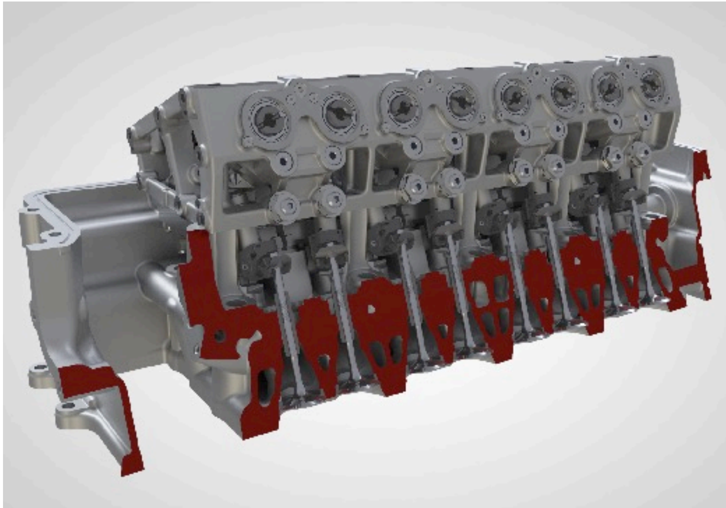
Intelligent Valve Actuation – a Radical New Electro-Magnetic Poppet Valve Arrangement

Roger Stone	**Camcon Auto Ltd**
David Kelly	**Camcon Auto Ltd**
John Geddes	**Jaguar Land Rover Ltd**
Sam Jenkinson	**Jaguar Land Rover Ltd**

Aachen Colloquium, 10th October 2017

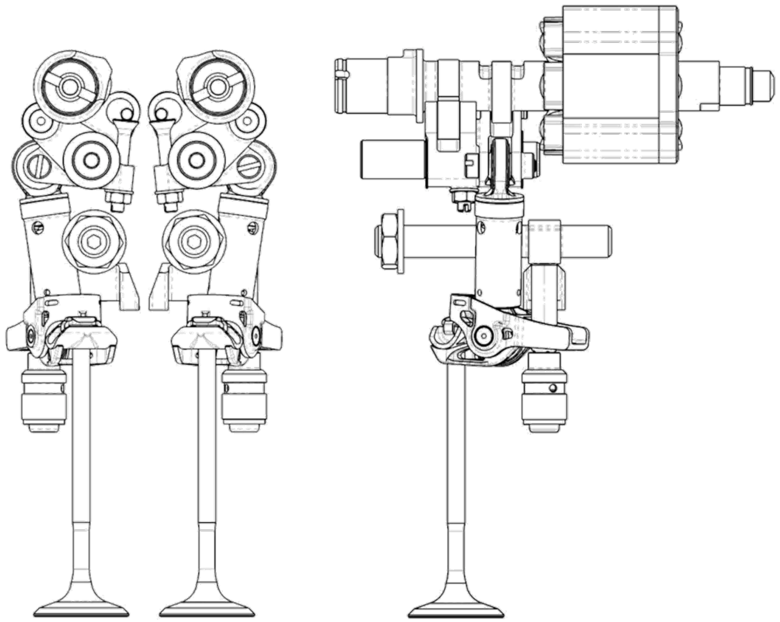
What is IVA?

- IVA is a full authority, purely electro-mechanical, variable valve actuation system for piston engines
- Unprecedented level of control – valve by valve
- Full, fast feedback control throughout the event
- Can be used on both inlet and exhaust valves, double events possible – an HCCI enabler?
- Digital control of gas exchange, the last controllable combustion variable



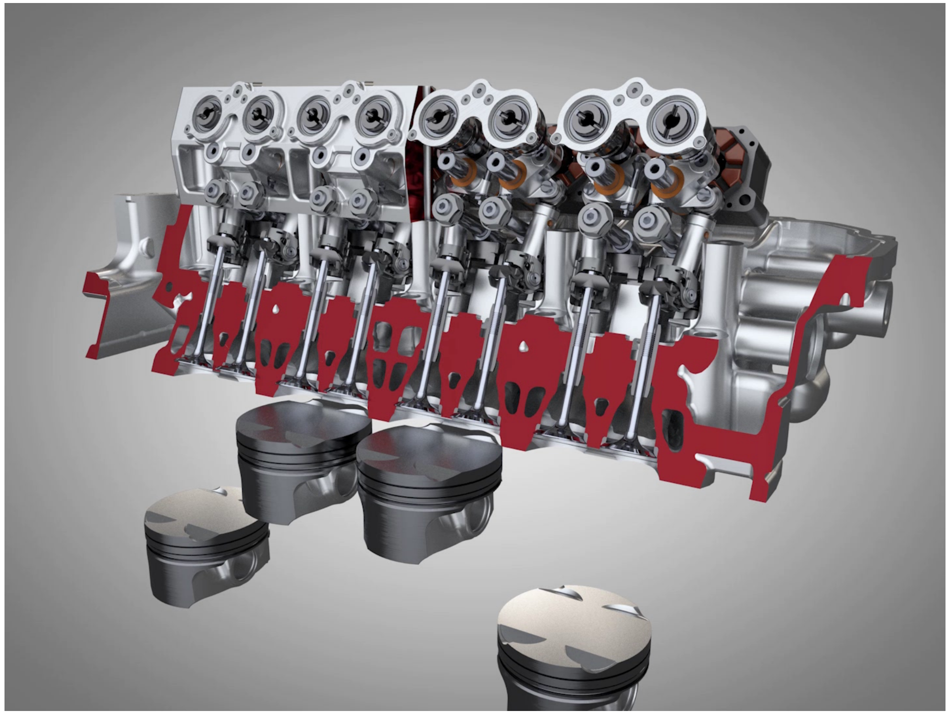
Intelligent Valve Actuation

- Uses an individual, electrically actuated desmodromic mechanism per valve or valve pair
- No mechanical drive from the crankshaft
- No conventional valve (or “helper”) spring
- Compliance to allow for seating loads, expansion etc. is built in to the drop link
- Operates on 12 or 48 volts



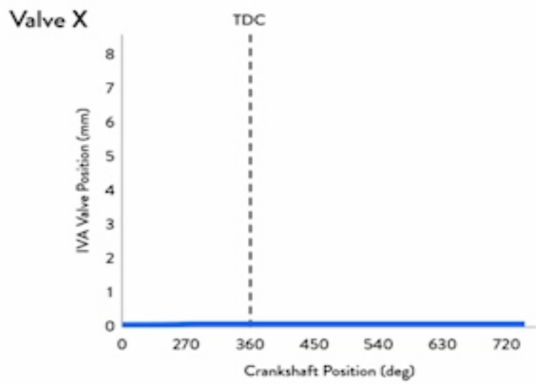
Operating Modes

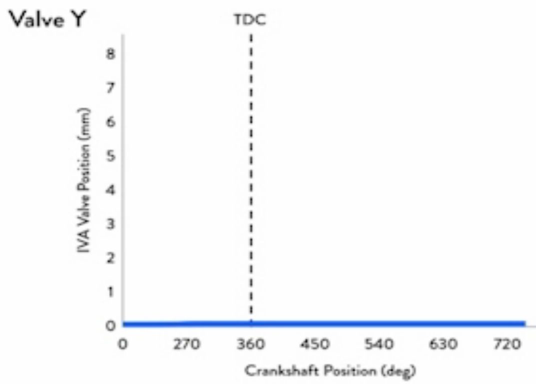
- Full lift = full rotor rotation
- Part lift = part rotation + return
- Rotor velocity never constant
- Rotor "parks" between most events
- Every event is independent of both its predecessor and its successor



What Does IVA Offer?

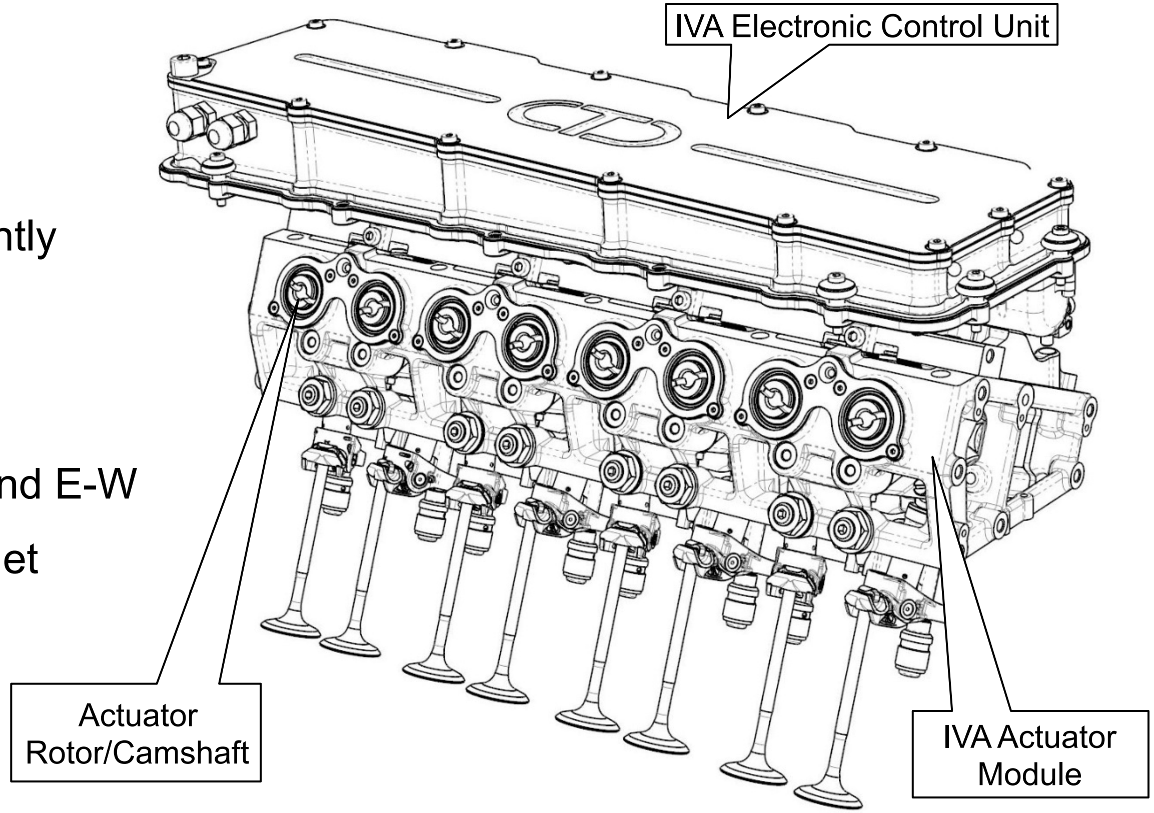
- Individual control over every valve, every cycle
    - Complete, infinitely variable, phase control
    - Complete, infinitely variable, period control
    - Complete, infinitely variable, lift control
    - Event shape control – and not just MOP shift
    - All virtually independent of each other
    - Multiple event, no event
- All from one valve event to the next





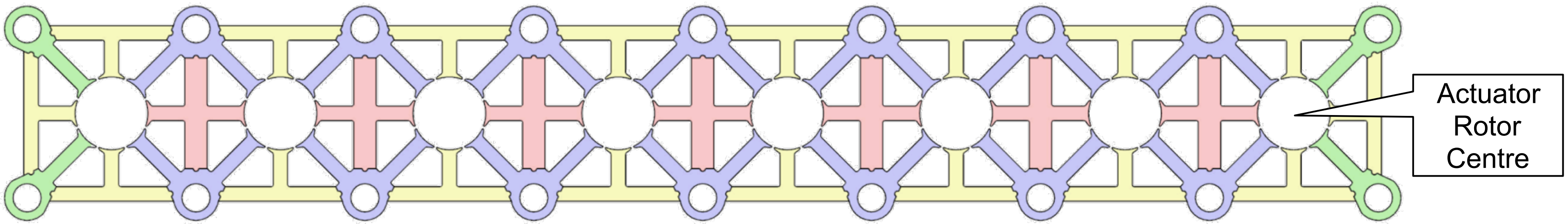
IVA Installation

- Actuator axis perpendicular to crankshaft
- Electronic control unit compliantly mounted over or alongside the mechanicals
- Packages within normal N-S and E-W layouts with conventional bonnet clearances



Electro-Mechanical Layout

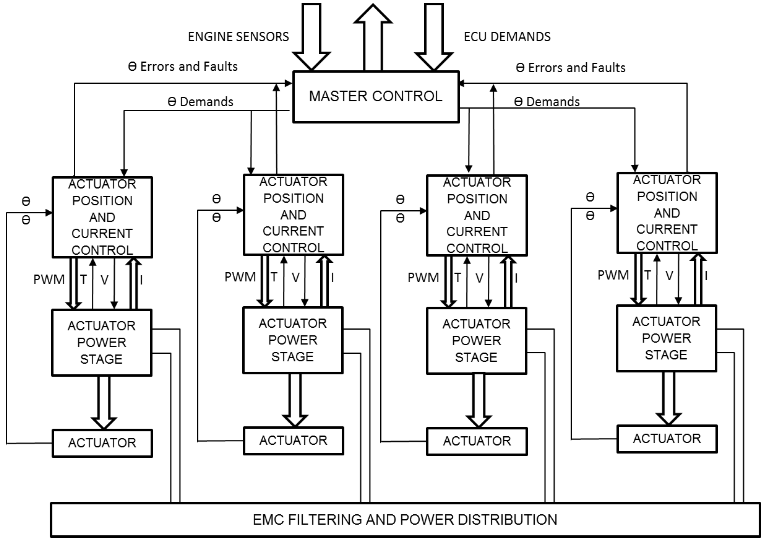
- Mechanically, the linkage contains nothing unfamiliar or of unusual precision
- Each actuator is an 8-pole, permanent magnet machine
- The stator is segmented and shared between actuators, maximising torque capacity and efficiency
- Asymmetry further improves performance/unit package volume and weight



End view of 8 valve stator laminate stack showing asymmetric slots for windings and the 4 different segment geometries

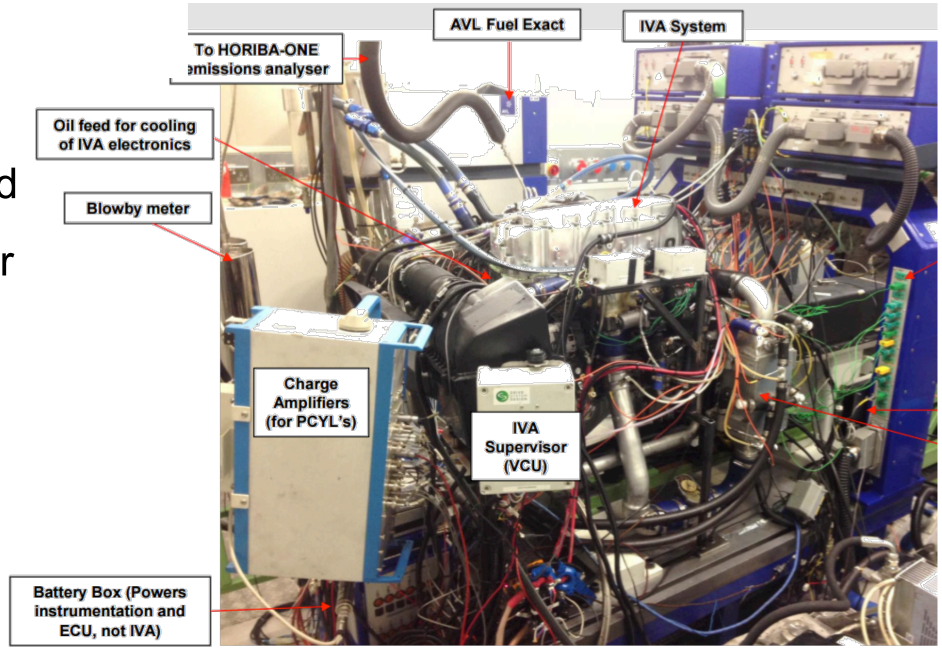
Control

- Master controller requests the required valve event
- Each actuator is under independent position control
- Local actuator controller determines the target rotor trajectory for minimal energy consumption
- The target trajectory is dynamically adjusted, compensating for transient engine behaviour during each valve event



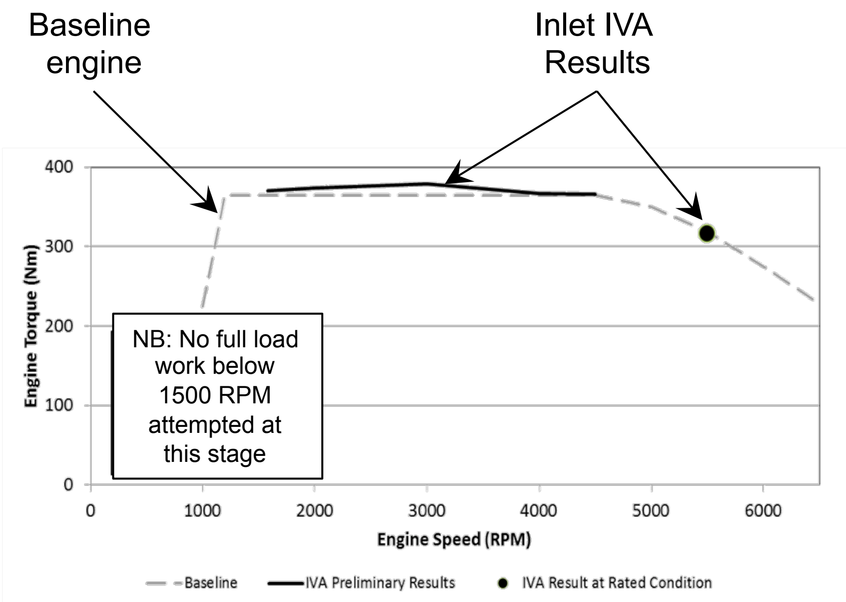
Testing

- Testing has been conducted both on test rigs and on the dynamometer
- The first IVA modules have been designed for the inlet valves of a Jaguar Land Rover Ingenium engine
- Successful completion of 500 hour OEM durability cycle on the rig
- >1200 hours on the engine dyno



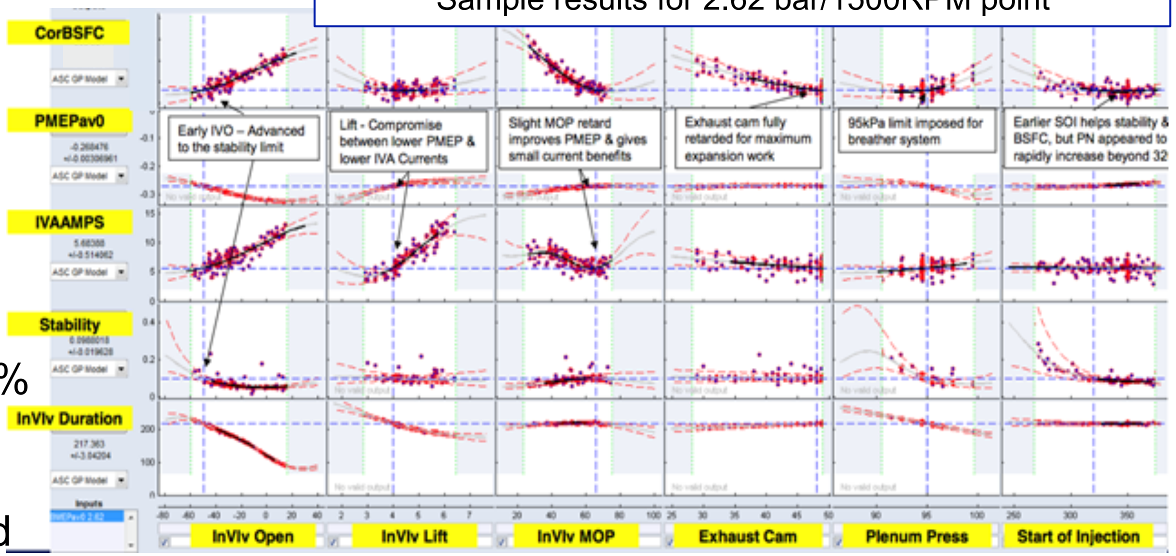
Engine Performance

- Max valve lift reduced to 7.8mm
- 1D analysis suggested similar performance-timing/period compensating for reduced lift
- The dynamometer results confirmed the predicted performance
  - Maintains engine performance at the same boost level
  - Reduces IVA electrical power demand
  - Eliminates piston interference



Dynamometer Testing

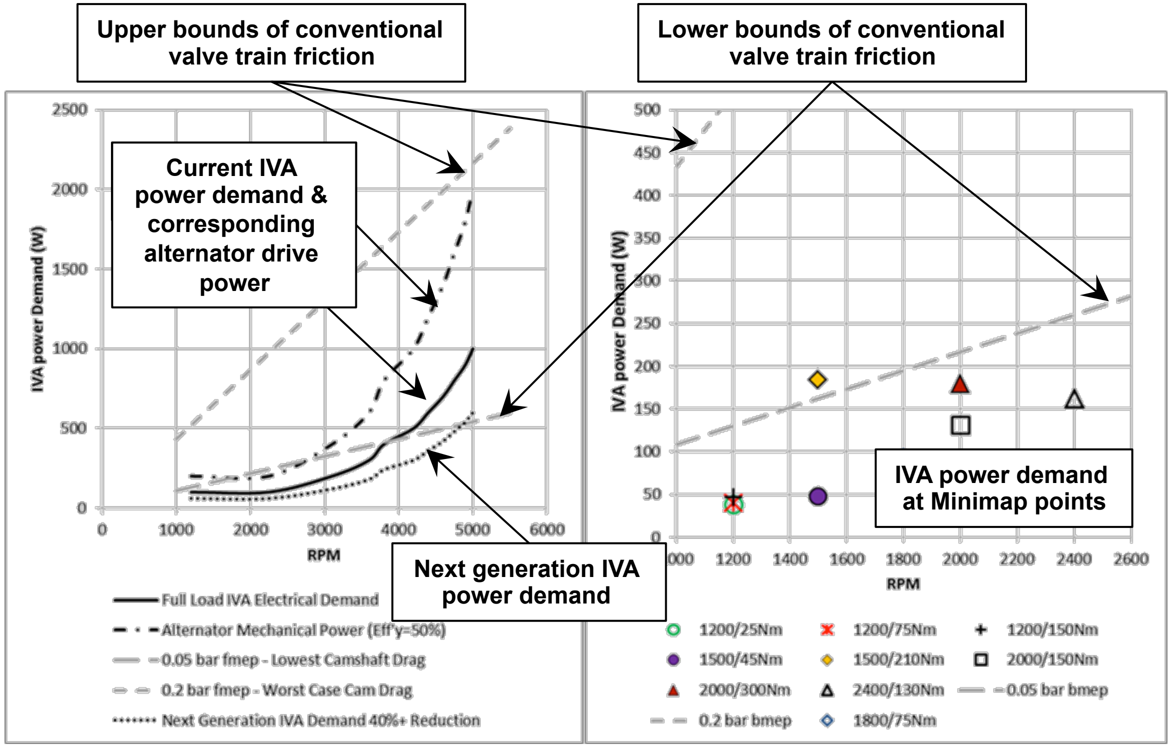
Sample results for 2.62 bar/1500RPM point



- 10 “minimap” steady state points defined
- Large DoE experiment completed (Inlet only)
- CO_2 improvements up to 7.5% recorded
- Optimised events established
- The VVT capability required is greater than any other available system
- Even greater IVA dynamic capability is now in development and will provide further benefit

Results Analysis

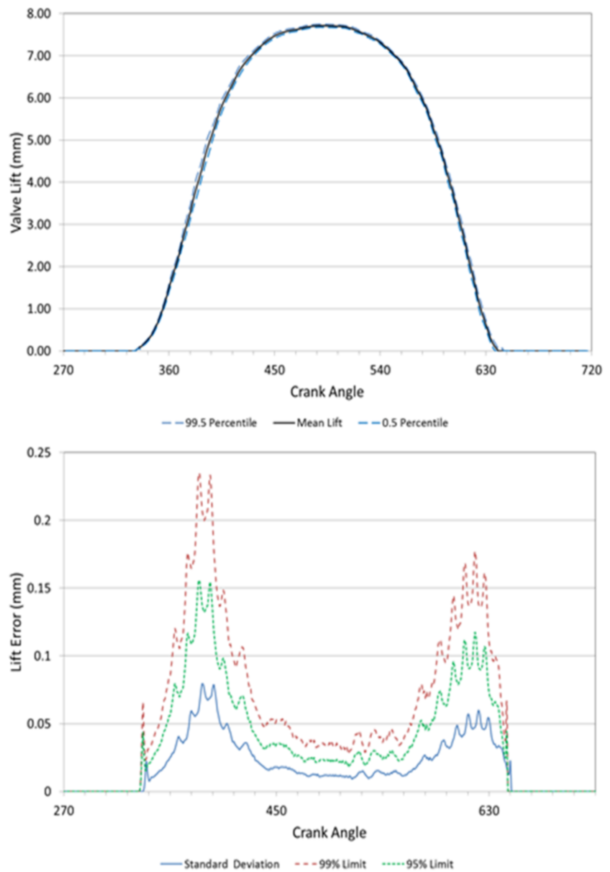
- The CO_2 benefits come from 3 sources:
  - Pumping loss
  - Heat release rate & knock sensitivity
  - Parasitic losses
- CO_2 results achieved with IVA power sourced from the alternator – opportunity for smart charging?



IVA Power Demand vs Conventional Valve Trains

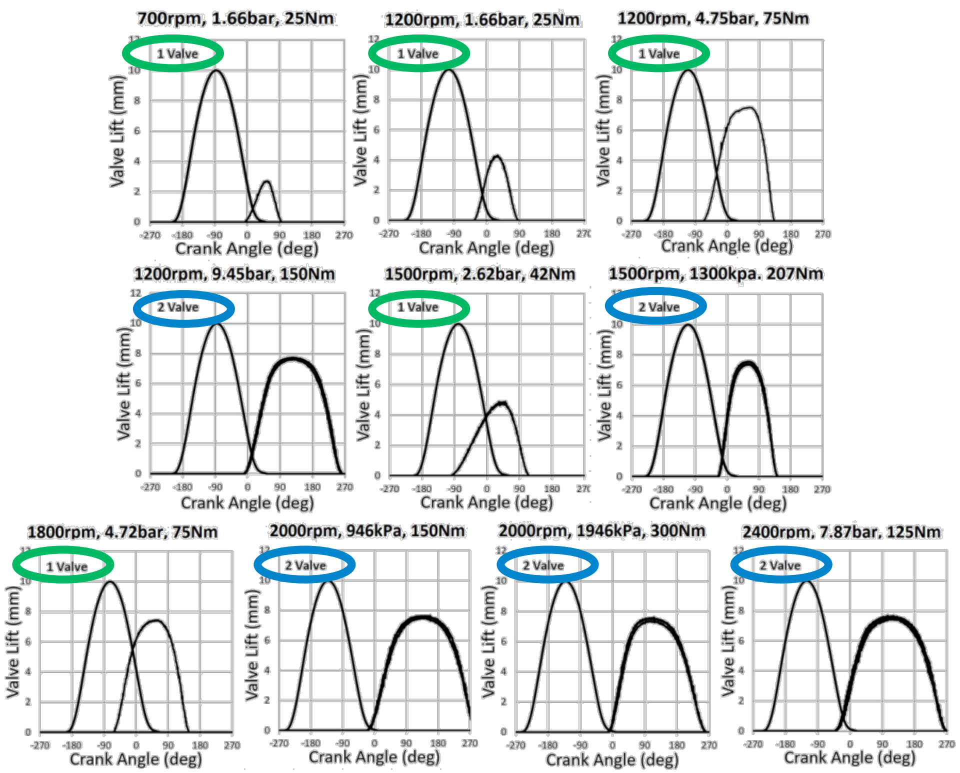
Event Consistency

- Valve position was measured on the fired engine for 300 consecutive events
- An example of the control achieved is shown
- Measurements of event quality have been established in order to ensure that other development improvements, e.g. power consumption, can be measured against a common standard



Optimised Events

- Throttle wide open in all cases, including idle
- Single valve mode often best
- Both EIVC *and* LIVC capability needed for different conditions
- Late MOP useful for some events
- Only steady state and the simplest IVA strategies have been explored so far – there is much more to come

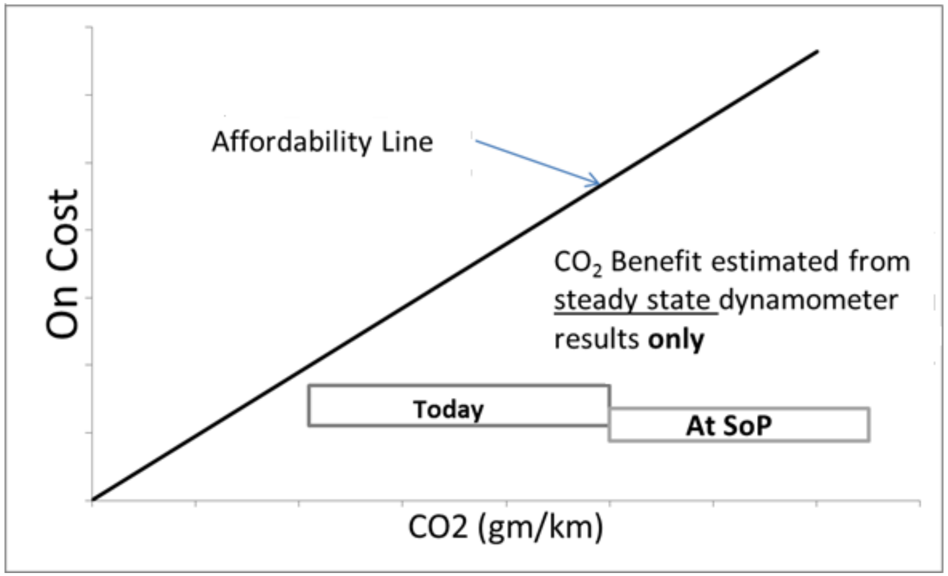


Other Aspects of Note

- VERY low mechanical noise
- Transient valve response: 0-100% in one cycle
- Significant detonation sensitivity improvement
- Cranking torque reductions of ~30% through reduced pumping loss have been demonstrated
- There are hybridisation synergies yet to be explored but deletion of the timing drive is an obvious benefit
- Demo car available now
- Single cylinder R&D programme support possible

Cost and Affordability

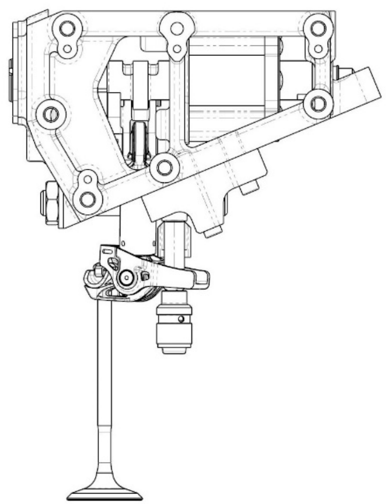
- On-costs have been estimated as a joint effort – a Tier 1, Jaguar Land Rover and Camcon:
  - The CO_2 benefit, even on the basis of today's steady state results alone "pays for" the system
  - There is much more to come in terms of CO_2 benefits



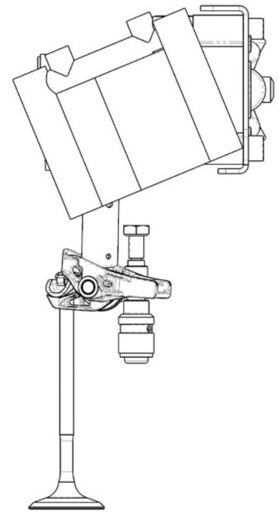
Inlet IVA only: Cost-Benefit

Next steps

- The next generation IVA prototypes are being procured now.
- The new actuators will be smaller, lighter, cheaper, >40% lower electrical power demand
- Improved dynamic performance will mean further improved CO_2 results
- Exhaust actuators and 16V engine testing included in the next stage of the programme
- And then: diesel, including heavy duty



Today's Prototype



Next Generation – Running in Q1 2018

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Thank you very much, questions?