SuperTruck Program: Engine Project Review

Recovery Act – Class 8 Truck Freight Efficiency Improvement Project

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Detroit Diesel Corporation
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Project ID: ACE058

This presentation does not contain any proprietary, confidential, or otherwise restricted information
Overview

Timeline
- Project start: April 2010
- Project end: March 2015
- Percent complete: 80%

Budget
- Engine Budget $31,633,001
  - DOE Share* $12,883,779
  - Detroit Share* $12,883,779

* Program spending through March 2014 for engine R&D; vehicle R&D expenses reported separately.

Barriers & Challenges
- WHR performance trade-offs and cooling challenges on-board vehicle.
- Complex controls architecture and integration of powertrain and novel technologies.
- Reliability of prototype systems in development and demonstration phase.
- Low temperature transient emissions controls.
- Realistic 55% engine BTE roadmap.

Partners
- Department of Energy
- Oak Ridge National Laboratory
- Massachusetts Institute of Technology
- Atkinson LLC
- Daimler Trucks North America
- Daimler Advanced Engineering
Daimler Truck SuperTruck Program

Develop and demonstrate a 50% increase in vehicle freight efficiency:

- 30% increase via vehicle improvements.
- 20% increase via engine improvements; specifically 50% brake thermal efficiency.
  - Identify pathway to 55% brake thermal efficiency via modeling and analysis.

Approach and Relevance

- ARRVT080 – DTNA SuperTruck vehicle program; PI – Derek Rotz
- ACE058 – Detroit Diesel SuperTruck engine; PI – Sandeep Singh
**SuperTruck Demonstration Status**

- Prototype A-sample SuperTruck vehicle built and being utilized for testing and development.
- Successful integration of complex technologies – EHR, hybrid & HV systems, controllers and network architecture, new cooling layout, new hydraulic systems, powertrain.
- Final demonstration truck builds in progress.

### Brake Thermal Efficiency

**Engine**

- PY3: 46.8%
- PY4: 47.9%

**WHR**

- PY3: 1.3%
- PY4: 2.3%

**PY3**

<table>
<thead>
<tr>
<th>Brake Thermal Efficiency</th>
<th>Engine</th>
<th>WHR</th>
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<tr>
<td>PY3</td>
<td>46.8%</td>
<td>1.3%</td>
</tr>
<tr>
<td>PY4</td>
<td>47.9%</td>
<td>2.3%</td>
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**Enablers for Project Year 4 (PY4)**

- BTE Improvement → 2.1%
  - Further increase in compression ratio (CR), piston bowl and matching injector profile optimization.
  - Third iteration of turbo-charger.
  - Optimized liner cooling.
  - EGR waste heat recovery.
  - WHR component and calibration optimization.
SuperTruck Core Engine BTE Status

47.9% BTE SuperTruck Core Engine Technology Package

- Downsizing to 10.7L from 14.8L
- Reduced EGR & optimized turbocharger and air system match
- Higher compression ratio, piston bowl optimization, matching injector nozzles
- Variable speed water pump
- Low viscosity oil and higher oil film temperatures
- Piston kit improvements
- High efficiency, lower restriction aftertreatment
Piston and Compression Ratio

- Optimized combustion package for best fuel economy.
- Peak firing pressure increased by 15%.
- Plans to test even higher CR. (55% scoping)
- Efficient part load operation, but challenges with high load durability, head & block design and material, NVH, emissions.

Fuel Injection System

- Best injector and piston combination selected after extensive testing.
- Combination of single cylinder and multicylinder platforms used for this investigation.
Air Handling

- Turbo sized for reduced EGR and air mass contributing to lower pumping losses.
- Tuned for a downsped engine.
- Engine air system design leverages a lower power rating required for the aerodynamically and parasitically efficient SuperTruck.
- Approach requires a very high efficiency SCR and low backpressure aftertreatment (ATS).

Parasitic Reductions

- Variable speed water pump, lower viscosity oil, bundled cylinder kit improvements.
- Altered cooling to mid-stroke area of the liner (Detroit/MIT).

Further Investigations (55% Scoping)...

- Next evolution of liner cooling optimization (Detroit/MIT).
- New lubricant formulation (MIT+oil supplier).
- Oil circuit and pump optimizations (MIT).
SuperTruck Engine Control Approach

- Model based controls (MBC) optimize fuel economy and constraint emissions in real time.
- Extensive transient & steady state mapping used to calibrate engine models.
- Both offline & real time optimization of engine set-points for improved transient performance & fuel economy.
Engine Controller Accomplishments

- Controller implemented on a micro-autobox on-board vehicle.
- Standardized and reduced calibration process for each hardware iteration.
- Real time optimization on dynamometer successfully drives the engine to a broad range of emissions/fuel economy trade-offs.
- Preparation for demonstration vehicle testing is currently underway, to quantify transient fuel economy impact on the vehicle.

- Future development of MBC includes
  - Predictive route adaptation
  - Environmental and aging adaptation
  - Virtual sensing for diagnostics
Technical Accomplishments and Progress

Aftertreatment System

ATS

2. Lower backpressure device
2. High performance SCR catalyst, thin-wall DPF, high flow DEF doser
2. Insulated exhaust and ATS on the vehicle
2. Very high NOx conversion over the road to maintain emissions compliance with high engine out NOx (steady state)

Engine

2. Low EGR reduces pumping losses.
2. Lower backpressure further reduces pumping losses.
2. Higher engine out NOx:PM ratio lends to an over the road passive regeneration tendency.
2. Savings in over the road active regeneration fuel.

Emissions Compliance

2. EPA10 RMC and road load compliance demonstrated.
2. Low temperature transient challenges being addressed by engine+ATS systems approach
2. Real world degradation/aging of a system required to consistently perform at high efficiency is a challenge
Waste Heat Recovery (WHR)

- System functional on A-sample SuperTruck prototype.
- Successful integration with the HV hybrid system and a modified cooling package.

Lab schematic of Rankine heat engine

- Coupled Expander Generator
  - Wound field, no-rare earth e-machine
  - Stator model

Prototype Components

Scroll Expander
WHR Progress & Accomplishments

- Primary contributor to PY4 efficiency improvement is EGR heat recovery and component optimizations.
- Current approach has numerous vehicle integration challenges.
- Analytical stretch projections assume improved component efficiencies, CAC heat recovery, and a low temperature condenser approach.
- Analytical stretch may prove to be impractical with state of the art vehicle technology.
WHR Vehicle Integration

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<th>Electrical</th>
<th>Mechanical</th>
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<tr>
<td>Pros</td>
<td>Better energy management</td>
<td>Higher efficiency</td>
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<tr>
<td>Cons</td>
<td>Hybrid dependent</td>
<td>System sealing challenges w/ shaft seals, mag coupling etc.</td>
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- WHR vehicle cooling requires a holistic approach.
- Integrated vehicle, engine & WHR system models leveraged for design and layout.
ORNL Collaboration on Dual Fuel

- Explore dual-fuel operation within the constraints of a stock engine
  - Potential petroleum displacement in conventional modes
  - Potential $\text{\eta\%}$ and emissions impact in low temperature combustion (LTC) modes (55% BTE scoping)
- Evaluate LTC and limitations on a multi-cylinder engine
  - Combustion stability & phasing
  - High $\text{P}_{\text{MAX}}$, $d\text{P}/d\text{t}$ & EGR
- Detroit engine modified for PFI natural gas, DI diesel
  - Fyda Energy Solutions providing Sequential PFI hardware
- Engine installation and system integration underway, dual-fuel experiments scheduled for Summer 2014

- Fundamentally targeting a more optimum ROHR at part load, within the mechanical constraints of the engine
55% BTE Scoping Activities in 2014

**Sub-System Testing**
- **Combustion**
  - Even Higher CR
  - LTC & Dual fuel
- **WHR**
  - Mechanical Feedback
  - Component optimization,
    Beyond exhaust recovery,
    Low temperature condensation

**Analytical**
- **Combustion**
  - Ideal HRR scoping
  - In-cylinder insulation
- **WHR**
  - Component optimization,
    Beyond exhaust recovery,
    Low temperature condensation

**Air System**
- **E-TC**
  - Further EGR reduction
  - High efficiency turbo,
    Low restrictions

**Friction Reduction**
- Liner insulation iterations,
  New oils

**Engine Simulations**
- Parameterized models
  for engine design &
  configuration impact
  on part load efficiency

**Voice**
- Preliminary analytical estimates for 55% BTE roadmap
SuperTruck Partnerships and Collaborations

Department of Energy:  → Roland Gravel  → Gurpreet Singh  
                      → Ken Howden  → Carl Maronde

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<th>Engine</th>
<th>Aftertreatment</th>
<th>Hybrid</th>
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<tr>
<td>Atkinson LLC</td>
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<td>OAK RIDGE NATIONAL LAB</td>
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<th>Powertrain/Parasitics</th>
<th>Fleet</th>
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16
SuperTruck Program Summary

- 50.2% engine BTE demonstrated including WHR.
- Weight neutral engine target; downsized engine with WHR.
- WHR functional on prototype A-sample SuperTruck.
- Remaining 1 year of SuperTruck.
  - Demonstrate efficacy and FE advantage of model based real time engine controls on-board the demonstrator SuperTruck vehicle.
  - Performance and controls tuning for engine & WHR ongoing for demonstrator chassis.
  - Demonstrator chassis and truck build ongoing; FE and performance demonstration to start September.
- Sub-system level testing and analysis for 55% BTE building blocks initiated.
- Final reporting.