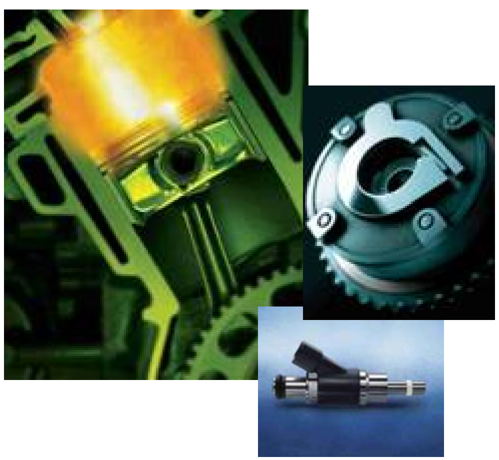
E85 Optimized Engine through Boosting, Spray Optimized GDi, VCR and Variable Valvetrain



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19May 2009 Presentation

Project ID: ft_14_confer

This presentation does not contain any proprietary or confidential information

E85 Optimized Engine through Boosting, Spray Optimized DIG, VCR and Variable Valvetrain

Overview

Timeline

- Project start: 10/1/07
- Project end: 9/30/10
- Percent complete: 55%

Challenges

- Fuel property differences
- Engine Controls
- E85 fuel economy

Budget

- Total project funding
  - DOE share $2,186,448 (44.5%)
  - Contractor share: $2,724,298 (55.5%)
- 2008 Funding: $1,561,120
- 2009 Funding: $2,094,342

Partners

- Delphi / Wayne State University
- Delphi is the Project Lead
- Interactions with OEM

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Objectives of work

- The objective of this project is to develop and demonstrate an overall engine hardware and control system implementation that minimizes the fuel economy penalty currently seen when bi-fueled ethanol enabled gasoline engines are run on high-percentage ethanol blends. This system could promote consumer acceptance of high ethanol blend fuels and associated gains for the US economy and environment.

- Project objectives completed over the past year:
  - Developed analytical models and defined E85 optimization strategy and hardware
  - Designed and built E85 optimized valvetrain, ignition, pistons and injectors
  - Constructed high temperature / high pressure injector test chamber
  - Evaluated injectors under simulated engine conditions

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Milestones

Phase 1 (Oct 07 – May 08)

- Development of Engine Models
- Injector Spray Modeling
- Development of Vehicle Level Model

Phase 2 (June 08 – Dec 08)

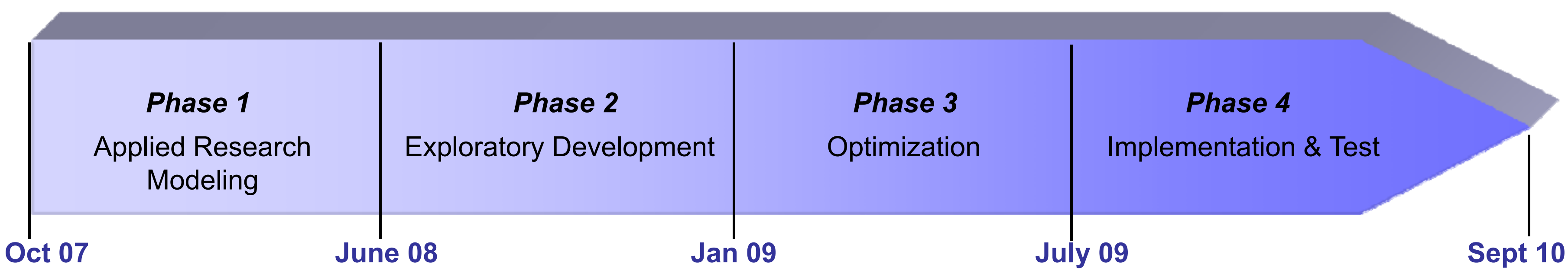
- Develop Baseline Fuel Specifications
- Baseline Definition of Fuel Injectors, Ignition and Other Components
- Test Chamber Construction
- Baseline Definition & Build of Valvetrain Hardware
- Hardware Verification and Testing

Phase 3 (Jan 09 – June 09)

- Injector Optimization Under Simulated Engine Conditions
- Single Cylinder Test Engine Modification
- Steady State Engine Characterization
- On-Engine Verification of Injector Spray Optimization

Phase 4 (July 09 – Sept 10)

- Implementation and Test of Ethanol-Optimized Engine
- On-Vehicle Implementation and Test of Ethanol Optimized Engine
- Project Close Out



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Approach

- Improve E85 fuel economy through increased compression ratio and variable valve actuation.
  - High compression ratio enabled by high octane number of ethanol fuels.
  - Atkinson cycle enables high efficiency – Early Intake Valve Closing (EIVC)
  - Variable Valve Actuation (VVA) provides unthrottled load control over 80-90% of FTP
- Avoid knock with gasoline by lowering effective compression ratio using variable valve timing.
  - Enabled by Dual Independent Cam Phasing (DICP) and 2-Step Valve Train
- Achieve high power density using turbo charging.
- Enable low emissions with stratified cold start for fast converter light-off.
  - Stoichiometric 3-Way catalyst provides cost effective after-treatment

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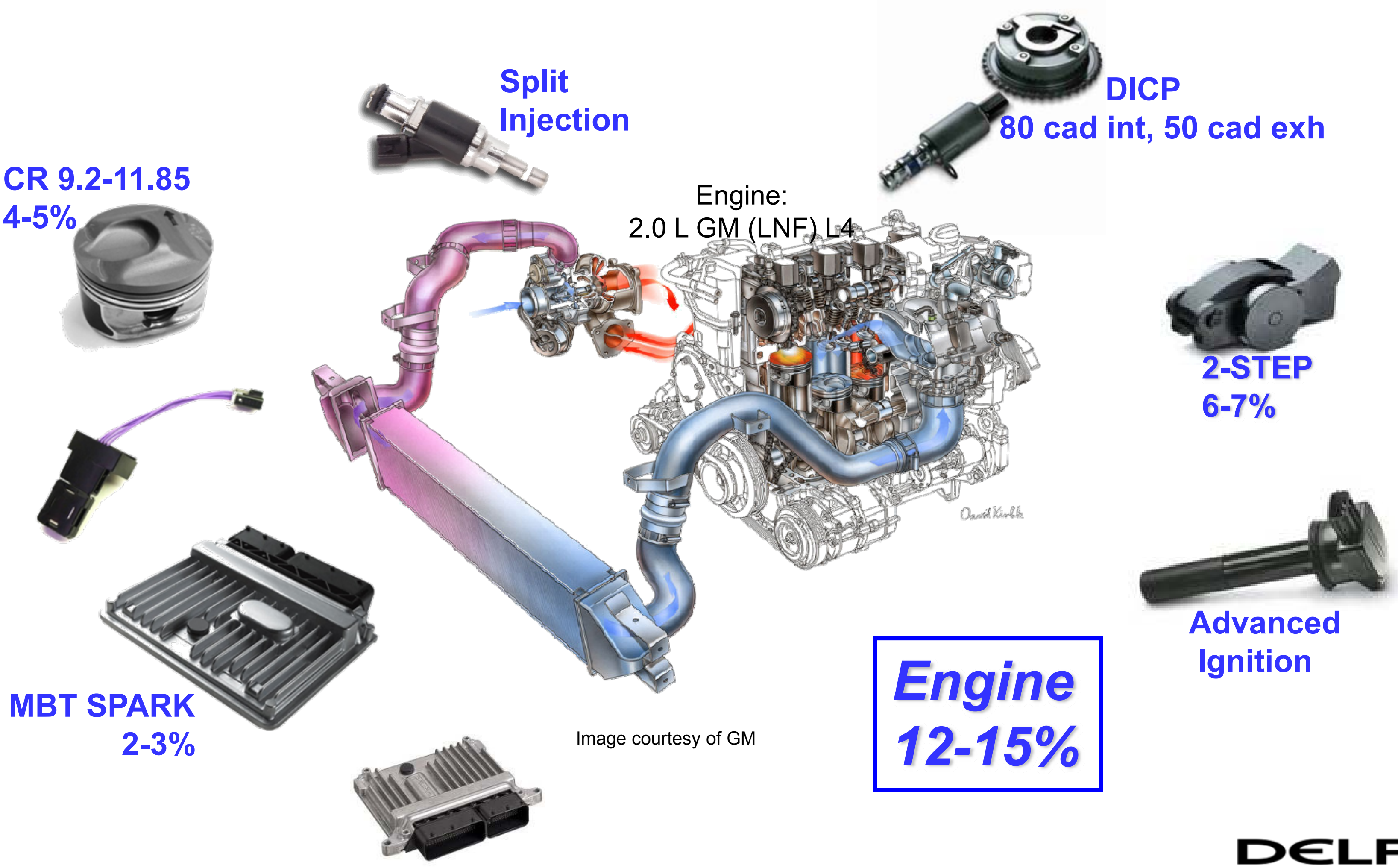
E85 Optimized Engine Project
Mechanization plan

Expected E85 fuel economy improvements based on analysis. An engine with these hardware improvements will be tested in CY 2009 to verify simulation results.



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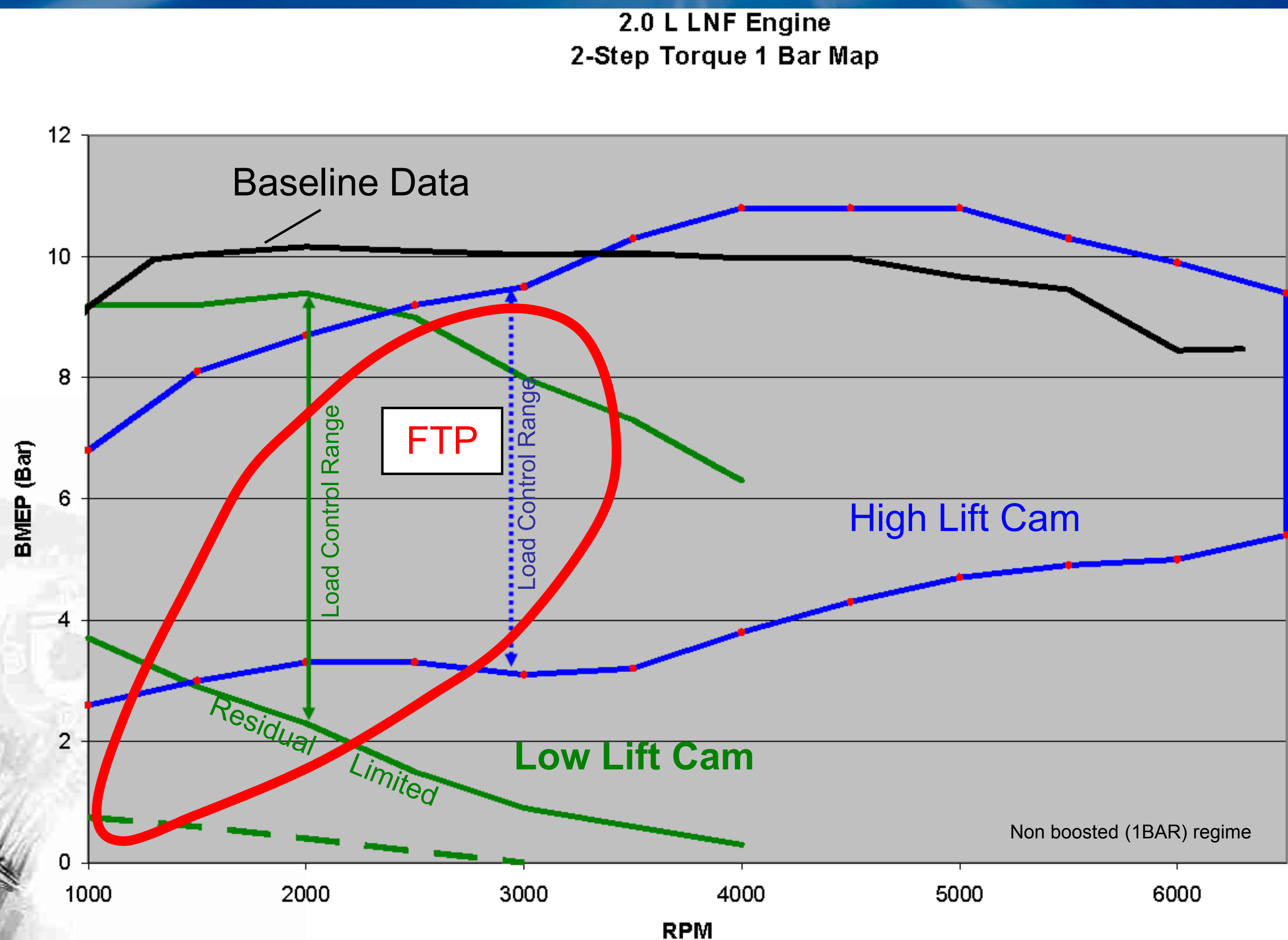
E85 Optimized Engine Project
Speed Load Map (cam selection)



–**Variable Valve Actuation (VVA), with extended timing range, provides un-throttled load control over 80-90% of FTP drive cycle.**

Piston Geometry Description

- Revised piston to increase CR from 9.2 to 11.85
  - Piston bowl feature to support stratified cold start and spray induced charge motion for split injection
    - Image shown at 20 mm Below TDC (52 Cad bTDC)
  - Valve clearance to allow intended cam phasing
  - Maximum cylinder pressure limit (100 Bar)
    - Limits power density of engine

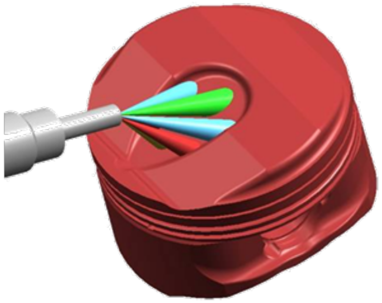


Photo of E85 project hardware

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E85 Optimized Engine Project
2-Step Variable Valve Definition

- 2 Step Variable Valve Actuation (VVA) on intake
  - Low Lift Cam (EIVC)
    - » Up to 4000 RPM
  - High Lift cam (LIVC)
    - » Up to 6500 RPM
- Production Exhaust Cam
  - Single cam profile

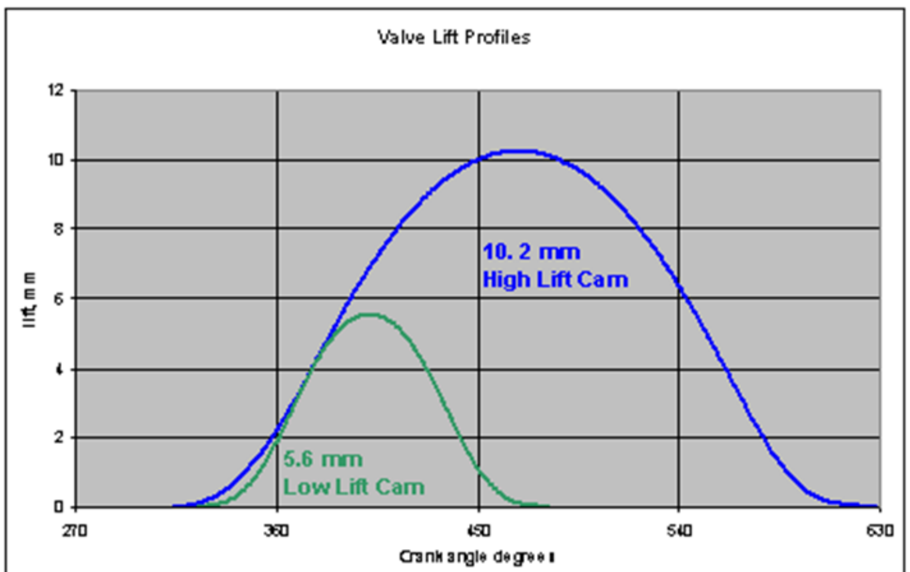
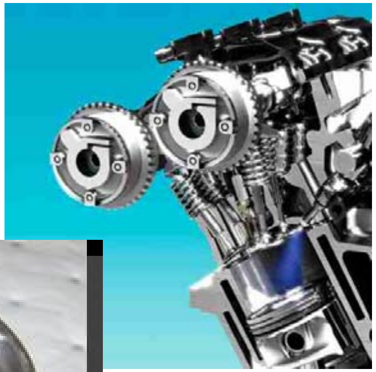


Photo of E85 project hardware

E85 Optimized Engine Project
Cam Phaser Description

- Intake Cam Phaser
  - 80 crank angle degree authority hydraulic intake phaser
    - » Authority range determined by GT Power simulation to meet load control window
    - » Extended phaser authority enables unthrottled load control from 2Bar to maximum BMEP
  - Cam phasing speed determines “throttle response”



- Exhaust Cam Phaser
  - 50 cad authority

Photo of E85 project hardware

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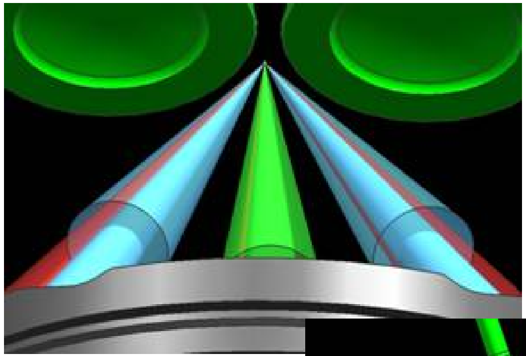
- E85 injector features:
  - Targeted to avoid valves
  - Minimize bore wetting
  - Interaction with piston bowl
    - » Stratified cold start
  - 20.4 g/s @10 MPa
  - Increased flow rate and dynamic range for flex fuel
  - Optimize injector driver strategy
  - All samples are characterized at Delphi



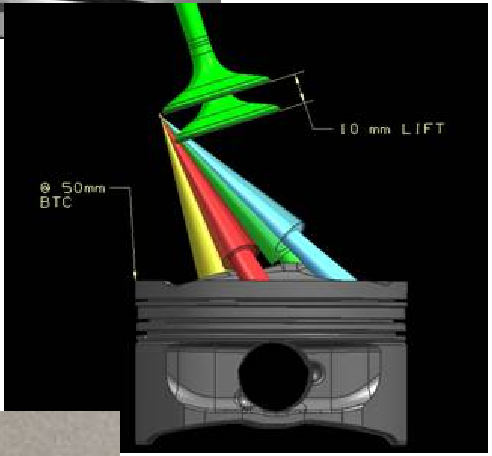


Photo of E85 project hardware

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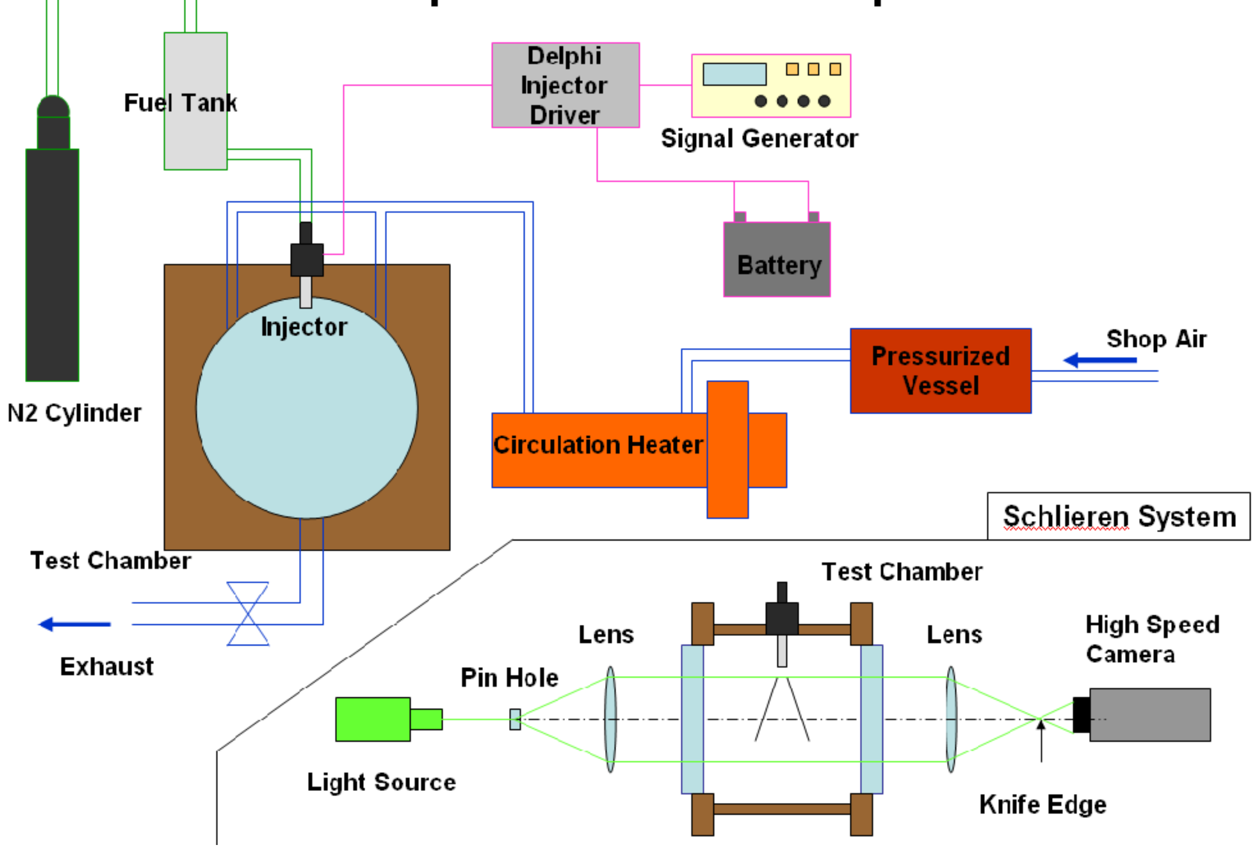
E85 Optimized Engine Project
Schematics for spray-visualization

Experimental Setup



Phase Doppler

Droplet Distributions

High Speed Imaging

Mie scattering

Penetration

Structure

Schlieren

Vapor Boundaries

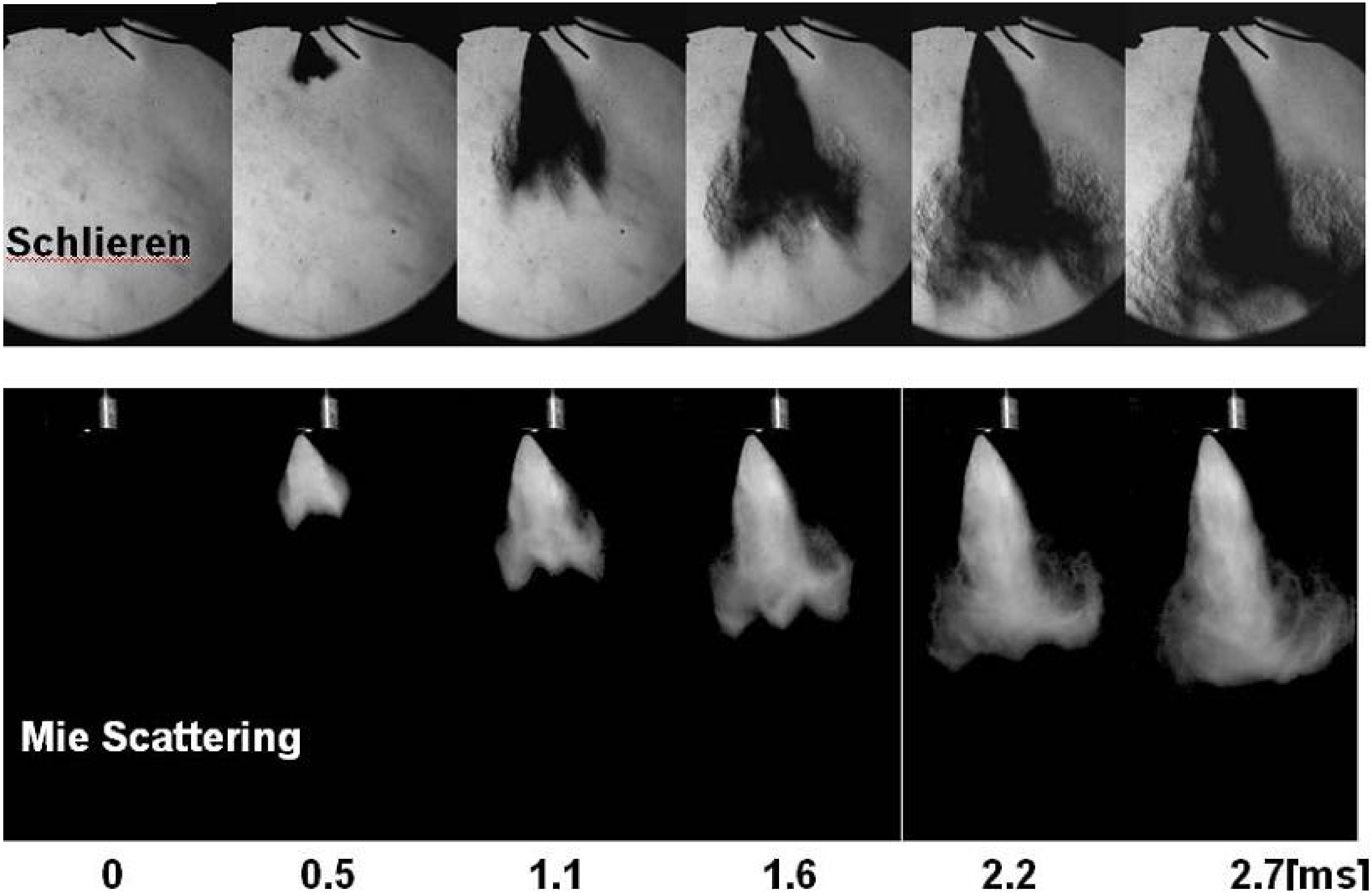
Test Conditions

Pressure 0.4-5 Bar

Temperature 20-250 C

Fuel Temperature 20-90 C

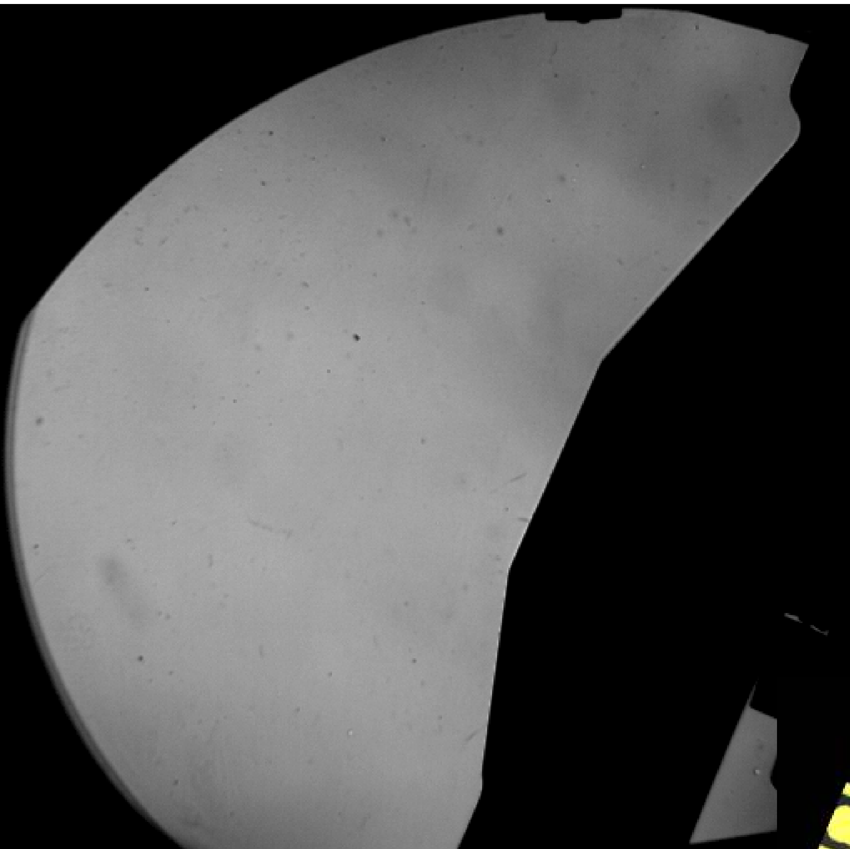
Comparison of High-speed Mie and Schlieren Spray Imaging (100 C, 1 Bar, E100)



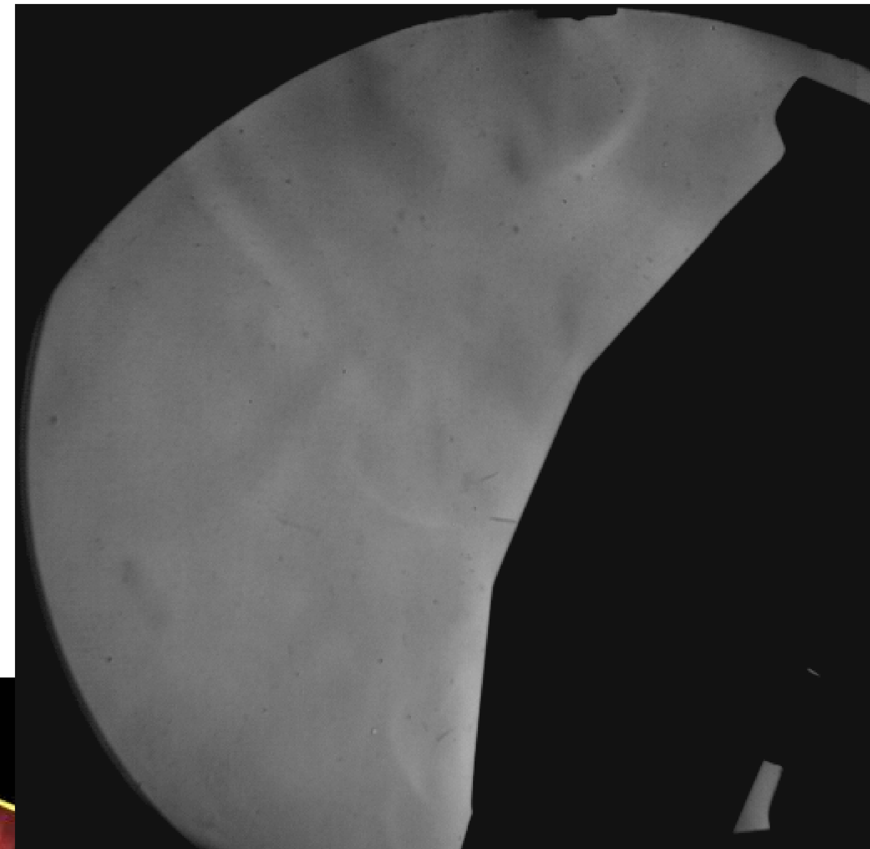
Spray – Piston Interaction

(Piston-15 mm, E100, 1.5 ms, 10MPa Fuel Pressure)

T_{fuel} 25 C, T_{test} 25 C, P_{test} 1Bar



T_{fuel} 60 C, T_{test} 210 C, P_{test} 3.2 Bar



Orientation of test chamber

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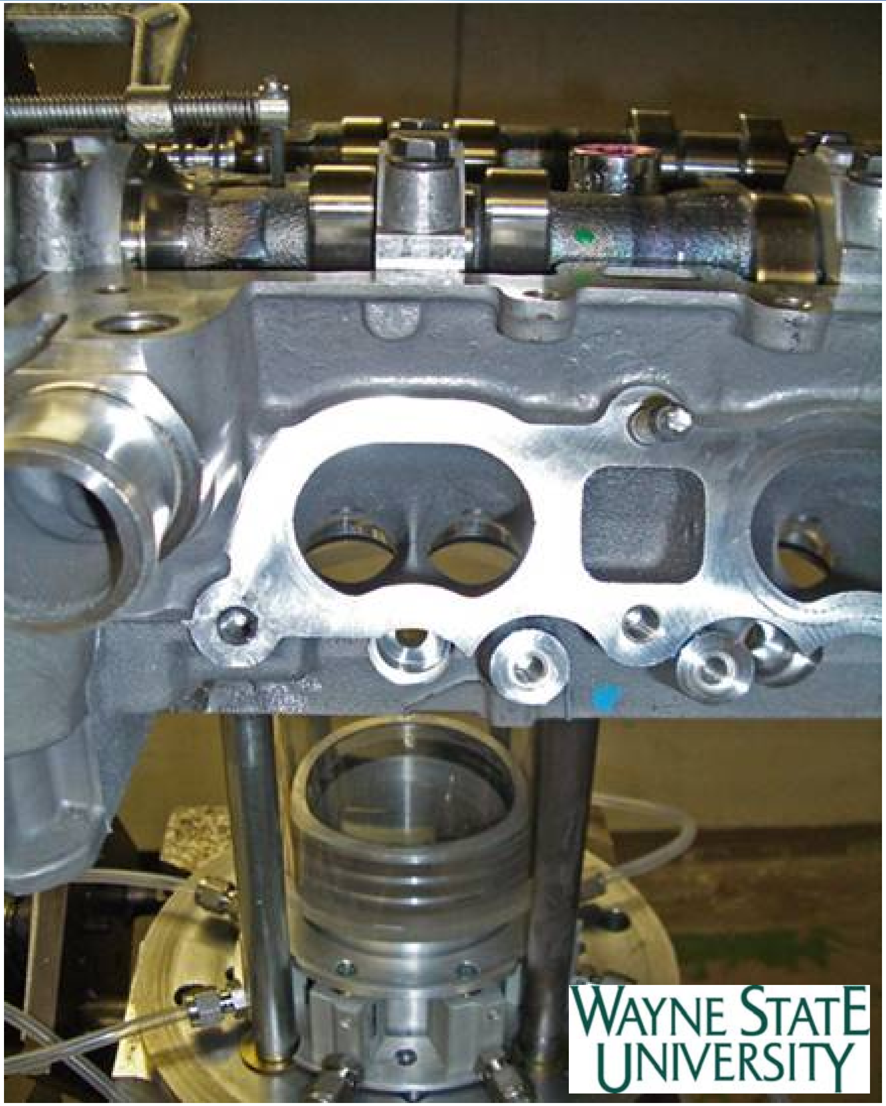
E85 Optimized Engine Project
Wayne State University Optical Engine



Optical Engine

- 2.0 L GM (LNF) Head
- 86 mm Bore
- Transparent Liner
- Optical Piston
- Delphi fuel injector
- Project specific camshafts
  - High and low lift fixed cams
  - Manual cam phasing

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Future Work

- The fuel injector test chamber, developed earlier in this project, will be employed to refine the prototype flex-fuel injector designs at pressure and temperature that simulate engine conditions.
- The optical engine will provide spray characterization in a dynamic flow environment with charge motion.
- The boosted engine will be retrofitted with pistons, injectors and valve train hardware. The engine will be tested on a dynamometer to validate fuel economy and performance with E85. The engine will further be used to develop integrated control strategies for E0-E85 fuel blends.
- Empirical data will be used to update and refine the analytical models.

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Summary

- Simulation confirmed the basic concept of the project:
  - A combination of increased compression ratio and variable valve actuation applied to a gasoline SI engine can improve the fuel efficiency when high ethanol fuel blends are used. This same variable valve actuation can be used to produce a lower effective compression ratio when the modified engine is run on gasoline.
- Fuel injection is being optimized for robustness to fuel variation of E0-E85
  - Homogeneous and stratified operation are being considered. Stratified for cold start situations and homogeneous for normal running conditions.
- Engine hardware for optimized E85 operation has been designed and built.
- Engine tests will be completed this calendar year to verify results of analytical studies.
- The project is progressing according to plan.

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