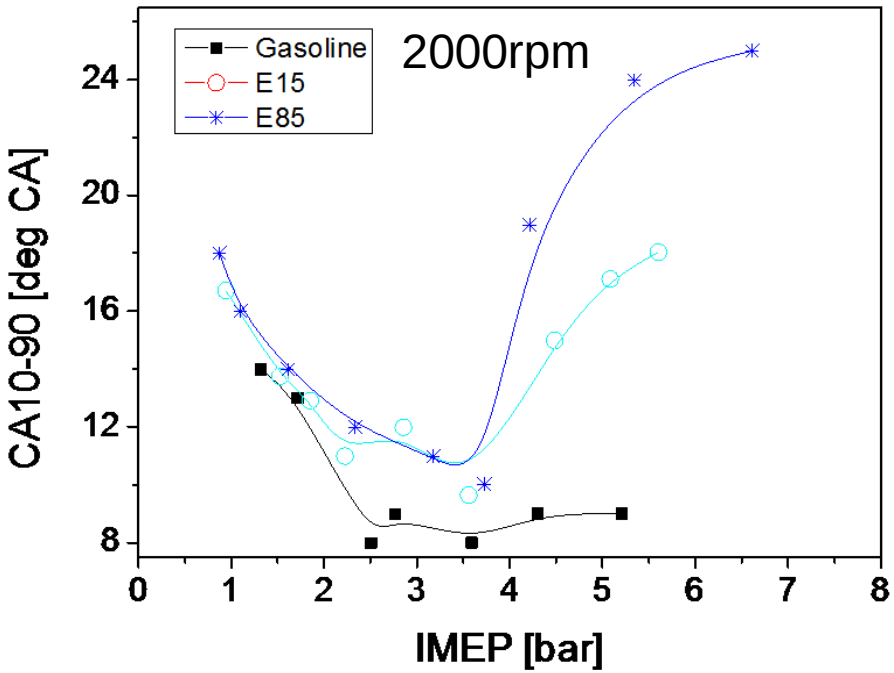
CAI Combustion phase (CA50) and Duration (CA10-90)





- Combustion phase is retarded by adding more ethanol in gasoline.
- Ethanol burns slower than gasoline in CAI mode.

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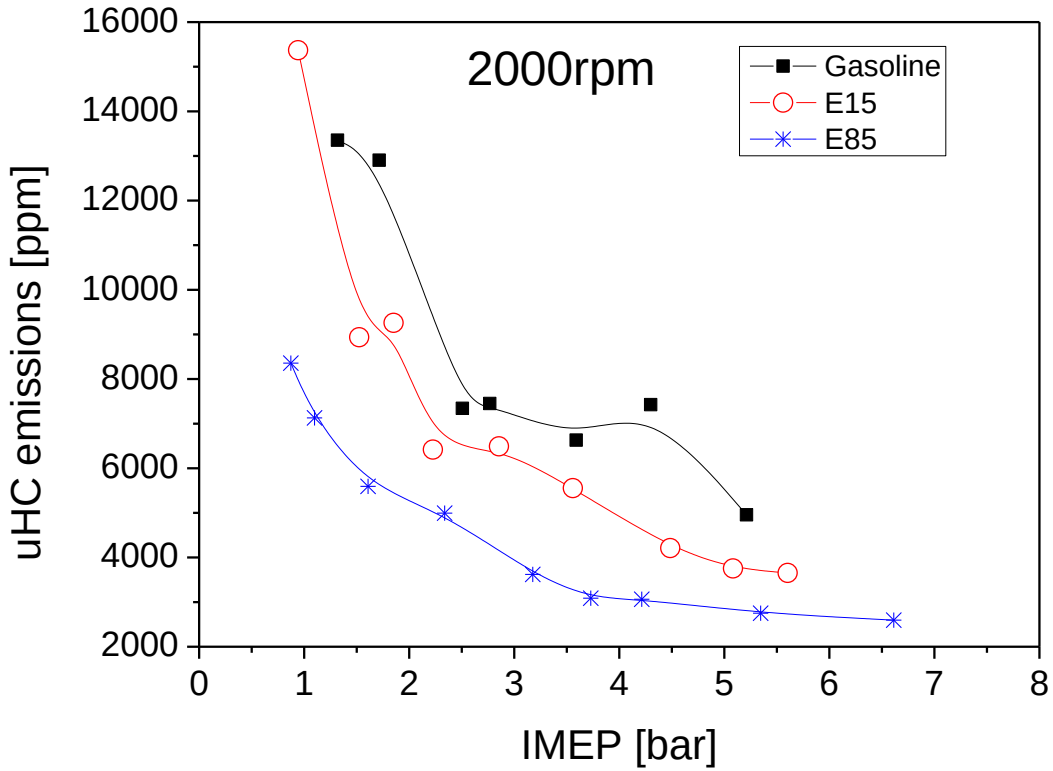
uHC Emissions



- The presence of ethanol reduced the uHC emissions throughout the load range. E85 produced about 50% less uHCs than gasoline.
- As the combustion temperature became higher with load, more complete combustion could take place and hence less uHC emissions

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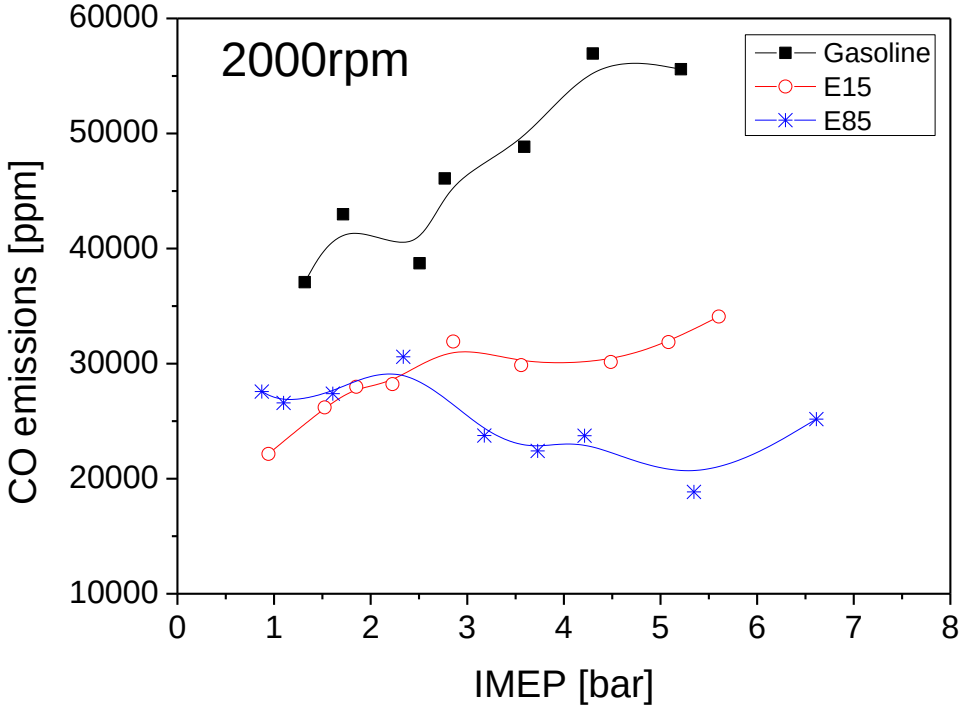
CO emissions



- E15 and E85 fuels produce less CO emissions, particularly at high load conditions, because of the more effective oxidation reactions of oxygenated ethanol.
- It is noted that gasoline produced significantly more CO at higher load whilst the CO emissions from E15 and E85 fuels remained relatively insensitive to the load.

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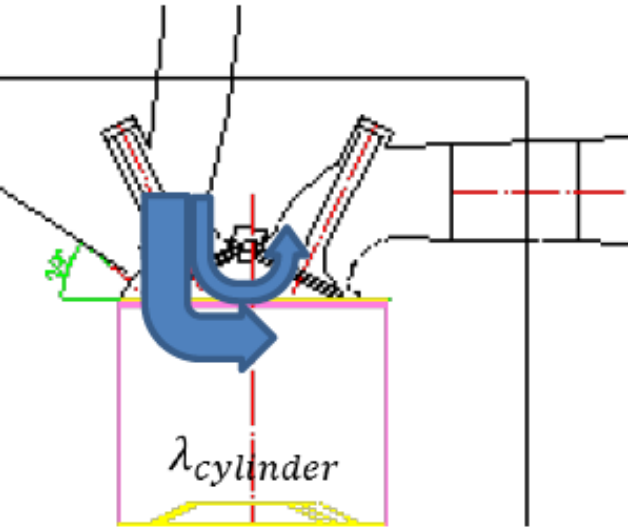
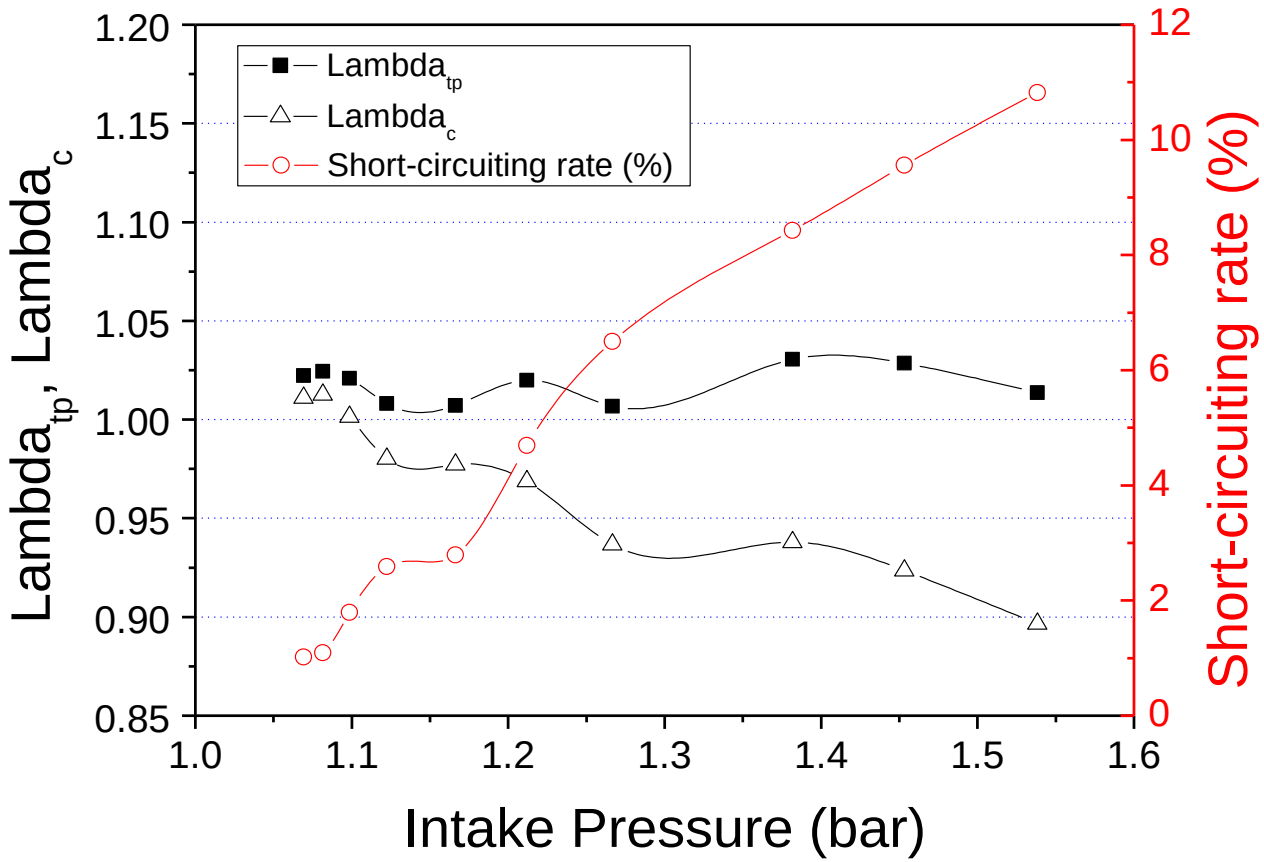
Effect of Air Short-Circuiting on In-Cylinder Mixture



$\lambda_{Exhaust} > \lambda_{cylinder}$



- Air short-circuiting was detected and determined quantitatively by a newly developed method that is capable of cycle resolved measurements.
- When the exhaust Lambda was 1.0, combustion took place with fuel rich mixtures. The mixture became richer at higher load as the short circuiting increased.

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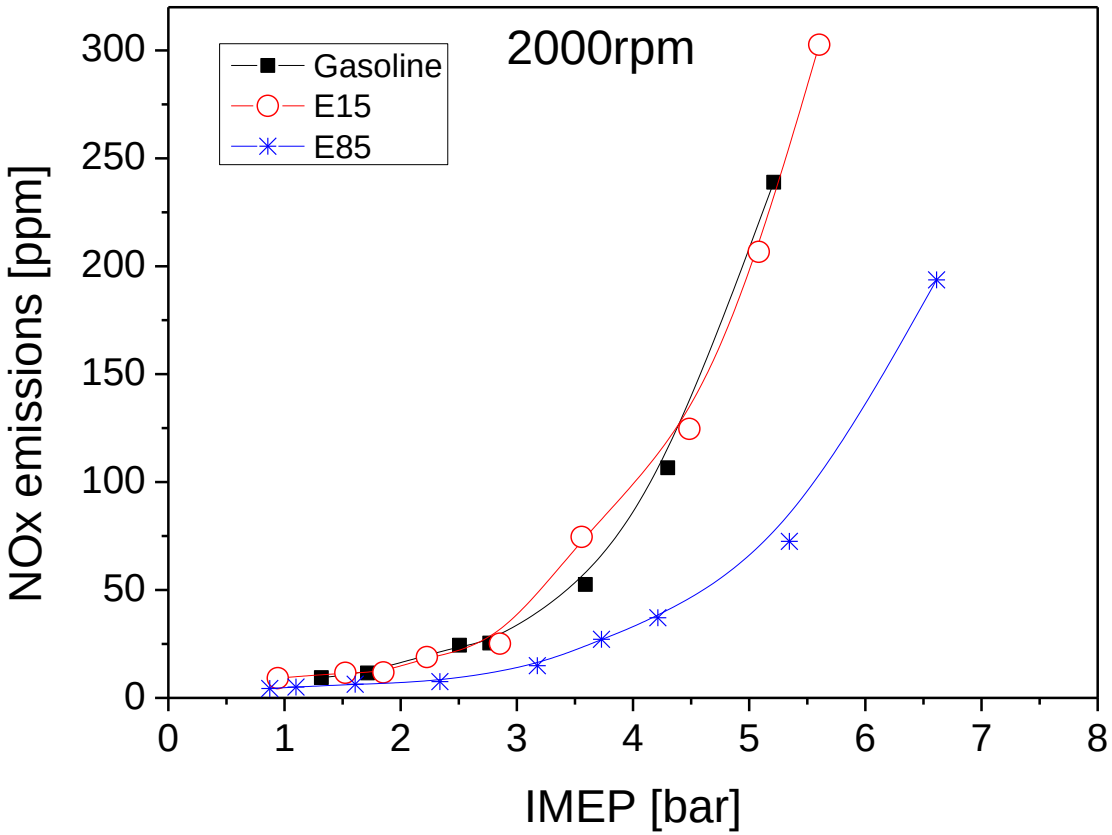
NOx Emissions



- E85 had significant effect on reducing NOx emissions at high loads mainly due to the cooling effect of ethanol.
- However, this effect became less significant at low loads as the combustion temperature and NOx emission were very low (less than 100ppm).

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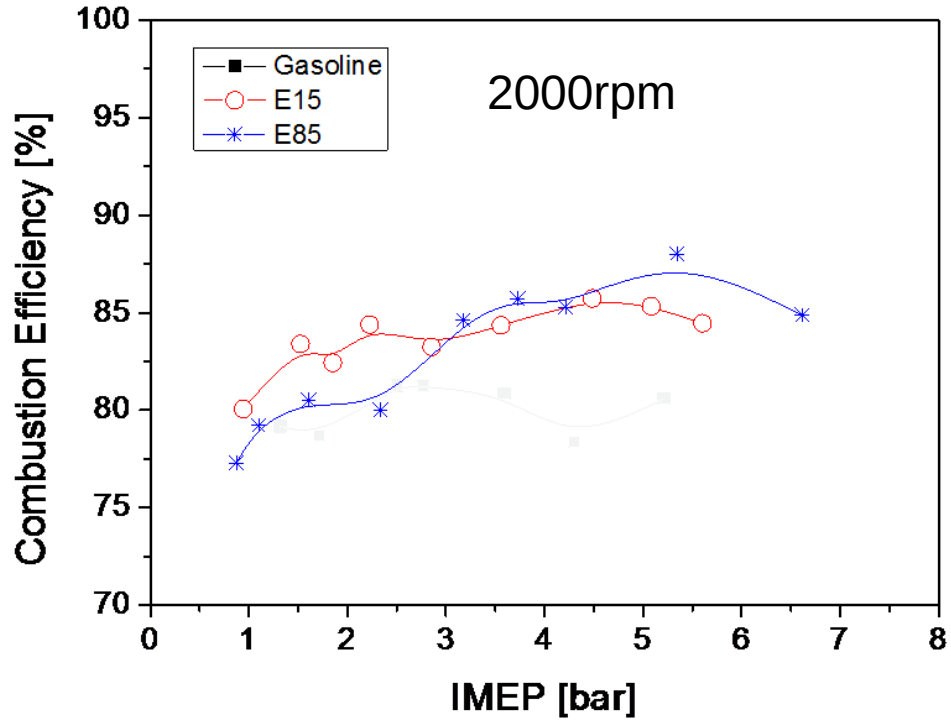
Combustion Efficiency

$$\eta_{Combustion} = \frac{Q_1}{E_{fuel}} = 1 - \frac{G_{CO} * 10.1 + G_{HC} * 43}{Fuel\ flow\ rate * LHV}$$

Where,

- Q_1 is the heat leased by fuel
- E_{fuel} is the chemical energy of fuel
- G_{CO} is CO emission mass flow rate
- G_{HC} is HC emission mass flow rate
- LHV is Low heat value of fuel



- The combustion efficiency is relatively low on this engine due to the rich mixture in the combustion chamber caused by the short-circuiting of the air and non-optimized injection system.
- Combustion efficiency was improved by 3-5% by blending 15% ethanol in the gasoline. Further increasing ethanol concentration to 85% in the fuel could further improve the combustion efficiency at high load operation.
- At low load operation the low temperature of the mixture caused by the higher latent heat value of ethanol led to lower combustion efficiency.

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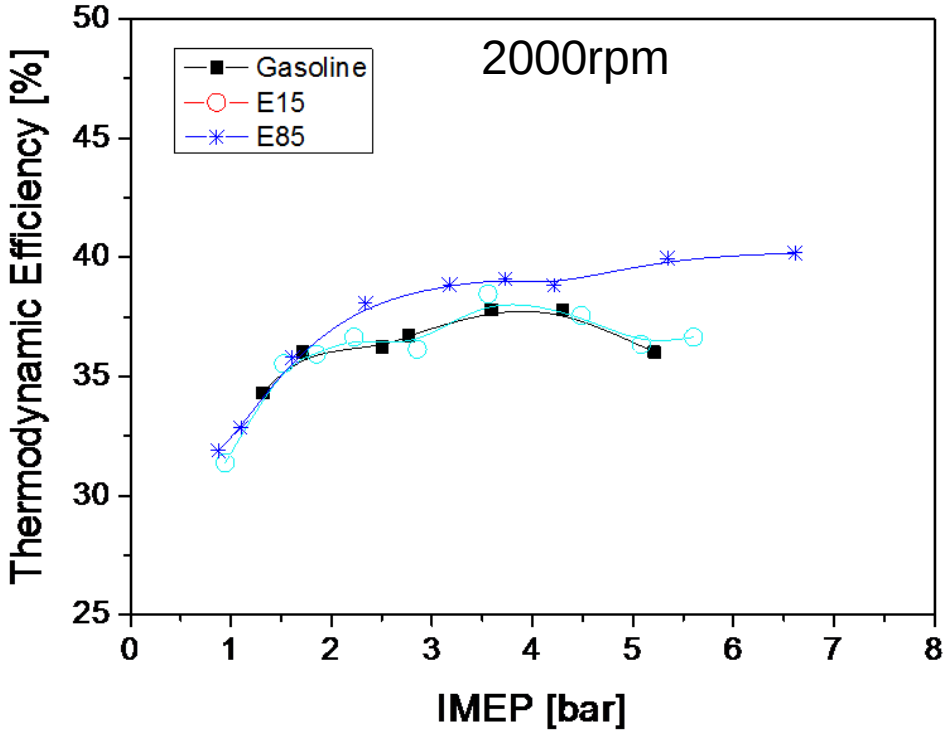
Thermodynamic Efficiency

$$\eta_{Thermodynamic} = \frac{W_{Gross}}{Q_1} = \frac{IMEP_{Gross} * V_s}{Fuel\ flow\ rate * LHV * \eta_{Combustion}}$$

Where,

- W_{Gross} is the gross work of the cycle
- Q_1 is the heat leased by fuel
- $IMEP_{Gross}$ is the gross indicated mean effective pressure
- V_s is the displacement volume



- The best thermodynamic efficiency was obtained with E85 at high load operation
- This was the result of optimised combustion phasing and reduced heat loss. during the combustion process because of the lower charge and combustion temperature of ethanol.
- The presence of ethanol had little effect at low load operations.

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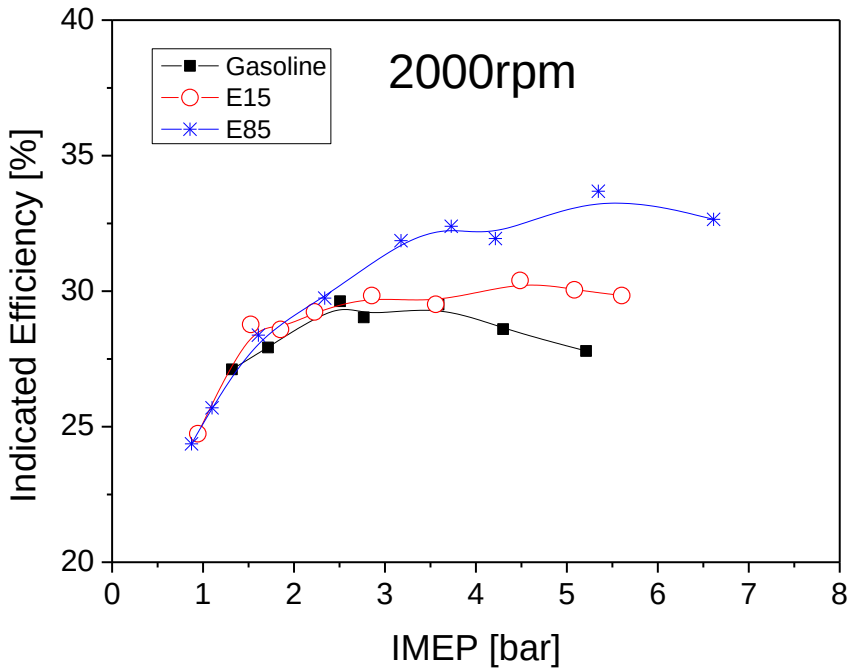
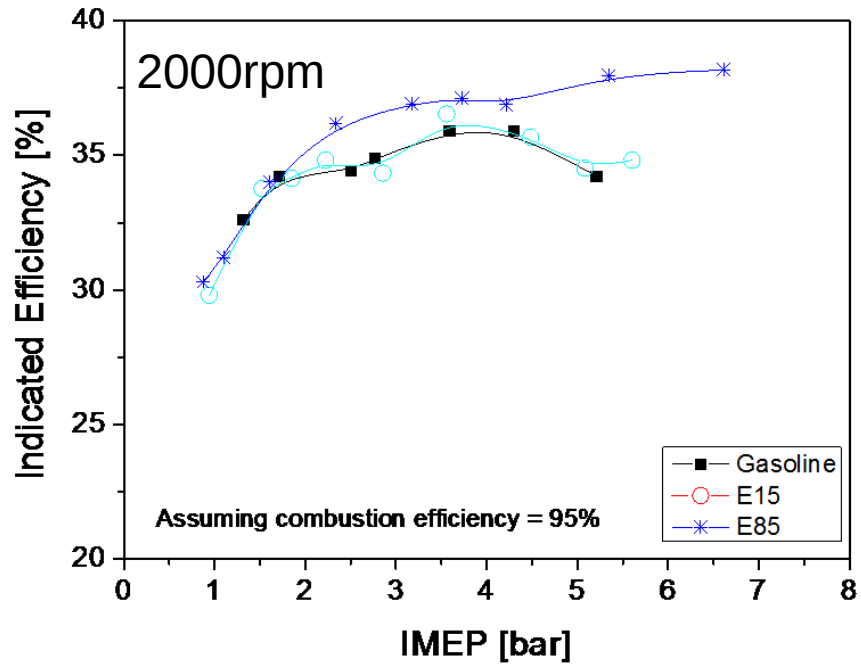
Indicated Efficiency





$$\eta_{Indicated} = \frac{W_{Gross}}{E_{fuel}}$$
$$= \eta_{Thermodynamic} * \eta_{Combustion}$$

Where,

- W_{Gross} is the gross work of the cycle
- E_{fuel} is the chemical energy of fuel

- At 5bar IMEP and 2000rpm, the indicated efficiency can be improved by 5% with E85 and 2% with E15.
- Assuming the combustion efficiency can be increased to 95%, which is the minimum for a normal complete combustion, the indicated efficiency could reach 38% with E85 at high load.

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Conclusions

- CAI combustion has been demonstrated on a poppet valve DI gasoline engine operating in the 2-stroke cycle. Gasoline and its mixture with ethanol, E15 and E85, were used and their ranges of CAI operations were determined as a function of the engine speed and load.
- The results show that
- 1. 2-stroke CAI combustion operation can be achieved over a wide range of engine speed and load conditions, including idle operations that could not be achieved with 4-stroke CAI.
- 2. The presence of ethanol allowed CAI combustion to be extended to higher load conditions. In the case of E85 the maximum IMEP of 8.4bar was obtained at 800rpm, significantly higher than the 4-stroke equivalent. Further improvement in the high load range at higher engine speeds can be achieved with a faster camless system or mechanical camshafts.
- 3. CO, uHC and NOx emissions are significantly reduced by injecting ethanol blended fuels. E85 has greater effect on the emission reduction than E15.
- 4. E85 improved indicated fuel conversion efficiency by over 5% at 2000rpm.
- 5. Ethanol content does have effect on reduction of particulates in big size but the effect becomes saturated when ethanol concentration reaches 15%, irrespective of the combustion modes.

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Thank you for your attention!

We would like to acknowledge EPSRC, UK for the financial support to this project.

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