A MultiAir / MultiFuel Approach to Enhancing Engine System Efficiency

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Overview

Timeline

- Project Start Date: May 07, 2010
- Project End Date: April 30, 2013
- Percent Complete: 17%

Barriers

- Lack of fundamental knowledge of advanced engine combustion regimes
- Lack of effective engine controls

Budget

- Total: $29,992,676
  - Partner Cost Share: $15,534,104
  - DOE Cost Share: $14,458,572

Partners

- Chrysler (lead)
- Argonne National Laboratory
- Delphi
- FEV
- The Ohio State University

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Project Objectives

- Demonstrate a 25% improvement in combined City FTP and Highway fuel economy for the Chrysler minivan
  - The baseline (reference) powertrain is the 2009 MY state-of-the-art gasoline port fuel-injected 4.0L V6 equipped with the 6-speed 62TE transmission
  - This fuel economy improvement is intended to be demonstrated while maintaining comparable vehicle performance to the reference engine
  - The tailpipe emissions goal for this demonstration is Tier 2, Bin 2
- Accelerate the development of highly efficient engine and powertrain systems for light-duty vehicles, while meeting future emissions standards
- Create and retain jobs in support of the American Recovery and Reinvestment Act of 2009

Development Approach

- Project Phases
  1. Design, Simulation and Analysis (to be complete by June2011)
  2. Hardware Procurement, Build and Development
  3. Design Optimization, including, Design, Simulation and Analysis
  4. Hardware Procurement, Build and Refinement
  5. Vehicle Build, Calibration and Fuel Economy Demonstration

Phases 1–2: **Alpha 1 Engine**

Phases 3–5: **Alpha 2 Engine**

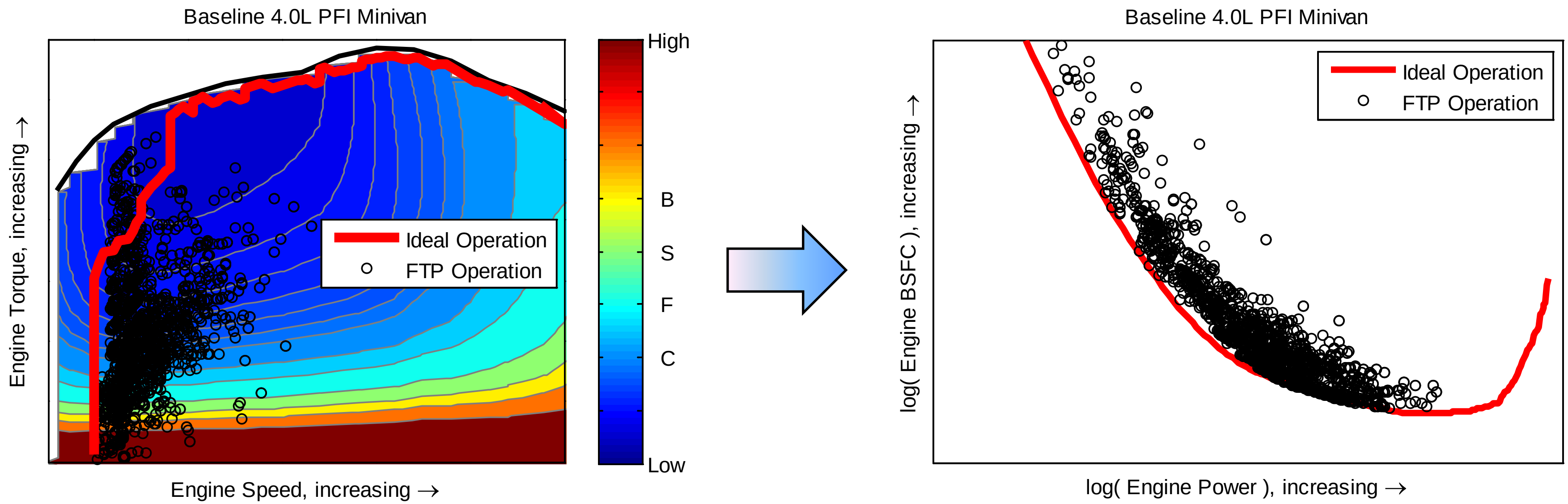
- Use production-style design and development techniques
  - A mixed experimental and simulation approach is being used to optimize the engine design and control
  - Given the timing and scale of the project, a multi-cylinder test bed will be used to ensure robustness of the design and controls for the vehicle demonstrator
  - Surrogate development hardware is being used to rapidly assess key technologies

Research Activities Related to Combustion

- Downsized and Boosted approach
  - Downsize (reduce engine displacement) to improve part load efficiency
  - Boost (pressure charging) to maintain full load performance
- High compression ratio to increase part load efficiency
  - High load operation with a high compression ratio will be limited by knock
  - High residual dilution will be used at high loads (cooled external EGR) to reduce the propensity to knock while maintaining good combustion phasing
- Further combustion actions to increase part load efficiency
  - High residual dilution at light loads (hot internal EGR) to minimize pumping losses
  - Investigate flexibility in the valvetrain design to further reduce light load losses
- Increase in ignition energy and burn rate to extend the dilution limit
  - Will improve efficiency at both part load and high load, following two approaches
  - Approach 1: Direct injection of diesel fuel, in addition to primary fuel (gasoline)
  - Approach 2: Multiple spark plugs per cylinder (1, 2, or 3)

Research Activities Related to Controls

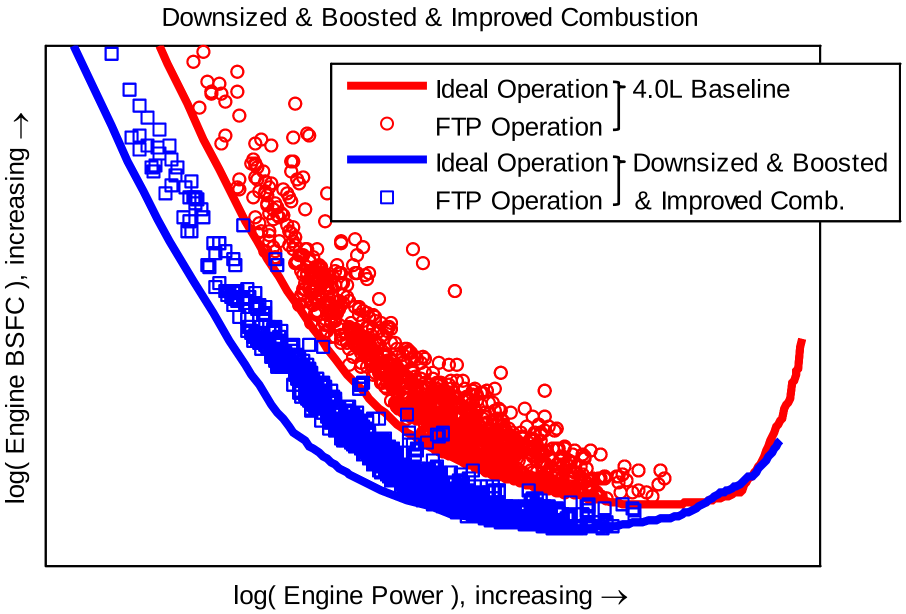
- For the baseline vehicle, much of the City FTP and Highway drive cycles have engine operation that is not at the ideal, most-efficient state
  - Transmission and torque converter control will be optimized to address this
  - The approach will be to operate the engine as close as possible to the most efficient speed and load to meet the requisite power demand
  - Efficient torque converter control will be further enabled by a novel crankshaft design



Research Activities Related to Controls

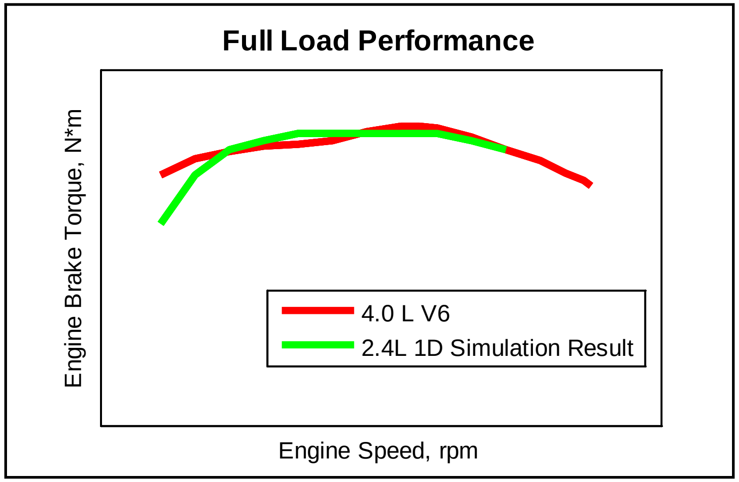
- The approach of downsized, boosted, improved combustion, <u>and</u> improved powertrain control is summarized in the graphic below
- Further controls related improvements to reduce vehicle fuel consumption include:
  - Enhanced fuel cut during vehicle decelerations (aka "fuel shut off")
  - Engine shut off at idle (aka "stop/start")
  - Powertrain thermal management control to reduce parasitic losses
  - Controls focused on optimizing overall system efficiency

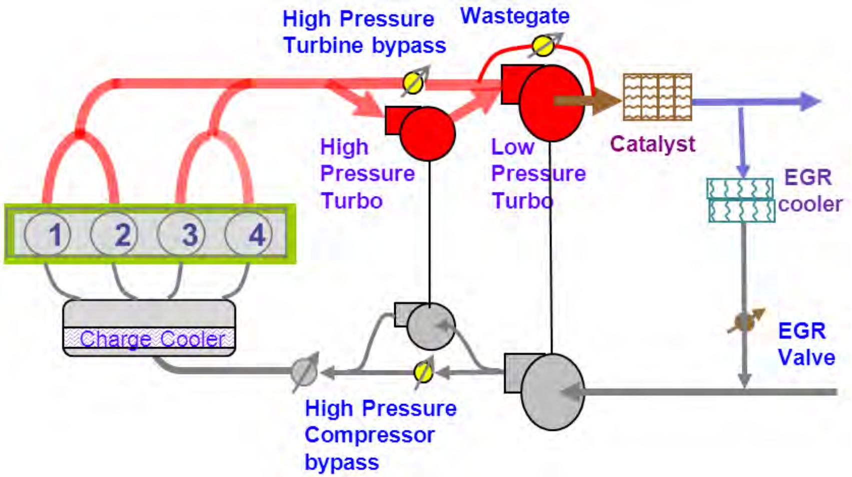
Preliminary vehicle simulation results suggest there is sufficient project content to achieve the fuel economy improvement goal



1D Engine Simulation

- Boundary conditions have been created to further sub-system development
  - P, T, and trapped mass to support 3D CFD analysis of intake port flow and in-cylinder charge motion
  - Peak in-cylinder combustion pressure for engine structure CAE / FEA
  - Thermal system heat rejection for EGR and Charge Air Cooler sizing
- Various boosting system architectures were evaluated, and one was selected
  - Boosting requirements are driven by full load performance, engine displacement, and EGR flow rate
  - Investigated options include:
    - Single turbocharger, single supercharger
    - Supercharger and turbocharger
    - Two turbochargers (2 stage turbocharging)
  - 2 stage turbocharging was chosen, along with an engine displacement of 2.4L
    - Result and architecture are shown at right





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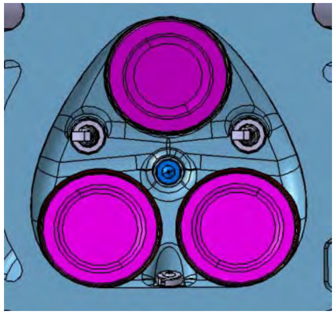
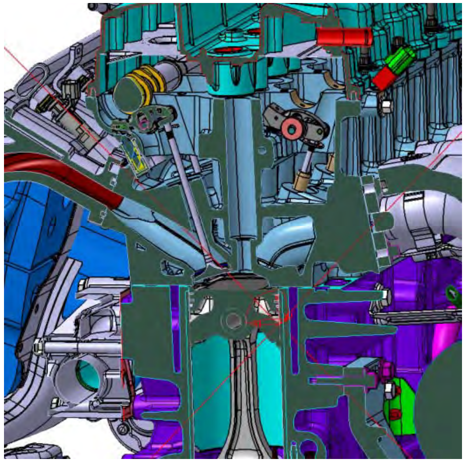
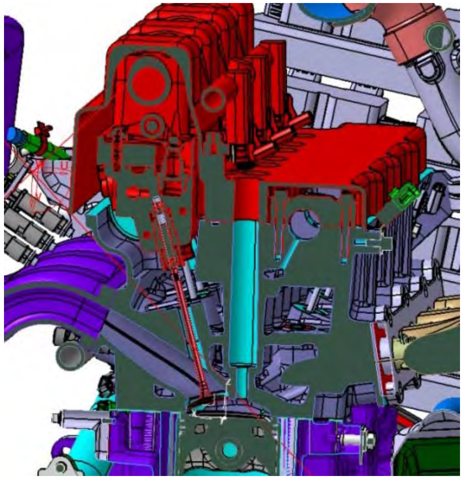
Engine Design

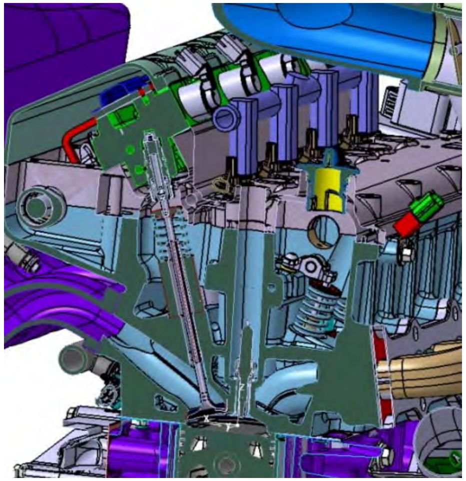
- Alpha 1 engine design is in process
  - 3 valve architecture chosen
- Cylinder head design is progressing
  - Various valvetrain options are being explored
  - Evaluating project benefit, risk, and commercialization potential
- Boosting system has been sized and packaged into engine design along with a new exhaust manifold
- Injectors / fuel system models have been supplied by Delphi and are included in the design
  - Packaging of side gasoline DI injectors / fuel pump is complete
  - Packaging of diesel system has been started
- Chrysler and FEV have conducted FEA analysis on several engine components
  - Increased loading from higher peak cylinder pressure is driving changes to engine materials and structures / modifications are in progress

Central location for diesel injector. Side DI injector for gasoline injector.





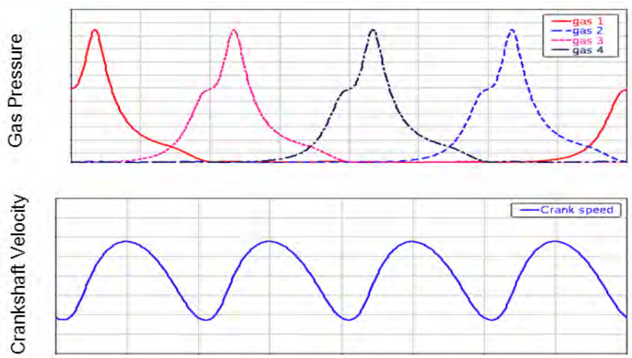




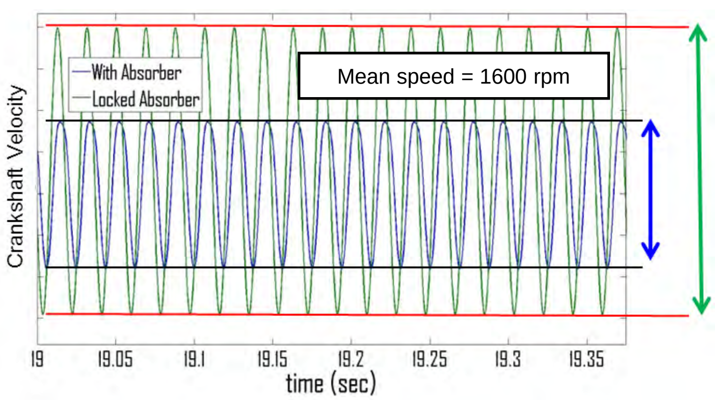
Crankshaft Mounted Absorber - 2nd order mitigation

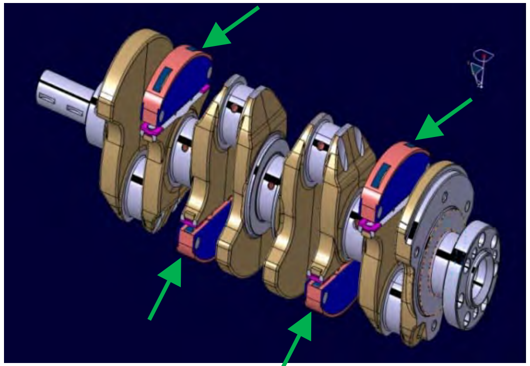
- A pendulum absorber system for mitigating 2nd order torsional vibration has been developed
  - Efficient 4 cylinder engine operation is limited at low engine speeds and high engine loads by 2nd order torsional vibrations
  - 2nd order torsional vibrations can excite the driveline and result in vehicle surging; the typical solution is less efficient open torque converter operation
  - Torsional vibration levels are expected to be high on this project, due to the low engine speed and high engine load approach
  - A design has been created where movable crank weights swing to create pendulums that reduce the high 2nd order torsional vibration
  - The design is order dependent, and corrects at all engine speeds
  - The design is complete, and validated by FEA
  - Analysis shows a significant reduction in the amplitude of the 2nd order vibration which will result in a significant reduction in torque converter lock-up speed (and more efficient engine operation)

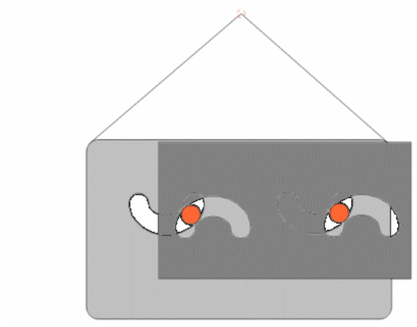
Typical Crankshaft Surging Due To Combustion



Crankshaft Velocity with & without Absorbers

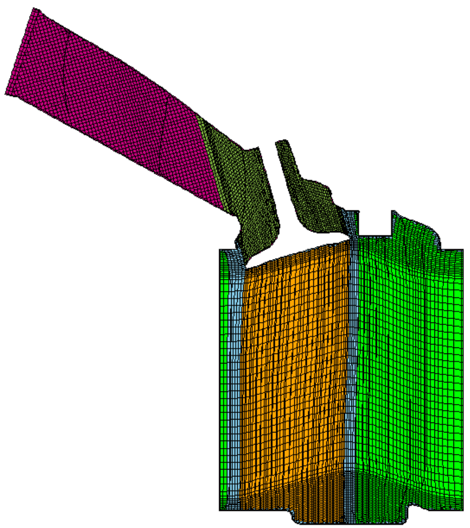






3D CFD Intake Port Flow & Charge Motion Analysis

- FEV is conducting the 3D CFD for the Alpha 1 engine design, drawing upon their proven industrial design practice and know-how
- Cylinder head design is now mature enough that 3D CFD may begin
- Initial geometries have been meshed, and simulation has started
- Simulation results will be assessed regarding:
  - Kinetic energy and tumble histories as well as visualization of the flow field
  - Fuel / air homogeneity throughout the chamber and near the spark plug



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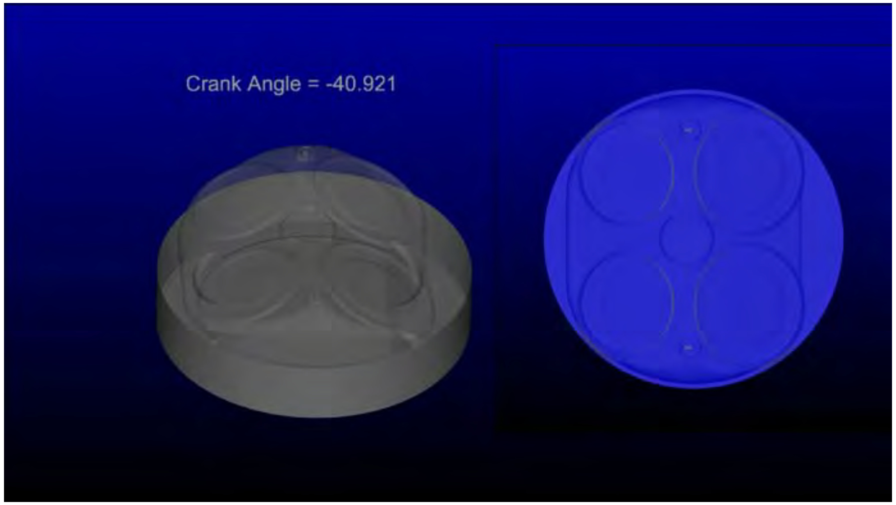
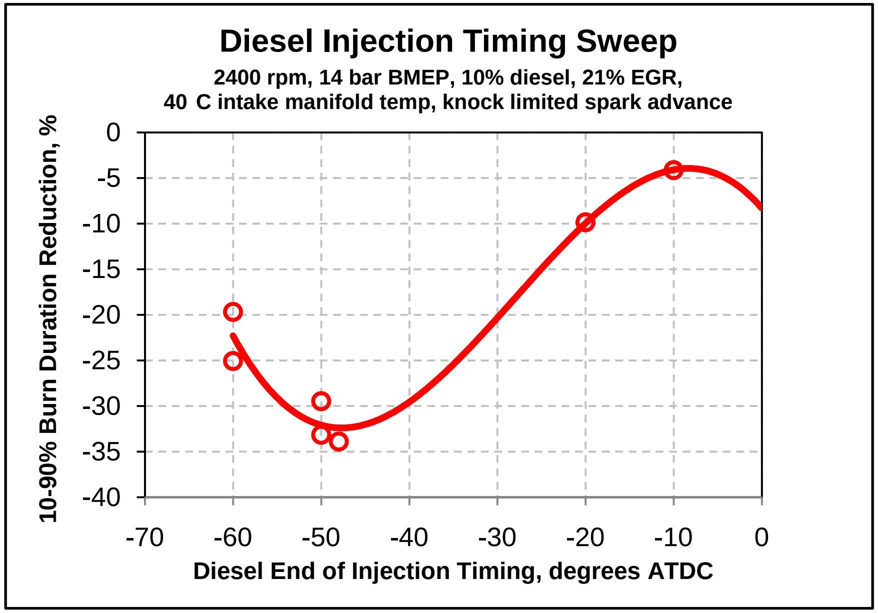
3D CFD Combustion Modeling

- For the Alpha 2 engine, 3D CFD modeling including state-of-the-art kinetics-based combustion simulation will be performed to optimize engine design and control
- Chrysler has the lead, and Argonne National Laboratory is supporting
- Five commercial codes were reviewed, and two were selected for evaluation
  - Based on the evaluation, one code will be selected and used to support Alpha 2
- The two codes have been acquired, installed and are currently running at Chrysler
- A 4V multi-fuel surrogate engine is providing the data for the evaluation, to determine the accuracy of the code predictions



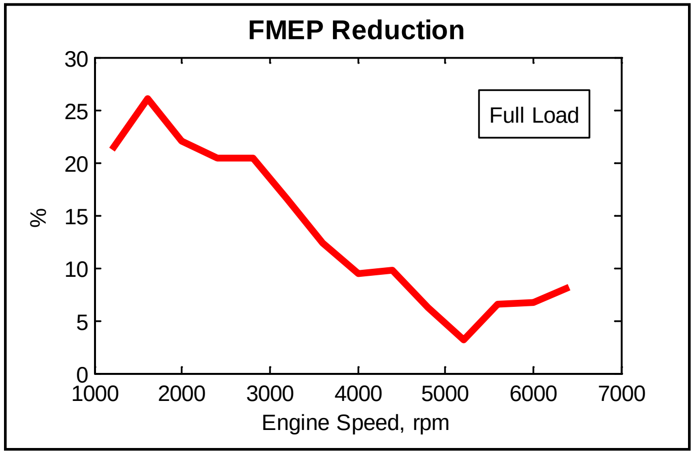
Experimental Work: Multi-Fuel Surrogate Engine

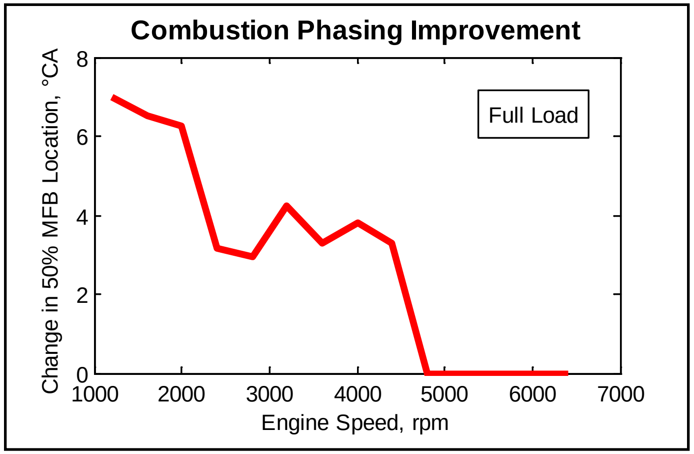
- A surrogate engine was built with port-injected gasoline, and direct-injected diesel
- This engine does not reflect the Alpha 1 design, but is intended to determine the accuracy of the 3D combustion simulation code predictions
  - The 3D geometry shown on the previous slide matches this engine
- Results to date show:
  - Combustion phasing is still controlled *via* spark ignition
  - The addition (and timing) of diesel fuel has a significant impact on burn rate

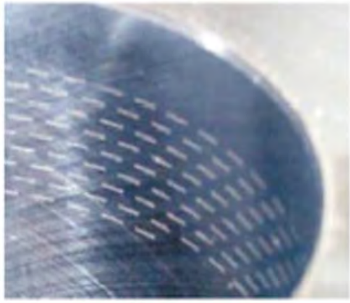


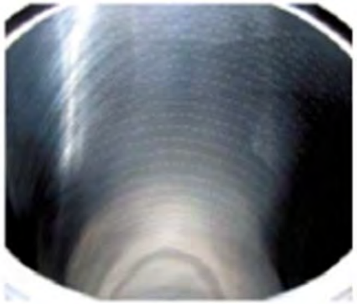
Experimental Work: Spray-on Bore Liner Evaluation

- Typical practice for aluminum block engines is to have a cast-in-place cast iron bore liner, surrounded by Aluminum
- Blocks made with a spray-on bore liner process, which eliminates the cast iron liner, were designed, procured, assembled and tested to assess:
  - Friction reduction, and knock relief (combustion phasing) improvement
- Test results show a significant friction reduction and combustion phasing improvement for the spray-on bore liner as compared to a standard cast-in-place cast iron liner (results shown to right)
- Parts have been procured for a second phase of testing, where a laser-honed pattern will be added to the spray-on bore liner (examples shown below)



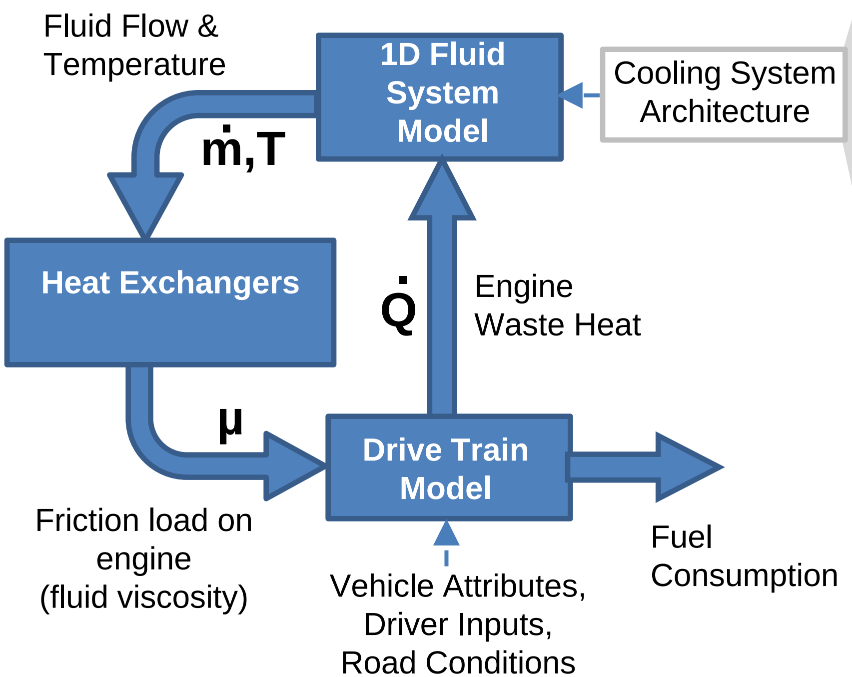


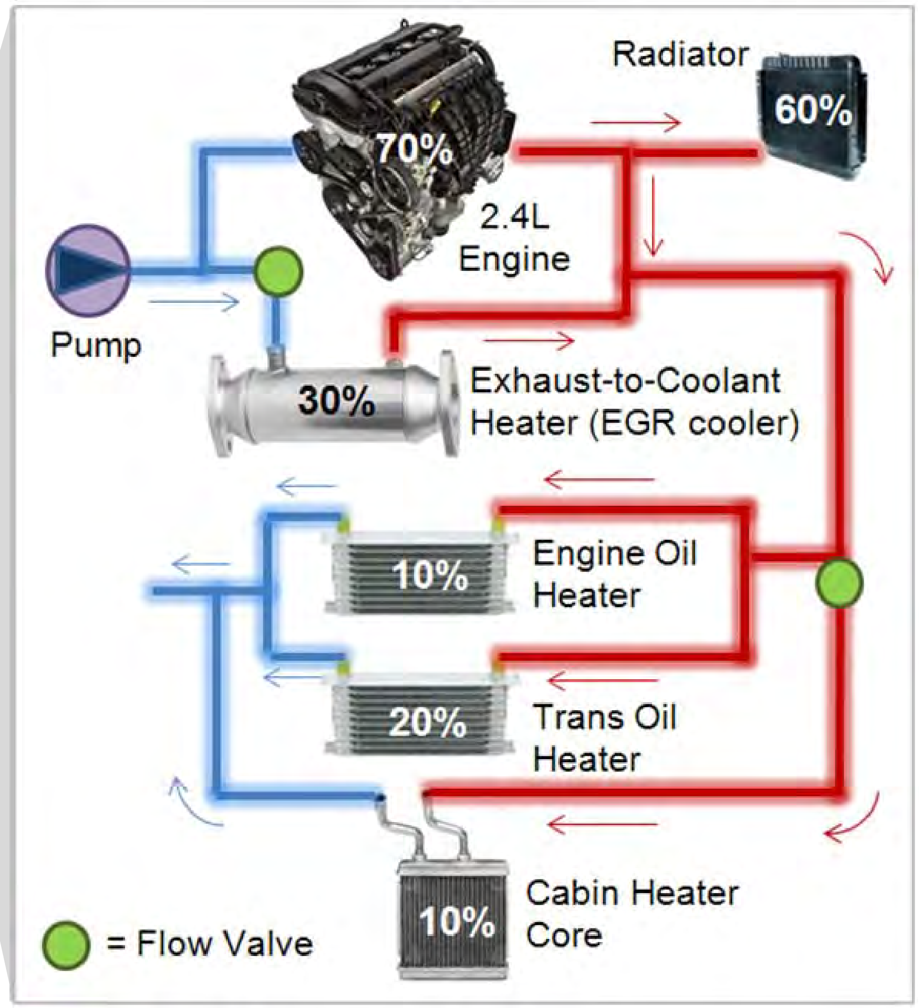




Powertrain Thermal Management

- Approach is to use waste heat to warm the powertrain lubricants and reduce parasitic losses
- A powertrain thermal model has been developed, and an initial cooling system architecture has been chosen
- Iterative component sizing is now in process





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Collaborations / Partnerships

- Argonne National Laboratory (ANL)
  - Combustion and fuel spray imaging, and simulation
- Delphi
  - Combustion sensing, gasoline and diesel fuel system & fuel control
- FEV
  - Engine design and CAE
  - Alpha 1 engine 3D CFD intake port flow & charge motion analysis
- The Ohio State University
  - Controls development for thermal system and ancillary loads
- Numerous hardware and software providers

Future Work

For the next 12 months:

- Complete Alpha 1 engine design and simulation, and procure hardware
- Complete the 3D combustion code evaluation, and begin the design and controls optimization for the Alpha 2 engine
- Conduct Hardware-In-the-Loop (HIL) testing with the intended controller architecture and begin controls development
- Test the Alpha 1 engine at Chrysler
- Test the multi-fuel engine at ANL, first with the surrogate engine (w/o optics), then with the Alpha 1 engine (w/ optics)
- Begin the design of the Alpha 2 engine

Summary

- Comprehensive approach to accomplishing the objectives
  - Fundamental combustion improvements
  - Reduction of parasitic losses
  - Focus on optimal engine operation and control
- Efficient and effective mixed experimental / simulation approach
- Two phases of engine hardware
  - The first (Alpha 1) developed using production development practices
  - The second (Alpha 2) using state-of-the-art kinetics-based combustion simulation
- Alpha 1 engine design, simulation and analysis is on track to be complete by June 2011
- From an ARRA perspective, the project currently has over 80 people involved at various levels of engagement across all the companies
  - Within Chrysler, 16 full time positions were created as a direct result of this project