High-Efficiency Clean Combustion Engine Designs for Compression Ignition Engines

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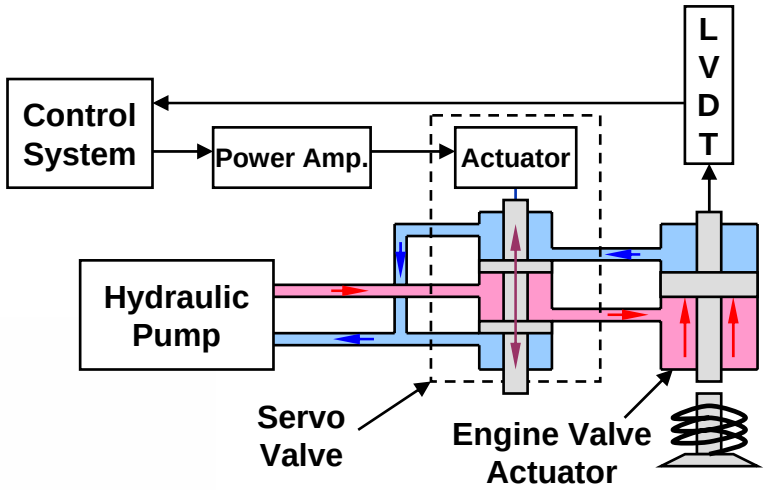
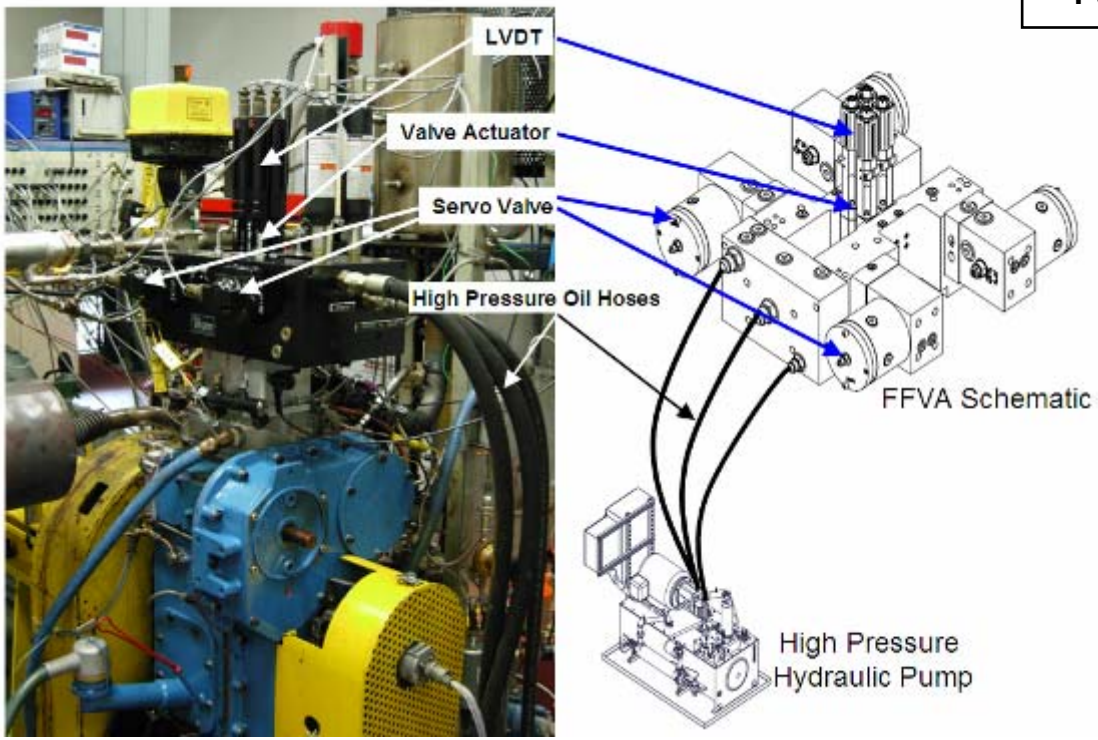
Purpose of Work

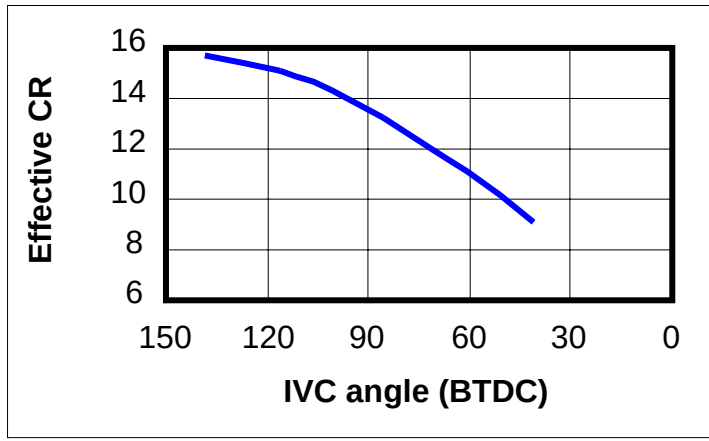
- **Investigate the use of variable valve actuation (VVA) as a means to improve the efficiency of a light duty diesel engine operating at Tier 2 Bin 5 engine-out NOx emission levels**
  - Task 1 - Single cylinder engine testing using a fully flexible electro-hydraulic VVA system
  - Task 2 - Multi-cylinder engine testing and a potential vehicle demo using a production viable VVA system
- **The fully flexible VVA work is a very valuable project to help understand the upper bound efficiency potential of VVA on a diesel engine.**
- **The multi-cylinder engine work will aid in understanding the requirements and performance capability of a production viable VVA system.**
- **It is important to develop technologies enabling ultra low engine out NOx levels approaching Tier 2 Bin 5 that also enhance fuel economy.**

Approach - Fully Flexible VVA System

- A research oriented VVA system using independent electro-hydraulic actuators for each valve
- Designed to achieve a very high level of control and flexibility
- Not a production intent system

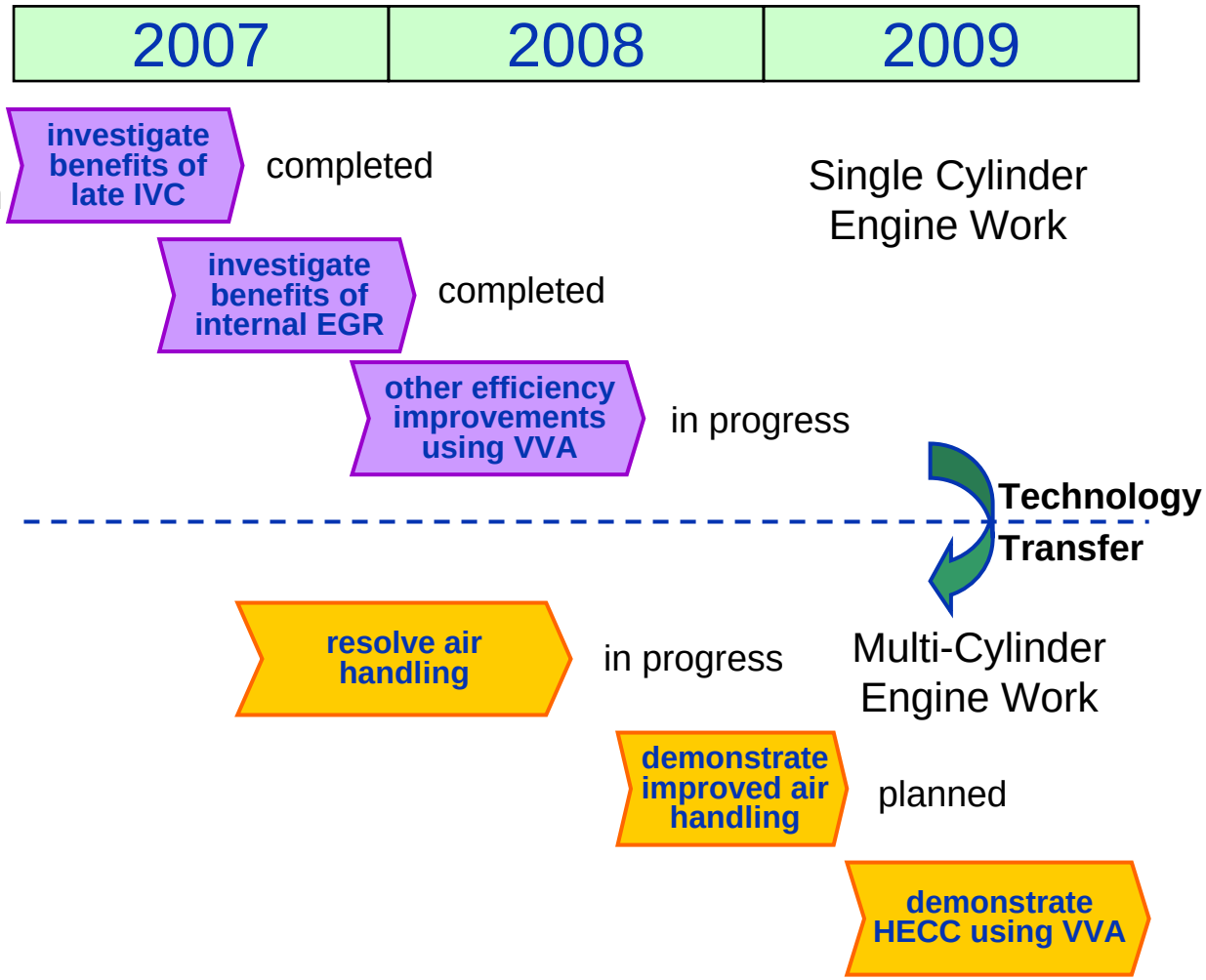






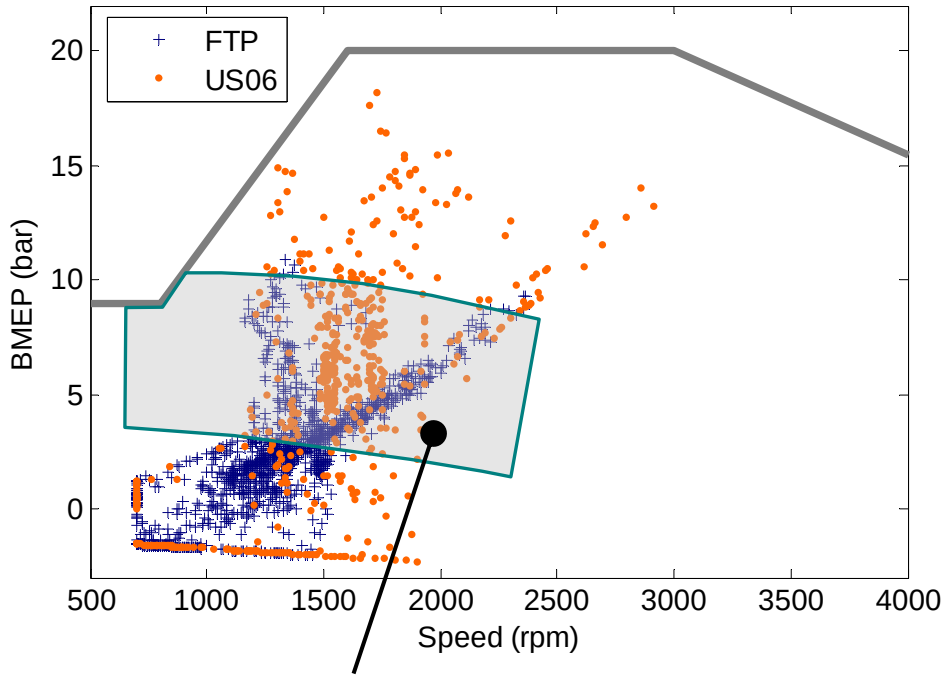
Performance Measures and Accomplishments

- **Single Cylinder Work**
  - LIVC investigation completed
  - Internal EGR investigation completed
  - Currently investigating other efficiency improvements
- **Multi Cylinder Work**
  - Working with supplier to define air handling requirements



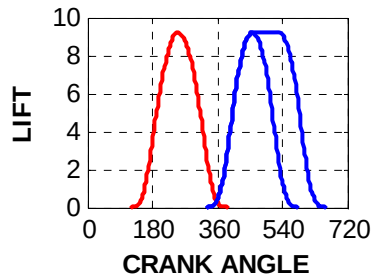
LIVC Conclusions

- **Conclusions based on single cylinder testing plus GT-Power modeling**
- **At Tier 2 Bin 5 NOx levels, LIVC showed a usable benefit over the load range between 2 to 10 bar BMEP**
- **LIVC can be used to reduce the EGR required by 15% to 25% (8 to 12 percentage points)**
- **LIVC significantly reduces the soot emissions at all operating conditions**
- **LIVC does not significantly affect the HC and CO emissions**
- **LIVC reduces the volumetric efficiency. At Tier 2 Bin 5 NOx levels, the baseline AFR is close to stoichiometric and there is very little margin to reduce the air flow. Need higher boost pressure to offset the lower volumetric efficiency.**



Late Intake Valve Closing:

- Expand Early PCCI operating range
- Reduce smoke emissions (50-90%)
- Improve fuel economy due to improved combustion phasing
- Can use simple VVA mechanism (Two Step or Phaser)



Summary

Phase 1 (Single)

- **Fully flexible VVA system in use on single cylinder engine**
- **Late intake valve closing work completed**
- **Internal EGR (re-breathing and recompression) has been investigated:**
  - Significant benefits at idle
  - Reduced HC/CO emissions
  - Improved combustion stability
  - Increased exhaust gas temperature
  - Reduce/eliminate external EGR

Phase 2 (Multi)

- **Worked with turbomachinery supplier to define air handling requirements for LIVC implementation on a multi-cylinder engine**

Plans

Phase 1 (Single)

- **Investigate other efficiency improvement strategies using VVA**
  - e.g. exhaust temperature management via EVO timing
- **Use fully flexible system to develop requirements for multi-cylinder system**
- **Complete single cylinder phase of the project in 2008**

Phase 2 (Multi)

- **Define and procure new hardware that meets requirements defined by single cylinder testing and GT-Power modeling**
- **Steady state testing**
- **Integrate VVA controls into ECU for transient testing**

- **Publication - SAE 2008 Congress paper on LIVC**