A New Generation of Lean Gasoline Engines for Premium Vehicle CO\textsubscript{2} Reduction

Future Powertrain Conference 2019
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Ricardo Introduction - Strategic mission

Our mission is to be the world’s leading organisation for engineering, technical and environmental consultancy within the markets of Transport & Security, Energy, and Scarce Natural Resources & Waste.
In an era of rapidly increasing vehicle electrification, the gasoline engine still remains a vital part of the passenger car powertrain portfolio...

BEV, PHEV and HEV sales forecast 2020 – 2030

ERTRAC prediction assuming breakthrough in energy storage cost reduction and major infrastructure investments for re-charging

ERTRAC prediction assuming CO₂ targets achieved via improvements in ICE-based vehicles and hybridisation

Ricardo view: xEV manufacture and sales at least 30-40% by 2030

Source: European Road Transport Research Advisory Council (ERTRAC), Ricardo analysis

EV and PHEV sales will be supported by micro/mild hybridisation of conventional engines
PaREGEn (Particle Reduced, Efficient Gasoline Engines) – EU Horizon2020 framework programme supported by seventeen partners

**Research understanding**

- Engine combustion and soot optimisation

**Modelling & Control**

- In depth understanding of the relationships between combustion process, engine design, engine operation, emissions and particle formation over the entire engine map
  - 0 to 3D modelling software
  - Virtual Gasoline Particle Sensor
  - GDI engine control strategy
- Knowhow for designing optimal aftertreatment systems

**Innovation & Demonstration**

- Development of Miller Cycle stoichiometric Combustion Engine
  - Improved bore:stroke ratio (and downsizing)
  - H₂O injection and improved fuel injection
  - SVL on intake & exhaust
  - Variable charge mode and new turbocharger
  - Implementation 0 to 3D modelling software, VGPS, advances in GDI control strategy
  - Implementation of aftertreatment (TWC-GPF)

- Development of lean Miller Cycle combustion engine
  - High compression Miller Cycle engine
  - Lean combustion with ‘dry’ air dilution
  - Continuously-variable valve-lift
  - Low-pressure EGR
  - Implementation 0 to 3D modelling software, vGPS, advances in control strategy
  - Implementation of aftertreatment (lean NOₓ reduction & GPF)

**Impact Assessment**

- Target setting, tracking and assessment

- Independent testing of EU6RDE and CO₂ improvement

- All technologies, engines, components, SW and controls at TRL6 and TRL7
- Optimised engines and ATS integrated into powertrains and demonstrator vehicles
- Capability to create future gasoline engines/powertrains complying with EU6 RDE and with very low particle emissions
- Knowhow and capability to test & assess particle emissions down to 10 nm under RDE conditions in 2020
- Significant contribution to lower CO₂ levels and improved air quality
Challenge - Reduce CO₂ emissions by 15% under Euro 6d RDE legislation and with particle number emissions measured down to 10 nm

- **Targets:**
  - Uncompromised performance, 200 ps, 75 kW/l
  - 15% reduction in CO₂ reduction over WLTC
  - Euro 6d including RDE with particulates measured down to 10 nm

- **Steps being taken:**
  - Multi-mode combustion system uses lean-homogeneous operation + other advanced technology
  - Gasoline Particulate Filter (GPF) capable of filtration down to 10nm
### Key Specifications

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
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<tbody>
<tr>
<td><strong>Displacement</strong></td>
<td>1.997 L</td>
</tr>
<tr>
<td><strong>Engine type</strong></td>
<td>In-line four-cylinder boosted gasoline</td>
</tr>
<tr>
<td><strong>Bore x Stroke</strong></td>
<td>83 mm x 92 mm</td>
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<tr>
<td><strong>Compression ratio (nominal)</strong></td>
<td>11:1</td>
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<tr>
<td><strong>Maximum power Target</strong></td>
<td>200 PS at 5500 rev/min</td>
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<tr>
<td><strong>Maximum torque Target</strong></td>
<td>320 Nm (1200 – 4500 rev/min)</td>
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<tr>
<td><strong>Valvetrain</strong></td>
<td>Intake CVVL, dual VVT</td>
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<tr>
<td><strong>Air system</strong></td>
<td>Variable Nozzle Turbine + 48V Electric Compressor</td>
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<tr>
<td></td>
<td>+ Low pressure cooled EGR</td>
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<tr>
<td><strong>Fuel system</strong></td>
<td>6 hole solenoid direct injectors, central transverse layout, 350 bar</td>
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<tr>
<td><strong>Cylinder head</strong></td>
<td>Integrated exhaust manifold, head-block split cooling, revised intake port</td>
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<tr>
<td><strong>Oil pump</strong></td>
<td>Fully variable displacement</td>
</tr>
</tbody>
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**Source:** Talue et al.: Introducing the Ingenium SI Engine: Jaguar Land Rover’s New Four-Cylinder Gasoline Engine. *38. Internationales Wiener Motorensymposium, May 2017*
Bespoke boosting system to match the requirements of a lean-burn engine

- Variable Nozzle Turbine (VNT) was chosen as the main boost provider
- Combined boosting system was found to offer the best balance of low turbine inlet pressures and transient response
- Supplemented by a 48V electric compressor
- Dual purpose:
  - Used during the mode switching
  - Used to improve transient response at low engine speeds
Emissions control - State-of-the-art aftertreatment system, operating under both lean and stoichiometric conditions

- Lean conditions - Lean NOx Trap (LNT) + active Selective Catalytic Reduction (SCR) system
- Stoichiometric conditions - Three way coated first catalyst + three way coated Gasoline Particulate filter (GPF)
- GPF coating optimised for lower backpressure & particulate filtration down to 10 nm
- Advanced prototype control system – maximum flexibility
Single Cylinder & Multi-Cylinder Testing

- Single Cylinder testbed data (JLR)
  - Gross Indicated Specific Fuel Consumption, 6% improvement
- Multi-cylinder testbed data (University of Brighton)
  - Combustion stability limit
  - Gross Indicated Specific NO\textsubscript{x}, 6% Improvement
  - Gross Indicated Specific NO\textsubscript{x}, 84% improvement

PaREGEn Demo vehicle build complete & testing is underway

- The advanced technologies have been built into a demonstrator vehicle
- Initial testing is underway utilising chassis dyno for dynamic and emissions testing

PaREGEN Demo vehicle – Successful lambda mode switch tested at a range of speed and loads, example 1500rpm, 40Nm

- Fast lambda switch < 1 second
- Fast control of target manifold pressure
- No NOx spike during lambda transition

**Target lambda**
Measured lambda

**Target manifold pressure**
Measured manifold pressure

- NO\textsubscript{x} Sensor 1 – engine out
- NO\textsubscript{x} Sensor 2 – Post TWLNT
- NO\textsubscript{x} Sensor 2 – Post TWGPF
Conclusions

- The internal combustion engine will remain a vital part of powertrains for the foreseeable future
  - Ricardo forecast that 70 – 80% of new passenger cars will have an ICE at 2030
- Initial tests show the combustion system can realise substantial reductions in both fuel consumption and engine out NO\textsubscript{x} emissions
- Successful switches between stoichiometric and lean operating modes has been demonstrated in vehicle
- Whilst there is plenty of work still to do, we are on-track to deliver the fifteen percent reduction in CO\textsubscript{2} emission
- Many thanks to the work package partners: