Global Powertrain Development at Ricardo

Powertrain Strategies for the 21st Century: Designing Global Powertrains

July 2012
Agenda

- Introduction to Ricardo
- Advanced Technology Development and Market Entry
- Engine Development Examples
- Competitive Cost Management
- Driveline and Hybridization
Ricardo is one of the world's leading management & engineering consulting firms

Established Success Factors

- Focused on value-adding services
- Solving key industry issues
- Programme delivery as a core competence
- Investment in people and technology
- Critical mass with revenues exceeding £190m and over 1800 people
- Independent and long established (1915)

Value-Adding Capabilities

International Presence

Global Client Base (selection)
### Ricardo’s contribution to some key developments in the history of transportation

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>1915</td>
<td>Engine Patents Ltd.</td>
<td>Harry Ricardo formed Engine Patents Ltd, the precursor of today’s Ricardo Plc becoming famous for the <strong>design of a revolutionary engine</strong> which was <strong>utilised in tanks, trains and generators</strong>.</td>
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<tr>
<td>1930</td>
<td>Fundamental Fuel Research</td>
<td>Development of a variable compression engine which was used to quantify the performance of different fuels. This was the forerunner of today’s <strong>Octane rating scale</strong> (RON).</td>
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<tr>
<td>1935</td>
<td>Citroën Rosalie</td>
<td>The <strong>world’s first diesel production passenger car</strong>, the Citroën Rosalie, was introduced featuring a Comet Mk III combustion chamber. Derivatives of this design are still used.</td>
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<tr>
<td>1951</td>
<td>Fell Locomotive</td>
<td>The 2,000bhp Fell Locomotive was the world’s first diesel mechanical locomotive, with a novel transmission invented by Lt. Col Fell. It was powered by four <strong>Paxman-Ricardo engines</strong>.</td>
</tr>
<tr>
<td>1966</td>
<td>Jensen FF</td>
<td>The 4WD system of the Jensen FF, the <strong>world’s first 4WD passenger car</strong>, was developed by Ferguson Research Ltd (which later became part of Ricardo) launched at British Motor Show.</td>
</tr>
<tr>
<td>1986</td>
<td>Voyager</td>
<td>Voyager was the <strong>first aircraft to fly around the world non-stop</strong> without refuelling. Ricardo redesigned the Teledyne Continental engine, improving fuel economy and reducing drag.</td>
</tr>
<tr>
<td>1999</td>
<td>Le Mans Successes</td>
<td>Advanced technology helped Audi to secure its special place in motorsport history with a novel transmission to <strong>win 5 races out of 6 entries at the 24-hour race of Le Mans</strong>.</td>
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<tr>
<td>2005</td>
<td>Bugatti Veyron</td>
<td>Development and manufacturing of the DCT (dual clutch transmission) for the fastest road going car in the world, the <strong>Bugatti Veyron</strong>.</td>
</tr>
<tr>
<td>2006</td>
<td>Record Breaking Year</td>
<td>Development of the <strong>world's fastest diesel engine</strong> for JCB. The DieselMax set the diesel land speed record at Bonneville with a <strong>speed of 350 mph</strong> (563 kph).</td>
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<tr>
<td>2011</td>
<td>NHTSA/CAFÉ Fuel Economy</td>
<td>Ricardo helped shape future North American <strong>CAFE Fuel Economy Ruling</strong>.</td>
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</table>
Ricardo’s world wide footprint allows us to support clients in their local markets

1800+ people based in main automotive centres around the world
Ricardo’s advanced propulsion technology market strategy development process

**Potential Growth Options for PowerGenix**

- **Vehicle Type**: Urban Buses, Long-Range Buses, Heavy-Duty Buses, Military Vehicles
- **Battery Technology**: LiFePO4, LiFeNi, LiMnO2
- **Vehicle Performance**: 20-50 Seats, 73 passengers
- **Battery Capacity**: 64 Ah
- **Energy**: 37 kWh
- **System Voltage**: 800 V
- **Cell Internal Resistance**: 1.4 m Ohms
- **Continuous Charge Current**: 40-60%
- **Peak Discharge Power**: 170-200 kW
- **Discharge Voltage**: 170-200 kW
- **Power Generation**: Optimistic Scenarios
- **Volume**: Xiamen Jinlong, Yutong
- **Target VM**: Yuchai, DFM
- **Powertrain**: HEV
- **Bus**: Electric
- **Operational Range**: 800L
- **Weight**: 475-500 kg
- **Kerb weight**: 13.2 Tonnes
- **Life-cycle Battery Cell Cost (NiZn, China)**: 6 years

**Define Opportunity**

- **Growth Option 1**: Bus market Entry
- **Define Strategy**
  - **Market Definition**: Target Chinese Domestic Bus VMs and down-stream integrators (eg. Yuchai, Weichai)
  - **Sales Channel**: Dual approach: Down-stream integrators, who integrate and sell solutions to bus VMs; sell bus powertrain packages to bus manufacturers, who integrate the drive-train into a chassis and may also integrate and sell solutions to bus VMs; sell bus power-train packages to bus manufacturers, who integrate the drive-train into a chassis and may also integrate and sell solutions to bus VMs
  - **Product Definition**: Dual approach: Down-stream integrators, who integrate and sell solutions to bus VMs; sell bus power-train packages to bus manufacturers, who integrate the drive-train into a chassis and may also integrate and sell solutions to bus VMs
  - **Value Proposition**: Dual approach: Down-stream integrators, who integrate and sell solutions to bus VMs; sell bus power-train packages to bus manufacturers, who integrate the drive-train into a chassis and may also integrate and sell solutions to bus VMs

**Technology Requirements**

- **Full Hybrid Bus Vehicle Battery Requirements**
  - **Typical Vehicle**:
    - **Manufacturer**: Shanghai Bus Company
    - **Model**: Urban Bus
    - **Typical Battery Requirement**:
      - **Battery Capacity**: 64 Ah
      - **Energy**: 37 kWh
      - **System Voltage**: 800 V
      - **Cell Internal Resistance**: 1.4 m Ohms
      - **Continuous Charge Current**: 40-60%
      - **Peak Discharge Power**: 170-200 kW
      - **Discharge Voltage**: 170-200 kW

**Identify Target Program**

- **Target Bus VM and Integrator Customer Programs**
  - **Vehicle Type**:
    - **Bus**: Electric
    - **Target VM**: Yuchai, Weichai
    - **Powertrain**: HEV
    - **Energy**: 37 kWh
    - **System Voltage**: 800 V
    - **Cell Internal Resistance**: 1.4 m Ohms
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**Filter Target Customer**

- **Long List of Potential Bus VM & Integrator Customers**
  - **Target VMs and Integrators**
    - **Bus VMs**: Xiamen Jinlong, Yutong, Shenzhen, CSR Times, GAIG Bus, Wuzhoulong, FAW Bus, BAIC, Zhongtong, ANX, ATL, Lishen (LiFePO4), MGL (LiMnO2)
    - **Bus Powertrain**: Yuchai, DFM, BAIC, Zhongtong, ANX, ATL, Shenzhen, CSR Times, GAIG Bus, Wuzhoulong, FAW Bus, BAIC, Zhongtong, ANX, ATL

Source: Ricardo Analysis
Ricardo scientists and engineers continue to develop and improve combustion engine technology

Advanced Combustion Technology for Improved engine-Out NOx

Test Data

System Optimisation Code

System Modelling

Vehicle Simulation

Analysis Thermal / FE

Low Compression Ratio Combustion System Design

Closed-Loop Model Based Control Developments

Cold Start & Drive Enablers

Fuel Injection Technology

EGR & Boosting System Developments

Low ENGINE-OUT NOx

Ricardo plc 2012
One of our latest accomplishments is the design and manufacture of the McLaren supercar engine.

McLaren MP4-12C Avoids Gas Guzzler Tax

- 3.8L Twin Turbo V8
- 592 Horsepower
- 443 ft-lbs peak torque
- 0-60 in 3.1 seconds
- Redline 7000 RPM
- 22 MPG EPA Highway
Our work for a regional OEM is a prime example of Ricardo’s capabilities to support development from beginning to end.

Projects Overview

- **Powertrain Seminar** (3 days)
  - Product Group conducted a three day seminar at OEM covering future engine and transmission technologies.
  - This triggered a discussion at OEM about their future engine strategy.
  - OEM subsequently asked Ricardo to assist with development of its future long term powertrain strategy.
  - R-UK handed over lead for proposal development to RSC Asia.

- **Long-term Power-train Strategy** (5 months)
  - Ricardo Strategic Consulting developed the long term engine and transmission strategy over five months.
  - Close collaboration between RSC, R-Malaysia and R-UK.
  - Two phased approach with RSC leading Phase 1 but much stronger R-UK participation in Phase 2 (Phase 2).
  - Key recommendation was to develop own engine programme.

- **Engine Feasibility Study** (6 months)
  - Six months concept feasibility study 3 years prior to SOP.
  - Engine concept proven and demonstrated.

- **Procurement and Quality Support** (6 months)
  - Procurement of first wave of components for new engine.
  - Very operational approach with emphasis on learning to doing.

Source: Ricardo Strategic Consulting.
After the architecture is defined, design begins with emissions and fuel economy targets.

**USA**

- Tier I
- Tier II
- CAFE (NHTSA)

**California**

- LEV2

**Europe**

- Euro 4 (2005)

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**Approximate Comparison of EU and US Legislation**

- Predicted NOx vs PM over FTP-75 cycle for various applications with Euro 4 PC technology

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**Engine Development Examples**

- Temperature (K)
- Local Equivalence Ratio
- Soot formation area
- NOx formation area

- Euro III
- ~3L Small SUV
- ~4.5L Mid SUV
- ~6L Large SUV

- Euro IV (2005)
- T2 Bin 10 (Max for HLDT)
- T2 Bin 9 (Max for LDV/LLDT)
- T2 Bin 8

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**NOx (g/mile)**

- PM (g/mile)
- Euro legislation represents Diesel passenger car

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Concurrent with design, supplier qualification, sourcing, and component costs are established.
Powertrain components are sourced in successive waves based on their cost and development lead time.

Commodity Segmentation

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<th>Cost Contribution</th>
<th>Development Lead Time Requirements</th>
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<tr>
<td>Low</td>
<td>Low</td>
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<tr>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>High</td>
<td>High</td>
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Wave 1: High Cost, Short Lead Time
- ECU
- Catalyst
- Sensors
- ECU
- Cyl. Block
- Fuel System

Wave 2: Medium Cost, Medium Lead Time
- Turbo
- Composites
- Valves
- Engine Covers
- Alternator
- A/C Compressor
- HPAS
- Starter
- VVT

Wave 3: Low Cost, Long Lead Time
- Sealing excl. Head Gskt
- Flexplate
- Flywheel
- Other
- Turbo
- Other

Source: Ricardo Strategic Consulting
Driveline and Hybridization

Additional final drive ratios enable downsizing allowing engine to operate in narrower peak power and efficiency bands

<table>
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<tr>
<th>Technology Development</th>
<th>Benefits to Boosted Vehicles</th>
<th>Market</th>
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<tr>
<td><strong>Automatic</strong></td>
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<tr>
<td>• Increase in the number of speeds offered by conventional planetary-torque converter automatics from the US standard 4 speeds to 6/7 combined with adaptive control strategies</td>
<td>+ Diesel engines with high torque at low engine speeds can capitalize on overdriven gears to reduce engine speed during cruising conditions and benefit from low gearing to improve launch feel</td>
<td></td>
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<tr>
<td><strong>CVT / IVT</strong></td>
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<tr>
<td>• Automatic transmissions using a variator to offer step-less ratio selection</td>
<td>+ Continuously variable ratios can be used to ensure the driveability of downsized / boosted engines by keeping the engine within its optimum operating window</td>
<td></td>
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<tr>
<td><strong>DCT</strong></td>
<td></td>
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<tr>
<td>• Hydraulically actuated, twin input shaft automated manual transmissions offering gear pre-selection and shifting without torque interrupt to optimize shift speed and quality</td>
<td>+ Increased ratio spread and control capabilities improve the driveability of downsized / boosted engines with mechanical efficiency approaching that of conventional manual transmissions</td>
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Hybridization of heavy vehicles shows substantial opportunities to reduce fuel consumption.